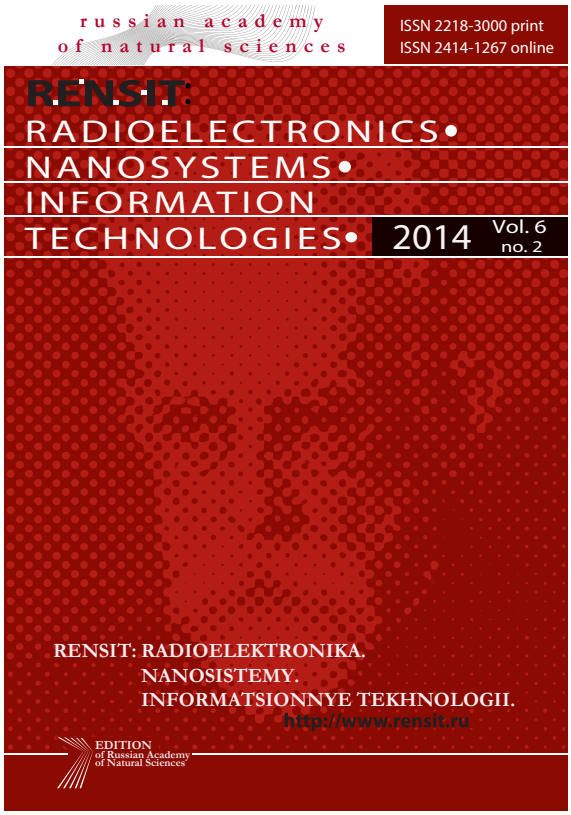

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ELECTROMAGNETIC SYSTEMS AND TOOLS OF INTENTIONAL IMPACT ON PHYSICAL AND BIOLOGICAL OBJECTS

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Abstract. **Modern development level of generation methods of powerfull electromagnetic impulses and radiation forming ways defines development possibility of wide class of directed energy systems and means. In electromagnetic systems and means impacted on biological objects (human) and environment development area and for force systems in electronic warfare (EW) area the following in most known: electromagnetic means of lethal effect, large power generation means for force systems of EW, electronic means of non–lethal effect and means of directed electromagnetic effect on environment.**

In the first part of the paper questions of powerful electromagnetic impulses generation improvement for force systems creation of radio–electronic suppression of different kinds of radio–electronic systems (RES) and especially systems of modern high–precision weapon are highlighted. It is exceedingly important problem in perspective armament and military equipment development. Methods and ways of powerfull nanosecond impulses generation are discussed. It contains the following works:

- theoretic justification of powerful nanosecond impulses generation method abilities and they's main parameters for possible practical use in perspective systems of force electronic warfare of RES termination development is made;

- results of foreign and domestic researches of creation of nano– and microsecond duration UHF–pulses and ultra–thin electromagnetic pulses and also electromagnetic radiators with magnetoimplosive current generators supply are given

- the variants of UHF weapon used abroad are presented and also examples are given for creation of means of directed electromagnetic impact to human for the fight against terrorism.

In the second part of the paper basing on interactive materials, issues of geophysical perturbations in ionosphere made naturally and artificially are highlighted as powerfull impact sources in nature. Corresponding description of deliberate methods and means of impact to environment (HAARP type of RLS) and directing of radiation heating stands and secondary ionosphere radiation radio–monitoring is given.

In the final third part of the paper problems of possible (expected) development directions of electromagnetic radiation impact on physical objects and environment methods and they's ways of solving are approximately formulated.

Keywords: **generators, electromagnetic radiation, electromagnetic suppression systems, physical objects, ionosphere, radiomonitoring, geophysical perturbation, heating stands.**

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Contents

1. INTRODUCTION

The present level of development of methods for the generation of powerful electromagnetic pulses and methods of forming radio emission has determined possible development of a broad class of systems and tools of directed energy. Given the current trends in the development of fundamental and exploratory research in the development of such systems and electromagnetic effects on biological objects (human) and the environment, as well as power systems in the field of radioelectronic warfare (REW) is currently the best known are the following means.

Electromagnetic means lethal effects. In the Russian literature often uses the terms: SHF-weapon, SHF-generators or generators of electromagnetic radiation (EMR), in foreign - microwave weapon (including EMR and super-EMP ammunitions). Under electromagnetic means (weapons) lethal effects (objects of defeat: personnel, weapons and military equipment (AME)) refers the directed energy weapons, the main damage factor of which is the electromagnetic radiation in the range of 100 MHz to 300 GHz (the maximum spectral density or the average frequency of the radiation) with a pulse energy of at least 100 J (or peak power greater than 100 mW or average power greater than 1 MW).

Means of generating high power for force systems radioelectronic warfare (REW). Intend to use method of generation the powerful nanosecond pulses for their practical use by the development of perspective systems of force electronic warfare on defeat radioelectronic systems (RES).

Electromagnetic means of non-lethal effects. This term means the weapon acting on enemy personnel by means of energy electromagnetic radiation for brief deprivation (from seconds to several hours) of his combat capability (to create conditions for the inability to perform set tasks).

Means of directed electromagnetic effect on environment. These funds combines some types of meteorological and geophysical weapon, using as a primary active factor the energy of electromagnetic radiation.

2. METHODS AND WAYS TO GENERATE NANOSECOND POWERFUL PULSES

Currently, areas of the opportunities and impact of electronic warfare to fight the warring parties largely expanded and becomes the basis of the information aspect of warfare, affecting virtually all processes of detection, collection, transfer, processing and use of information. The emergence of complex multilevel systems radio-radioengineering intelligence, combat control, REW and precision weapons defined sharply increased dependence of the course and outcome of combat operations on the readiness and effectiveness of operation of these systems. The purpose of electronic warfare became not only the solution of particular problems to disrupt the functioning of control systems of weapons and of troops (forces) of the enemy, but also to achieve a decisive advantage over him in efficiency, stability and quality of control.

Thus, electronic warfare is a set of activities undertaken to identify (intelligence) and subsequent electronic suppression (SES) electronic systems of different purposes (radar systems and radio communication systems), as well as for the radioelectronic protection (REP) of its RES.

Along with the evolutionary development of EW in the forecast period abroad is possible to create and deploy a new class of technology - a complex electromagnetic weapons, created through the development of generating devices with high-powered directional radiation in the microwave range, defined as *force REW on defeat different types of RES* [1, 2].

2.1. THEORY AND PRACTICE GENERATING NANOSECOND POWERFUL PULSES

Therefore, improvement of methods of generation of powerful electromagnetic pulses for creating of force systems SES of various types RES and especially modern high-precision weapons systems (HPW) is a relevant and important issue in the development of promising arms and military equipment (AME).

Generally class of objects RES can be quite wide: the input circuits of devices air defense equipment of aircraft, satellites, etc. However, the most relevant at the present time is the problem of efficient use of force REW to fight high-precision weapons.

Work to solve this problem (because of its extreme urgency) is conducted for a long time, but until now unknown to others (except as described in this paper) methods and apparatus for generating packs of powerful microwave ultrashort pulses (USP). Known and used methods and apparatuses have several drawbacks. For example, in the microwave radiolocation station (radar, MRLS), acting on the basis of parametric absorption effect (EPA), the United States used the delay unit, which due to the equidistant gap junctions provide a decomposition of a single super-power (from a few to hundreds of megawatts) microwave pulse for a pack of powerful ultrashort pulses. Disadvantages of this method are well known and are described in the scientific literature, however, so far other solution of set tasks were not.

Known not only methods how to use the packs powerful microwave USP in order to radar detection of stealth aircraft, but also a attempts to use such USP to create a stable energy formations or clots (SEC). However, to date such attempts have led to positive results in the US alone (SEC creation with time stabilize the order of several microseconds). Interest in such use USP , as well as to methods and apparatuses for generating such reams of USP, stems from the fact that a single electromagnetic pulse (EMP) emitted by SEC by destabilization can reach the energy performance comparable to a EMP of nuclear explosion of average power (which is highly relevant in terms of destructive factor, and in the sense of nuclear explosion imitation).

2.1.1. THEORETICAL RATIONALE FOR THE USE OF THE METHOD OF GENERATION OF POWERFUL NANOSECOND PULSES IN FORCE ELECTRONIC WARFARE

Purpose of this paper is a theoretical justification the possibilities of method of generation of powerful nanosecond pulses, their main parameters for possible practical use in development of advanced of systems of force electronic warfare on defeat RES.

2.1.1.1. DEVELOPMENT OF SYSTEMS OF FORCE DEFEAT RES BASED ON MODERN METHODS OF GENERATING HIGH-POWER RADIATION

In the field of elaborating as of methods of powerful radiation so and the electromagnetic weapons, now stands out area of the creation of various types of *electromagnetic weapons*. Their destruction facilities are not only the RES, but even and personnel.

Currently abroad intensive research is being conducted on the development of means of functional lesion using powerful microwave generators of different wavelength range, which indicates the relevance of the impact of powerful electromagnetic pulses on the RES as a means of the forced REW [1-8].

Analysis of the available results of works on creation of microwave means of influence (weapons) shows that the most active works in this field are deployed in the United States. In recent years, research in this area were also deployed in France, England, Germany, Israel, Japan, China and Sweden. Practically all departments of USA Ministry of Defense ordered the creation of SHF means of acting. At the same time for a tactical means of SHF (SHF generators, powerful amplifying modules and antenna systems, power supply, etc.) is characteristic the functional convergence or uniformity with promising radar technology and means REW. In particular, elaborating of tactical SHF weapons examines the concept of complex performing the radar detection and tracking of the target in reduced power mode, and at maximum power mode - its functional or forced defeat. As typical objects of defeat by the powerful microwave radiation are considered:

- digital special calculators of control systems of intercontinental ballistic rockets, tactical and operational-tactical rockets;
- systems protection and charging combat equipage of rockets;
- electrical devices undermining mines and roadside bombs;
- navigation receiverssystem "GLONASS";
- RLS of systems of AD/MD (air defense/missile defense);
- RES of homing heads of anti-aircraft guided rockets and rockets "air-to-air" and others.

The present level of development of methods for the generation of powerful electromagnetic pulses determines completely the possibility of development of a broad class of directed energy weapons.

Analysis of existing and emerging types of microwave weapons, ways to combat employment allowed to form a common scheme of classification and identify the overall dynamics of the development of such systems in the United States for the period up to 2017 as set out in **Table 1**.

The analysis of existing foreign press and data of Table 1 give the opportunity to believe that the overall dynamics of the developments in the field of *electromagnetic weapons* (microwave weapon) abroad is based primarily on the basis of the creation of the following types of sources of high-power microwave radiation:

- sources on the base of microwave generators of different wavelengths and phased arrays, which summarize power of individual microwave generators in a narrow beam of microwave radiation;
- microwave generators on relativistic electron beams;
- sources of quasi-isotropic, including broadband microwave radiation on the basis of explosion-magnetic generators;
- microwave generators on the basis of special nuclear ordnances with ultra-low power.

In Russia also performed similar work on the creation of a means of generating powerful radiation. First and foremost is work on the creation of a powerful pulsed sources of broadband microwave radiation.

Here are the results of work carried out in IRE RAS in the 2000s under the leadership of RAS Corresponding Member Cherepenin VA, on

Table 1

Overall dynamics development of existing and emerging types of microwave-forces systems in the US

Years		
2002	2003-09	2010-17
Microwave systems for protection of objects AME		
Demonstration: - small-size broadband radio-emission source high power - narrow-band radio-emission source with high pulse energy	**Demonstration:** - opportunities of small-size systems of microwave weapons to defeat of air targets	**Demonstration:** - naval systems microwave weapons for protection against high-precision weapons; - systems microwave weapons to defeat munitions, missile warheads
Microwave systems for defeat of management tools and communication		
Theoretical and experimental research, technical development	Ground tests	Tests in structure of air-basing means
Microwave systems to defeat air defense radiotechnical facilities		
Demonstration small-size narrow band radio-emission source high power	Microwave weapons systems single action of an explosive type	Impuls systems of multiple actions
Microwave systems of space–basing for AD/MD		
Theoretical and experimental research, analysis of effects	Modelling and imitation for development of concept of combat use	Ground tests complexes of defeat operative-tactical, Intercontinental ballistic missiles and space vehicles

elaborating new methods of detecting objects based on effects of use of ultrashort pulses [1, 2]. This is due primarily with the work on study the characteristics of radar systems with broadband pulses for the detection of little-noticeable objects. Work was done on the modeling and estimation of parameters of ultra-wideband pulse of the locator by the *single-pulsed location* of little-noticeable objects. Were conducted researches direction-finding complex objects on the background of the underlying surface by the monopulsesystems.

As a result, created and tested the device, where voltage source, is the high-power nanosecond generator of pulse voltages. A legitimate source for the specified conclusion are the received results of studies of a new method of radiolocation - detection of small-dimensional and weakly-emitting objects (such as "Stealth") on the basis of high-power nanosecond pulses. It is advisable for more detail elaborate on the basic provisions of this interesting research direction, the results of which can be successfully used as a basis of creating the generators of large power for forced radioelectronic means of REW.

2.1.1.2. GENERAL PROVISIONS OF THE METHOD OF SINGLE-PULSE LOCATIONS

It is known that the most commonly used in modern radiolocation the modulation method of signal forming of angular error determines the modulation depth, and the phase is determined by the direction of mismatch of antenna axis. There are three basic ways to determine the coordinates of the single-pulse direction-finding in systems - amplitude, phase and complex. Modulation method of the forming of signal angular error requires a sequence of reflected pulses, which determines its sensitivity to fluctuations in the amplitude of the received signals. This is most significant drawback of single-channel direction finding method using a conical, linear and sequential switching of directivity diagram. This deficiency in single-pulse radio location is missing. In this case, the reflected pulse contains complete information on angular position of the target with two independent receiving channels. In this case the direction-finding is carried out by one pulse at the same time on two independent channels of reception in the coordinate plane. The fluctuations of the reflected signal practically almost have no influence on the accuracy of the measurement of angular coordinates.

The single-pulse location is prospective in detection of objects on the Earth's surface, as well as in detecting low-flying objects.

Complex problem arises under location of small objects on earth and sea surface, as well as under detecting low-flying aircraft. By using long pulses in RLS the range resolution is improved with use of frequency modulation, spreading its effective spectral range. However, herewith arise spurious sidebands, through which can be fed powerful interferences, whereby a small target may mask a large target. This problem does not exist for radar with short microwave pulses, as there is no need to change compression schemes of pulses.

Reducing the pulse width reduces the range of action of monopulse radar system (detecting object and impact on it). This confirms the need to use in radar systems the super-power microwave pulses. In

this case also necessary when switching to shorter pulses save total power, which also allows to obtain a higher resolution of objects.

2.1.1.3. CHARACTERISTIC OF PARAMETERS OF RADIO- AND VIDEO-PULSES OF MONOPULSE LOCATION

What ways use now are russian and foreign researchers by creating tools generating of high power?

1st direction. With the help of a relativistic backward-wave tube in the early 90s at the Institute of Applied Physics (Nizhny Novgorod) and at the Institute of High Current Electronics (Tomsk) were obtained the high-power nanosecond radiopulses in decimeter range [9, 10]. As a result, radiopulses were generated at a frequency of 10 Hz and a duration of 5 ns at a repetition frequency of 100 GHz. Average power generator was 250 watts. Nanosecond digital locator consisted of the receiving and transmitting antennas.Isolation of the antennas was 60 dB.

At present, the test of similar radar successfully passed in England: at a distance approximately of 100 km was clearly visible small plane with an effective area of cross section (CSA) of 1 m2. Distance resolution was provided 1 m. The repetition frequency of RLS was 150Hz. The width of the diagram amounted 3º. Under digital processing of signal the noise level was reduced by 30 dB.

It was found that meter resolution on this distance enabled to identify the different purposes, including distinctly observed the rotational movement of the blades of the helicopter at the same distance.

2nd direction. Another mode of generating microwave videopulses differs significantly due to the lack of high-frequency oscillations filling, herewith had the relatively large spectral width.In fact, a video-pulse is a 1-2 oscillations with a selected carrier frequency. Wave generator voltage can be effectively converted into an electromagnetic wave at a direct radiation of special antenna, herewith high-frequency filling missing, video-pulse is characterized by a relatively large of spectral width. Development of nanosecond high-voltage powerful generators based on cutting of short pulse out of more longer pulse using sharpening and shear gas discharger (slicer). Dischargers worked in a nitrogen atmosphere at a pressure of 60 atmospheres, and were powered by transmitted high-voltage nanosecond generators (drivers) through the 50-ohm line as capacitive energy storage.

On such a device were obtained 1-5 ns pulses with an output power to 400 mW with the prospect to increase to one GW with a repetition rate of 100 Hz with a stability no less than 3%. Stability of pulse duration was less than 10%, which is insufficient to detect small effective area of the scattering. For radiation the nanosecond powerful video-pulses can be used TEM horns in the form of non-uniform strip lines.

Fig. 1 shows form of such powerful video-pulse of generator.

2.1.1.4. ADAPTATION OF SPECTRAL CHARACTERISTICS OF LOCATION PULSE

Methods of generating high-power nanosecond electromagnetic pulses, in principle, allow rapid adjustment of the parameters of radiated signals and, in particular, changes in the emission spectrum, including through the use of modular method of construction of the radiating system. Adaptation of the locator pulse can be in this case is based on the following principle.

In the first phase of the adaptive procedure is performed irradiation of space by powerful ultra-wideband electromagnetic pulse and the reflected signal gives the opportunity to make a decision about the detection of the object. In parallel with the emission of the probe pulse is carried out its spectrum analysis and the results of $S_0(\omega)$ are recorded in the information storage unit. In the case of a positive decision about detecting is produced spectrum analysis of the reflected signal $S(\omega)$.To find the maximum in the spectral characteristic of the reflecting target surface $\sigma(\omega)$, in the computer system is formed ratio $\sigma(\omega)$ =

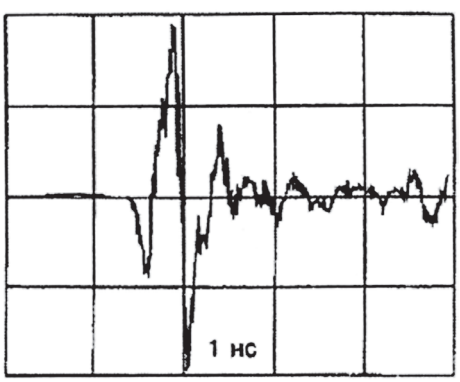

Fig. 1. *Shape of toutput video-pulse of powerful nanosecond generator.*

$S(\omega)/S_0(\omega)$ and the analysis of the maximums of this magnitude. If one or more maxima are above the average value of the effective reflecting surface, then adjusted the spectrum of the emitted pulse so, that the maximum spectrum components of location pulse accounted for the maximum value of the effective spectral reflective surface. In this case the spectral width of the emitted pulse must also be consistent with the dependence of σ(ω), so that energy of the reflected signal was taken as the maximum possible value. Concrete laws change in the spectrum of the emitted pulse, depending on the measured value of σ(ω) should be developed for specific experimental parameters generating system, in particular, the number of independent channels radiation, frequency overlapping of generation range, possible characteristics of the intended targets, coefficient of possible narrowing of spectrum of pulse generation around the carrier frequency, etc. Note that in the presence of errors in determination of the spectral amplitudes effective reflecting surface of the target the adaptation should be carried out when the difference between the maximum value of σ(ω) and average value will be more of error of determination of spectral components σ(ω).

In the process of tracking are possible slow changes of the spectral characteristic of an effective reflective surface, caused by a turnoff of target, for example, etc. In this case, to maintain high accuracy of determination of the dynamic parameters of the target is necessary periodic to conduct correction spectrum of locating pulse, which will consist the repeated measurement of spectrum of reflected signal, determining σ(ω) and changing in accordance with this new dependence of the spectral characteristics of the emitted pulse.

Note that the measurements of the spectral characteristics of effective reflecting surface targets also allows you to define a class of object to which it refers. In the case of a creation bank of information on the spectral portraits of possible targets the periodic correction of the locating pulse parameters can be carried out without feedback (without repeated measurements σ(ω)) only on data stored in a bank of information, and the dynamic characteristics of the target (distance, speed, angle of observation and etc.).

2.1.1.5. THE MAXIMUM DETECTION RANGE BY MEANS OF THE OPTIMUM RECEIVER ON NOISE BACKGROUND

In the absence of active interference noise component of signal can be considered as white Gaussian noise with spectral density $N_0 = kT$, where k - Boltzmann constant.

Signal-to-noise ratio (S/N) of the optimal receiver coherent signal will be

$$\mu = \frac{1}{N_0}\int_0^{\tau}\xi(t)dn = \frac{E}{N_0}, \quad (1)$$

where $E = \int_0^{\tau}\xi(t)dn$ - is the total energy $\xi(t)$ during the pulse duration τ.

Signal is considered to detected if the signal/noise ratio is greater than a certain threshold $\varsigma(\alpha_1, \alpha_2)$, that depend on the parameters of the probability of correct detection and probability of false alarm: $\mu > \varsigma(\alpha_1, \alpha_2)$.

Maximum range of target detection will be:

$$R_{\max} \le \frac{G_r A_r \sigma}{(4\pi)^2 \zeta} \cdot \frac{E}{N_0}. \quad (2)$$

According to the formula (2) was calculated for the initial data: $\sigma = 0.1$ m^2, the pulse duration $\tau = 5$ ns, $T = -300$K, parameter $\varsigma(\alpha_1, \alpha_2) = 5$. Admits that the receiving and transmitting antennas are identical, the output aperture videopulses $50\lambda^2$, and CSA (effective area of cross section) is 10 m^2.

The calculation results are shown in **Table 2**.

2.1.1.6. DETECTION AND ESTIMATION OF THE PARAMETERS OF THE OBJECT BYAPACKET OF LOCATING PULSES

To improve the characteristics of detection and target tracking at monopulse location of little-noticeable objects is possible, using for the location a few identical pulses. In this case it is still possible definition of all parameters of target for each of pulses, however, estimation of parameters on packet is the better, the more pulses in a packet. Further more, for effective use of an adaptive procedure locating requires relatively large value of signal/noise ratio, which also requires the use of multiple locating pulses.

Table 2

Maximum range of target by different capacities and types locating pulses

	Maximum detection range of object, km	
	Pulse power of 0.5 GW	Pulse power of 1.0 GW
Radio pulses	550	655
Video pulses	250	310

Evaluation of signal/noise ratio and detection range for packet of locating pulses. Devices generating ultra-wideband powerful microwave pulses capable of operating in the frequency mode with a repetition rate of 100-200Hz. Therefore possible monopulse location as single pulses and pulse packet, comprising up to a few thousand pulses.

In case of reception *k* pulses on the background stationary random process, quality detection characteristics are the same as by the reception of one pulse, but having in *k* times greater energy. Indeed, energy of locating signal is proportional transmitter power multiplied by pulse duration. In the case of a packet of pulses the total duration of signal is increased in *k* times that correspondingly increases in *k* times signal/noise ratio. **Table 3** shows the values of the target detection range in the case of the location of radio pulses and video pulses with different number of pulses in a packet. As is easily seen, the maximum range of video pulses location at 100 pulses per pack can reach 1000 km, and at radio pulses locations even is more than 2000 km. The total duration of location signal in this case is 1 second at a pulse repetition rate of 100Hz.

It should be noted that this gain in detection range can be achieved only in the case of coherent filtering of all the pulses of pack (phases of all pulses must be the same). This is possible in the case of simultaneous detection and estimation of target velocity. Then speed of target is a parameter, and it is possible to coherently accumulate all impulses of the pack. A "fee" for increase of sensitivity is a significant complication of optimal receiver, as in this case requires presence at least of three-dimensional comb filter for evaluation of velocities in distance and two angles.

Table 3

Maximum range of target detection by various capacities and types locating pulses and for different number of pulses in a pack

Signal characteristics	Maximum detection range of target, km	
	Pulse power of 0.5 GW	Pulse power of 1.0 GW
Locating radio pulses		
One radio pulse	550	655
Pack of 5 radio pulses	7820	980
Pack of 20 radio pulses	1160	1385
Pack of 100 radio pulses	1740	2070
Locating video pulses		
One video pulse	260	310
Pack of 5 video pulses	390	460
Pack of 20 video pulses	550	655
Pack of 100 video pulses	820	980

At the same time there is possibility of parallel processing of all information, needed for coherent accumulation, which in principle allows the preservation of the same time characteristics (speed of processing of reflected signal) as and for a single pulse in pack.

Estimates of parameters of object for locate by packet pulses. The increase ratio signal/noise through the location by pack of pulses also allows to substantially improve accuracy of estimation of object parameters – speed, angular position, angular velocity, etc. It should be noted that improvement of accuracy of parameter estimate is proportional to the square root of energy of received signal, ie, of S/N ratio, and is much more pronounced than the increase in detection range. Indeed, for 5 locating pulses in pack the estimation accuracy of target parameters increased by 2.2 times, for 20 pulses - by 4.5 times, and for 100 pulses - even 10 times. Again, as in the case of detection, increase the accuracy of the estimates is associated with a significant complication of optimal receptor that require the comb of optimal filters for each parameter of signal, since otherwise fail to implement coherent pulse accumulation.

A significant increase in signal/noise ratio by means of the location of the pack of impulses also increases the efficiency of using adaptive procedures of location. Indeed, suppose when using only one pulse locating, object can be detected (signal/noise ratio is the multiple units). This is not enough for effective use of adaptive procedure - relative accuracy of the estimate of frequencies at which the spectral amplitude of the effective reflectivity of the target surface reaches a maximum, is of ten percent. At the same time use of a pack of 100 locating pulses for the same purpose provides signal/noise ratio already several hundred, which is sufficient for adaptive procedure of tuning of the locating pulse spectrum, because the relative error in determining of required frequencies of location is no more five percent.

Note that the measurement of the spectrum using a pack containing *k* pulses is completely equivalent

to averaging over the ensemble of realizations of k. The reduction of variances of the estimates occurs in this case also k times.

Thus, applying pack of pulses instead of a single locating pulses by monopulse location of little-noticeable objects can significantly improve characteristics of detection and assessment of target parameters. Thus, an increase in the detection range may be more than three times for 100 pulses per pack. At the same time significantly are reduced errors of estimation of the parameters of the object and is increased the efficiency of adaptive procedure of location.

2.1.1.7. THE LIMITING ACCURACY OF ESTIMATION OF PARAMETERS OF REFLECTED SIGNAL

To assess the accuracy limit parameters by monopulse location we use the inequality Cramer-Rao [11-14]. n this case, errors variance of measurements is determined by following expression:

$$\sigma_\lambda^2 = -\left(\frac{d^2 S(\lambda)}{d\lambda^2}\right)_{\lambda=\lambda_0},$$

where $S(\lambda) = \frac{2}{N_0}\int_0^\tau s(t,\lambda_0)s(t,\lambda)dt,$ $s(t,\lambda)$ - signal, λ_0 - the true value of the parameter λ.

Received for error estimation the following expression:

$$\sigma_R^2 \geq c\tau\left(\frac{E}{N_0}\right)^{-1}. \quad (3)$$

Calculations according to (3) showed that when a large signal/noise ratio error of determination range may in principle be smaller than length of pulse of electromagnetic radiation in space τ.

Dispersion of determining angular coordinates, based on Cramer-Rao inequality, is as follows:

$$\sigma_\theta^2 \geq \theta_{1/2}\left(\frac{E}{N_0}\right)^{-1},$$

where $\theta_{1/2}$ - a characteristic directivity diagram width of the receiving antenna.

Analysis of researches results of monopulse radar method on detection of small-dimension and weak-emitting objects (such as "Stealth") on the basis of powerfull nanosecond pulses shows that there are a number of new significant advantages of powerful ultrashort pulses in a location that can be summarized as follows.

1. Use of the nanosecond short and powerful pulses provides a range of several hundred kilometers, allowing you to escort objects with low CSA on background of large stationary noises.
2. When monopulse location by powerful nanosecond pulses with Doppler modulation, the problem of blind speeds disappears completely.
3. If pulse duration ~ 5 ns and duration of interval between pulses of about 0.01s, problem of "dead time" disappears when is blocked receiver radar station and receiving of signals about the object in this case is absent.
4. So as detection of all parameters of an object by themonopulse radiolocation occurred for the one pulse, then at the pulse repetition rate of 100 Hz there is no ambiguity on range of target. Indeed during 0.01s all echo-pulses have time to reach the receiving antenna, if the maximum detection range does not exceed 1500 km.
5. High range resolution allows for identification on a single reflected pulse. Indeed all the details of an object with dimensions of the order of 1 m^2 (planes, screws) will work as independent reflectors, creating a sort of three-dimensional portrait of the object.
6. High range resolution can give information about the height of low-flying aircraft over the relatively smooth terrain on a temporary division of solitary response and diffuse echo-signal from the underlying surface.

Overall, the single-pulse radio location by powerful nanosecond pulses, is a new direction in the radar, and represents of undoubted interest for civil and military applications.

The use of nanosecond pulses provides a good range resolution and allows you to detect and track moving targets with a small effective scattering on large stationary background noise.

These findings allow to obtain and other results, which are the main goal of this paper, ie, give suggestions of possible use of the method of generation of powerful nanosecond pulses for their practical use in the creation of prospective systems forced electronic warfare on defeat RES.

2.1.1.8. MAIN PROVISIONS IN CREATION OF LARGE GENERATORS FOR FORCED SYSTEMS REW

On basis of final results and common sense of scientific assumptions in this paper is defined the forecast of following provisions for implementation of method of generating nanosecond pulses of high-power power in forced struggle on defeat RES.

1. To facilitate penetration of electromagnetic radiation into defeatable equipment is desirable to use the most short-wave radiation of the microwave range. Optimal for stations of functional damage is a millimeter range radio waves. Most suitable for use in mobile stations is Cherenkov's generator, giving in 8-mm range a power of more than 1 GW, which is more than an order of magnitude more powerful than other generators in the microwave range.
2. For radiation of microwave pulses of millimeter range appropriate to use an active phased antenna arrays (PAAR). This increases the power level and, therefore, range lesion. Herewith takes place process of addition power in the space.
3. From analysis of circuit-design solutions foster circuits modern radio-electronic means is shown that among the semiconductor elements are most exposed to the influence a point-contact diodes with Schottky barrier, herewith possible as a forced act in pass band, so and an out-band defeat of input circuits of RES.
4. It is expected that the level of coming to these elements from external sources of microwave energy pulses is largely determined by the electoral and other characteristics of the antenna-feeder devices and the input circuits (AFU and VTs). Depending on mutual arrangement on frequency axis bandwidth AFD and spectrum of microwave pulse with its center frequency the filtering properties are determined by AFD as a whole, as well as by filtering properties of input circuit of receiver.
5. Criterial levels of destruction of microwave diodes and transistors can be the following

- when irradiated by nanosecond pulses, following with a repetition rate of $F_r \leq 1000$ Hz: up to 12 W (in the frequency range up to 10 GHz), up to 100 W (in the frequency range up to 20 GHz) and 30 W (in the frequency range up to 36 GHz);
- irradiation pulse duration of 1 ms, followed with F_r = 25-50 Hz - less than 26 W (with effects on bipolar transistors in the centimeter range);
- irradiation pulse duration of 1 ns - 1 ms, followed with F_r = 4 kHz - 8-20 W (when exposed to low-noise amplifiers);
- irradiation pulses 1.5-10 ns, following with F_r = 10-100 Hz - 4-30 W (when exposed to bipolar transistors cm range).
- level criterion of destruction microwave diodes decreases with increasing length of his working wave and with the expansion of the working bandwidth of diode. Depending on the location and conditions of the placement of sensitive elements in the equipment, type of contacts with elements of the installation, the possibility of concentration and channeling of energy of external fields by elements and circuits inside the block, actual criterial level can change on order or more.

6. Can be considered not only as a new method of registration of microwave oscillations, but also as a mechanism for disabling the input elements of the RECs and the possibility of transformation of high-power nanosecond electromagnetic pulse in acoustic.

Under the guidance of Professor JM Perunov also conducted theoretical and experimental studies on creation of powerful short microwave pulses for radar detection or defeat air targets. It is concluded that the use of high-power short-pulse radar signals in REW with the radioengineering systems is very promising.

2.1.2. GENERATORS OF MICROWAVE PULSES OF MICRO- AND NANOSECOND DURATION

As a sources microwave radiation with gigawatt levels power can be considered relativistic pulse-periodic generators and complexes with lower levels of pulsed power - traditional non-relativistic electronic devices. Multi-channel radiating systems with non-relativistic devices provide a higher level of average power, control parameters of the radiation, electronic scanning by beam. However, compared to relativistic they are difficult and have large mass-size characteristics.

Currently, highest peak power achieved in generators on high-current relativistic electron

beams generated by cold cathode, which operates on principle of explosive emission.

High repetition frequencies (up to 1 kHz) at the output pulse power of more than 1 GW can be obtained on relativistic backward-wave tubes (carcinotrons) and resonant traveling-wave tubes with rectilinear electron beams and with Cherenkov's mechanism of generation. Servis life of generator is determined to a greater extent by the durability of cathode and gas-discharge tube. For the currently used graphite cathodes and for a removable dual-channel gas arrester, this is about 108 pulses. Characteristic power of carcinotron generator, working in 3-cm wavelength range, is about 1 GW, with the pulse repetition frequency up to 500 Hz.

In particular, the maximum power is extracted into the atmosphere microwave radiation reached the generator Cherenkov type (setting I-3000 microwave, VNIIEF (Sarov), the beam energy of 3 MeV) and is 3 GW in the 3 cm band with a pulse duration of about 20 ns. There is possible generation of a train of 2 pulses. A further increase in beam energy leads to a drastic reduction in duration of pulse due to the development of breakdown at the output of the electromagnetic structure and on the output window.

Increasing of power carcinotron generator can be achieved by increasing efficiency of interaction of electron beam with electrodynamic structure. By increasing coupling parameter of structure with electron beam from input to output of structure, optimal phasing of reflector, the use of an electron gun with a high compression and application of multi-channel spark gap, according to the developers of the device, will be able to increase efficiency of 20-25%, output power of up to 2 GW and repetition rate of 1 kHz.

High level of power can be obtained in generator with relativistic resonant traveling-wave tube (TWT). In resonance TWT, an electron gun, forming a tubular beam of large diameter, and collector removed from the interaction space. This determines a high power device. Feedback in the electrodynamic structure to ensure adaptive properties of generator can be accessed by using the Bragg reflectors on input and output of structure. Projected a very high efficiency of up to 30-35%. Increasing efficiency may allow to increase power up to 3 GW.

For systems operating in UHF and in long-wave part of the centimeter wavelength range, it is possible to consider applying relativistic magnetron generators. These devices have a fairly high efficiency (up to 30%), good mass-size characteristics and a phase stability.

Adaptive properties of the magnetron compared to carcinotrons listed below. Due to the pollution of the slow-wave structure in the process of operation of the device in pulse-periodic mode can happen reducing efficiency. Magnetron has large times of establishment of vibrations (5...10 ns), which limits the efficiency of formation of short nanosecond pulses.

Since geometrical dimensions of the anode block of magnetron are proportional to wavelength, it limits energetic parameters of device and its stability with decreasing wavelength. When working magnetron with a large pulse repetition frequency important task is to ensure removal of heat from the device.

Another class of super-power microwave generators are generators with a virtual cathode - vircators. They relatively simple to manufacture, capable of operating without focusing magnetic field and over a wide range to change the frequency of oscillation. In particular, exactly on the magneto-insulated vircatorwas reached the power of 22 GW (no radiation in the atmosphere) in the US in the early 90s. This record power is not available yet for generators of other types.

In Russia today reached power levels of 1 GW at a pulse duration of 10...30 ns (with output of radiation into atmosphere). Duration of radiation pulse in vircatoris determined by the speed of movement of anode plasma to cathode. Offered in VNIIEF variant of vircator with plasma anode has allowed to solve this problem. The result was generated radiation, duration of which (3μs) is determined only by energy-capacity of capacitor power source.

At the same time, due to the multimode, multi-frequency nature of field the efficiency of vircator is low, there are complexities of effective output radiation from a space of interaction and beamforming. At the present time it was not possible to achieve high stability of powerful vircators. It should also be noted that resource of work of vircators can be substantially constrained by possibilities of anode (in most cases the grid).

All this excludes the possibility of his work in the repetitively pulsed regime with high repetition rate. Apparently, vircatorshould be considered as a source of high-power microwave radiation single acting with explosive-magnetic generator.

A promising area of researches is the development of microwave generators on the lines of magnetic insulation (*MILO*). In particular, MRTI RAS (Moscow) is developing this kind of device with a power of about 1 GW, a pulse duration of 50 ns and efficiency at the 10% level. Electrodynamic structure of this generator is a coaxial waveguide with diaphragms. In such a structure, the electron beam creates its own magnetic field, able to hold it, so it does not require an external magnetic field and the fine-tuning of the device. Another important advantage of generator is large size of cathode, which provides opportunity to work with low-impedance pulse power source, that is preferable at generation of high powers.

Of foreign works in this direction should be allocated researches on radial acceletron, belonging to group of span generators, which lead in laboratory of the North American branch of Philips (USA). Acceleron has a simple coaxial design, in which the anode of the coaxial generator diode serves simultaneously as the outer conductor of the coaxial resonator. Advantages of acceletron are compact design, exception of need of focusing magnetic system and lack a partitions of foil, that are prone to erosion, what allows increase the pulse repetition rate, that is limited only by maintaining vacuum in generator. Besides, effective grouping of electrons in the radial acceletron provides it high efficiency, and coaxial design due to the small impedance allows obtaining a high output power.

According to the calculations of developers, radial acceletron can provide generation in range 1...20 GHz with an output of more than 1 GW when powering by a DC pulses with voltage of 350 kV and a duration of 200 ns. As shows simulation, acceletrons, having a radius and a length of emitting part of the cathode, respectively, 23.4 and 3.2 cm, radius of anode 27 cm and length coaxial resonator of 6.4 cm with a unoptimized design including load, generates at a frequency of 3.1 GHz, providing an output power of about 0.6 GW when powering voltage of 300 kV. Herewith, optimization of design will provide an efficiency of over 50% and reach a output power of 2 GW at a pulse repetition rate of 1 kHz in 3 cm acceletron.

Russian achievement are relativistic beam-plasma microwave generators, developed in Prokhorov IGP of RAS (Moscow), in which the electron beam interacts with a smooth waveguide filled with plasma. Herewirh radiation is broadband (spectral width - up to 4 GHz). Beam-plasma generators have the unique possibility of tuning the frequency of radiation from pulse to pulse by changing the density of the plasma, filling the waveguide. The range of frequency tuning is unprecedentedly wide and can exceed up to an octave. Disadvantages of these generators, are relatively low efficiency and the need for a strong and uniform magnetic field. Power of available today monopulse beam-plasma generators reaches hundreds of MW for a pulse duration of 300 ns.

Main directions of development of this technology in near future, are development of pulsed-periodic systems (physically possible to build such generators with a pulse repetition rate of up to 5...10 kHz) and transition to a more high-current electron beams, which can significantly raise the level of the generated microwave power with virtually no increase mass-size characteristics.

Along with relativistic generators as sources of high-power microwave radiation can be considered the traditional non-relativistic pulse generators (magnetrons and amplifying klystrons).

Advantages of magnetic generator, are compact design, maximum power density per unit weight, high efficiency, low cost. Pulse power magnetrons is about 1 MW and 10 MW at frequencies of 10 GHz and 2 GHz, respectively, pulse period-to-pulse duration ratio is about 1000, pulse duration 1...5 ms. Efficiency of powerful magnetrons is 30...50%. Magnetrons operate in aAutogenerating mode. Operating frequency of a number of magnetrons can be tuned within a small range (~ 1%). Pulsed magnetron can be considered as a master oscillator for shapers powerful short-pulse radiation by a method of active compression.

On the klystrons can get higher power levels. Klystrons can operate in enhanced mode with a gain of over 40 dB. However, mass-size characteristics of klystron worse than that of the magnetron, this is particularly noticeable for klystrons power of more than 0.5...1 MW. Klystrons, it is preferable to use as elements of a multi-channel transmission systems

phased antenna arrays (PAAR), and in systems with phase of different frequency generators.

2.1.3. GENERATORS OF ULTRASHORT ELECTROMAGNETIC PULSES

These devices usually emit short UWB pulses with maximum spectral density, lying in long-wavelength part of microwave range. In the ultrashort pulse generators energy is stored in electric or magnetic field of accumulator, then using a key is thrown into the load. Pulse duration in load is determined or by transition of key into initial state or by time, required to fully accumulator discharge. Wavefront of pulse is determined by time of key transition from one state to another. In powerful keys the times of forward and reverse transitions may differ by many orders of magnitude. In this case, minimum time defines the edge of the pulse, and maximum time - limiting frequency their recurrence.

It is currently used many different types of quick keys, the main ones are spark arrestors and semiconductor devices.

Generators using arresters are used when you want to get a extra-large powers at low pulse repetition rates. Currently, these generators have following parameters: rise time pulses up to 100 ps, pulses amplitude of 1 MV, pulse repetition rate to 1 kHz. These parameters are, apparently, close to maximum possible at current level of technology. In particular, currently, the research-production company "Era" (S.-Petersburg) develops a generator that will have power to 20 GW when generating packs of pulses of 1 s with a pulse repetition rate inside packs of up to 100 Hz. In the US, work in this direction was carried out in framework of the project "Gindenberg-3", in which generator has been created with the same parameters.

General and most significant drawback of spark arresters is the erosion of electrodes, which originates as in gas, and in oil and linearly dependent on amount of charge flowing through the gap. It is known that erosion is caused by local melting of metal in contact area of a spark channel with electrode. It is clear that to deal with it should be used as the electrodes material the refractory and well-conductive materials. Moreover, where it is possible (in first sharpened arrester, which generates front about 1 ns) necessary to increase the working surface of electrodes. This allows in spite of erosion increase the working life of the arrester is proportional to work area of electrodes, that is treated by spark discharge. Due to the large surface area of electrodes, resource of first arrester in 2...3 times exceeds resource of output arrester, and is about 10^6 pulses. Transformer oil has about same resource.

Another disadvantage of generators based on arresters are large size and weight of the instruments, as well as the complexity of their exploitation. These deficiencies have no the rapidly developing today semiconductor generators of ultrashortpulses. In particular, in the US was being developed the radiating system GEM-2, in base of which are photo switchers on the gallium arsenide, that are synchronized with a laser beam with an accuracy of 50 ps, that provides the coherent power supply for elements of phased array antenna. Device power was 1 GW, with MTBF is 10^4 positives. Easy to calculate, at a repetition rate of 100 Hz the resource of work of installation GEM-2 does not exceed two minutes.

In Ioffe Institute of Academy of Sciences (St. Petersburg) have been developed have no analogues in the world, the silicon semiconductor switches, based on the work of two effects: the effect of ultrafast recovery voltage (drift devices with a sharp recovery) and the effect of ultrafast reversible breakdown in the high-voltage transitions (devices on delayed ionization). Currently, developed an effective technology increase the voltage, by assembling devices into "stack". Herewith In the case of two-electrode devices, assembly looks to the user as one, also the two-electrode device of greater thickness.

Drift devices are the keys-Disconnect used with drives magnetic type (inductive). Energy accumulation in a magnetic field is possible at low voltage level. High voltage at load and at break only occurs for a short time pulse. As is known, resistance to breakdown of all materials is improved by reducing the time during which high voltage is applied. Thereby there is a unique opportunity to forming voltage pulses of tens of kilovolts without immersion elements in transformer oil or other insulating liquid.

Maximum peak power of semiconductor generators is hundreds of MW at a pulse repetition rate up to 100 Hz. Essential feature of this technology is virtually unlimited service life and high stability - low jitter (phase and/or frequency random

deviations of transmitted signal).

In addition, it has been possible to create powerful nano- and subnanosecond generators with a peak power of tens and hundreds of kilowatts at pulse repetition rates up to 10 MHz.

Due to extremely small jitter exists possible of "unlimited" increase of power capacity by summing the pulses of a large number generators, herewith each generator is a simple and small-sized device.

The main disadvantage of generators of ultrashort electromagnetic pulses from the practical point of view is the low value of the average radiation power. However, in Russia (RPC "Istok" Fryazino, Moscow region) there is now scientific and technical potential, allowing in the near future to begin developing a generator layout based on electrovacuum device, wherein as output of the resonator is used multi-frequency coaxial resonator, excited grouped electron flow, similar to klystron. This unit will combine high average power, durability and efficiency of traditional electrovacuum devices, as well as ultra-widebanding, characteristic for emitters of ultrashort electromagnetic pulses. Generator will emit pulses of hundreds of ps with a repetition rate of about 1 GHz. Emission spectrum will be in the range 1...8 GHz, the average power is 1 kW or more. This elaboration of RPC "Istok" currently has no analogues in the world.

2.1.4. ELECTROMAGNETIC EMITTERS WITH THE POWERING FROM EXPLOSIVE-MAGNETIC GENERATORS CURRENT

Crucial for appearance and characteristics of throw sources of microwave pulses have parameters of power supply sources. Basis of these sources, are piezoelectric and magnetocumulative (explosive-magnetic) generators. In this field Russia holds a leading position in world.

Energy conversion explosive-magnetic generator into the microwave radiation was first carried out in Russian Federal Nuclear Center - the All-Russian Research Institute of Experimental Physics (RFNC-VNIIEF, Sarov) and the Institute of Radioengineering and Electronics named after V.A. Kotel'nikov of Russian Academy of Sciences (IRE RAS), and later its effectiveness has been confirmed in experiments under the guidance of by VE Fortov and AN Didenko.

The leading role in this area, both in the country and in the world belongs to RFNC-VNIIEF and IHED of JIHT of RAS (Moscow). As part of the program to establish basic technologies was developed a series of compact explosive-magnetic generators, satisfy the requirements for throw-source microwave radiation.

In particular, by use of explosive-magnetic generator EMG-100 (VNIIEF) is formed an electric pulse with parameters of 600 kV, 30 kA, front 50 ns, sufficient for the formation of the electron beam used to generate high-power pulse of microwave radiation. When testing EMG-100 on layout of microwave generator was obtained pulse of radiation capacity of 350 MW with a duration of 50 ns. According to estimates based on model experiments in a laboratory experimental base VNIIEF with implementation of radiation level of order of 1 GW in dimensions suitable for practice, is quite possible to get radiation of 2...3 GW. When powering of Cherenkov electromagnetic structure of EMG on the diode were provided following pulse parameters: the current of 12 kA, duration of 100 ns, electrons energy of 450 keV. This led to a microwave pulse of 3-cm range with a maximum capacity of 350 MW. In this case output power was limited of the opportunities EMG. Using modern EMG, this limitation can be overcome and move closer to powers of pulses, which are limited by the electrical strength electrodynamic structures and output windows.

To some extent, these limitations can be overcome by using generators with electrodynamic systems, parallel are connected only at entrance. When working with a six-channel TWT, investigated on the electron accelerator of direct action "Ark" (Sarov), succeeded in to achieve of addition of radiations of all channels. Processes of phasing of radiation and problem of efficiency of the antennas, to be output to high-power microwave pulse in this case require further study.

With regard to foreign developments, in France being developed the throw microwave radiation source, with a capacity of about 1 GW on the basis of explosive-magnetic technology and vircator systems. On the establishment of such a source and putting it into service in the UK reported repeatedly. However, level of open works on technique of explosive-magnetic generators compels one take

these messages quite critical.

In the USA (work on orders of the Air Force) came close to the implementation EMG, of corresponding on parameters described above EMG-100. Modern state of American researches in vircators field, apparently, corresponds to Russian.

Promising areas of research in this area seems to be finding ways of creating EMG, which generate not one current pulse, but sequence of several pulses. In addition is of great interest the develop of relativistic beam-plasmic generators, which are powered from EMG (estimates show that it is quite possible). Combining these elaborations allow by undermining VMG to generate powerful pulses, whose spectrum covers the range 1...7 GHz or 5...30 GHz. This result would be very interesting from the practical point of view. Another promising direction is to create generators ultrashort pulses, which are powered by EMG

Projected potentially possible characteristics of radiation generators, developed in the framework of non-nuclear microwave systems, are presented in **Table 4.**

Among the most research priorities in the

Table 4

Predicted characteristics of EM radiation for various types of microwave systems

Microwave generator types		Characteristics					
		Pulse power	Pulse duration	Average frequency, GHz	Spectrum width, %	Frequency repetition, kHz	Divergence, rad (antenna type)
mobile	Traditional (klystron, magnetron, etc.)[1]	up to 1 GW	1...10 μs	1...10	0.1	up to 1	0.01 (PAAR[4])
	Solid[2]	up to 10 GW	units ns	0.1...10	50...100	up to 10	no data (PAAR)
	Relativistic						
	BWT, magnetrons, klystrons, etc.	1...5 GW	tens ns	1...10	1	up to 1	0.01 (reflector)
	Beam-plasma	up to 1 GW	10 ns...1 μs	1...50	100	up to 0.1	0.1 (рупорная)
	Vircators	1...5 GW	10...500 ns	1...l0	10...100	units	0.1...0.01 (reflector, horn)
	Free-Electron Lasers	up to 10 GW	tens ns	35...100	1	up to 10	0.01...0.001 (reflector)
throwing	Vircators with powering from EMG	up to 1 GW	10...500 ns	1...10	10...100	mono-pulse[3]	0.2...0.05 (horn)
	BWT, magnetrons, klystrons and others. with powering from EMG	up to 1 GW	tens ns	5...35	1	mono-pulse	0.1...0.01 (horn)
	VMG direct conversion	0.1...100 MW	10 ns...1 μs	0.1... 100	100	mono-pulse	4π
	Beam-plasma amplifiers	tens of kW	continuously	1...8	30...40	continuously	0.1...0.2 (reflector, horn)
	Solid	up to 1 GW	units ns	0.1...10	50... 100	up to 10	no data (PAAR)
stationary	Traditional (klystron, magnetron, etc.)	up to 1 GW	100 ns...5 ms	0.3...300	0.1	up to 1	0.001 (PAAR)
	Traditional with time compression	up to 10 GW	1...10 ns	1...10	0.1 ...1	up to 1	0.001 (reflector, PAAR)
	Relativistic	1...5 GW	tens ns	1...10	1	up to 1	0.001 (reflector)

[1] For a traditional generator provides the power output of entire system, rather than one generator
[2] At output of generators this class is generated video pulse which is then fed to a special antenna
[3] Perhaps formation of pulses pack duration tens ns with a pulses repetition rate in pack tens to hundreds of Hz
[4] PAAR - phased antenna arrays

development of powerful electromagnetic emitters for the next 5-10 years include:

- Development of semiconductor generators providing formation at distances up to tens of meters of ultrashort pulses of electromagnetic radiation with duration of 50 ps, with amplitude of electric field strength up to 50 kV/m and pulses duration of 100...300 ps, with amplitude of electric field strength up to 500 kV/m, with frequency repetition of 10 kHz.
- Development of generators of ultrashort pulses based on electrovacuum devices that provide average power of radiation up to several MW for a pulse duration of order of 1 ns and pulse repetition rate greater than 1 GHz.
- Creation of relativistic beam-plasmic microwave generators with pulse power of more than 1 GW, providing restructuring of the carrier frequency radiation in the range 1...10 GHz and working in pulsed-periodic mode with a pulse repetition rate to 1 kHz.
- Increasing the duration of pulses of relativistic high-powered generators to several microseconds while maintaining the pulse power at level 1 GW and realization pulse-periodic mode of operation with a pulse repetition rate to 1 kHz.
- Development of explosive magnetic generators, providing at blasting explosive the generation of a sequence of several pulses.
- Development of beam-plasmic emitters, which are powered from explosive-magnetic generators.
- Development of emitters of ultrashort electromagnetic pulses, which are powered from explosive-magnetic generators.
- Development of phased array antennas that emit pulses with a duration to 10 μs gigawatt power level.

2.1.5. MICROWAVE WEAPONS

Study of mechanisms of AME vulnerability is at stage of elaboration of possibility of using EMR and microwave radiation to destroy AME with energy levels much lower than that required for implementation of destructive mechanisms of action. Revealed the presence of various manifestations of exposure to EMR and microwave radiation on radioelectronic and electrical systems, due to the complexity of the design solution, element base, differences in purpose, a wide range of used electromagnetic frequencies, etc.

It was expected that to 2005 must be completed theoretical and experimental works on creation database of mechanisms and threshold levels of defeat of main types of arms and military equipment (AME).

Most active works on creation of microwave weapons are held in US and Russia. In recent years, studies in this area have been deployed in France, England, Germany, Israel, Japan, China and Sweden. All R&D on creation of microwave weapons are aimed at creation of models of weapons for the following tasks: disorganization combat control, intelligence and communication in strategic and tactical scales; protection of objects from precision weapons with any guidance systems; suppression of air defense systems and missile defense; decommissioning of space objects; antiminestruggle. Already during the Gulf War, in US have been tested prototypes TFR "Tomahawk" (*Block IV*) with experimental microwave warheads, and bombs *BLU-109*, *BLU-113* with microwave-combat equipment.

American studies in the field of microwave weapons are carried out in two major, interrelated areas:

- development of microwave strategic weapon (includes terrestrial microwave complex anti-space defense, nuclear microwave weapons and cruise rockets "Tomahawk" sea-based);
- creation of a complexes microwave weapons of tactical purposes.

Creation of *tactical* microwave weapons are practically all the Contracting Departments of US Ministry of Defense. Herewith for tactical microwave weapons, due to common developtechnological base (microwave generators, powerful amplifying modules and antenna systems, power supply sources, etc.) is characterized by functional convergence or unification with promising radar technology and means of electronic warfare. In particular, by development of tactical microwave weapons examines the concept of complex, generating in reduced power mode radar detection and tracking of target, and at maximum power - its functional or forced defeat. As typical goals defeat by powerful microwave radiation are considered digital special-processors of control systems ICBR, TR, OTR; system protection and cocking fighting equip rockets, electrical appliances of undermining mines

and roadside bombs, navigation receivers of system "GLONASS", radar air defense/missile defense, electronics of the homing missiles and missiles of "air-to-air" and others.

Analysis of existing and emerging types of microwave weapons, methods of combat application has allowed us to identify common perspectives of development of such systems in United States for the period up to 2017 (Table 1).

In the area of electromagnetic weapons (microwave weapons) intensively developed the following types of sources of high-power microwave radiation:

- sources on the basis of microwave generators and phased antenna arrays, summing capacities of individual microwave generators into a narrow beam of microwave radiation;
- microwave generators on relativistic electron beams;
- quasi-isotropic sources, including broadband microwave radiation on the basis of explosive-magnetic generators;
- microwave generators on the basis of special nuclear munitions ultra-low power.

Source on basis of microwave generator and phased antenna arrays is a microwave device, that summarizes power of low-power microwave generators or amplifiers, which are excited by a single master oscillator. As a master oscillator are used magnetrons and klystrons. Currently, the most developed are the questions of creation of microwave sources based on magnetrons, compression pulse shapers (based on the long-term accumulation of microwave energy in the cavity resonators and quickly eliminate it in the load) and PAAR.

Pulse generators on relativistic electron beams, are a set of compact high-current accelerator, operating in a pulsed mode, and special electrodynamic system in which electron beam energy is transformed into energy of microwave radiation.

Sources of quasiIsotropic, including and broadband microwave radiation on basis of explosive-magnetic generators, are devices of single use, based on conversion of chemical energy of condensed explosives substances into electromagnetic energy of microwave band. There are two classes of explosive-magnetic generators: with relativistic microwave sources and direct conversion (the EMG frequencies and shock-wave radiators).

Explosive-magnetic generator acts as a power source for the relativistic oscillator single action. Principle of operation is to convert current pulse generated EMG, with help of special transformers and sharpeners of voltage, in high-voltage pulse applied to vacuum diode relativistic generator (vircator, gyrotron, Cherenkov generator, etc.). At the output of such devices received a single relatively narrow-band pulses. Operating principle of explosive-magnetic generator is based on amplification of the initial magnetic field, generated by a system permanent magnets due to work, that is performed by explosion products above moving core EMG, consistently closing coils of the circuit and reducing it inductance. Part of energy is displayed in form of microwave radiation by the turns of circuit, acting as effective radiated helical antenna (for low-frequency harmonics current circuit).

Operating principle of shock-wave emitter (SWE) is based on implementation of processes of compression of magnetic field with help of shock wave in solid body (in initial state - dielectric) by powerful converging shock wave. At the front of the shock wave occurs transition of substance single crystal into state of metallic conduction and creates a mode of radiative magnetic cumulation, occurs an ultrafast relaxation of the energy stored in single crystal due to rapid change of magnetic field.

Among the sources of radiation on the basis of special ultra-low power of nuclear munitions, which are transformed by thermonuclear or nuclear reactions into sources of energy directional flow of microwave radiation, there are two classes: generators of quasi-coherent microwave pulses, which use for their generation the electrodynamic systems similar to those used in the sources on relativistic electron beams, and generators of the two-half-cyclic electromagnetic pulses of wide spectrum. In this forecast prospects for nuclear generators are not considered.

A special place among the already builted prototypes electromagnetic weapons takes "HF-bomb" (*E-bomb*). It is assumed that the "HF bomb" will be powered from EMG, piezoelectric generators or specialized nuclear munitions. Discusses options in which as the antenna system of "HF bomb" will be used special (metallized) parachute straps.

Very promising here, are studies of new features (effects) interaction of superpowerful radiation with

matter. In particular, intensively unfolding studies of the peculiarities of relativistic mode of interaction with use of petawatt lasers power. It has been proved that mutual attraction of currents produced by "fast" charged particles inside self-focusing filaments radiation causes them to merging into a single channel with significantly increased density of radiation energy.

Thus, in the creation of powerful electromagnetic generators can distinguish following main areas of researches and development:

- development of devices traditional and relativistic microwave electronics, generating pulses with a duration of ten or more periods of carrier frequency;
- development of generators of ultrashort electromagnetic pulses, duration of which does not exceed 2...3 half-cycles of oscillations;
- creating electromagnetic emitters with powering from explosive-magnetic generators current.

2.2. TOOLS OF INTENTIONAL ELECTROMAGNETIC IMPACT ON A HUMAN

On the basis of actually existing, potential and hypothetical feasibility of realisation of weapons of non-lethal action, accepted to allocate one of its possible forms - *electromagnetic weapons of non-lethal action* (EWNA).

In studies on the mechanisms of action of EMR on human body usually allocate energetic and information processes. Most fully to date, was studied energetic impact of microwave radiation of relatively high intensity.

Depending on frequency and power of radio frequency radiation on humans observed following effects: disruption of the brain and central nervous system, sense of noise, whistling, temporary incapacitation, defeat of internal organs with a certain probability lethal outcome. Modern assessment of nature of biological action of electromagnetic fields (EMF) for creation of non-lethal weapons are shown in **Fig. 2**.

Most rapidly being developed low-power electromagnetic devices for short-term suppression psycho-volitional sustainability (management of activity nervous system) humans. From viewpoint of influence on bioobjects, electromagnetic radiation such devices are characterized, mainly, several biotropic parameters. Most important ones are intensity and frequency of exposure to EMF.

Analysis shows that the mechanisms of information exposure relatively low power microwave radiation have been studied very little. In the 70 years was reported the discovery in the US so-called effect radio-earshot (radiosound). Effect supposedly was in fact that people who were in a strong field of broadcasting stations, began to hear "inner voices", music and the like. Presence of effect was due to possibility detecting of modulated carrier oscillations radio stations in internal nonlinear media of human body with subsequent conversion into signals perceived by auditory nerve. In course conducted in first half of 70s studies have identified threshold powers for effect in microwave range in pulse mode. Feeling of audible sound occurs in humans during it irradiation by pulse-modulated electromagnetic radiation microwave range. In the event that pulse repetition frequency of microwave radiation lies in the audio frequency range the perceived sound is reminiscent usually high-frequency whistle, like tinnitus, arising from a sudden change in pressure

Maximum sensitivity of brain tissue, regulation of biorhythms (6-20 Hz frequency EMF, level of 10 W/cm^2)	→		←	Resonance with biocurrents brain, dysfunction of heart muscle (300-700 Hz frequency EMF, level of 10 W/cm^2)
The heating of deep parts of the brain, the heating of the temporal lobes, hemodynamic disturbances in peripheral circulation (300-1200 MHz frequency EMF, level of 100 mW/cm^2)	→		←	Jump of conductivity biological tissue (10-100 kHz frequency EMF, level of 10 W/cm^2)
Instability of the pulse, changes in systolic blood volume, blood pressure, peripheral vascular spasm (460 MHz frequency EMF, the level of 50 mW/cm^2)	→		←	The effect of "string of pearls" - alignment of erythrocytes and leukocytes in field (EMF frequency 1-100 MHz, level of 100 W/cm^2)
Greatest impact on central nervous system; after prolonged exposure, a violation of a regular function of higher vegetative organs (10-100 GHz frequency EMF, level of 10 mW/cm^2)	→		←	Changing level of EEG (1-100 MHz frequency EMF, level of 0.1 W/cm^2)
			←	Pain threshold for cutaneous receptors (EMF frequency 20 GHz, level of 100 mW/cm^2)

Fig. 2. *Characteristics of bioeffects, caused by energetic impact to EMF on humans.*

or various diseases of the ear. Most sensitive to irradiation is parietal head region. At irradiation of occipital and temporal areas this effect is somewhat weaker. To date found that when a frequency of 3 Hz with a pulse duration of about 20 μs the energy threshold of radio-earshot is 10 μJ/cm^2.

As shown by the analysis, for explain the radio sound effect most widespread became a scientific hypothesis of thermal mechanism action. According to this hypothesis, the microwave exposure is accompanied by a negligible temperature rise of brain that can lead to vibration effects, associated with tissue expansion. However, a complete physical picture is quite complex and for its explanation is necessary to study of timing synchronization of flows of nerve impulses in the ascending neural structures of auditory apparatus. It can be expected that in future is possible to create EWNA on radio-sound effect, which capable of providing as psychological treatment of small groups of soldiers (divisions of enemy, terrorist groups, etc.) and of large masses of population.

In the US, work on EWNA conducted in the framework complex target program "*Joint Non-Lethal Weapons Program*" (JNLWP). In the early 2000s on the orders of the Ministry of Defense have been carried out fundamental and applied researches on the development of application technology of pulsed electromagnetic radiation (millimeter wave) for non-lethal effects on biological objects. The developed technology called "*Active Denial Technology*" (ADT). On its basis in framework of projects of applied research and technological development of the Ministry of Defense US are working on creation of prototypes of non-lethal weapons - "Systems of active microwave-exposure" (Active Denial System - ADS)[1]. It should be noted that basic technical characteristics of new weapons such as ADS, thus far unknown.

Available data allow us to identify the following features of technology of ADT. The technology is based on the property of intolerance thermally induced pain, that is created by heating skin from directed intense EMR in 3-mm wavelength range (in different sources are given frequencies from 94 to 96 GHz). Within this range EMR penetrates into the skin tissue to a depth of 0.3 mm, where pain receptors are located. EMR parameters are chosen so that its action does not cause burns and permanent injuries, and occurring pain effects were of short duration. Possibilities of frequency-modulated signals in system ADS are unknown. However, if we assume that modulation is supported properly, then ADS can be not only a thermal weapon, but and means, which causing obscuration consciousness.

It should also be noted that to date there has been a steady growth in studies of various biologically significant effects of electromagnetic exposure on most important functional systems of the body, such as the nervous, endocrine and humoral. Predict their results over the long term is not possible because of the high secrecy works and significant differences in the experimental results. However, it can be expected that up to 2015 will be developed generators of weak EMR, are able to effectively influence the biochemical and cellular homeostasis, modify central nervous system, alter cell morphology, i.e. are able to provide to human the non-lethal effect.

In general, direction of research in field of creation of electromagnetic weapons non-lethal action can be considered as very promising (especially for fight against terrorism), but it requires solving a number of medical, biological and radiophysical problems.

3. GEOPHYSICAL DISTURBANCES IN IONOSPHERE CREATED BY NATURAL AND ARTIFICIAL WAY AS A SOURCE OF POWERFUL EXPOSURE IN NATURE

Natural magneto forming phenomena in nature are occur in near-earth of atmosphere, in its upper layers - in ionosphere and magnetosphere, so it is advisable to briefly discuss the basic characteristics of the ionosphere, ionospheric processes of formation of radiation, as well as role of Earth's magnetosphere in the near-earth processes and what are the arising herewith the managed plasmoids.

[1]In 2003, research and development on create ADS provides project №7757, program element PE 0602202F (applied research with funding of $4.6 million), №3552, program element PE 0603605F (technological developments with funding of $2.012 million). In the future plans of R&D of Ministry of Defense US (JWSTP-2002, DTO-2002) was determined that work to create a mobile version of ADS (based on vehicle HMMWW) should be completed by 2006, and at aircraft - in period of 2010 -2012 years)

3.1. PHYSICS AND ORIGIN OF MAGNETO-EMITTING NATURAL PHENOMENA IN NATURE

3.1.1. IONOSPHERIC RADIATION AND ITS MAIN CHARACTERISTICS

Ionosphere (from the ions and the Greek. spháira - ball) – ionized part of upper atmosphere; located greater than 50 km. Upper boundary of ionosphere is outer part of Earth's magnetosphere. Due to its high electric conductivity it has specific properties that determine nature of propagation in it of radio waves and various ionosphericdisturbance. Only due to ionosphere is possible such a simple and convenient form of communication over long distances, as radio communication [15].

It is known that concentration of ions and electrons in ionosphere is distributed unevenly, there are regions or layers, where it reaches a maximum. [15, 16, 17] (**Fig. 3**).

Such ionosphere layers there are several, they do not have sharply defined boundaries, their position and intensity are changed regularly throughout day, season, and 11-year solar cycle. Top layer of *F* corresponds to principal ionization maximum of ionosphere. At night, he rises to heights of 300-400 km, and during day (mainly in summer) splits into layers F_1 and F_2 with peaks at altitudes of 160-200 km and 220-320 km. At altitudes of 90-150 km is area *E*, and below 90 km area *D*. Stratification of ionosphere caused by an abrupt change on height of conditions of its formation.

Formation ionosphere. Observed in ionosphere concentration of ions and electrons is result of a balance between rate ionization and rate recombination of electrons and ions (up to their destruction), etc. Sources of ionization and recombination processes are different in various areas of ionosphere [18-20].

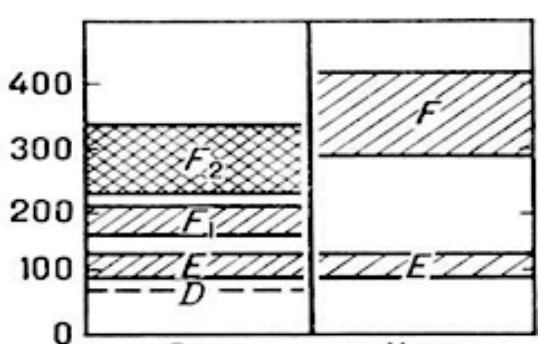

Fig. 3. *Scheme of distribution layers of the ionosphere for height (km). Left - day, right - night.*

Main source of ionization of ionosphere during the day is short-wave solar radiation with a wavelength shorter than 1038Å, but are also important corpuscular streams, galactic and solar cosmic rays and others. Each type of ionizing radiation has greatest effect on atmosphere only at certain altitudes, corresponding to its penetrating power.

Composition of ionosphere. Under influence of ionizing radiations in ionosphere there are complex physical and chemical processes, which can be divided into three types: ionization, ion-molecule reactions and the recombination corresponding to three stages of life as ions: their formation, conversions and destruction.

Changes of ionosphere. Ionosphere is continually changing. Distinguish between regular changes and indignant states. Since main source of ionization is short-wave radiation of sun, many regular changes of ionosphere are the result of changing either height of sun above horizon (diurnal, seasonal, latitudinal changes), or level of solar activity (11-year and 27-day variations).

Solar flares sharply increase ionizing radiation that causes so-called sudden *ionospheric disturbances.* Indignant states of ionosphere are often associated with *magnetic storms.* Many phenomena that occur in upper atmosphere and in Earth's magnetosphere, are closely related.

Characteristics of ionospheric layers. Regularities of parameters change of ionosphere - degree of ionization and ion composition and effective recombination coefficient are different in different areas of ionosphere. This is primarily due to a significant change on height of concentration and composition of neutral particles of upper atmosphere.

At present, *study ionosphere* continues to evolve in two directions - in terms of its impact on *propagation of radio waves* and study of *physical and chemical* processes occurring in it, which led to birth of a new science - *Aeronomy*. Modern theory helped to explain distribution of ions with altitude and effective recombination coefficient. Now next task is to build a unified global dynamic model of the ionosphere. Performance of this task requires a combination of theoretical and laboratory researches with methods of direct measurements on rockets and satellites and systematic observations of ionosphere on a network of ground stations.

3.1.2. PHYSICAL CONCEPTS OF TYPICAL CHANGES IN STRUCTURE OF MAGNETOSPHERE

Magnetosphere - the region of near-earth space from 10 to 25 Earth radii. Its boundaries and configuration are defined by solar wind, that flowing around earth - a constant stream of helium-hydrogen plasma of solar corona into interplanetary space. Processes of restructuring of the magnetosphere, local or large-scale, are significant, if not major factors of perturbed magnetosphere, that create in ionosphere *auroral radiations, auroras and magnetic substorms.* In [21] it is noted that magnetosphere is rarely quiet. Perturbations are divided into three types: permanent polar perturbations, substorm activity, magnetic storms.

Auroral radiations. Often term "auroral zone" is translated as "Northern Lights". This is due to the fact that in polar regions of Earth at high altitudes in ionosphere there are heterogeneities, that called auroral. [21-23]. This a excited ions gases united in so-called plasma ropes, stretched along the magnetic field lines of Earth. They have a length several tens of meters, and a thickness of about 10 centimeters. Causes appearance of these structures and their physical essence so far almost not been studied. During periods of solar storms a number of auroral structures, heated to degree of luminosity, increasing rapidly, and then they in the form of Aurora Borealis are visible even during day up to the equator. In [21] distinguish two areas - the auroral magnetosphere, main region habitat of auroral radiation, located within area of quasicapture (AQC), and magnetospheric tail, where streams of energetic particles appear sporadically, for a short time (**Fig. 4**).

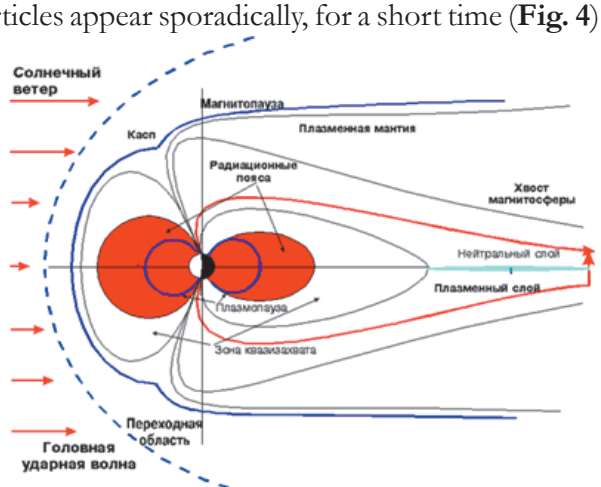

Fig. 4. *Dependence of boundaries auroral oval from level of magnetic activity: region quasicapture - auroral magnetosphere.*

AQC - unstable radiation region is located between radiation belt and tail of magnetosphere.

Auroral radiation occurs during magnetosphericsubstorms, and on different stages, phases of substorm there are several mechanisms of particle acceleration, and therefore auroral radiation should be divided into several types according to the origin, nature of temporal variations and energy spectrum.

Area in which appears and remains for some time flow of freshly accelerated particles (auroral magnetosphere), is located inside the AQC. Its instant and average statistical boundaries do not coincide with boundaries of AQC, so how determined not only by configuration of magnetic field, but also size and depth of penetration of large-scale electric field of convection and dynamics of substorm process in general.

Energy spectra of auroral protons are in range from 100 eV to 500 keV in preliminary phase of a substorm. Three energy regions, three populations of protons can distinguish here: 0.1-5 keV low energy, great variability of which indicates ionospheric origin, energetic above 50-70 keV and intermediate, units and a first tens of keV.

Thus, a common source of ionospheric and magnetic disturbances and auroral on substorm active phase is the precipitation of auroral electrons into atmosphere.

Auroras. According to accepted classification, auroras are divided into three groups: *ribbon-like, diffuse* and *rays* [24-27].

A ribbon-like forms are arcs and bands, which are characterized by a continuous lower boundary. Arcs have form of arches, which stretch from west to east with correct, usually sharply defined lower edge. Often there are a multiplet arcs at intervals of 30-40 km. If lower edge of auroral is wrong, and contains a bend or crease, form aurora called stripe. Stripe is generally more mobile than arc.

Diffuse auroral forms may be in form of spots with indistinct borders resembling clouds, illuminated by moon, and in form of veil, which is an extended homogeneous illumination and cover most of sky. The spots usually appear in the auroral zone on the last stage of development of the phenomenon.

So-called *rays* are narrow beams of light, located in the space along the magnetic field lines of the Earth, which are divided into three groups (depending on

their length): short (bright at the bottom edge and pale with height), medium (same brightness over the entire height) and long (usually uniform in brightness, but rather weak). Can also be seen bundles of rays is closely located near each other or scattered. Rays often observed in conjunction with other forms.

According to international classification, there are three types of *structures of elements auroras:* homogeneous, fibrous (grooved) and radiant. Homogeneous radiance has no internal structure of glow, with no visible rays. Fibrous structure consists of a rather chaotic strips or filaments, strips are directed substantially parallel and can have a quite regular structures of glow separated by dark intervals. The radiant structure of glow how would is woven from the masses of individual, often shimmering rays.

Magnetospheric substorms. The term substorm was introduced in 1961, C-I. Akasofu (Syun-Ichi Akasofu) to denote auroral disturbances in auroral zone lasting about an hour. Over time, term "magnetospheric substorm" combined aggregate of many processes in ionosphere and magnetosphere.

Substorms power can be estimated by the maximum value of magnetic field component (from ~100 to 1000 nT) and area space, covered by perturbation and length of substorm expansion to pole. The total potential difference is estimated at 40-100 kV. About the physical mechanism of occurrence of electric field is still there is no single universally accepted opinion.

Most widespread is idea communication electric field with vortex large-scale convection of plasma in magnetotail, so it is often called the field of convection. Convective field, intensifies and shifts to the Earth of the drift current in zone quasicapture that changes the configuration of magnetosphere, pulling lines of force into tail. The magnetic field in tail lobes increases due to the transfer of magnetic flux with day hand, and plasma layer thickness in the tail decreases. However, convective hypothesis has faced a number of difficulties.

- firstly, idea of laminar plasma flows in the tail is not confirmed by experiment, speeds of random motion on the order exceed a directional component.
- secondly, registered rapid changes of electric field are not provided by slow process of unwinding of convective vortex.

According to observations of auroras they are characterized by phases of expansion and damping.

Expansion phase can be traced from time to time according to observations of auroras that occur in north and moving south (diffuse arcs) and is most pronounced process of active phase. At the same time still remains unclear why some perturbations lead to expansion, and others - no. Perhaps a significant suppression of expansion can be caused by electric field of solar wind. If the beginning of substorm was spontaneous and the interplanetary magnetic field is negative, then expansion is suppressed and its spatial mileage limited to a few degrees. On other hand, often substorms begin when sign changes from negative to positive; wherein electric field is reduced and does not prevent expansion.

Active auroras forms may not be very bright, as in the beginning, that continue to arise and move across sky. In direction from auroral ledge to the equator develops pulsating glows, mostly in form of spots, in this way, magnetic trap is freed from excess of auroralparticles. On western flank of active aurora in area of sharp boundary of his convexity, flows powerful jet the longitudinal current, are separated populations of particles, and preparing a new intensification of substorm with expansion through jump to the west.

Phase damping. The boundary between the active phase and the phase damping rather conventional. As conventionally, and the end time of phase damping. Magnetosphere returns to relaxed structure of boundaries for 1-2 hours, if there is no new disturbance. Outer radiation belt is released from excess particles accelerated during substorms, for a long time, certain types of microbursts X-ray, evidence of dumping of particles observed one day after strong substorm.

On the discussed issues [24-27] can be made the following conclusions. Over half a century of research magnetospheric disturbances made great progress, and can even give the impression that structure, dynamics, basic processes of magnetospheric disturbances are understood and are in the process of drilling, deepening in some private questions. However, this impression is false, as is still the knowledge of dynamics and structure of electric fields is insufficient.

Electric fields are measured with great difficulties and limitations, theorists can not come to a consensus

on key issues of emergence of electric field, its penetration into magnetosphere and relationship with reconfiguration of magnetic field and the particle fluxes.

To fully clarify physical concepts of types of changes in structure of magnetosphere also is required study of many issues in solving the problem the acceleration of energetic ions. Still very rough ideas about structure and fine temporal history of auroral activations, about relationship between substorms and global magnetic storms. That's enough to make sure that study of magnetospheric disturbances is still much to come.

What is a plasmoid. Generally currently assumed two fundamental ways to impact on ionosphere - spraying it chemicals and "pumping" of selected sites by the focused beams of radio waves, "excitement" of atoms. Thus it is possible to influence the auroral streams of charged particles in vicinity of North Pole, which then are distributed along magnetic field lines of Earth over long distances, or create the local highly ionized areas of ionosphere - plasmoids (size is usually several tens of kilometers).

In principle the plasmoids are not anything special. Daily in atmosphere is registered several such natural formations arising under influence of "solar wind" and quickly absorbable. But artificial plasmoids have one distinctive feature: as long as there is "pumping", they are stable and have exogenous characteristics.

Artificial plasmoids can be used for example to improve radio communications when at certain parameters of the pump radiation they are converted into a giant mirror reflecting radio waves. But this is only one side of coin. If you change pumping parameters, you will receive a giant "jammer". If you can force "excited" atoms synchronously reset pumping energy, you get a set atomic lasers, defeating, primarily, electronic system potential enemy.

According to [15], *plasmoid* - is a *plasma* clot, limited configuration of magnetic fields and plasma. Natural plasmoid formed by interaction of *magnetic earth's field* and *solar wind* (see. Fig. 4).

At his time, Nikola Tesla received spherical plasmoids on resonant transformer using a high-voltage discharges [16-17]. Possible using of plasmoid, that generated by microwave radiation, in industry [15].

Currently literature introduces the concept of autonomous plasmoid, when plasmoid's magnetic field is maintained by own currents of plasma, and than less leakage of energy, the longer it can exist [15]. It is believed that in study of physics and natural origin magneto-emitting phenomena, study plasmoids - a possible way to obtain, for example, ball lightning in laboratory [15]. Because it is believed that formation of plasmoids occurs on model of ball lightning, according to which the plasma phase holds a thin molecular-crystallic shell consisting of electrically charged clusters "hidden" water phase [15]. And then you can get closer to a fuller comprehension of the problem being addressed in obtaining results, which explain more accurately formation of plasmoids and their management.

However, much about the shape of plasmoids was clarified already during lifetime still Tsiolkovsky, when he expressed hypothesis of existence of *life on Sun* in form of plasma, and about the plasmoid as a source of life on Earth. Was obtained experimental evidence that under certain conditions, plasmoids can multiply that illustrates their potential to be basis for life [15]. But this is not enough.

Plasmoid formation in troposphere near surface the Earth's are formed mainly over degassed structures and tectonic faults. Plasmoids sizes range from 3-5 cm up to 100 meters and more. Some of them may be recorded by camera (infrared and ultraviolet ranges of frequencies of electromagnetic waves), in rare cases can be detected even with naked eye.

To plasma formations in nature, or so-called plasmoids today accepted to attribute not only unidentified flying objects (UFOs) and ball lightning, but all that is localized in free space and illuminates some time without apparent consumption of energy [28-29].

Thus, to understand nature of plasmoids, scientists and sympathizers curious people are not limited to natural observations and descriptions of witnesses and trying to get plasmoids at least in laboratory.

3.2. GEOPHYSICAL IONOSPHERIC DISTURBANCES CAUSED BY ARTIFICIAL MEANS

Opportunity to influence the surrounding atmosphere and emergence of geophysical

disturbances by artificial means, and above all impact by electromagnetic means, began at the turn of XX-XXI centuries subject of active research. Because of direct communication of results such research with conditions of life on Earth, they have also been widely discussed in media, especially in electronic - online [see. eg., 30-42], at main resource of information infrastructure of society.

For a complete understanding of these effects we stop on natural effects and their implications for other active influences on various geospheres.

3.2.1. NATURAL PHENOMENA AS A RESULT OF THE ACTIVE IMPACT ON VARIOUS GEOSPHERE

An important problem is evaluation of criteria of impacts on one or another geosphere which may lead to planned effect. Indicative list of geophysical effects and consequences of impacts on various geosphere, compiled on basis of very limited material, as well as on basis of general physical considerations, is presented in **Table 5.** Here are the possible methods and means of influence. Obvious approach to assessment of such criteria is to compare, for begin, of total energy of any natural process with the active impact energy.

It is quite clear that with few exceptions (nuclear explosions, asteroid-meteor weapon), energetics of any active effects is incomparably small compared with the energetics of their geophysical implications.

There would be appropriate to give some examples of Internet materials of natural catastrophic events that are still not entirely clear on, but the alleged reasons occurred in recent decades in the world.

Table 5

List of effects and consequences of active impacts on different geosphere

	Geospheres	Methods and means of impact	Effects and consequences
1	Lithosphere, including crust and soil	- underground and underwater nuclear explosions or explosions of chemical explosives; - explosions on offshore or in coastal waters; - seismic vibrators or vibrators in underground mines or wells filled with water; - artificial change of trajectories of falling asteroids and meteors	- initiation of earthquakes; - possible increase volcanic eruptions and occurrence of effects of tsunami; - changing chemical and physical composition of soil, including radioactive and chemical contaminations
2	Hydrosphere (oceans, seas)	- the discharge into atmospheric near-ground layers, different chemically active substances or dust components that affect solar radiation; - creation of the regional greenhouse effect that could lead to formation of atmospheric phenomena, such as those arising in development of process of El-niño; - artificial change of trajectory of falling asteroids and meteors	- destruction of plankton and other species living organisms; - development of typhoons, hurricanes and storms; - occurrence of tsunami waves and storm surge; - changing weather and possible short-term climate changes
3	Atmospheric near-earth laye	- the discharge into atmosphere of various chemical active and aerosol (dust) components; - impact of electromagnetic microwave radiation and heat flux	- increase in rainfall, causing to floods; - accelerating melting of snows and glaciers; decrease in precipitation leading to droughts; - occurrence of devastating hurricanes at different latitudes; - changing transparency of atmosphere and, as a consequence, the weather at local or regional scales
4	Ozonosphere	- the discharge into ozonosphere different chemical substances; - creating at altitudes of ozonosphere artificial forms affecting the distribution of solar radiation; - exposure to UV and microwave radiation	- creation of new and expansion of existing ozone holes and a corresponding increase in intensity of hard ultraviolet radiation incident upon earth; - growth of ozone concentration; changes of radiation balance of atmosphere
5	Ionosphere	- injection of various chemicals (gaseous, dispersed); - injection of electrons, ions; impact of powerful VLF, HF and microwave radiations and UV radiation sources; - explosions of chemical explosives	- changes in ion and neutral composition of medium with subsequent significant impact on functioning of various radio engineering and optical means; - initiating precipitation of charged particles from different layers of ionosphere; - variations of magnetic and electric fields of Earth of local and another scale; - emergence of artificial lightnings
6	Magnetosphere and near-earth space	- injection of electrons and plasma; - impact of powerful VLF radiation; - discharge of finely dispersed matter (like “pins and needles”); - explosions of chemical explosives	- change of Earth's magnetic field; - change of electric field of near-ground layers of atmosphere; - appearance artificial or changing of parameters natural radiation belts of Earth; - possibility of increasing "space debris"

Shortly after the end of World War II in United States began to conduct research on the study of processes in atmosphere under influence of external factors: "*Skyfire*" (formation of lightnings), "*Prime Argus*" (call earthquakes), "*Stormfury*" (management of hurricanes and tsunamis). About results of these works nothing and nowhere was not reported. However, it is known that in 1961 in USA was conducted experiment on an throwing into upper atmosphere more 350 thousand two-centimetric copper needles, which dramatically changed a heat balance of atmosphere. As a result there was an earthquake in Alaska, and part of Chile coast collapsed into Pacific ocean.

"*Spinach" against guerrillas* [31]. During Vietnam War (1965-73) the US used dissipation of silver iodide in the rain clouds. Operation took place under the code name "Project Spinach» (*Project Popeye*). In five years were spent 12 million. pounds on "seeding" of clouds for artificial stimulation of heavy rains to destroy crops of enemy. Was washed out and the so-called Ho Chi Minh Trail - supply route of south-vietnamese guerrillas arms and ammunition. During operation "Spinach" rainfall in affected area increased by a third: climatic weapon successfully worked!

Very strange tsunami. In early 2003, the Americans openly announced trials of some "beam gun" in Alaska [32], that generates a control plasmoid. From specified source is provided image (**Fig. 5**): a huge wave, formed by using managed plasmoid could collapse at any coastal area, causing extensive damage.

In press via Internet (topics: tsunamis, climate weapons, nature, disasters, catastrophes) for 2007 noted: "It's been more than two years after hitting giant waves on coast of Indonesia, Thailand, Somalia, Sri Lanka and Sumatra (December 2004). It is assumed that test secret geophysical weapons in Alaska caused a tsunami that killed more than 400 thousand people in Indonesia, over the Tennessee tornado swept", consequences - **Fig. 6** [33].

Fig. 5. *Type of wave formations, caused by means* of plasmoid.

Mysterious weather phenomena in Russia. In our country, frequency of mysterious natural phenomena over the last 15 years has doubled. Even in Siberia came hurricane-force winds, tropical storms and tornadoes - phenomena that previously been considered absolutely impossible in our climate, not to mention winter thaws and frosts in July. Such extraordinary natural examples include following:

- May 29, 2002 in Kemerovo region tornado destroyed village Kalinovka. Two people were killed and 20 were wounded. Prior to that, such natural phenomena in Novosibirsk or Kemerovo regions was not observed.
- Huge, with pigeon's egg, hail fell in 2006 in village Gagino in Nizhny Novgorod region. 400 houses completely lost their roofs.

And in general - only in June 2006, Russia has flown 13 tornadoes and hurricanes. They walked the Azov, Chelyabinsk, Nizhny Novgorod (touched 68 settlements of region), then moved to Bashkiria and Dagestan. Destructions was enormous.

Let us state a hypothesis: it is possible that today's heat in the central regions of Russia is also the result of action of such weapons.

With actions radar, with powerful electromagnetic radiations is associated series of man-made disasters and strange weather phenomena observed in recent years in Europe, Asia and America. Project of impacts on ionosphere has been operating since 1960, when the United States exploded a nuclear bomb in the ionosphere. Then it became apparent that the ionosphere reacts to such effects: violations radio communication after explosion were recorded for almost a month. Since that time, have been held electromagnetic broadcasts of varying intensity and related experiments in the US (Colorado), Puerto Rico (Arecibo) and in Australia (Armidale). At about this same time on planet began to frequent disasters and climate changes. Now there is a possible explanation

Fig. 6. *Blow of giant waves on coast of Indonesia (left), right side - consequences of a tornado, swept over Tennessee (April, 2006).*

for why weather has become less predictable.

In 2002, the first deputy commander of the Russian Space Forces, General Vladimir Popovkin, [41] in his letter to DG pointed out that "at inaccurate reference to upper layer of atmosphere can be catastrophic consequences planetary character". He was supported by an expert on active influences in the atmosphere of Federal Service for Hydrometeorology and Environmental Monitoring Valery Stasenko: "Disturbances in the ionosphere and magnetosphere affect the climate. Acting on them artificially with the help of powerful settings, you can change weather, including globally".

3.2.2. INTENTIONAL METHODS AND MEANS OF ENVIRONMENTAL IMPACT

To date, the US formed a powerful set of research and development devoted to study and practical application of new propagation effects and interaction of electromagnetic radiation in radio frequency range with artificial (or natural) ionosphericirregularities. Main part of planned basic and applied researches U.S. Department of defense associated with results of realization of program *HAARP* (*High Frequency Active Auroral Research Program*), a program of high-frequency active auroral researches, initiated in 1990 in research laboratories of Air Force, Navy and of largest universities in the US. Under this program deployed a construction of research station *Gakona* (pcs. Alaska) with a powerful radio transmitting equipment and the latest set of measuring equipment. This project is closely "linked" with researches, carried out under program *HIPAS* (Research Station *Fairbanks,* pcs. Alaska).

In 2002, construction of transmitting station *Gakona* (program *HAARP*) has been completed, and its technical capabilities currently have no counterparts. Huge opportunities radiative energy equipment will allow to carry out unique experimental researches for the benefit of a comprehensive study of radio-physical properties of ionosphere, working out the mechanisms of exposure on it and arising in this study various secondary effects.

Radar complex (RLC) *HAARP* is located 320 km north-east of Anchorage (latitude 62°23'N, longitude 145°8'W). Generation of low frequency signals - is today the main objective of program *HAARP*. In 1995, this object consists of 48 antennas and transmitters capacity 960 kW. At present, company BAE Systems was able to significantly improve performance characteristics of system: object has 180 antennas, height each 24 meters, total power of 360 ionospheric radio-emitters reached 3.6 MW [41]. Whole structure occupies 15 hectares of land at the foot of the mountains (**Fig. 7**). At its creation took almost 20 years and $250 million [30-40]. The complex deployment and research on it is engaged in "Phillips Laboratory", located on US Air Force base in Kertlend, New Mexico. It includes laboratories astrophysics, geophysics and means of destruction Space Technology Centre of Air Force US.

Officially complex ionospheric research *HAARP* is built to study the nature of ionosphere and development of systems air defense and missile defense. *HAARP* is supposed to use to detect submarines and underground tomography of bowels the planet. However many researchers argue that, in fact, a monster in Alaska intended for the impact on local and global mechanisms of nature in the vicinity of US adversaries. After all, today, using *HAARP* equipment, it is possible to form plasmoids and purposefully move them almost anywhere in Northern hemisphere. For Russia this means almost complete covering from east to west, from Kaliningrad to Kamchatka, and from north to south about to forty-fifth parallel. That is up to the

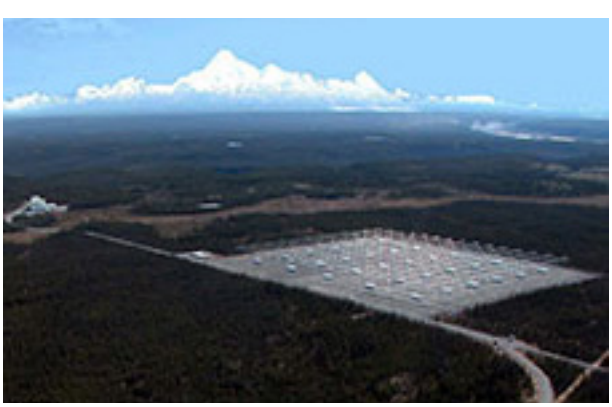

Fig. 7. *The radar system HAARP.*

level of Krasnodar and Stavropol.

If Americans build *HAARP* type setting and in Southern Hemisphere, it will cover all countries located to south of equator. *HAARP* is not so harmless project, as Americans are trying to present. Result of these risky experiments can be global cooling, destruction of ozone layer of Earth's atmosphere and the unpredictable climate changes on entire continents.

3.3. SYSTEMS (WEAPONS) ON NEW GEOPHYSICAL PRINCIPLES

Content of term "geophysical weapon" is not precisely defined. However it is implied that the object of impact of these weapons is the surrounding natural (geophysical) environment - lithosphere, hydrosphere, near-surface layers of atmosphere, ozonosphere, ionosphere, magnetosphere, near-Earth space, which are united by a common concept - geosphere.

At the present stage problem of creation and use of geophysical weapons seriously emerged in late 70's - early 80-ies of last century. Since 1987, USSR launched an extensive theoretical and experimental studies on behavior of various geophysical media (solid ground, ground-level atmosphere, ozonosphere, ionosphere, magnetosphere, near-Earth space) under a wide variety of active influences on them. So, in the one of topics are developed methods of remote influence on the earthquake weak seismic vibrations, which are known to occur by underground explosions of a nuclear or conventional chemical explosives even a relatively small capacity. This line of research in future is called "tectonic weapon". But after collapse of USSR it was abandoned. Final results were not compiled and decorated in any specific recommendations. We emphasize that the same works intensively conducted in the US.

Basic principles of weapons based on new geophysical principles. For weapons on geophysical principles or as called in [15] - hypothetical weapon, the object of influence is natural (geophysical) environment. Proof of the existence of such weapons at present in principle nonexistent.

Idea of geophysical weapons is to create a mechanism of artificially induce and targeting on certain regions, of natural phenomena leading to considerable destructions and casualties. Among such natural phenomena, above all, are called as the following:

- arthquakes, tectonic faults, volcanic eruptions and caused by them secondary disasters, such as tsunamis;
- atmospheric disasters (tornadoes, typhoons, tornadoes, heavy rains), as well as the general state of climate on certain territory (droughts, frosts, erosion);
- destruction of ozone layer over separate territories for purpose of "burning" and exposure of natural radiation of Sun;
- impacts on water resources (floods, tsunamis, storms, mudslides).

It is believed that possibility of covert use of geophysical weapons is small, since a number of countries, including the US, Russia, Germany, France, Britain and Japan have a variety of environmental monitoring system [15-17].

However, under geophysical weapon is understood a weapon that is striking when used in military applications of natural phenomena and processes induced by artificial means. Depending on the environment in which these processes occur, this weapon is divided into *atmospheric, lithospheric, hydrospheric, biospheric and ozonic* weapon. The means by which stimulated geophysical factors may be different, but energy expended at these funds is always much less than energy released as a result of forces of nature caused by geophysical processes.

Atmospheric (weather) weapons - the most studied to date a view of geophysical weapons. Its affecting factors are various kinds of atmospheric processes and their associated weather and climate conditions, which may affect life both in individual regions and entire planet. Today found that many active agents, such as silver iodide, solid carbon dioxide and other substances being scattered in clouds can cause heavy rains over large areas. On the other hand, reagents such as propane, carbon dioxide, lead iodide, provide fog dispersal. The spraying of these substances can be carried out using ground-based generators and on-board devices installed on aircraft and missiles.

In areas where the moisture content of the air is large, this method can cause torrential rains and thereby change water regime of rivers, lakes, marshes, significantly degrade trafficability of roads and terrain, and in low-lying areas to cause floods. On the other hand, if you provide an artificial rainfall at

the approaches to areas with large moisture deficit, can achieve a significant removal of this water from atmosphere and cause dryness in these areas.

Lithospheric weapons based on energy use of lithosphere, ie the outer sphere of "solid" earth, including crust and upper mantle. Here a striking effect provide such catastrophic events as earthquakes, eruption of volcanoes, movement of geological formations. In this case source the energy is the tension in seismically hazardous areas.

Experiments have shown that in some earthquake-prone areas of Earth by ground or underground nuclear explosions relatively low power can initiate earthquakes, which can lead to catastrophic consequences.

Hydrospheric weapons based on use for military purposes of energy of hydrosphere. Hydrosphere is intermittent water shell of the Earth, located between atmosphere and solid earth crust (lithosphere). It represents the totality of the oceans, seas and surface waters. Energy use hydrosphere for military purposes possible when impact on water resources (oceans, seas, rivers, lakes) and the hydro facilities, not only by nuclear explosions, but also large charge of conventional explosives. Factors of defeat of this weapons will be strong waves and flooding.

Biospheric weapons (environmental) based on catastrophic changes in biosphere. Biosphere covers part of the atmosphere, hydrosphere and the upper part of the lithosphere, which are interconnected complex biogeochemical cycles of migration of matter and energy. Currently, there are chemical and biological means, the use of which in large areas can destroy the vegetation cover, fertile surface layer of soil, food stocks, etc.

Artificially induced soil erosion, perdition of vegetation, irreparable damage to flora and fauna due to the use of various kinds of chemicals, incendiary weapons could lead to catastrophic changes in the biosphere and, consequently, the mass destruction of people.

Ozonic weapons is based on use of energy of ultraviolet radiation emitted by sun. Ozone shielding layer extends at a height of 10 to 50 km with a maximum concentration at a height of 20-25 km and a sharp decrease of the up and down. Under normal conditions surface of Earth reaches a small part of ultraviolet radiation with λ = 0.01-0.2 microns. Its main portion, passing through atmosphere is absorbed by ozone, air molecules and scattered by dust particles. Ozone - one of the strongest oxidants, kills microorganisms, toxic. Its destruction is accelerated in the presence of a number of gaseous impurities, in particular bromine, chlorine, fluorine and their compounds that can be delivered in ozone layer with missiles, aircraft and other vehicles.

Partial destruction of ozone layer over enemy territory, an artificial creation of the time "windows" in the protective ozone layer can lead to the defeat of the population, flora and fauna in planned area of globe due to the effect of large doses of UV radiation and other radiations of cosmic origin.

Despite the signing of majority of countries - UN members the Convention, 1978 "On the Prohibition of Military and any Other Hostile Use of Environmental Modification Techniques" and availability of possibility of leading industrialized nations to implement global monitoring of physical parameters of environment, a number of major corporations and firms from industrialized countries (primarily the US, Japan and the UK) in recent years have greatly expanded topics of researches on active modification of the human environment, as well as on processes that can have a significant impact on providing space systems (intelligence, communications, navigation) [36].

Thus, analysis of carried out in recent years research in the field of geophysical environmental impact indicates the probability of occurrence in the XXI century of fundamentally new approaches to technology of creation of certain types of geophysical weapons.

3.3.1. PROGRAM «HAARP» - WAY TO CREATION OF PLASMA WEAPONS

Essence of military technology is the following: above the ozone layer lies ionosphere - gas layer enriched with electric particles (ions). When this layer heats concentrated beam of high-frequency radio waves by powerful *HAARP* antennas, are created an artificial ion clouds in form similar to optical lenses. These lenses can be used to reflect low-frequency waves and for producing energetic "death rays", focusable in a given geographic location.

In the US, one of the key elements of project to create a global missile defense was the development of *plasma weapons* - one of varieties of geophysical weapons. Its action is to focus in the ionosphere

with high-energy microwave electromagnetic pulse, resulting in a plasmoid is born - a localized area of highly ionized gas, or a ball lightning. Plasmoid heats the gas of the ionosphere and are formed an artificial magnetic storms. These storms have a catastrophic impact on navigation systems, weather and mental state of people. Plasmoid moves in atmosphere and leaves a trail of heated air with reduced pressure. This trail is an insurmountable obstacle for aircraft. They get into this trail as in mouth of a tornado and are destroyed.

New mobile "plasma gun *MIRAGE*», openly now being developed in the US, will disable communication and navigation systems enemy within a radius of tens of kilometers. Device is able to change state of the ionosphere - upper layer of Earth's atmosphere, which is used as a "mirror" to transmit radio signals over long distances. Plasmoid generated in a special microwave oven, will injected by a rocket to a height of 60-100 km and will disrupt natural distribution of charged particles. According to military experts, this way you can get rid promptly from the several problems:

- firstly, the "excessive" plasma will create a barrier to enemy radar, which under normal conditions due to ionosphere can see aircraft below the horizon;
- secondly, "plasma shield" will prevent contact with satellites, whose signal passes through atmosphere.

It will create problems with orientation on ground, if for it has used GPS-receivers. Design represents a small van that easily can deliver you to the hostilities place.

Inability to control by the other countries over the use of plasma weapons, makes it dangerous not only for the country, which directly receives the impact, but also for the whole world. US presents the project *HAARP* as a research, yet it is realized mainly in the interest of the Air and naval forces of the USA. As noted in the media, experts in the field of missile defense believe that it is the *HAARP* program eventually "will grow into a key component of global US missile defense."

3.3.2. POSSIBLE APPLICATIONS OF GEOPHYSICAL SYSTEMS AS A WEAPON

On the Internet, are discussed various areas of possible military applications of *HAARP*, the most important of which are following (here we do not consider the most exotic) [36]:

- communications with submarines at low frequencies;
- a system of early warning of missile and air attack;
- exposure on electronic equipment, in particular - on communication and navigation systems of ships, spacecraft, aircraft, missiles and ground-based electronic warfare of enemy;
- geophysical weapons - you can control and change weather over territory of other country or geographic region;
- weapons for organization of large-scale accidents in electricity networks, at nuclear power plants, oil and gas pipelines;
- anti-missile and anti-air (aerospace) defense - controlled plasmoid can deform high-speed flow front of the aircraft or ballistic missile warheads, leading to a deviation of their trajectory from calculated and even to destruction of structure;
- impact on mental and physical condition of people;
- promotion of earthquakes or tsunamis.

About military capabilities of *HAARP* system, of course, created a lot of myths. In particular that it can cause destruction of ground infrastructure, including pipelines and power lines over large areas, and also destroy aircraft on airfields and missiles in mines.

Russian experts believe that with help of directional antennas such as of *HAARP*, is quite possible such "discharge" of energy of plasmoids and ionospheric currents that occur in the polar regions, which can cause serious effects "combat" application. Thus, they argue that very real the following "combat" effects:

- complete failure of electronics and control systems aircraft and cruise missiles;
- blocking or complete failure the electronic systems of ballistic missiles in the boost (before stages separation of motors) and ballistic (secession MIRV) parts of the trajectory. In particular, when rockets are launched through circumpolar region, as well as with the submarines in the waters of Arctic Ocean.

However here again it should be recalled that we are talking about impacts in polar zone. Only where there are very high density of auroral currents and

the energy of ionospheric plasma formations, are fully realizable above-described "military" effects. And exactly in the polar zone pass, according to doctrines of Russian strategic nuclear forces (SNF), main ballistic trajectories of our missiles aimed at the US. And they pass in ionosphere at altitudes of up to 400-600 km, where you can "unload" accumulated energy of plasma formations and ionospheric currents. Here pass basic combat courses of our strategic bombers with cruise missiles aimed at the US. From here it are assumed the launches (including "subglacial" starts) missiles with russian nuclear submarines.

And it is in this area:

- there are ("hanging"), american satellites of system of early warning (AWS) of missile attack;
- here there is also placed the most powerful ground-based radar stations NATO united in "their" AWS, - in the UK, Norway, Greenland, Alaska, in the Aleutian Islands;
- here there are also the antenna fields of first active system *HAARP* in Alaska under Anchorage, as well as of second, hastily expanding similar system - Tromso in Norway.

However military applications of these effects - no simple matter. And if polar area as a result will be virtually impervious to russian strategic bombers and missiles, what trajectories they have to fly to US? Of course, bypassing polar zone. That is, then you have to run them from "inconvenient" regions and through "uncomfortable ", including more longer, ballistic trajectories.

Then they will have to fly, primarily across north Pacific, where they will intercepting missile defense and air defense ships USA, in Alaska, as well as at anti-missile base, that being constructed in California.

And they will have to fly through Europe where they will be intercepted by missiles-interceptors in Poland and other countries, including Scandinavia (which by that time will be not 10, but 50 or more), as well as missiles-interceptors from ships in North Atlantic and bases in the Northeast US.

It is believed that all of this can very greatly complicate Russia's strategic nuclear forces the solution to the problem of effective response, or especially retaliatory strike against targets in the US.

And as we still need in this situation to relate to such "trifles" as creation at our borders, in the Czech Republic and Poland (and then, apparently, everywhere), the missile defense system? And what do we do if at the first stage this European missile defense would be "small", designed primarily to intercept cruise missiles and their carriers, and then - why not? - "supplemented" by the echelon of intercept of strategic missiles at a high ballistic part of trajectory?

After analyzing statistics for last decade [40-45], it is possible to find conclusive evidences of appearance of a terrible weapon, which no one can suppose that could happen to the planet if inclusion of this giant "beam gun" will at full capacity. According to experts, the power of this weapon is a thousand times more powerful than atomic bomb. Directing the beam of this "beam gun," for example, in England, it can be destroyed in a matter of seconds. Possible destroy whole ionosphere.

Below is given an example of successful researches in field of secondary radiation of ionosphere, that conducted a team of scientists of Institute Geospheres dynamics of Russian Academy of Sciences, using special heating stands.

3.4. RADIO MONITORING OF RADIATION OF THE HEATING STANDS AND SECONDARY RADIATION OF THE IONOSPHERE

Heating stands are a new technology of active effects on the ionosphere, by which is manifested complex variety of effects. Therefore, study of these effects require use of a broad class of both existing and specially designed measuring methods [43-46].

The aim of this work is to carry out theoretical estimates of conditions and characteristics of radio monitoring system to detect and analyze signals radiation of heating stands and secondary radiation excited ionosphere.

Were installed approximate values of power levels of signals at input of receiving equipment of radio monitoring systems. Shown the possibility of receiving weak signals of radiation at large distances before the heating stands.

In **Fig. 8** is a diagram [45] of possible determination the coordinate of distance before the radiation source as a function of elevation angle of wave arrival by the jumps of ionosphere-earth propagation for cases of secondary radiation of ionosphere at the point A_1 (Scheme 1) and stand at point A (Scheme 2).

As can be seen from Fig. 8, by direction finding a source of secondary radiation of the ionosphere (point A_1) possible to determine the distance to direction finder radio monitoring system (point C), including in conditions of jumps signals the earth-ionosphere. Value of distance is determined by formula:

$$L_2=\left(2N-1\right)R\left[\arccos\left(\frac{R\cos\beta_2}{R+H}\right)-\beta_2\right], \quad (4)$$

where β_2 - elevation pelenguemogo signal of secondary radiation of the ionosphere; L_2 - distance on the Earth's surface between the transmitting and receiving systems; R - radius of the Earth; N - number of jumps in the propagation path of radio signals; H - height F layer over the surface of the Earth.

Analogously, when determining the elevation angle of direction finding radiation of the stand or any other ground source in conditions of multiple reflections signals from the ionosphere is possible to determine the distances from the stand (point A) before the receiving device of monitoring system (point B), including when multi-jumps modes of radio propagation. Value of distance from the stand up to direction finder is defined as:

$$L_1=\left[\arccos\left(\frac{R\cos\beta_1}{R+H}\right)-\beta_1\right], \quad (5)$$

where β_1 - is the angle of elevation of direction finding signal of radiation stand.

One of parameters identification of radiations of the heating stand, when known distances between the stand (point A) and receiving devices monitoring system (point B), is tracking angle of arrival of signals radiation of stands β_1, whose value is determined by formula:

$$\beta_1=arctg\left[ctg\frac{L_1}{2NR}-\frac{R}{\left(R+H\right)\sin\frac{L_1}{2NR}}\right], \quad (6)$$

Possibility of receiving signals of heating stands by radio monitoring instruments is determined by the characteristics of the radiation patterns of these antennas stands - by level and by angular distribution of side lobes.

In **Fig. 9** for antenna pattern stand *HAARP,* which is the result of calculating the synthesis of 180-element phased array antenna with active A_{eff} = 128,000 m^2, are graphs of distance dependence of possible detection of signals of the stand from the height of F-layer of ionosphere.

Presented dependences allow to reliably determine the range to placement heating facilities subject to a determination of radio monitoring systems receiving equipment arrival angles β_1 radiation source.

Power level of signals at input of the receiving equipment of radio-monitoring systems defined as:

$$P_{in}=\frac{PG'KK_F^nK_Z^m\gamma}{4\pi D^2}, \quad (7)$$

where where P - is integral power of transmitting modules of heating stands, G'- gain of sidelobe radiation of phased antenna arrays in a direction of radio monitoring system, K - integral coefficient of radiosignal propagation losses on track is an average in HF range 0.9 at 1000 km; K_F^n - loss factor of radio wave by reflection from F-layer of the ionosphere; n - number of radio wave reflections from F-layer of ionosphere on track of heating stand-reception apparatus; K_Z^m - loss ratio of radio wave by

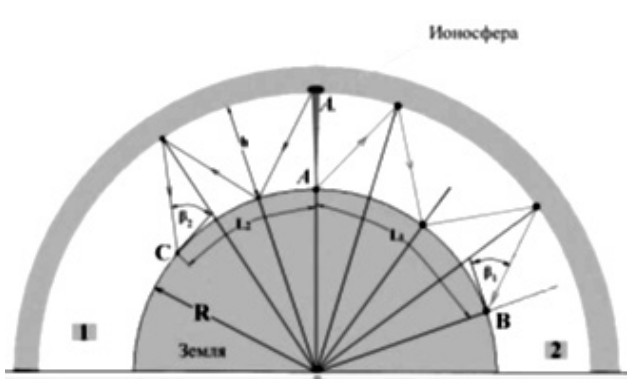

Fig. 8. *Scheme of receiving by terrestrial finders of signals of stand and the secondary radiation ionosphere in conditions jumps propagation.*

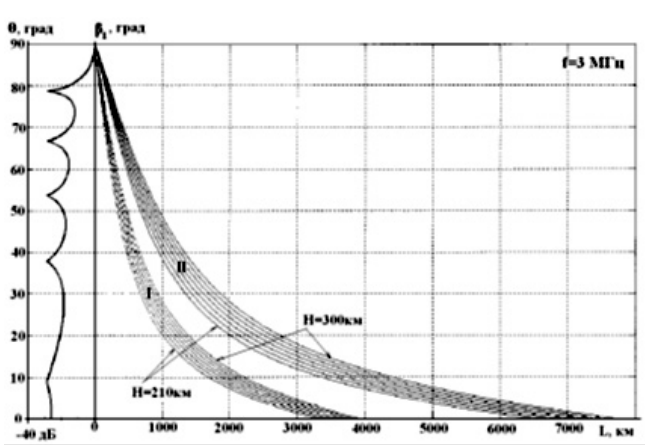

Fig. 9. *Graph of distance of detection of signals HAARP against the radiation at a frequency of 3MHz (I - one-fold reflection, II - two-fold reflection).*

reflection from surface of the Earth, whose average value in HF range of wavelengths at grazing angles 5...30 degrees is 0.95; *m* - number of reflections from surface of Earth in propagation track; *D* - total distance of propagation of signals radiation; γ - losses coefficient of mismatch the polarization of signals of radiation of stands and antenna characteristics of the receiving equipment.

Assessments of estimated the average values of losses coefficients, calculated using the model of the ionosphere *IRI*, equal at reflection from ionosphere in summer day 0.01 and winter night 0.1. Power level at location of the receiving equipment of radio monitoring system will be equal in summer day $5\cdot10^{-11}$ W/m^2 (electric field strength 7μV/m, magnetic field strength 2.1pT) and in winter night $5\cdot10^{-10}$ W/m^2 (electric field strength 22 V/m, magnetic field strength 6.6 pT) for values of coefficient of polarization losses of 0.5 and distance of passing radio waves about 4000 km (Fig. 9). It is provided with a single signal reflection from the ionosphere in conditions a detection of radiation of stand *HAARP,* having integral power of 360 MW and the side-lobe level minus 0.1 relative to main lobe.

Most important task of effectiveness of monitoring the signals radiation of heating stands in conditions a large number of interfering signals of radiation of radio stations, are a criteria the identification the signals of these radiations, which determined:

- by stable and high-precision information about the locations of the heating stands;
- in most cases by difference between the radiation signals of stands from signals of radio stations in spectral characteristics;
- by high correlation the signals radiations of stands and secondary emission signals in excited ionosphere.

Application of these criteria identification and adaptation to radiosignal situation in the location of the receiving equipment of the monitoring system, are implemented by the excluding analysis of previously detected signals interfering radio stations. These provides in real time with a high probability, the detection and analysis of signals radiation from heating stands [19-20].

Heating stand generates harmonics of secondary radiation of ionosphere of carrier frequency of stand to level 53...57 values, i.e. almost up to 180 MHz, and also radiation at the modulation frequencies from a few Hertz to kiloHertz.

Height of secondary radiation of the ionosphere depending on frequency radiation of stand is approximately 90...300 km. As shown in Fig. 8 this source conditionally, can be at point A_1. Track of signals propagation of secondary radiation of ionosphere will be different from track of stand signals propagation.Because reflection comes from earth's surface, and then from ionosphere, etc. This effect of radiosignals propagation can be applicable for HF band of wavelengths.

In low-frequency ranges, and particularly in units of hertz, radio waves propagate in a natural ionosphere-Earth waveguide. This determines necessity to incorporate these features when creating radio monitoring equipment of secondary radiation excited ionosphere.

Tracking angle of signals β_2 secondary radiation of ionosphere for HF range of wavelengths in the location of receiving equipment of radio monitoring system (point *C* in Fig. 8) is defined by:

$$\beta_2 = arctg\left[ctg\frac{L_2}{(2N-1)R} - \frac{R}{(R+H)\sin\frac{L_2}{(2N-1)R}}\right], \quad (8)$$

Fig. 10 shows calculated dependences of tracking angles of secondary radiation of ionosphere for different conditions of the propagation track

In general, power level at input of receiving equipment monitoring system of signals secondary radiation ionosphere is defined as:

$$P_{in} = \frac{PGKK_F^n K_Z^m K_t \gamma}{4\pi D^2}, \quad (9)$$

where *G* - gain of main lobe of the heating stand PAA, K_t - loss rate of transformation of power of radiation heating stand into signal power of secondary radiation of ionosphere, value of which depends on state of ionosphere and characteristics of heating stand radiation, is 0.001-0.1%.

Values of power signals of secondary radiation, calculated by formula (9) at input receivers of radiomonitoring system at distances of 4000 km and at minimal value of transformation coefficient 0.001% in HF range of wavelengths for summer time day, will be approximately $5.8\cdot10^{-14}$ W/m^2 (electric field strength of 0.24 μV/m, magnetic field strength 0.07 pT) and in winter night $5.8\cdot10^{-13}$ W/m^2

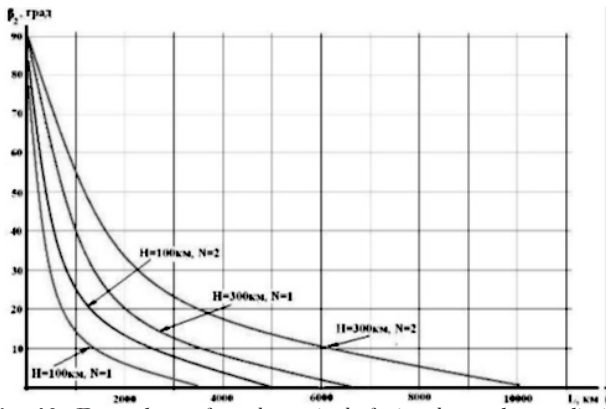

Fig. 10. *Dependence of angles arrival of signal secondary radiation ionosphere β_2 from distance L_2 in formation of signal in ionosphere at altitudes H = 300 km and H = 100 km when N = 1 and N = 2.* (electric field strength of 0.78 μV/m, the magnetic field 0.23 pT).

Absence of sufficiently reliable values of loss coefficients appearing in expression (9) for low frequency range of lengths, does not allow estimate the values of signal levels of secondary radiation of ionosphere in this range. However, given the available data of propagation studies Schumann waves signal levels in low frequency range of wavelengths will have approximately same values as in HF range.

Obtained values of signal levels of secondary radiation are estimates and may vary plus or minus order of magnitude or more. Especially if these levels will have a tendency to change in smaller side. And if they require development and introduction of new technologies creation a high sensitivity and resolution of receiving equipment of radio monitoring system that provides necessary probability of detection and analysis of signals of radiation ionosphere.

Meeting the challenges of creating a high-performance radiomonitoring systems, providing large areas of detection space, analysis and identification of signals from radiation sources, it is possible to create a spatially distributed systems radiointerferometers constructed on basis of foster unified modules, that are united by systems of processing and analysis of detected radio sources.

Space-correlation processing of signals, that were received each receiving module, provides ability to increase equivalent sensitivity radiointerferometer and accuracy determining angular coordinates of radio source due to forming of the receiving phased antenna array.

Multifunctionality of radio monitoring system is determined by its capabilities of detection, analysis, coordinate determination and identification of essentially all radio-sources of land, air and space-based emitting in working frequency range of radio interferometers, as well as conduction basic and applied research on propagation of radio waves and geophysical processes under impact on ionosphere powerful electromagnetic radiation. Frequency range of radio monitoring system should be divided into three sub-range: <10 kHz, 10...100 kHz and 2...20 MHz.

Thus, with modern technologies of development of radioelectronic systems virtually is real creation of systems of radio monitoring to ensure reception of signals heating stands and secondary radiation ionosphere almost in all territory of Russia.

3.5. POSSIBLE CONCEPTS OF APPLICATION ARTIFICIAL IONOSPHERIC STRUCTURES IN ORDER TO CREATE A FUNDAMENTALLY NEW TYPES OF WEAPONS AND MILITARY EQUIPMENT

In field of creation of means of directional electromagnetic effects on environment take an important place studies on formation and military use of artificial ionospheric irregularities. Greatest interest here are the developments related to formation of artificial ionospheric irregularities (breakdown of ionosphere), created in the crossed beams of radio emission. Herewith in atmosphere is created an artificially ionized region where concentration of charged particles significantly (on 3-4 orders) exceed concentration of surrounding plasma. This area can be used for radio communication, because the radio waves reflect from it. The break-down expedient to carry out by short pulses. Their repetition period is chosen from condition of weak variation of plasma concentrations between pulses due to relaxation processes. This requires a very moderate average radiation power, which increases rapidly with decreasing altitude intersection of beams, place of breakdown. At altitudes, above 70-80 km, increase ohmic losses. Therefore for creation artificial ionized region is the most favorable altitude range from 30 to 70 km.

Depending on the choice of a range of radio-emitting means which form crossed beams, are formed and dimensions of region of increased ionization. So depending on the particular problem to be solved as sources forming the break-down, can

be used radio funds in ranges HF...SHF , as well as open laser systems.

Prospects use of such artificially created ionospheric mirrors are connected not only with radio communications, but also with production of noise due to reflection interference signal from region of ionosphere with high concentrations, as well as with masking surface facilities (territories) from radar surveillance from space. In addition, here seems to be a very remarkable possibility to create of "intentional" interference condition over a given area of earth's surface through use of nonlinear properties of ionospheric plasma in layers *E* and *F,* and in lower layers of artificially created areas with high ionization, in particular, biharmonic irradiation of their boundary with air.

Manifestation of nonlinear properties of ionosphere was installed with the discovery of Getmantsev effect (1980, Gorky, USSR): when exposed on lower ionosphere by the powerful modulated radioradiation, natural current systems of ionosphere are generate low-frequency radiation at frequency of modulation of signal irradiation.

Biharmonic irradiation of such surfaces with a high concentration of active particles significantly reduces energy costs for radiated HF range. Control of parameters of difference frequency and of methods of its manipulation dramatically increases efficiency of reaction of means jamming to enemy radio links at the distances. Rapidly are developing methods of targeted amplification of arbitrary components of spectrum of the combined frequencies, produced by mixing the oscillations of two frequencies on nonlinearities ionosphere and, therefore, increasing level of necessary (signaling) radiation jamming, generated by ionosphere. Orientation direction of radiation can be installed either on basis of phase relationships oscillations irradiating ionosphere, or of appropriate placement on terrain of their sources. This approach allows you to control voltage of movement of ionospheric current, taking into account the Earth's magnetic field. And, consequently, to control direction of jamming in ELF...LF at distances of 1,500 to 2,000 km. Herewith can be used as the jammers the means of KV-range, with average power transmitting devices.

We can also assume that by 2015 development of research in the use of the properties of artificial ionospheric structures (heterogeneities), will address a wide range of military tasks, such as:

- defeat of electronic equipment of AME, energy systems, communications and telecommunications, including in shelters, due to generation of a powerful electromagnetic pulse by means of non-nuclear method;
- creation of local changes in the geomagnetic field, as well as magnetic and electromagnetic anomalies (storms) in order to influence weather, objects of AME and personnel;
- hidden "information" exposure (irradiation to electromagnetic radiation of ELF, LF, VLF ranges) for personnel in places of their dislocation;
- functional defeat of the nodes of automatics system and homing warheads of ballistic missiles, powerful performances interference and also protection of space navigation systems and communication navigation system from the impact of funds the radio electronic suppression;
- detection and identification of underground military facilities (buried command facilities, depots with chemical, biological and nuclear weapons, underground utilities and other likely targets);
- ultra-long detection of small-observable air and sea targets (beyond-horizon location);
- creation of a fundamentally new radio systems (combat control) with submarines and buried objects in traditional ranges 30-300 Hz and 3-30 kHz.

It should be noted that within framework of project *HAARP* also addresses issues related to use of extremely weak alternating magnetic fields (EW AMF) as a factor affecting psycho-physical characteristics of person, as well as on human body as a whole. Impact EW AMF usually carried out against background of a constant magnetic field of Earth. Therefore, should consider bioeffects of modulated or combined magnetic fields (CMF) with very weak variable component of B_{AC} (term "biological effects CMF" is used for conciseness, as well as to emphasize the difference between the mechanism of action of this type fields on biological systems from the effects of the CMF in other modes).

1. *μT(micro-Tesla)-fields*. According to experts, available theoretical and experimental data suggest

BBT.

that variables μT-fields can induce biological effects at magnetic induction in excess of 10 μT, while possibility of biological effect of variable μT-fields at values B_{AC}<10 μT is virtually eliminated. Such a conclusion is made on basis of conflicting data regarding biological effects of "micro tesla" fields, conducted in many laboratories around world starting with first message by Spanish authors (1982) about origin of anomalies in development of embryos (teratogenic effects) when exposed to such fields (works funded by the US Navy). We can assumed, however, that contradictory of results obtained in the study of the influence of "micro tesla" fields on embryonic development, due to, first of all, dramatic differences in parameters (frequency, amplitude, pulse shape) which use a variable magnetic fields and relative complexity of registration and quantitative description of anomalies in developing embryos. It is obvious that to solve the fundamental question of "biological effectiveness" "micro tesla" fields more appropriate to use the no pulse but sinusoidal magnetic fields and relatively simple test systems. Indeed, results obtained in last 10 years using the same type (sinusoidal) CMF in four laboratories in the USA on biosystem of the same type, allowed an unambiguous conclusion about biological effectiveness "micro tesla" sinusoidal magnetic field (B_{AC} = 1.2·10^{-6} T, f_{AC} = 60 Hz). To date, the biological effectiveness "micro tesla" fields has been shown for principally different test systems and using a variety of different combinations of frequency and amplitude. However, question about mechanism of action "micro tesla" fields remains open.

2. *"nT"-fields*. There is increasing experimental evidence concerning impact of "nano tesla" fields on properties of biological and physico-chemical systems. In particular, Canadian scientists have received results of studies indicating the possibility of influence of these fields on psycho-physical and other characteristics of physiological state of a person. Results of several works of Russian scientists show that in basis of biological effects "nano tesla" and "micro tesla" fields can lie their interaction with aqueous component of biosystems.

3. *"pT"-fields*. There are only a few reports on laboratory studies of possible biological effectiveness CMF "pico tesla" range. In one of them reported on the impact of variable electric fields with parameters that mimic the Schumann resonances (amplitude of 1 mV/m, 10 Hz) on the psychophysical indicators of a man, the other was shown the possible role of Schumann resonances as a circadian synchronizer in humans. However, hypothesis on exposure to magnetic component of Schumann resonances on biological systems has not yet been subjected to a comprehensive experimental evaluation. Apparently, the main reason for the lack of open researches in this area lies in the a priori denial of the potential biological effectiveness of superweak magnetic fields characteristic for Schumann resonances. It should be noted that amplitude of magnetic component of the Schumann resonances at a frequency of 8 Hz is 1.3-3 pT (picotesla), ie, close to the magnitude of the magnetic field on the surface of the Earth, created under the program *HAARP*.

3.6. CONCLUSIONS

On the ground of the analysis of the provided materials the following conclusions can be made. But it is necessary to note that all conclusions in the text and in the final report can't be entirely true, because all problems mentioned in the report, especially in the field of creation of the special climatic weapon, require to make more theoretical and applied researches. Nevertheless, there are the following preliminary conclusions:

a) in the field of physics and origin of magnetic radiation phenomena, which are created naturally

1. Physics of origin of magnetic radiation phenomenon begins and occurs in the environment of the Earth:

- in the ionosphere as ionospheric rays and their size depends on ion and electron concentration;
- in case of changes in the magnetosphere structure with formation of plasmoids under the effect of natural phenomena (the Sun's short-wave radiation, corpuscular streams, galactic and sun space rays and other).

Each type of the ionizing radiation influences mostly on the atmosphere only in a certain area of high dimension corresponding to its penetrating capability.

2. Ionosphere study and its basic characteristics is still improving in two directions - its effect on radio waves transmission and physical-chemical processes

research, which are occurred in the ionosphere that has produced a new science - aeronomy.

3. The process of reconstruction of the magnetosphere either local or large-scale is important, if not the basic factor of the disturbed magnetosphere, creating *auroral radiations, aurora polaris and magnetospheric substorms*. The common origin of ionospheric, magnetic disturbance and aurora polaris during active phase of the substorm is a precipitation of auroral electrons in the atmosphere.

4. To understand fully physical notions about typical changes in the magnetosphere structure it is required also to study different questions about problems solving in energy ions acceleration. Also the conceptions about the structure and short period of the history about auroral activization, substorms and world magnetic storms interconnection. I.e. there will be more researches about magnetospheric disturbances.

b) in the field of geophysical disturbance in the ionosphere, which are created naturally

1. The important problem is an evaluation of effects criteria on the certain geosphere, which can bring to the planed effect. It is clear that any active influence cannot compete with more powerful energy of natural phenomena and processes that have common energetic capabilities. However, there are few exceptions (nuclear explosions, asteroidal-meteor weapon).

There is only one conclusion that humanity should think carefully and to take care about our beautiful existence on the Earth and about extremely reach nature sphere. Any rude interference into nature condition can bring to disasters.

2. Some examples of the natural disasters, which are occurred because of still unknown, but supposed reasons during last ten years on the Earth remember us that there can occur an irreversible situation, when the whole *climate control system is used, which kills its creator*.

3. The project *HAARP* is not so harmless, as the USA try to show. As a result of risky experiments there can be a global freezing, destruction of ozone layer of the Earth atmosphere and unpredictable climate changing in whole continents. There is no limit in experimentation of weather abroad, which are made on these complexes with certain types of apocalyptic weapon, which is using now actively.

c) in the field of weapon with new geophysical principles

1. The term's content "geophysical weapon" is still not defined, but it is implied that the object of the influence of such weapon is the environment (geophysical), natural atmosphere - lithosphere, gydrosphere, ground layers, ozonesphere, ionosphere, magnetosphere, circumterrestrial cosmic space, which are included into the common notion of the geosphere. The idea is to create a mechanism of artificial induction and direction on certain regions of natural phenomena causing significant destructions and victims. Among these natural phenomena are the following:

- earthquakes, tectonic faults, eruptions and secondary disasters caused by them, for example, tsunami;
- atmospheric disasters (tornado, typhoon, waterspout, storms) and also common condition of the climate in certain area (drought, light frosts, erosion);
- destruction of the ozone layer over separate territories in order to "burn" and to radiate by the natural radiation of the Sun;
- influence on water resources (flood, tsunami, storms, torrent).

2. There are possible directions of the military implementation of the *HAARP* system:

- connection with submarines on low frequencies;
- warning system about rocket and air attack;
- influence on radio electronic equipment, especially - communications and navigational systems of ships, cosmic devices, air planes, enemy's rockets and also on ground radio electrical means of the enemy;
- geophysical weapon: the weather in the country or in the geographical region can be controlled and changed;
- the weapon for organization of large-scale damages in networks, atomic stations, oil and gas pipelines;
- anti-missile and anti-aircraft (air-cosmic) defence - a guided plasmoid can deform a high-speed current in front of the flying machine or battle ballistic missile, changing their trajectory from the rated data and even to destruction of the machine;
- influence on psychological and somatic condition of people;
- stimulation of earthquakes or tsunamis.

3. Russian experts think that using a directed influence of antennas as *HAARP* it is possible to become such "sort" of plasmoid energy and ionospheric current, occurring in polar areas, which can bring to serious effects of "battle" implementation:

- full loss of electronics and air planes and cruise missiles' systems of control;
- blocking or full loss of electronic systems of ballistic rockets on boost (till motor's stages separation) and ballistic phase (till divding reentry vehicles) in certain areas of the trajectory.

In particularly, the question is about effects in polar territory, where there are high density of auroral currents and energy of ionospheric plasmic formations, which help system to function:

- there are ("hang") American satellites with early warning systems about the attack;
- there are also the most powerful ground radar stations of NATO, combined with "their" EWSA - in Great Britain, Norway, Greenland, on Alaska and Aleutian island;
- there are also aerial areas of the first active system *HAARP* in Alaska under Anchorage and also the second similar hastily extensible system in Tromso in Norway.

d) with modern technologies of radio electronic systems creation it is almost real to create radiomonitoring system with signals accepting and secondary ionosphere radiation with heated stands in almost the whole territory of Russia.

4. POSSIBLE DIRECTIONS OF IMPROVEMENT OF METHODS OF INFLUENCE OF ELECTROMAGNETIC RADIATION ON PHYSICAL OBJECTS AND ENVIRONMENT

4.1. ESTIMATED PROBLEMS:

Development of the methodology of researches of electromagnetic radiation interaction with biological and radio technical military objectives.

Development of regulations of formulation of the basic principles of formation of coupling and accepting devices, measuring technical equipment for military implementation, including the equipment for study of theoretical and practical basics for creation of radiation facilities with ultrashort and strong impulses.

4.2. SOLUTIONS (METHODS) APPROACHES

For practical implementation of MWF radiation in its remote influence on radio technical and biological objects it is necessary to develop:

- *MWF radiation generators with high power capable to radiate short and powerful radiation impulses in broad band;*
- *highly sensitive receive box with threshold sensitivity not less than 10-20W/Hz, accepting at the same time even low signals in a range of radiation of coupling devices, protecting biological objects and also identifying permissible flows of MWF radiation, which are safe for radio technical systems functioning and protection.*

Development of wide-range spectrometers with the resolution not less than 0.01 sm^{-1} for study of the areas of quasiresonant interaction between radiation and bioobjects.

Development of new generation principles of ultrashort and powerful radiation impulses and also development of necessary element base and measuring equipment for creation and researching of powerful radiation generators.

4.3. POSSIBLE METHODS OF RESEARCH WORKS FOR LONG TERM

Searching researches testing in studying of characteristics of spread of ultrashort and powerful radiation impulses in absorbing areas and also in development of methods and ways for design of interaction of such radiations with radio technical and biological objects (results assessment).

It is reasonable to concentrate efforts of phyicians who try to solve the problem about microwave radiation interaction with radio technical and bioobjects for next important researches in the field of:

- *development and theoretical researches of models of input circuits of radiolocators accepting devices, radio communication systems and navigational on-board receivers and also responsive computer elements;*
- *choosing of wave range for theoretical influence microwave modelling on input circuits in concentrated and integral implementation;*
- *analysis of generation principles in optimal choosing of microwave characteristics of the device suitable for experimental researches;*
- *development of the powerful relativistic generator of ultrashort impulses with variable power in impulse;*

- *creation of working model of the powerful wide-range relativistic microwave generator and its testing;*
- *experimental test of the results of theoretical analysis of influence and including the analysis of microwave input circuits parameters degradation depending on the level of declining power, frequency and force duration;*
- *researches of microwave radiation beams attenuation and short microwave impulses in earth atmosphere;*
- *experiments on short and strong microwave impulses effect on input circuits of receiving devices and computer;*
- *creation of the half-industrial model of powerful radiator for electronic force on certain radio technical systems (connection, location, computer machines);*
- *experimental researches of microwave ultrashort impulses influence on biological objects of vegetable and animal origin.*

5. CONCLUISION

The modern level of development of generation methods of powerful electromagnetic impulses and methods of creation of radiation showed possibility of development of wide group of systems and means of directed energy. In the field of development of electromagnetic systems and means of influence on biological objects (aman) and environment and for heavy systems from radio electronic warfare (REW) the most well-known means are the following: electromagnetic means of lethal action, generation of high power for the heavy systems REW, electromagnetic means of nonlethal action and means for directed electromagnetic action on environment.

In the first part of the article the following questions are covered: about improvement of generation methods of powerful electromagnetic impulses for creation heavy systems of radio electronic neutralization of different types of radio electronic systems (RES) and especially the systems of precision weapon. It is an extremely urgent problem in improvement of advanced armory and military technology. The methods and means of generation of nanoseconds powerful impulses are considered, including:

- it is prepared a theoretical explanation of possibilities of generation methods of nanoseconds powerful impulses and their basic characteristics for possible practical implementation with creation of advanced systems of heavy radio electronic warfare RES destruction;
- there are the results of foreign and domestic researches of generators creation of macrowave-impulses with micro-nanoseconds duration and ultrashort electromagnetic impulses and also electromagnetic radiators, which are powered fromexplosion and magnetic current generator;
- there are variants of microwave weapon, using practically abroad and also examples of creation of means for electromagnetic influence on human in favour of anti-terrorism effort.

In the second part of the article following from Internet there are considered the questions about geophysical disturbance in the ionosphere created naturally and artificially as the origin of powerful influencein nature. There is an appropriate description of the methods and means of influence on environment (RD type *HAARP*) and radiomonitoring direction of radiation of heat stands and secondary ionosphere radiation.

In the final third part of the article there are considered the problems and solutions of possible (expecting) direction of improvement of influence methods of electromagnetic radiation on physical objects and environment.

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SURFACE MAGNETOSTATIC WAVE RESONANCE WITH ORIENTATION

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Abstract. **Surface waves in thin isotropic ferromagnet slab magnetized in its plane are considered in the magnetostatic limit. Magnetostatic waves are considered as a type of spin waves. The special attention is given to the propagation directions of the waves, which are not orthogonal and parallel to the magnetization of the film. Two features of these waves have not been discussed earlier: the wave resonance with orientation and the existence of a new type of the surface magnetostatic waves. The position of the resonance peak depends not only on the frequency, but also on the direction of wave propagation, and we use the term "wave resonance with orientation". The wave resonance with orientation predicted theoretically on the basis of the dispersion relation of Damon-Eshbach [5]. The existence of a new type of surface waves (waves of second type) also follows from [5]. These waves propagate almost parallel to the magnetization of the film. The frequency of waves of second type can greatly exceed the frequency of Damon-Eshbach. The frequency of Damon-Eshbach limits previously studied surface waves (of the first type). Resonance with the orientation of the waves of the second type is also considered. Estimates and graphics are provided for the parameters of YIG films [7].**

Keywords: **magnetostatic waves, spin waves, isotropic ferromagnet, magnetic films, spectra of electromagnetic waves.**

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Contents

1. INTRODUCTION

In [1, 2] the need to develop devices with using of magnetostatic waves (MSW) and ferromagnetic films is associated with the trends in modern information processing systems: to use more broadband signals with a higher center frequency, with the ability to select materials with low attenuation MSW, with prospects for the development of devices with using of magnonic and photonic crystals. Magnetostatic waves can be considered as a simple type of spin waves, when the inhomogeneous exchange interaction can be neglected. The observed complexity rise of the spectra of the MSW with the complication of the structure of the films [3, 4], apparently, indicates the need for a more detailed theoretical investigations of the fundamental properties of the MSW. Research conditions limiting the range of MSW with high frequencies may be important. Well studied and usually used MSW propagating either to parallel or to orthogonal the magnetization of the film [5-8]. Forward volume MSW is tipical in films magnetized perpendicular to their surface. Two other types MSW used in tangentially magnetized films. Backward volume MSW propagate in the direction of the magnetization of the film. Surface MSW (SMSW) has frequencies higher than the backword valume waves. SMSW is generally assumed orthogonal to the magnetization of the film [8]. Dispersion relations are valid for an arbitrary direction of propagation of the wave is obtained for surface magnetostatic waves in

[5]. The existence of the special directions of propagation of waves in a tangentially magnetized films is noted in a number of experimental and numerical studies of surface magnetostatic waves [6, 9, 10]. These directions do not match the magnetization or orthogonal directions however, are the predominant directions. Nonparallel and nonorthogonal to the magnetization SMSW have features that interesting for generalizations design principles of the devices with using of the MSW. The explanation of the observed effects in form a narrow wave rays emanating from the edges of the emitter, explained in [6, 9, 10] using the decomposition of the waves on the Fourier-harmonics and numerical accounting of the dispersion relation, equivalent to the results of [5]. The results of this research must give understanding of more delicate experiments on surface waves.

The SMSW dispersion relations for thin isotropic ferromagnetic slab are derived in [5] based on Walker's equation [7]. Thin isotropic ferromagnet slab magnetized in its plane is considered in the magnetostatic limit. Magnetic damping is important but not considered. The surfaces of the slab plane are "free", i.e. the slab is surrounded by a vacuum. In [5] it is assumed that film is magnetized to saturation along the z axis. The plane of film is $x = 0$. Thickness of film is s. The components of Polder magnetic susceptibility tensor ($\hat{\chi}$) determine properties of magnetostatic waves $\kappa = \chi_{11} = \chi_{22}$ and $j\nu = \chi_{12} = -\chi_{21}$ (j is imaginary unit). We denote by ($k_x^{(i)}$, k_y, k_z) components of the wave vector of magnetostatic waves in the film. The index $i \in \{1, 2\}$ corresponds to waves that are formed within a free film as a result of reflections from the surfaces of the film. The film is called "free" film, if both its surface adjacent to the vacuum. MSW is a limiting case of wave, when in sufficiently thin films wave properties cease to depend on the dielectric permittivity of the materials. Therefore, the results for the "free" films remain true when the film is covered with a thick and good dielectric. (The results obtained for MSW in free films that are obviously false for metallized films). In free films $k_x^{(1)}$ and $k_x^{(2)}$ differ only in sign. It is assumed that the components of the wave vector can be not only real numbers, but also complex. The imaginary part of the wave vector corresponds to an exponential change of amplitude of a wave at the increase of the corresponding coordinates. If $k_x^{(i)}$ is real then wave is called the volume MSW. If $k_x^{(i)}$ is imaginary then wave is called the surface MSW (SMSW). Parameter $\eta = k_z/k_y$ is the cotangent of the angle between the magnetization of the film coinciding with the z-axis, and the direction of propagation of magnetostatic waves in the plane x = const. In this case, the Walker's equation is written in the form [5]:

$$(\kappa+1)((k_x^{(i)})^2 + k_y^2) + k_z^2 = 0, \tag{1}$$

It leads to ratios

$$k_z = \eta k_y;\ k_x^{(i)} = \pm j k_y \sqrt{\frac{1+\kappa+\eta^2}{1+\kappa}}. \tag{2}$$

Therefore, in the following formulas it is possible to exclude k_z, $k_x^{(i)}$ and to leave only one component of the wave vector k_y. The dispersion relation is derived from the conditions for the fields at the boundaries of the film. Appropriate variation of the dispersion relation for a free film with thickness of s can be found in [5, formula (19)].

$$(1+\eta^2) + 2(1+\eta^2)^{1/2}\left(-\frac{1+\kappa+\eta^2}{1+\kappa}\right)^{1/2}(1+\kappa)ctg\left[k_y s\left(-\frac{1+\kappa+\eta^2}{1+\kappa}\right)^{1/2}\right] + $$
$$+(1+\kappa)^2\left(\frac{1+\kappa+\eta^2}{1+\kappa}\right) - v^2 = 0. \tag{3}$$

Functions tangent and cotangent are comfortable in the formula (3) on the stage of the derivation of the equation, but complicate the analysis. These functions go to infinity and there their sign is changed. In addition, in the formula (3) there are some other features that would make it difficult analysis by using as numerical and analytical methods. In this article these difficulties, to the extent possible, eliminated.

The purpose of this article is to obtain the conditions of formation of the predominant directions of propagation of the SMSW in tangential magnetized free films of isotropic ferromagnet neither parallel nor orthogonal to the direction of magnetization of the film. The concept of group velocity is not used.

2. THE CONVERSION OF THE DISPERSION EQUATION

Get rid of tangents and cotangens in the formula (3). It is necessary to reduce variable η to $u = \frac{1}{\sqrt{\eta^2+1}}$, The variable u is the sine of the angle between the magnetization of the film and the direction of propagation of the SMSW. In this paper we deal with

only surface waves (imaginary $k_x^{(i)}$), so we can use the substitution:

$$ctg(jx) = \frac{a}{b} \Leftrightarrow \exp(-2x) = \frac{a+jb}{a-jb},$$

where j is the imaginary unit.

After transformation formula (3) is reduced to the form:

$$k_y = \frac{u}{2s}\left(\frac{1+\kappa}{1+\kappa u^2}\right)^{1/2} \ln\left(\frac{(uv)^2 - (1-\left((1+\kappa u^2)(1+\kappa)\right)^{1/2})^2}{(uv)^2 - (1+\left((1+\kappa u^2)(1+\kappa)\right)^{1/2})^2}\right). \quad (4)$$

The amplitude of the MSW is proportional to the wave vector [5], therefore, the formula (4) allows to make qualitative conclusions not only about the length of the MSW, but also about the amplitude of the waves. (The components of the wave vector are proportional to k_y in accordance with (2)) From the formula (4) it follows that if the direction of wave propagation coincides with the direction of magnetization of the film ($u = 0$), then SMSW is not exist. This fact allows us to understand the attention of researchers mainly to SMSW at $u = 1$. This estimate does not preclude the existence of surface magnetostatic waves at the corners, a small but not zero.

Formula (4) can be regarded as a method of calculating the wave vector only with restrictions. Sometimes the formula (4) is useless as there are uncertainties at the most interesting frequencies. At frequency $w_\perp$, the value κ is equal to (-1). In $\left(\frac{1+\kappa}{1+\kappa u^2}\right)^{1/2}$ there is an uncertainty factor for $u = 1$ and $w = w_\perp$, however, the expression under the logarithm in (4) takes a value of 1 so the wave vector is zero. MSW not exist at a frequency $w_\perp$. At frequencies more than $w_\perp$, factor $\left(\frac{1+\kappa}{1+\kappa u^2}\right)^{1/2}$ is real therefore the MSW are SMSW. When the expression $(1 + \kappa u)$ vanishes, uncertainties in the formula (4) complicate the analysis and can lead to incorrect estimates. These uncertainties create special difficulties at analytical and numerical analysis.

In [7, 8] properties of an isotropic ferromagnet is determined using the characteristic frequencies $w_M = 4\pi\gamma M_0$ and $w_H = \gamma H_0$. γ is the gyromagnetic ratio, M_0 is the saturation magnetization, H_0 is the internal magnetic field corresponding to the saturation magnetization. The components of the tensor Polder are expressed through characteristic frequencies [6-8]:

$$\kappa = \chi_{11} = \chi_{22} = \frac{w_M w_H}{w_H^2 - w^2};$$

$$v = \frac{\chi_{12}}{j} = -\frac{\chi_{21}}{j} = \frac{w w_M}{w_H^2 - w^2}.$$

Necessary condition for the existence SMSW is $1 + \kappa > 0$, it is transformed to

$$w > w_\perp = \sqrt{w_H\left(w_H + w_M\right)}.$$

In accordance with [11] we introduce the notation

$$W_\perp = w^2 - w_H^2 - w_M w_H,$$
$$W_u = w^2 - w_H^2 - w_M w_H u^2,$$
$$W_H = w^2 - w_H^2.$$

The value $W_\perp$ turns to zero at the frequency $w_\perp = \sqrt{w_H\left(w_H + w_M\right)}$. W_u vanishes when $w_u = \sqrt{w_H\left(w_H + w_M u^2\right)}$. If $w = w_H$ then $W_H = 0$. (4) reduces to

$$k_y = \frac{u W_\perp^{1/2}}{2s W_u^{1/2}} \ln\left(\frac{\left(w w_M u\right)^2 - \left(W_H - W_\perp^{1/2} W_u^{1/2}\right)^2}{\left(w w_M u\right)^2 - \left(W_H + W_\perp^{1/2} W_u^{1/2}\right)^2}\right). \quad (5)$$

In (5) there is uncertainty on the frequency w_u. The denominator of (5) and the logarithm is equal to 0. Let us introduce the function:

$$m(z) = \frac{\ln\left(1+z\right)}{z},$$

The formula for calculating the components of the wave vector is

$$k_y = \frac{u W_\perp^{1/2} R}{2s} m\left(R W_u^{1/2}\right), \quad (6)$$

where

$$R = \frac{4 W_H W_\perp^{1/2}}{\left(w w_M u\right)^2 - \left(W_H + W_\perp^{1/2} W_u^{1/2}\right)^2}. \quad (7)$$

The function $m(z)$ has no singularities at zero since $\lim_{x\to 0} m(z) = 1$. $zm(z) = ln(1 + z)$, so $\lim_{x\to\infty} zm(z) = \infty$.

When R goes to infinity, then k_y and the amplitude of the wave goes to infinity. I.e., take place the wave resonance. If denominator in the formula (7) goes to zero we obtain the resonance condition.

$$\left(w w_M u\right)^2 - \left(W_H + W_\perp^{1/2} W_u^{1/2}\right)^2 = 0. \quad (8)$$

Solving equation (8), we obtain 4 solutions for predominant waves

$$u_{1,2} = \frac{w \pm W_\perp^{1/2}}{w_M + w_H} = \frac{w \pm \sqrt{w^2 - w_\perp^2}}{w_M + w_H};$$

$$u_{3,4} = -\frac{w \pm \sqrt{w^2 - w_\perp^2}}{w_M + w_H}. \quad (9)$$

Solutions $u_{3,4}$ and $u_{1,2}$ are symmetrical about the origin. Solutions $u_{1,2}$ form two branches.

Predominant wave branch with the sign "+" is more familiar. The angle between the wave vector of a wave and the magnetization of the film is close to right angle. This branch can be called as "orthogonal" SMSW, or "the first type SMSW".

There are no SMSW at $w = w_\perp$. At this frequency $W_\perp^{1/2} = 0$, hence $R = 0$ and $k_y = 0$. However, from (9) at a frequency of $w = w_\perp$ we derive $u_\perp = \frac{w_\perp}{w_M + w_H}$. We can say that $u_\perp$ makes sense thresholds, which separates different branches SMSW.

In (9) with the sign "-", the branch corresponds to the waves, not previously known to the author. These waves are possible in the region of small angles (if the angles of 10-30 degrees can be called small).

Frequencies of "orthogonal" SMSW are limited to top the Damon-Eshbach's frequency $w_{DE} = w_H + w_M/2$ [5-9]. We substitute $w = w_{DE} = w_H + w_M/2$ in the formula (9) and get:

$$u_{1,2} = \frac{w_H + w_M/2 \pm \sqrt{(w_H + w_M/2)^2 - w_H(w_M + w_H)}}{w_M + w_H} =$$

$$= \frac{w_H + w_M/2 \pm w_M/2}{w_M + w_H}; \quad u_1 = 1; \quad u_2 = \frac{w_H}{w_M + w_H}.$$

Predominant direction $u_1 = 1$, as expected, corresponds to the "orthogonal" SMSW. With increasing frequency above w_{DE} from the formulas of this branch, we get the values of u, contradicting the condition $1 > u = sin(\varphi)$. Such decisions should be deleted. The second predominant direction $u_2 = \frac{w_H}{w_M + w_H}$, occurring at the Damon-Eshbach's frequency, corresponds to the "parallel" SMSW or "the second type SMSW". The absolute value of u_2 is less than unity. It corresponds to a corner and continues to exist with increasing frequency above the Damon-Eshbach's frequency. For frequencies much larger than $w_\perp$, we get the asymptotic evaluation:

$$u_2 = \frac{w - \sqrt{w^2 - w_\perp^2}}{w_M + w_H} \approx \frac{w_H}{2w}.$$

In more detail the conditions for the existence of "parallel" SMSW discussed in section 3.

3. GRAPHS OF THE DISPERSION RELATION FOR YIG

The most simple model of Yttrium Iron Garnet (YIG) is the model of an isotropic ferromagnet, neglecting anisotropy, exchange fields and magnetic damping [7]. (The term "isotropy" characterizes the state of a ferromagnet before its magnetization. After magnetization film up to saturation, film becomes anisotropic.) Equation (3) and formula (6), (7) have been derived with this simple model of the isotropic ferromagnet. The following fact, that has been discussed in [7], is useful for development of MSW models. For more accurate models, you can use the formulas MSW-approximation (this article is of the formula (6)-(7)), if to consider amendments at w_H. The rationale of this technique is also considered in [12]. To account for the magnetic damping, it is enough to do the replacement $w_H \to w_H + j\alpha w$. Value w_H becomes a complex number that depends on the frequency w. Value α is the coefficient of magnetic damping in the equation of motion of the magnetization in the ferromagnet, written in the form of Hilbert [7]. More complex but the same way is possible to take into account the inhomogeneous exchange field. Numerical experiments show that, the magnetic damping cannot be neglected, but a more careful specification of α without changing its sign does not change graphs for YIG noticeable way. Accounting for exchange field complicates the solution of the problem, but also does not lead to a noticeable change in graphic for isotropic YIG. In the present work for YIG, magnetic damping is taken into account, and the inhomogeneous exchange field is ignored.

As parameters we select values $\gamma = 1.76086 \cdot 10^7\ c^{-1}T^{-1}$, $H_0 = 1250\ Oe$, $M_0 = 139\ Gs$, $\alpha = 5 \cdot 10^{-5}$. For these parameters, the following values of the characteristic frequencies in GHz have been derived:

$$\frac{w_H}{2\pi} = 3.50, \quad \frac{w}{2\pi} = 4.90, \quad \frac{w_{DE}}{2\pi} = 5.42, \quad \frac{w}{2\pi} = 5.95.$$

$2\pi/cm$ is unit for wave vector, $3 \cdot 10^{-4}\ cm$ as a thickness of slab.

In [7, page 175] for these parameters, there are graphs of the frequency on the wave vector, when the wave vector and the magnetization are orthogonal.

Fig. 1 shows a plot of the wave vector on the direction for frequencies at 5% below the Damon-Eshbach's frequency (near the middle of the frequency range between $w_\perp$ and w_{DE}). The wave vector is shown in the graph only one component k_y. This is sufficient, since according to (2), the remaining components of the wave vector are proportional to k_y. The direction of wave propagation is represented by the value u (varying from (-1) to (+1)); u is equal to the sine of the angle between the magnetization of the film and the direction of wave propagation (directions lie in the plane of the film). In the graphs

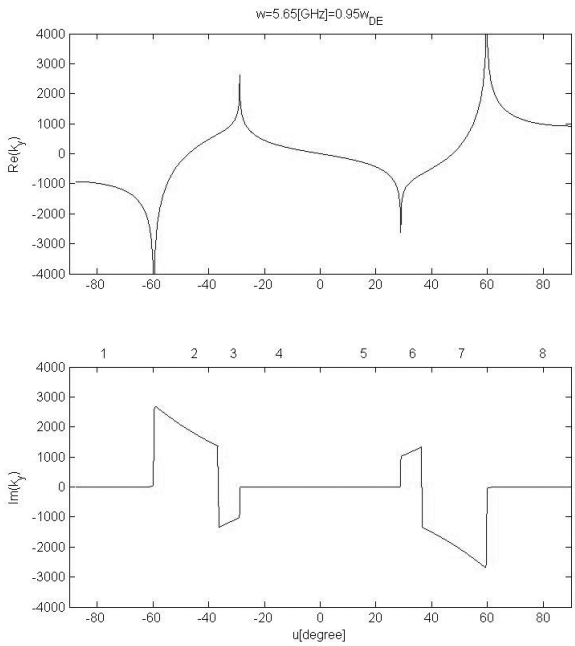

Fig. 1. *For YIG, the dependence of the wave vector on the wave direction is presented when frequency is at 5% below the Damon-Eshbach's frequency.*

the value of the parameter u are translated into degrees of the corresponding angle. For one value of a sine corresponds not one, but two angle that are symmetric with respect to the right angle. I.e. graphs can symmetrically continuing, reflecting from vertical boundaries.

As follows from (5), graphics should be centrosymmetric with point reflection at zero. This is a nontrivial property of waves of free films as a manifestation of nonreciprocity wave in magnetic media and as a result of the vector nature of the magnetization. If **k** is the wave vector of a surface waves, the wave propagating in the opposite direction **-k** can have very different properties. Vector **-k** is the decision where the amplitude should increase with distance from the surface of the media and hence must be removed from the results. In graph, for a section of surface waves, there are corresponding symmetrical sections with unrealizable waves that should be excluded from the solution.

In the Fig. 1, there are 8 regions with different behaviour. They are labelled on the top of Im(k_y).

Region 8 corresponds to the more familiar "orthogonal" SMSW. At region 8, the undamped (within the MSW approximation) surface waves occur near the direction orthogonal to the magnetization of the film (90 degrees). The real part of the wave vector increases with the deviation of u from orthogonal directions. The amplitude SMSW is proportional to the wave vector, so we can talk about resonant increase of the wave amplitude in the direction of the wave, i.e., about the "wave resonance with orientation". The resonance peak differs from that of a Gaussian curve, characteristic of usual resonance. When the maximum of k_y is reached then the damping of waves turns on. The direction corresponding to the maximum of k_y, we call the predominant (resonance) direction. In fig. 1 predominant direction is separates the region 8 and 7. Region 8 "orthogonal" SMSW corresponds to the region 1, where waves are unrealizable wave. They should be excluded from the solutions of the problem.

A large dumping of the wave amplitude takes place on region 7. The length of the damping and the wavelength has the same order. Region 2 is symmetric to region 7.

Region 4 corresponds to the "parallel" branch SMSW. Conditions for the existence of these waves differ from the conditions of existence "orthogonal" SMSW. To change the sign of the parameter u need to get a wave propagating in the opposite direction, or to magnetize the ferromagnetic material in the opposite direction, or place the emitter on the opposite end of the film. The peak of "wave resonance with orientation" takes place on the border of the region 4 and region 3. At region 3 there are large dumping of the waves. On the border region 4 and region 5 the parameter u and the wave vector vanish.

At region 5 and 6 the waves are unrealizable and should be excluded from the solution.

Note that to obtain Fig. 1 with the correct signs damping of the waves must be taken into account magnetic damping. If we change the sign of the coefficient of magnetic damping then the picture changed dramatically in regions where a large increase or damping of the waves. Moreover, the change in the value of the coefficient of magnetic damping, without changing its sign does not change significantly the graph. Magnetic damping cannot be neglected when describing the wave resonance with orientation.

Fig. 2 shows a graph of the frequency twice the Damon-Eshbach's frequency. The branch of "orthogonal" SMSW disappeared, but the branch of "parallel" SMSW exist. The region of surface waves

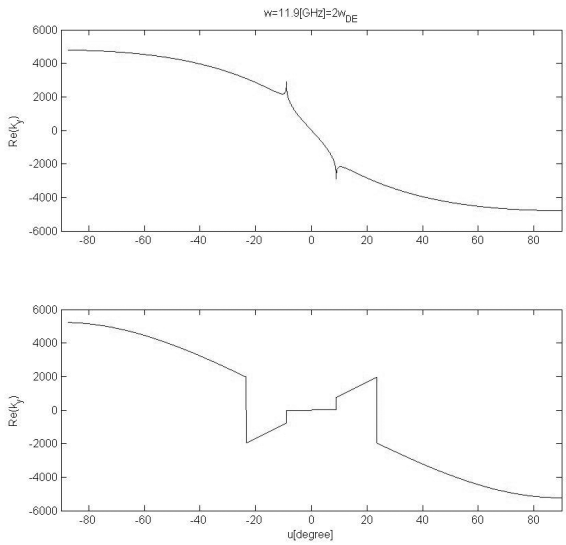

Fig. 2. *For YIG, the dependence of the wave vector on the direction is presented, when wave frequency is twice the Damon-Eshbach's frequency*

narrows if the frequency increases. It is inversely proportional to frequency.

4. PREDOMINANT DIRECTIONS OF SMSW IN YIG

Fig. 3 allows us to estimate the angles between the magnetization and the predominant direction of wave propagation. We plot the ratio (9), where instead of the parameter u used the angle between the wave vector and the magnetization of the film, expressed in degrees. With plotting the chart, we take into account that for any value of a sine not one but two angle take place. They are symmetric with respect to the right angle. The frequency is given in *GHz*.

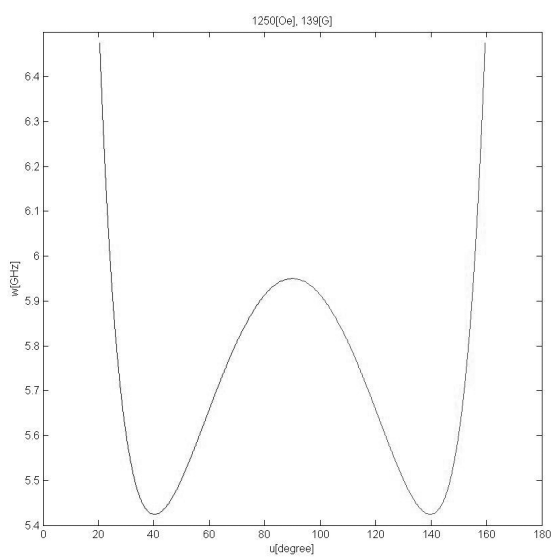

Fig. 3. Directions of the wave resonance with orientation (predominant modes) for YIG

A 90-degree angle in Fig. 3 corresponds to the Damon-Eshbach's frequency. At lower frequencies there are symmetric predominant directions. The minima in Fig. 3 corresponds to the frequency $w_{\perp}$ and direction $u_{\perp}$. At this frequency cannot be SMSW. $u_{\perp}$ is the ultimate value that separates the branch "orthogonal" SMSW from "parallel" SMSW. The frequency of "parallel" PMSW may greatly exceed the Damon-Eshbach's frequency.

5. CONCLUSION

In magnetic film an wave resonance with orientation can be considered as selecting of predominant harmonics. This phenomenon is very similar, but different from the caustic. Caustics are interpreted in terms of geometric optics, but with interesting wave justifications and generalizations [13]. In [6, 9, 10] the formation SMSW by means emitter of finite size is explained as the result of the interaction of spatial modes.

Understanding the details of the analysis of the dispersion relation allows to clarify this interpretation. The middle part of the flat emitter gives the main contribution to the amplitude of the harmonics propagating orthogonal to the emitter, while the ends of the flat emitter give harmonic propagating in all directions. Resonant amplification of selected two harmonics leads to formation of two narrow SMSW beams from each of the ends of the emitter when the frequency is slightly lower Damon-Eshbach's frequency. Although any resonance phenomenon can be mathematically described in the style of the catastrophe theory [13], it seems promising to move away from a beautiful picture of the wave fields, and focus on the more simple effects and experiments. "whiskers" waves can be interpreted as resonance peaks with unusual properties. After research of features of this wave resonance can put more specific targets for investigation of wave fields.

Developed in the present work, ideas, formulas and estimations can be useful when searching other, maybe less spectacular, but more constructive solutions for the development of new SMSW devices. Probably if to go closer to the predominant directions we can to try to reduce the power consumption of the devices on SMSW and to propose new methods of signal processing. "Parallel" SMSW predicted by the theory, have a frequency range exceeding the Damon-Eshbach's frequency. From the point of

view of the opinions expressed in [1, 2], (mentioned in the beginning of the article) the study of such waves and their properties should be promising. For this branch SMSW the wave resonance with orientation takes place also. At high frequency, the predominant direction comes near to direction of film magnetization inversely proportionally to frequency.

The orientation of the resonance and the existence of branch of the "parallel" SMSW derived theoretically and experimental confirmations are required. If experiment would not confirm theoretical prediction, what conclusions may follow? All transformations of equation (3) presented in this article do not contribute to the model SMSW any simplifications or generalizations, they only result in equation (3) is more convenient for the analysis of mind and computer. So the question would be arise: why is the model SMSW proposed in a classic paper [5] would sometimes not give the correct results? Refined definition of the problem will be not less interesting than the direct experimental confirmation of the theoretical predictions.

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TIME COMPRESSION OF X-RAY FREE-ELECTRON LASER PULSES UNDER CONDITIONS OF BRAGG DIFFRACTION

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Abstract. **In the last years several laboratories actively work on construction of X-ray free electron lasers (XFEL) with wavelength of radiation of the order λ ~ 0.1 nm. Theoretical calculations show, that self-induced amplification of spontaneous radiation on the exit of an XFEL undulator forms a pulse composed of many ultra-short peaks with duration from a fraction up to tens femtosecond. A further tailoring of the X-ray radiation parameters is necessary for most experimental application. A quite natural solution for this task is diffraction on ideal single crystals.**

A dynamical theory of diffraction of X-ray pulses with arbitrary form in the Bragg and the Laue cases was developed, which allows to consider special and temporal distribution of reflected and transmitted pulses at any given distance from a crystal with account of diffuse spreading of these pulses in the process of their propagation in space. It is shown, that super-short pulses with the duration about 0.1-1 fs are strongly widened in time and are deformed in form by the diffraction process.

In the present paper I investigate the possibility of time compression of pulses, i.e. the reduction of their duration by means of the Bragg reflection. It is shown, that in the case of incident chirp pulses, for which the instantaneous frequency of radiation has a linear time dependence, and the phase – a quadratic one, it is possible to achieve for 1-10 fs incident pulse a reduction of duration by a factor of 10. The effect is based on a large spectral width of the chirp pulses, comparable or even exceeding the typical width of a Bragg reflection for the plane wave case.

Keywords: **free-electron lasers; ultrashort X-ray pulses; X-ray optics; dynamical diffraction.**

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Contents

1. INTRODUCTION

The generation of an X-ray free-electron laser (XFEL) is based on the phenomenon of the self-amplified spontaneous emission (SASE) of high-energy electron bunches at their transmission through a lengthy undulator system [1-3].

Three XFEL projects are now actively developed: the European XFEL Facility in Germany with radiation in hard *X*-ray range (λ ~ 0.1-1.6 *nm*) [4], the *X*-ray lasers LCLS (Linac Coherent Light Source) in the USA [5] and the SCSS (Spring-8 Compact SASE Source) in Japan [6].

According to the calculations and experimental results reported in [2, 7-10], the parameters of the European XFEL and its radiation in the SASE 1 channel are expected to be as follows: electron energy 17.5 *GeV*, total length of superconducting undulators ~150 *m*, central radiation wavelength λ_0= 0.1 *nm*, and the pulse full duration width at half maximum (FWHM) τ_p ~ 100 *fs*. These pulses have a very irregular multispike temporal structure with a width of individual random subpulses (spikes)

τ_s ~ 0.1-0.2 *fs* and time intervals of ~ 0.3-0.4 *fs* between them, the transverse pulse size at the undulator output $r_0 \approx 40$ μm, and an angular divergence $\Delta\theta_0 \approx 1$ μ*rad*; peak power ≈ 10 *GW*, average power ≈ 40 *W*. The expected XFEL peak brightness should exceed that of modern third-generation synchrotron radiation sources by nine orders of magnitude [4].

X-ray diffraction phenomenon is widely used for monochromatization, collimation and polarization changes of *X*-rays. In this connection, great interest is the consideration of the diffraction reflection and transmission in perfect single crystals for controlling the characteristics of the laser radiation in the hard *X*-ray wavelengths, and for the development of diagnostic methods of XFEL pulse parameters.

The analysis of diffraction of XFEL radiation has been restricted so far to the approximation of a plane (unlimited) wavefront for the Bragg case "on reflection" [11-14] and for the Laue case "on transmission" [13, 15, 16]. The time structure of the incident pulse has been approximated either by a δ-function [11-13, 15, 16] or by a Gaussian [12, 14]. Although giving some insight into the physics of short-pulse diffraction, such an approach cannot in principle take into account the presence of transverse mode structure and, even more essential, a non-uniform distribution of the field phase inside a pulse. However, such a phase distribution will inevitably arise at large, of the order of 100-1000 *m*, distances from the undulator to the sample or monochromator crystal. Besides, all analysis [11-16] so far has been to the reflected pulse field on the exit surface of a crystal, whereas significant practical interest is for spatial (transversal) and temporal (longitudinal) smearing of pulses during their further propagation in vacuum from an output undulator window to the crystal-monochomator or to the crystal for investigations.

In the articles [17, 18] a general theory of dynamical diffraction of *X*-ray pulses with an arbitrary spatial and temporal structure of the field on crystals with arbitrary thickness and asymmetry coefficient in the Bragg and in the Laue cases is developed. Such an approach allows us to analyze the structure of fields of forward-diffracted (transmitted) and diffracted (reflected) pulses at any distance from the crystal, and also the degree of space and time coherence of these pulses and their relation with the statistical properties of the XFEL radiation field. The analysis of pulse form and duration transformation in the process of diffraction and propagation in vacuum is also conducted. It is shown, that only the symmetrical Bragg case can be used to avoid a smearing of reflected pulses.

Time-resolved experiments, *X*-ray photon correlation spectroscopy, coherent diffraction, and phase-contrast imaging depend to a great extend on the coherent properties of *X*-ray pulses [19, 20]. XFEL radiation is almost completely spatially coherent and is characterized by a fairly moderate temporal coherence. In the saturation mode, the length of the spatial (transverse) coherence is comparable with transverse pulse size, whereas the coherence time (longitudinal coherence) $\tau_c \approx 0.2$ *fs* $<< \tau_p$ much less the total duration of XFEL pulse; as a result, the relative spectral pulse width $\Delta E/E \approx 0.1\%$ [8, 10].

Diffraction reflection of X rays from crystals and multilayer periodic structures is widely used to make radiation monochromatic and collimated. It was shown in [17, 18] that, in the case of a diffraction reflection of deterministic femtosecond pulses from single crystals, the reflected pulses broaden in time by 1-2 order of magnitude, their shape significantly differs from the time profile of the incident pulse, and the peak intensity is several (or even several tenths) of a percent of the incident pulse intensity. In addition, in all cases except for the symmetric reflection in the Bragg geometry, the reflected pulse orientation changes rather nontrivially and the pulse begins to diffusely spread in space and time at distances of 0.1-1 *m* from the crystal [18]. The reason for this is that the spectral width of

these short incident pulses significantly exceeds the spectral range of diffraction reflection.

In [21, 22] based on the formalism used in the statistical optics and radio-physics [23], the statistical theory of the Bragg reflection of random femtosecond XFEL pulses from multilayer periodic structures was developed. It is shown that the use of quasi-forbidden second-order reflections from a periodic multilayer structure Al_2O_3/B_4C allows monochromatization of femtosecond X-ray free-electron laser pulses at level $\Delta E/E \approx 0.04\%$ with an efficiency of ~60%. The intensity, duration, and statistical characteristics of the reflected pulses are studied.

In the paper [24] we report the results of a theoretical analysis of the spatial and temporal transformations of the field of *X*-ray pulse and its statistical properties under pulse propagation in free space and at a diffraction reflection in the Bragg and Laue geometries from one crystal or two crystal oriented parallel to each other. Particular attention is paid to the influence that the pulse path length has on the spatial, temporal, and statistical pulse characteristics, because the distances from the XFEL to the first optical elements and, even more, to the measuring stations are fairly large (400-900 *m*) [4-8]. It has been shown that the diffraction reflection significantly increases the reflected pulse coherence time, while the shape of the temporal-coherence function of the reflected pulse differs significantly from the Gaussian incident pulse and has a characteristic triangular shape with damping oscillations at the edges. Earlier, it was investigated the influence of the spatial coherence of the *X*-ray beam, limited in space, but continuous in time, on the diffraction in crystals [25] and multilayer periodic structures [26].

As was mentioned above, the XFEL pulses are characterized by an almost complete spatial coherence and a very moderate temporal coherence, leading to a spectral width of pulses of $\Delta E/E \approx 10^{-3}$. The authors [27-29] suggested various four-chip and single-chip circuits to reduce the spectrum width to $\Delta E/E \approx 10^{-5}$, allowing us to attain a so called self-seeding mode and better laser generation with the crystal placed between two undulators. In the self-seeding regime *X*-ray pulse delayed as a result of the passage of the incident XFEL pulse on the crystal in the Bragg geometry is broadened in time and, therefore, has a narrow spectrum. It is this pulse is the seed of coherent excitation of electron bunches in the next undulator. The diffraction reflection of femtosecond pulses from single crystals and multilayer periodic structures with the aim of their monochromatization and raising the degree of temporal coherence was considered in [17, 18, 21, 22, 24].

Pulse energies of the European FEL in channels SASE1 and SASE2, depending on the bunch charge, are 20÷2500 μ*J* [30], leading to average energy flows of 60 $W \cdot cm^{-2}$ to 80 $kW \cdot cm^{-2}$ in the region of the first elements of *X*-ray optics at distances of 500-900 *m* from the undulator. Allowance for and prevention of the strong thermal heating of the crystal and multilayered mirrors is one of our most serious problems.

The need to analyze the heat load, in [31] we consider the effect of such factors as the pulse energy; the temporal structure of the XFEL radiation; the distance from the undulator; the initial and maximum temperatures of the crystal; the temperature dependences of the coefficients of specific heat capacity; the heat conductivity; and the linear thermal expansion coefficient on the diffraction reflection and transmission. Spatiotemporal dependences of the distribution of the crystal temperature under the effect of pulses of a free-electron X-ray laser are found using the solution of a thermal conductivity equation. The effect of temperature, its gradient, and the deformation of the crystal lattice on the diffraction reflection and the transmission of pulses in crystals of synthetic diamond are considered.

It follows from the Van Cittert-Zernike theorem that the length of spatial coherence (LSC) of radiation $\varrho_c = \lambda z/\pi r_0$ growths as distance

z increases and the source size r_0 decreases, where λ is the wave length [23]. A number of the channels of synchrotron radiation sources are therefore being updated to extend their length and reduce the transverse dimensions of electron bunches. For example, the channels of *X*-ray free-electron lasers and SPring-8 and APS synchrotron sources can be as long as 1 *km* [3].

As was noted above, an expression for the length of spatial coherence ϱ_c was obtained for a monochromatic source and a completely incoherent (δ-correlated in space) source typical of heat radiation. For the synchrotron radiation of a third-generation LSC, length ϱ_0 at the output window of the undulator can be commensurate with source size r_0 [32]; for *X*-ray free-electron lasers, ϱ_0 is often greater (and even much greater) than r_0 [30, 32]. The Van Cittert-Zernike theorem was extended in [21, 22, 24, 25, 32-34] to sources with arbitrary lengths of spatial coherence, with due account of the parabolic bending of the regular part of the initial wave front [21, 22, 24, 25, 34].

In the monograph [23] (p. 294), it was noted that as distance $z \geq z_r$ from a spatially δ-correlated source grows, the partial temporal coherence of its radiation field (i.e., its non-monochromaticity) begins to affect the spatial coherence; an estimate was offered for the corresponding critical distance $z_r \approx c\tau_c(\pi r_0/\lambda)^2$, where τ_c is the coherence time. This effect may be ignored at distances $z << z_r$. In [21, 22, 24, 34], it was shown that as the length of the active channel of a free-electron *X*-ray laser grows, the temporal coherence of pulses, which was ab initio poor ($\tau_c \sim 0.2$ *fs*; i.e., $\Delta E/E \sim 10^{-3}$ [30]), can lower an initially high degree of spatial coherence. For the typical parameters of a free-electron *X*-ray laser (λ ~ 0.05-0.16 *nm*, $r_0 \sim 10$-50 μ*m*, $\tau_c \sim 0.1$-0.3 *fs* [30]), critical distance $z_r \geq 1$ *km* [21, 22, 24, 34].

In [35] conducted a generalization of Van Cittert-Zernike theorem on sources with arbitrary spatial and temporal coherence. This work presents the results from a theoretical analysis of variation in the spatial coherence function versus the distance, size, length of spatial coherence, and coherence time of a radiation source. A more general expression for the critical distance is obtained; it is also shown that this distance shrinks, relative to the above simple estimate for zc, as the length of spatial coherence of the source radiation grows, what is characteristic for X-ray free-electron laser. We also show that the form of the spatial coherence function is distinct from the original Gaussian form and depends on the choice of a point in the cross section of a beam or a pulse.

As was noted above, X-ray diffraction in crystals is an effective method of managing such characteristics of the incident radiation as monochromaticity, angular divergence, duration and shape of the reflected and transmitted pulses. In the present paper, based on the results obtained earlier in [17, 18, 21, 22, 24], the possibility of temporal pulse compression, i.e. reduce their duration as a result of Bragg reflection from perfect single crystals is investigated.

It is shown, that in the case of incident chirp pulses, for which the instantaneous frequency of radiation has a linear time dependence, and the phase – a quadratic one, it is possible to achieve for 1-10 *fs* incident pulse a reduction of duration by a factor of 10. The effect is based on a large spectral width of the chirp pulses, comparable or even exceeding the typical width of a Bragg reflection for the plane wave case.

2. X-RAY PULSE PROPAGATION IN FREE SPACE

Before proceeding to the consideration of diffraction XFEL pulses in a single crystal, we first consider the transformation of the pulse as it propagates in free space in the path from the output window of the undulator to the crystal. At exit from undulator in the plane $\boldsymbol{\varrho} = (x, y)$ at $z = 0$ the XFEL pulse radiation field is given by

$$E_0(\boldsymbol{\varrho},t) = A_0(\boldsymbol{\varrho},t)exp(-i\omega_0 t), \quad (1)$$

where the amplitude $A_0(\boldsymbol{\varrho}, t)$ is a complex slowly varying function of time (wave package), ω_0 is an average (central) frequency. A slow variation of amplitude implies, that $|dA_0/dt| << \omega_0|A_0|$. If τ_0 is the characteristic time of a pulse, $\Delta\omega \approx 1/\tau_0$ is the spectral width of a wave package and $\Delta\omega/\omega_0 << 1$ (it is the condition of quasi-monochromaticity).

Let us now find the field $E(\mathbf{r}, t)$ at any point of space $\mathbf{r} = (\boldsymbol{\varrho}, z)$ and at any moment of time t. Expanding the field (1) over a plane waves provides

$$E_0(\boldsymbol{\rho},t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E_0(\mathbf{q},\omega)\exp(i\mathbf{q}\boldsymbol{\rho} - i\omega t)d\mathbf{q}d\omega, \quad (2)$$

where spectral amplitudes $E_0(\mathbf{q}, \omega)$ are defined as

$$E_0(\mathbf{q},\omega) = 1/(2\pi)^3 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E_0(\boldsymbol{\rho},t)\exp(-i\mathbf{q}\boldsymbol{\rho} + i\omega t)d\boldsymbol{\rho}dt. \quad (3)$$

Here $\mathbf{q} = (q_x, q_y)$ is a transversal vector. The field $E(\mathbf{r}, t)$ should satisfy to the wave equation in free space

$$\Delta E - (1/c^2)\partial^2 E/\partial t^2 = 0$$

with a boundary condition $E(\boldsymbol{\varrho}, z = 0, t) = E_0(\boldsymbol{\varrho}, t)$. It is easily to show, that the required field has the following general integral form:

$$E(\mathbf{r},t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E_0(\mathbf{q},\omega)\exp(i\mathbf{q}\mathbf{r} + ik_z z - i\omega t)d\mathbf{q}d\omega, \quad (4)$$

where $k_z(\mathbf{q}, \omega) = (k^2 - q^2)^{1/2}$, $k = \omega/c$.

We shall obtain an expression for the field $E(\mathbf{r}, t)$ in so called the quasi-optical approximation [36], i.e. under the assumption, that the function $E_0(\mathbf{q}, \omega)$ (3) significantly differs from zero only at $|\mathbf{q}| << k$. Such approximation is justified in the case, when the characteristic size a_0 of an initial pulse is much larger than the wavelength $\lambda = 2\pi/k$. In this case it is possible to expand k_z in a series keeping terms up to the square terms over q:

$$k_z \approx k_0 + \Omega/c - q^2/2k_0,$$

where $k_0 = \omega_0/c = 2\pi/\lambda_0$, $\Omega = \omega - \omega_0$. Substituting (1), (3) and k_z into (4), we shall obtain

$$E(\mathbf{r},t) = A(\mathbf{r},t)\exp(k_0 z - i\omega_0 t). \quad (5)$$

Here $A(\mathbf{r}, t)$ is a slowly varying complex amplitude, which has the following form:

$$A(\mathbf{r},t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(\boldsymbol{\rho}-\boldsymbol{\rho}',z)A_0(\boldsymbol{\rho}',t - z/c)d\boldsymbol{\rho}', \quad (6)$$

with the Green function of the free space (so called propagator)

$$G(\boldsymbol{\varrho} - \boldsymbol{\varrho}', z) = (1/i\lambda_0 z)\exp[i\pi(\boldsymbol{\varrho} - \boldsymbol{\varrho}')^2/\lambda_0 z]. \quad (7)$$

For numerical calculations, but also for a more detailed analysis of the features of XFEL pulse diffraction it is convenient to use the following equivalent spectral representation for slowly varying amplitude:

$$A(\mathbf{r},t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} A_0(\mathbf{q},\Omega)\exp[i\mathbf{q}\boldsymbol{\rho} - iq^2 z/2k_0 - i\Omega(t - z/c)]d\mathbf{q}d\Omega, \quad (8)$$

where $A_0(\mathbf{q}, \Omega)$ is the Fourier amplitude of a source field $A_0(\boldsymbol{\varrho}, t)$ in the plane $z = 0$.

From equation (6) it is clear, that in vacuum, as in medium without dispersion, the perturbation reaches an observation point z after a time period z/c, and this delay does not depend on the wave spectral structure. In other words, the temporal structure of a pulse does not vary during the propagation in free space, whereas the space distribution undergoes diffraction induced diffusion, connected with the limited cross section of a pulse [17, 18, 24].

We shall investigate the modification of amplitude and phase of a wave depending on the distance z for a practically important example of the Gaussian pulse with a quadratic variation of the initial phase:

$$A_0(\varrho,t) = \exp[-(\varrho/a_0)^2 - (t/\tau_0)^2 + i\varphi_0(\varrho) + i\psi_0(t)], \quad (9)$$

where a_0 is a characteristic width of a pulse in a plane $z = 0$, τ_0 is the duration of a pulse; $\varphi_0(\varrho) = \beta_\varrho(\varrho/a_0)^2$ and $\psi_0(t) = \beta_\tau(t/\tau_0)^2$ are spatial and temporal phases, accordingly. Here β_ϱ and β_τ are dimensionless parameters, equal to the phase at $\varrho = a_0$ and $t = \tau_0$, accordingly. In the case of a flat phase front the value $\beta_\varrho = 0$. Substitution of (9) into (6) or (8) results in the following exact analytical expression for the complex amplitude in the observation plane z:

$$A(\varrho,z,t) = |A|\exp[i\varphi_z(\varrho) + i\psi_0(t - z/c)], \quad (10)$$

where

$$|A| = (1/W)\exp[-\rho^2/r_0^2 - (t - z/c)^2/\tau_0^2],$$

$W = [(1 + \beta_\varrho D)^2 + D^2]^{1/2}, \quad r_0 = a_0 W,$

$\varphi_z(\varrho) = \beta_z(\varrho/r_0)^2 - arctg[D/(1+\beta_\varrho D)],$

$\beta_z = \beta_\rho + (1+\beta_\rho^2)D.$

Here $D = z/L_d$ is dimensionless diffraction length (the so called wave parameter [36]), and $L_d = \pi a_0^2/\lambda_0$ is the distance, at which $D = 1$. If, for example, $a_0 = 30$ μm and $\lambda_0 \approx 0.1$ nm, then $L_d \approx 30$ m.

As it is clear from (10), during the propagation of a pulse the wave front of a wave is distorted. At distances $D >> 1$ the amplitude of a wave decreases as $|A| \sim L_d/z$, and the cross-section of a pulse grows according to the linear law $r_0(z) \approx a_0(1+\beta_\varrho^2)^{1/2} z/L_d$. The width of angular ($\Delta\vartheta_d$) and frequency spectrum ($\Delta\Omega$) do not depend on distance z and are determined by the values λ_0, a_0 and τ_0, but also by parameters of an initial phase β_ϱ and β_τ:

$$\Delta\theta_d = (\lambda_0/\pi a_0)(1+\beta_\rho^2)^{1/2}, \tag{11.1}$$

$$\Delta\Omega = (2/\tau_0)(1+\beta_\tau^2)^{1/2}. \tag{11.2}$$

The consideration of diffraction of any X-ray pulse with a general form (5) or in the special case (10) represents a rather difficult problem. However, if the cross-section size of a pulse in the location of the crystal $r_0 >> \Lambda$, where Λ is the extinction length, and the width of an angular spectrum $\Delta\vartheta_d << \Delta\vartheta_B$, where $\Delta\vartheta_B$ is the width of diffraction reflection curve, the problem is much simplified. For example, if (as in the project European XFEL [30]), wavelength $\lambda_0 \approx 0.15$ nm, pulse size $a_0 \approx 50$ μm, $\beta_\varrho \approx \pi/2$ and the distance from the X-ray laser $z \approx 500$ m ($D = 9.8$), then pulse size in the region of the crystal $r_0 \approx 0.1$ mm and angular divergence $\Delta\vartheta_d \approx 0.4''$, whereas for the reflection (220) from the single crystal Si one has extinction length $\Lambda = 2.16$ μm and the Bragg width $\Delta\vartheta_B = 2.56''$. In this case it is possible to neglect the dependence of amplitude and phase of a pulse from the transverse coordinate x, to neglect the edge effects and to take into account only dependence of the field on the time t.

3. TIME COMPRESSION OF X-RAY PULSES

In the previous papers [12-14, 17, 18] we saw, that in the case of incidence of a super-short X-ray pulse on a crystal the duration of a reflected pulse is much increased. We shall now discuss an opportunity of time compression of X-ray pulse, i.e. the generation of a reflected pulse with duration shorter than the incident pulse. We shall obtain also the ratio for parameters of an incident pulse and the crystal, necessary for time compression.

Let us present the field of incident plane quasi-monochromatic wave of X-ray pulse in a form

$E_{in}(t) = A_{in}(t)exp(-i\omega_0 t),$

where $A_{in}(t)$ is slowly varying complex amplitude. We shall consider for clarity a Gaussian pulse with quadratic modulation of the phase $\varphi(t)$:

$$A_{in}(t) = exp[-(t/\tau_0)^2 + i\varphi(t)], \tag{12}$$

where time-depended phase $\varphi(t) = \beta(t/\tau_0)^2$. Here τ_0 is the duration of a pulse, β is the constant, which is numerically equal to a phase of a pulse field amplitude at times $t = \pm\tau_0$. The quadratic dependence of a phase on time means linear dependence of an instantaneous frequency on time:

$\omega(t) = \omega_0 - \beta t/\tau_0^2.$

Such a pulse, in which the instantaneous frequency varies in time, is called a chirp pulse, and β is the chirp parameter.

The wavelength of a generated XFEL radiation is determined by the expression $\lambda \approx d_{un}/2\gamma^2$, where d_{un} is the space period of the undulator, $\gamma = E/mc^2$, E is the energy of relativistic electron [1-3]. The chirp is generated by the loss of electron energy in an undulator ($\leq$10% [1-3]) as a result of the induced deceleration and grouping in the bunches by transfer of energy in a form of X-ray quanta in a field of bremsstrahlung radiation along the axis of an electronic beam.

The frequency spectrum of the incident pulse (12) has the form

$$A_{in}(\Omega) = [\tau_0/2\pi^{1/2}(1-i\beta)^{1/2}]\exp[-\Omega^2\tau_0^2/4(1-i\beta)]. \tag{13}$$

Half-width of this spectrum at the level e^{-1} is equal to

$$\Delta\Omega_{in} = (2/\tau_0)(1 + \beta^2)^{1/2}. \quad (14)$$

It is clear from expression (14), that at weak phase modulation ($\beta << 1$) the width of a spectrum is determined by the pulse duration τ_0: $\Delta\Omega_{in} = 2/\tau_0$. In the case of strong modulation, when $\beta >> 1$, the width of a spectrum is increased with increasing of $|\beta|$ irrespective of a sign of parameter of modulation β: $\Delta\Omega_{in} \approx 2|\beta|/\tau_0$.

We shall consider now the Bragg reflection and transmission of an *X*-ray pulse. The spectral distribution of a reflected pulse $A_R(\Omega)$ is determined by the product

$$A_R(\Omega) = A_{in}(\Omega)R(\Omega), \quad (15)$$

where $R(\Omega)$ is complex amplitude coefficient of the Bragg reflection of a plane wave in the space of frequencies (for further details see in [17, 18]). The spectral width of the function $R(\Omega)$ has the form [37]

$$\Delta\Omega_B = \omega_0\Delta\theta_B ctg\theta_B, \quad (16)$$

where $\Delta\theta_B$ is the angular width of the curve of diffraction reflection. In the case of symmetric reflection from a thick crystal ($d > \Lambda$, where Λ is the extinction length [37]) the width $\Delta\theta_B = \lambda/2\pi\Lambda cos\theta_B$. In the case of a thin crystal with thickness $d << \Lambda$ (kinematical approximation) $\Delta\theta_B = \lambda/2d cos\theta_B$.

In **Fig. 1** the frequency spectrum of an incident *X*-ray pulse is shown for various values of chirp parameter β together with the reflection and transmission curves.

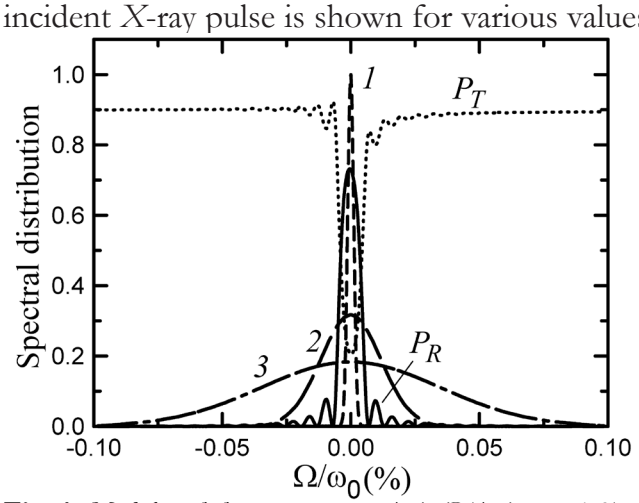

Fig. 1. *Modulus of frequency spectra $|A_{in}(\Omega)|$ (curves 1-3) of an incident X-ray pulse for different values of chirp parameter β: 0 (curve 1), 10 (curve 2), 30 (curve 3). Functions P_R and P_T are the intensity curves of the Bragg reflected and transmitted waves in the case of plane monochromatic incident wave, respectively. Pulse duration τ_0 = 10 fs, crystal thickness d = 3 μm, symmetric Bragg reflection Si(220), wavelength λ = 0.154 nm.*

From (15) it is follows, that the spectral width of the reflected pulse $\Delta\Omega_R$ is determined approximately by the expression

$$\Delta\Omega_R \approx \Delta\Omega_{in}\Delta\Omega_B / (\Delta\Omega_{in}^2 + \Delta\Omega_B^2)^{1/2}. \quad (17)$$

The duration of a reflected pulse $\tau_R \approx 2/\Delta\Omega_R$ strongly depends on the ratio of spectral width $\Delta\Omega_{in}$ (14) and $\Delta\Omega_B$ (16) We shall consider two limiting cases.

a) The case of a long pulse, i.e. the pulse with a narrow spectrum: $\Delta\Omega_{in} << \Delta\Omega_B$. In this case from (17) it is follows, that $\Delta\Omega_R \approx \Delta\Omega_{in}$ and the duration of a reflected pulse is equal to

$$\tau_R \approx \tau_0/(1 + \beta^2)^{1/2}. \quad (18)$$

Thus, in the case of strong phase modulation ($\beta >> 1$) a significant time compression of reflected (**Fig. 2**) and transmitted (**Fig. 3**) pulses with $\tau_R << \tau_0$ is possible.

b) The case of a short incident pulse, i.e. the pulse with a wide spectrum: $\Delta\Omega_{in} >> \Delta\Omega_B$. In this case from (17) follows, that $\Delta\Omega_R \approx \Delta\Omega_B$ and the duration of a reflected pulse is

$$\tau_R \approx \tau_b \equiv 2/\Delta\Omega_B. \quad (19)$$

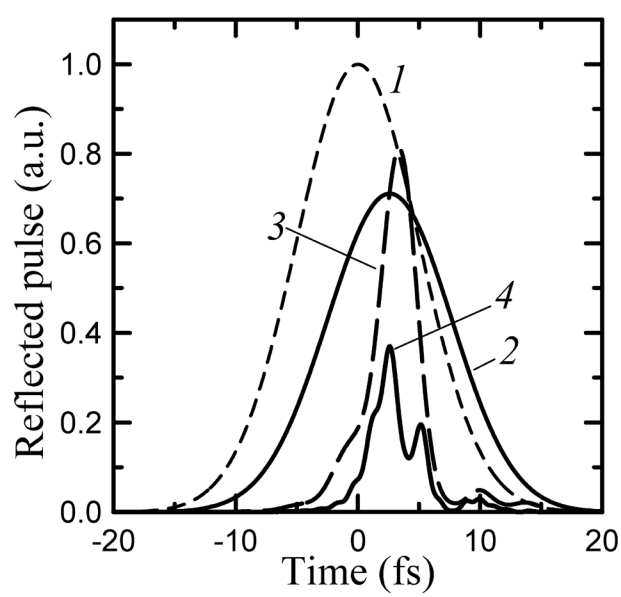

Fig. 2. *Intensity of the incident pulse (curve 1) and intensity of the reflected pulse (curves 2-4) versus time for different values of chirp parameter β: 0 (curve 2), 10 (curve 3), 30 (curve 4). The units of the abscissa are femtoseconds, whereas the ordinate is in arbitrary units. Time compression of a diffracted pulse by a factor of 4.4 and its splitting can be clearly seen (curve 4). Other pulse and crystal parameters are as in Fig. 1.*

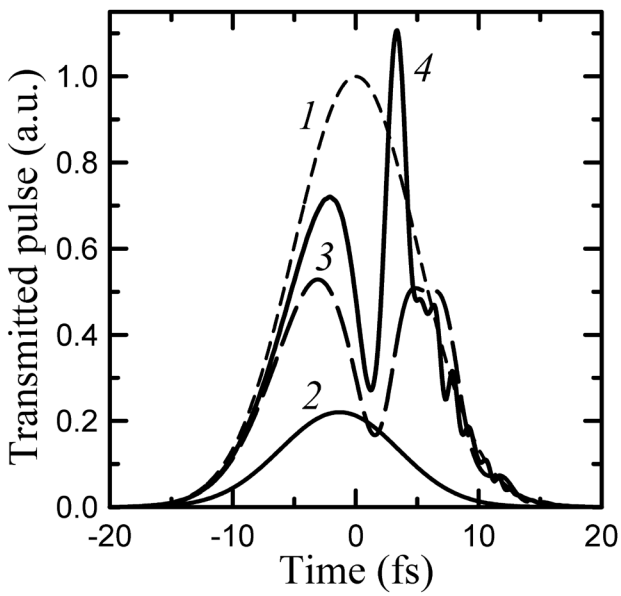

Fig. 3. *Intensity of the incident pulse (curve 1) and intensity of the transmitted pulse (curves 2-4) versus time for different values of chirp parameter β: 0 (curve 2), 10 (curve 3), 30 (curve 4). The transmitted pulse becomes higher and consists of two narrow peaks. Other pulse and crystal parameters are as in Fig. 1.*

Clearly, the duration of the reflected pulse is defined by the spectral width of diffraction reflection curve alone. Thus, pulses with the duration $\tau_0 << \tau_b$ can not be compressed in principle (see **Fig. 4**).

In the case of a thick crystal the duration $\tau_b = 2\Lambda sin\theta_B/c$. For instance, for the symmetrical reflection *Si*(220) and $\lambda = 0.154$ *nm* the value $\tau_b \approx 5.7$ *fs*. The boundary value of τ_b can be reduced by use of a thin crystal with thickness $d << \Lambda$, for which $\tau_b = 2dsin\theta_B/\pi c$. If, for example, $d = 0.1\Lambda$, then $\tau_b = 0.2$ *fs*. However in this case the intensity of a reflected pulse sharply decreases together with the coefficient of the Bragg reflection $|R|^2 \sim (d/\Lambda)^2$.

For super-short pulses with $\tau_0 < \tau_b$ the duration of a reflected pulse is determined, actually, by the time of propagation of a wave with speed c in sub-surface layer with the thickness Λ in the case of a thick crystal and in a crystal with thickness d in the case of a thin crystal.

From **Fig. 5** it is clear, that with the reduction of a crystal thickness the reflected pulse duration also decreases. Full width at half-maximum Δt_R = 1.18, 4.45, 2.03 and 1.21 *fs* for curves 1-4, accordingly. From these data it is clear, that the condition $\tau_0 \sim \tau_b$ is met only for a thin crystal with $d = 0.2$ μ*m* (curve 4), therefore only in this case it is possible to carry out a time compression of an incident chirp pulse (see **Fig. 6**).

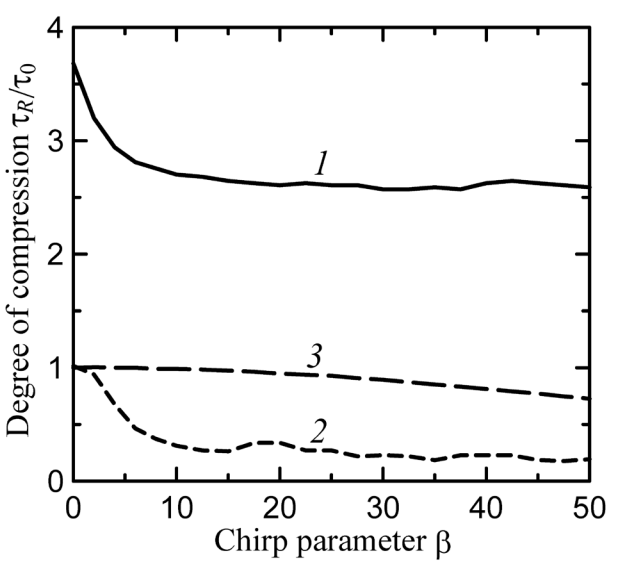

Fig. 4. *Dependence of degree of time compression τ_R/τ_0 on the chirp parameter β at different incident pulse duration τ_0: 1 fs (curve 1), 10 fs (curve 2), and 100 fs (curve 3). Significant time compression is carried out only for incident X-ray pulses with the duration $\tau_0 \sim 10$ fs. Crystal thickness d = 3 μm, symmetric Bragg reflection Si(220), wavelength λ = 0.154 nm.*

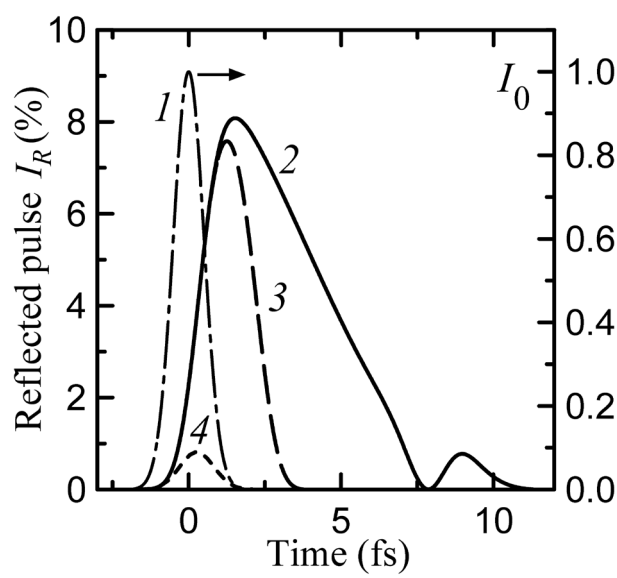

Fig. 5. *Intensity of the incident pulse with the duration τ_0 = 1 fs (curve 1, right ordinate scale) and the intensity of the reflected pulse (curves 2-4) versus time at different thickness of a crystal d: 3 μm (curve 2), 1 μm (curve 3), 0.2 μm (curve 4). The units of the abscissa are femtoseconds, whereas the ordinate is in percents with respect to the incident pulse maximum. Symmetrical Bragg case, reflection Si(220), chirp parameter β = 0, wavelength λ = 0.154 nm.*

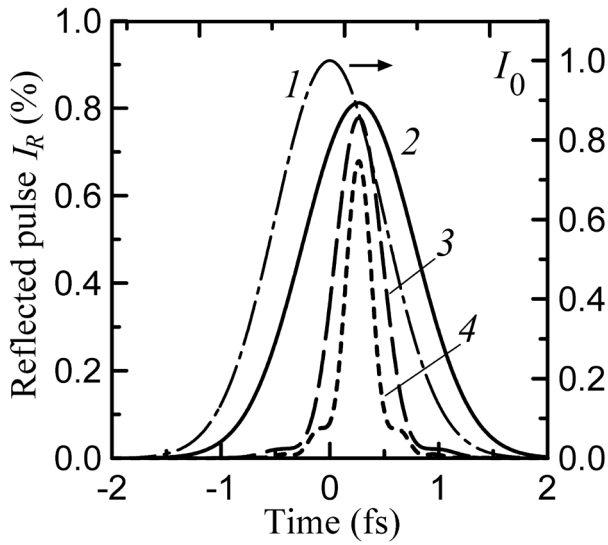

Fig. 6. *Time compression of an incident pulse with the duration τ_0 = 1 fs (curve 1, right ordinate scale) after the Bragg reflection (curves 2-5) from a thin crystal with the crystal thickness d = 0.2 μm at different values of chirp parameter β: 0 (curve 2), 10 (curve 3), 20 (curve 4), 30 (curve 5). The units of the abscissa are femtoseconds, whereas the ordinate is in percents with respect to the incident pulse maximum. Symmetrical Bragg case, reflection Si(220), wavelength λ = 0.154 nm.*

With the increase of chirp parameter β (see Fig. 6) the duration of a reflected pulse decreases almost by a factor of 6 from Δt_R = 1.21 *fs* at β = 0 (curve 2) up to Δt_R = 0.21 *fs* at β = 30 (curve 5).

From **Fig. 7** it is clear, that the reduction of thickness of a crystal also results in reduction of reflected pulse duration for a super-short incident pulse with τ_0 = 0.1 *fs*. However the effect of time compression cannot be reached at any reasonable chirp parameters β, and in any practical case the duration of a reflected pulse Δt_R exceeds τ_0 even for a thin crystal.

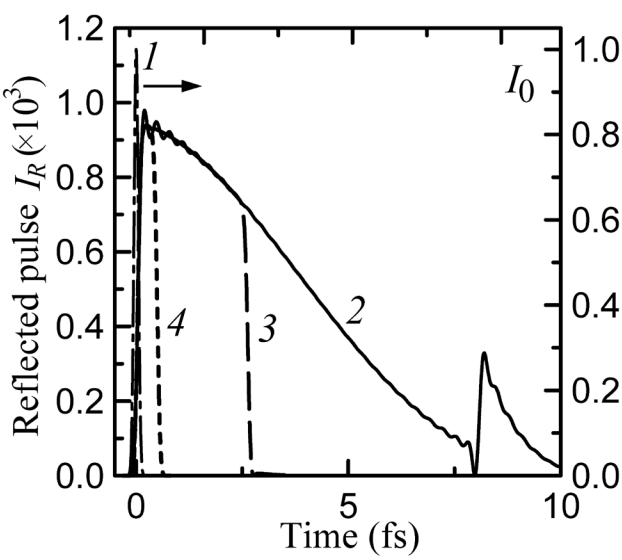

Fig. 7. *Intensity of the incident pulse with the duration τ_0 = 0.1 fs (curve 1, right ordinate scale), and the intensity of the reflected pulse (curves 2-4) versus time at different thickness of a crystal d: 3 μm (curve 2), 1 μm (curve 3), 0.2 μm (curve 4). Symmetrical Bragg case, reflection Si(220), chirp parameter β = 0, wavelength λ = 0.154 nm.*

4. CONCLUSIONS

In conclusion, this paper presents the results of theoretical investigation of the possibility of time compression of *X*-ray free-electron laser femtoseconds pulses, i.e. the reduction of their duration under conditions of the Bragg diffraction on single crystals. It is considered the cases of short and long pulses, and also the cases of the Bragg reflections from thick and thin single crystals. It is shown, that in a case of incident chirp pulses, for which the instantaneous phase of radiation has quadratic time dependence, it is possible to achieve for 1-10 *fs* incident pulses a reduction of duration of the diffracted pulses by a factor of 10.

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THE BIOFUEL ELEMENTS ON THE BASIS OF THE NANOCARBON MATERIALS

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Abstract. **The state of studies and the new directions, which are developed recently with the creation of the biological-fuel elements of devices, based on the biological material and generating the direct generation of electrical energy with the oxidation of substrata was examined. The functioning of the microbial biological-fuel elements, which oxidizes ethanol was investigated. The bioelectrocatalyst were the intact Gluconobacter oxydans bacterial cells or their membrans fractions. The application of nanocarbonic materials at the development of the electrodes for the biological-fuel elements was considered. The cell of the biological-fuel element on the basis of thermo-expanded graphite was experimentally studied. The special features of graphene as the bases of electrodes in the biological-fuel elements at the development of electrodes was reviewed. The successful development of this subjects, which relates to the bioenergetics, possibly with the close cooperation of such areas of biotechnology as the biosensor and electrochemical studies, which are rested on the application of microelectronic technologies.**

Keywords: **biofuel elements, bioanode, direct obtaining electric energy, oxidation of substrata enzymes and microbe cells, membrane fractions, nanocarbon materials.**

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Contents

1. INTRODUCTION

Development of methods for the electricity generation using biological material as one of the main components in this process, gained breadth in recent years. The reasons of keen interest in this subject are connected with common problems of mankind - search for new power sources, as well as with the environmental problem, associated with the use of fossil energy sources - release a significant amount of carbon dioxide when they are burnt for use. The biggest challenge that humanity throws down to the natural environment consists in maintenance of electric energy production while reducing carbon dioxide emissions. It is necessary to develop an essentially new platform that will enable to produce a sufficient amount of energy while reducing the evolved CO_2 quantity. Development of microbial fuel cells technology is the newest alternative approach to this method of electricity generation [1]. Systems or fuel elements, in which is generally used a biological material, oxidizing inorganic materials (gaseous hydrogen) or, as in most cases, organics, and the generation of electric potential is produced, are called biofuel (BFC). The BFC materials are widely represented in the scientific literature [2-6]. Apparently, the first publication on this topic belongs to 1911 [7]. In the early 1990s, there was a new wave of interest in describing microbial biofuel cells (MFC) on the basis of mediators. The subsequent dush of researches refers to 1999, when the possibility of non-mediated electron transport was shown [8].

In the microbial cell the oxidation energy of organic substrates turns into two components - the electrical part, providing membrane potentials, and chemical, in the form of ATF. The BFC is an essentially cell model, simulating the electric potential generation. The electrodes can be closed by load resistance, and it is possible to obtain data on the BFC electric power by measuring there the voltage and current. In the classical microbial BFC the anode and cathode compartments, separated by a proton-permeable membrane. Microbial cells are located in the anode compartment, making oxidation of substrate and releasing electrons that are transported to the anode, and protons in the surrounding solution. The cathode compartment is sated with air, from which is used an oxygen that is reduced to water by the electrons, which flew to the cathode. The BFC releasing electric power (P) is determined by the formula $P = I \times V$, where I – the current, flowing through an external load, V – the voltage on it. Theoretically, the voltage V is determined by the difference in the formal potentials of the oxidizer $E_{oxidizer}$ and oxidized substrate $E_{substrate}$, i.e. $V = E_{oxidizer} - E_{substrate} - \mu$. At the same time, there are irreversible losses μ, reducing the real value of the effective potential. Losses are caused by the ohmic resistance of the electrolyte, presence of the electrolyte's concentration gradient, kinetic limitations of electron transfer reactions on an electrode, internal resistance of BFC. The formal potential E is defined in terms of the Gibbs free energy change ΔG, connected with oxidation/restoration reactions of the substance $E = -\Delta G/nF$, where n – number of transferable electrons, F – Faraday's constant.

In the work [2] is proposed the general classification, including almost all types of existing fuel elements and cells and briefly describing their features. Schematically, such structure in the modified form shown in **Fig. 1** and **2**.

According to [2], the electrochemical fuel systems include those, which provide direct reception of electric energy from chemical and photochemical reactions. These include batteries, fuel elements/cells and solar cells. It is typical for batteries that anode and cathode fuels remains in the system and can't be replaced. For sources of this type are used inorganic chemical solutions. The situation changes for fuel elements/cells, where anode and cathode fuels (oxidizable substrates) are remained out of cells and can be replaced. The BFC belong to this group of current sources. Their conversion element – biological catalyst – may be both enzymes and whole microbial cells. Membrane enzymes, localized intracellularly, are involved in bioelectrocatalysis in cellular microorganisms.

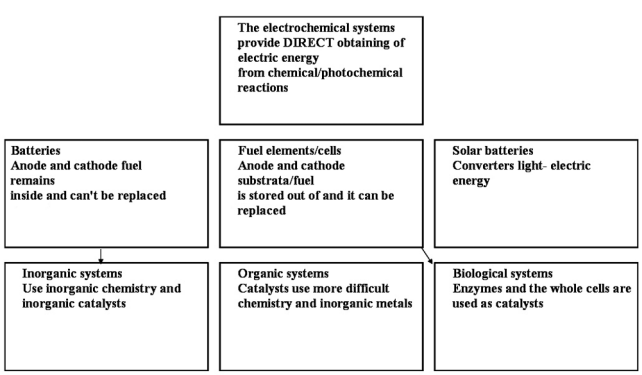

Fig. 1. *Classification of the electrochemical fuel systems.*

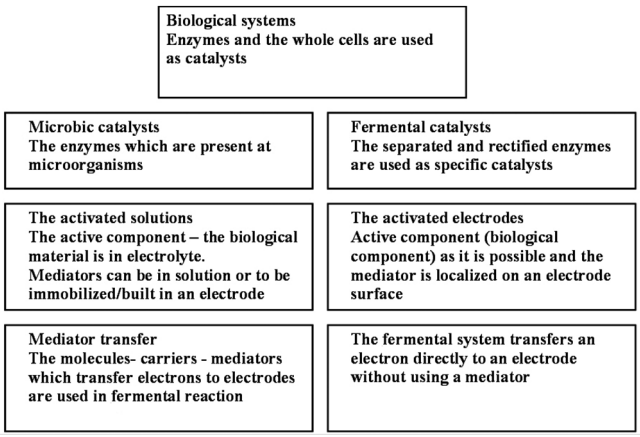

Fig. 2. *Classification of biofuel systems.*

The important characteristic of the current sources is their power characteristics (**Fig. 3**). Thus, batteries and solar cells have, depending on a structure, a wide range of developed powers, comprising in the range of from 10^{-3} to $10^{7}W$. The power level from 10^{0} to $10^{7}W$ is filled with fuel cells, related to the batteries, accumulators – to the elements, working in the redox reactions. Next is the so-called "empty segment" – 10^{0}-$5\cdot10^{-3}W$. The range, relevant to biosensors and biofuel cells, amounts from 10^{-10} to 10^{-5} and 10^{-7} to $5\cdot10^{-3}W$.

As the main point of the process in BFC can be described by the scheme of electron transfer chain "organic substrate – enzyme/cell – mediator – electrode (anode) – external chain – electrode (cathode)", having added oxygen restoration processes in the anode compartment, so it is possible on the base of this example to investigate the main directions of conducted researches on BFC in the world at the present day.

The first most significant results in the development of the alcohol dehydrogenase-based BFC were achieved by Finnish researchers, led by prof. Aarne Halme [9]. Interests of this group were concentrated on the study of various types of fuel cells and modeling of electricity generating processes [10]. For BFC, described in the work [9], the authors have provided detailed information on device parameters. It was shown that from methanol oxidation of 1 gram is theoretically possible to receive about 5A·hour of electricity.

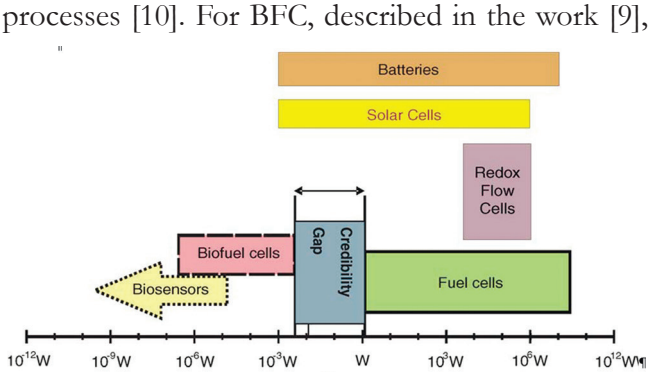

Fig. 3. *The power characteristics of various current sources.*

Considering the publications of the last 3-5 years, it is possible to specify the main directions of development. Today is intensively developed the application of new materials in electrodes' creating. Generally, the attention is directed to the use of carbon nanomaterials. In the work [11] is considered the option of glucose oxides immobilization onto platinized carbon nanotubes, providing the facilitated transfer of electrons on an electrode. The use of carbon nanotubes is also described in works [11, 12]. The search for new types of mediators [14] and their embedding into the electrode assemblies of BFC is performed [15]. In this case, the attention is paid not only to the anode, but also to cathodic mediators [16].

The use of osmium-based polymers allows to form structures, which are both holding elements and mediators at the same time. In the work [17] is represented the new method for the synthesis of osmium polymer, intended for use in BFC. As fuel for BFC is proposed an ethanol. This option of BFC is described in [18].

New BFC structures, including membraneless, are developed [19]. Different methods for an immobilization of glucose oxidase enzyme onto the surface of carbon nanotubes, providing the facilitated non-mediated electron transfer, are considered [20]. It is shown that a rather efficient structure of enzymatic BFC is a flowing non-membranous system [21]. The new type of BFC on the basis of two enzymes – glucose oxidase and urease – is presented in [22]. In this BFC the electromotive force was created by the enzymatic activity and generation of a difference in *pH* in the anode and cathode compartments, wherein the element power was in the range of tens microwatts.

Testing of new strains of bacteria for their efficiency [23] is made and new types of catalysts [24] are developed for use in BFC. The BFC on the basis of organelles are developed. In the work [25] are represented the system characteristics on the basis of mitochondrions. In the review [26] the advantages, resulting from the use of enzymes in BFC, are considered. The important direction of development is connected with the use of BFC as

source of electric energy for the implanted devices in an organism and possibility of its mode control [27]. Approaches to a non-mediated bioelectrocatalysis are covered in [28].

In the work [29] were studied the peculiarities of charge transfer in the system "oxidizable substrate-bacterial cell-mediator-electrode" for bacterial cells of the genus *Gluconobacter*. The election of a water-soluble electron transport mediator, interacting with membrane-localized enzymes of bacterial cells. It is shown that the most efficient mediator is 2,6-dichlorophenolindophenol in comparison with 1,4-benzoquinone and potassium hexacyanoferrate (III). The effective type of a biocatalyst was chosen and evaluation of biocatalytic oxidation of substrates by genus *Gluconobacter* cells was carried out. It was found that the maximum capacity of the generated potential is reached for *Gluconobacter oxydans sb strain. sp. industrius* (VKM B-1280), using glucose as a substrate oxidation. The influence of substrate concentration, mediator, *pH* buffer solution and geometric sizes of the electrodes on the sizes of the generated potential and BFC averaged parameters were the following: the developed voltage about 6 mV at current value of 0.5 μA and loading value of 10 kOhm for the case when the internal resistance value was 90 kOhm. It is shown that the oxygen, dissolved in the anodic compartment, has no significant impact on operation of a biofuel element. In the range from 10 to 40°C, the influence of the temperature on size of the generated EMF is investigated and possibility of using waste fermentation productions as fuel is shown [30].

Application of microbial cells in BFC has its own advantages and disadvantages in comparison with enzymes. So, as an advantage of microbial BFC may be noted:

- substrate specificity of microorganisms is very diverse, in this connection, they can serve as biocatalysts for a wide range of substrates,
- the cost of biocatalysts production on the basis of micro-organisms is low in comparison with the cost of the enzyme release,
- at several stages of the electrochemical oxidation of the substrate, the electrochemical signal of whole cells will be higher, than in case of the isolated enzyme,
- some potentially suitable for BFC enzymes are unstable,
- enzymes in microorganisms are provided with the best way of protection against interfering solutes,
- many microorganisms are in detail characterized genetically,
- reasonable use of mutations can further increase the activity, selectivity and specificity of microbial BFC.
- The disadvantages of microbial BFC include the following:
- high adaptability and variability of microorganisms' properties that can change the parameters of BFC uncontrollably,
- the problem of microbial activity maintaining unchanged for long periods of time,
- the electron transfer using mediators may interfere with atmospheric oxygen in recovery reactions of microorganisms,
- microbial catalysts have a larger volume than the enzyme.

The listed features testify that in the presence of a specific practical task it is necessary to be guided by these data for search of the optimum decision.

2. MODERN DEVELOPMENT DIRECTIONS FOR BFC

Considering the possible directions of researches on BFC, in particular, on the BFC on the basis of microbial cells, we can point out several major problems.

The major task is an improvement of BFC parameters, in particular, energy efficiency increasing. This question is related to the structure of electrodes, their type, material and fuel. As the analysis of the literature data shows, a rather great value is attached to development of new types of electrodes. The challenge is to find the conditions of maximum energy output of a single BFC by finding of optimal conditions for charge transfer. For finding of optimal conditions, it is necessary to increase the electrode surface area, available for the biomaterial immobilization, and also to test the used material for creation of electrodes with the smallest resistance.

Among the actual directions of micropower is the development of the hybrid device model for power supply of micropowerful radio-electronic devices, in which the BFC is interfaced to an electronic accumulative element in the form of the high-capacity supercapacitor (ionistor) for transfer

and storage of electric energy, and also system of contactless supply of energy from the ambient electromagnetic field.

An important practical problem is to reduce the BFC sizes. The researches on miniaturization of BFC, global tendency of creation of machines and devices with a high density of functional elements have long been developing in the world. So, in 1999, were published materials of Japanese researchers, where was offered a multi-channel version of BFC, executed by means of microelectronic technology. The multichannel BFC represented a device, containing 25 pairs of BFC-cells in series and each pair contained an anode and cathodic compartment, separated by an ion - permeable membrane. As an operating enzyme was used glucose oxidase. The estimated capacity of such battery should be several watts. Its use was planned in the robotized systems [31].

In 2012, a series of works on creation of hybrid systems such as "BFC-living organism" was published [32, 33]. The research subject is not new: about a decade was discussed the possibility of oxidized substrates receiving for BFC, implanted into an organism, from living being organic resources. However, earlier the works raised the question purely theoretically and there are still only single examples of implementation in practice. In fact, in the work [32] was realized for the first time the practical option, which presents the BFC of membraneless type, implanted in freely moving snail. For the BFC formation was used a *PQQ*-dependent glucose dehydrogenase and in the cathode compartment - laccase. Electrodes represented the carbon nanotubes, providing non-mediated electron transport. The implanted electrode system provides long-term registration of current generation. So, after two weeks of BFC functioning the current level was almost equal to the initial.

The next step in the development was an attempt to show that the electric power, generated by a low-power BFC, can efficiently be accumulated by means of an ionistor – high-capacity condenser [34]. For the BFC model was used a supercondenser with a capacity of about 1 *F*. For its charging were used three BFC cells, connected in parallel. During about 60 minutes, the capacitor voltage increases to 240 *mV* at a total cumulative energy of about 28 *mJ*. The accumulated energy was enough to turn a minielectric motor rotor by 90°. Apparently, the further developing will allow to use such systems for energy provision of biomicrodevices.

The second direction of researches provides an approach to the creation of the BFC new type. We are talking about the kind of bacterial cells *Desulfobulbus*, forming a filament structure and living on the border with a high gradient of dissolved oxygen [35]. Bacteria of this type are anaerobes (oxidation of organic substances - hydrogen sulfide - occurs in anoxic conditions) and can be found in benthonic layers of reservoirs. The community of bacteria represents threads, positioned vertically. The approximate length of a single thread is about 1-2 cm with an average thread diameter of about 1-5 microns. The thread part that is above lives in excess of oxygen. They have a little or not at all oxidizable substrate – hydrogen sulfide. The thread part that faces downward is in reciprocal conditions – the environment has a high concentration of oxidizable substrate – hydrogen sulfide, but little or no oxygen for oxidation. As a result the bacteria, in the combined threads, represent electrical cables, where electrons are continuously transported in direction "bottom-up". The electrons are generated at the bottom of the thread during oxidation of hydrogen sulphide. They are transported upwards in each bacterial chain, where they participate in oxygen restoration reaction.

Analyzing this situation, it is possible to note that this structure type of the combined bacterial cells represents the BFC perfect type, created by the nature:

- bacteria are combined in the structure, performing the BFC functions – chemical energy is converted into electrical energy,
- there are no problems, associated with the immobilization of cells on electrodes for the charge transfer,
- there are no problems of using mediators
- there is no need for ion-selective membranes for separation of charges,
- thread structure must have a high degree of mechanical strength,
- conditions for preservation of electric isolation of such "electric cable" are created.

The practically important task is a performance of modeling of conditions and development of technology for receiving such threads by artificial

means or use of natural structures to form the BFC, based on the combined type of bacterial cells *Desulfobulbus*.

3. DEVELOPMENT OF THE BIOANODE OF A FUEL ELEMENT ON THE BASIS OF THERMOEXPANDED GRAPHITE

The work purpose is to develop the bioanode of a fuel element, based on bacterial membrane fractions of *G. oxydans*, immobilized on the electrode surface from thermoexpanded graphite (TRG), while oxidation of ethanol and study of its load characteristics.

The direct transformation of chemical energy compounds into electrical energy is carried out in the biofuel elements. The electrode material choice is important for development of BFC on the basis of the immobilized microorganisms or enzymes. The electrodes for BFC have to possess a number of unique properties. They must provide good electrical conductivity, chemical resistance, biocompatibility, high specific surface and processability, including the reinforcement and injection to composite materials. In this regard, the nanocarbon graphene materials, for example, thermoexpanded graphite, are rather perspective.

Original crystalline graphite is oxidized in the production of TRG. The oxidation is reduced to injection of molecules and ions of sulfuric or nitric acid in the presence of an oxidizer (hydrogen peroxide, potassium permanganate, etc.) between the layers of the graphite crystal lattice. The received oxidized graphite is washed and dried. Then the oxidized graphite is exposed to very specific heat treatment – high-speed heating at a rate of 400-600°C/s. Due to the extremely high rate of heating, there is an extreme allocation of gaseous products of decomposition of the embedded intercalates from the graphite crystal lattice. As a result, the interlayer distance increases sharply, and a small flake of graphite becomes fiber. Due to the fibrous structure, the thermally expanded graphite is well pressed, formed, rolled and reinforced with different additives for products receiving.

In this work, as the electrode material was firstly used nanocarbon material – graphene-based thermally expanded graphite [36]. Technologies of thermal expansion of intercalated graphite particles and receiving of highly conductive materials with a well-developed surface belong to nanotechnological processes. The **Fig. 4** shows that the graphite particles under the influence of temperature are split practically to graphene layers.

The layered-fibrous structure of TRG allows by rolling on rollers to receive a sheet material, having a high conductivity. By sealing of a porous initial sample when changing the gap between the rolls of rollers and shift tension, generated during rotation of the rolls, the sufficient dense structure of the sheet material from TRG is formed.

We investigated experimentally the temperature dependence of the electrical conductivity of the received sheet material from TRG. The sample for the study is a plate 22 mm wide and 0.35 mm thick. The resistance measurement was performed according to the two-electrode scheme by the digital voltmeter. Maintenance of the temperature was carried out by means of the muffle MIMP-3P furnace, and the sample was placed in the measuring cell with nickel tubular electrodes on a ceramic base. It is shown that planar electrodes on the basis of TRG

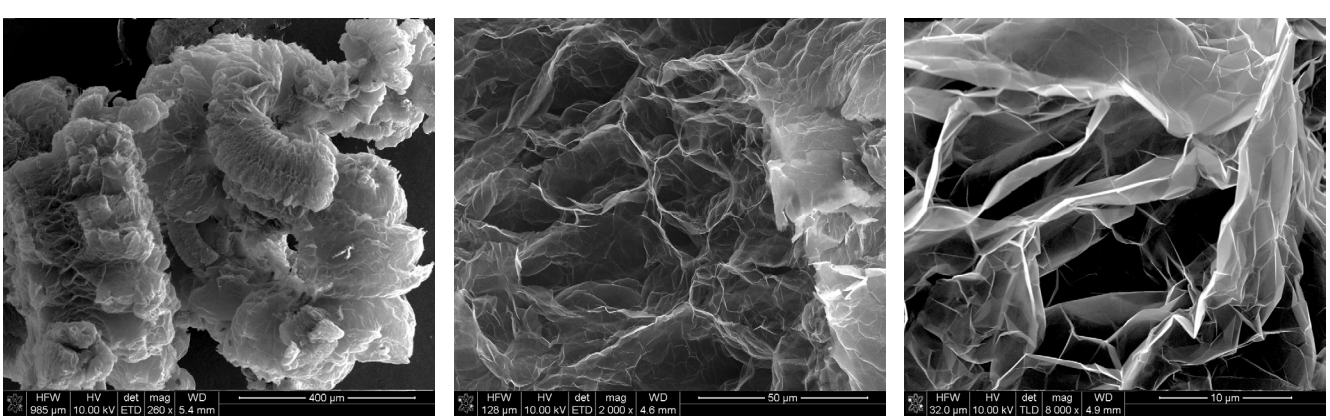

Fig. 4. *Images of TEG structure at various scales.*

possess good thermomechanical properties and rather low conductivity (**Fig. 5**).

Thus, the thermally expanded graphite is a material with good electrical conductivity, high specific surface area up to 2000 m^2/g, biocompatibility, chemical resistance in corrosive environments and can be a long time in the technical operation [37]. These qualities allow immobilization on the electrode TRG surface of the high superficial concentration of bacterial or their membrane fractions. The TRG also makes possible to form the electrodes of different shapes by a simple method of pressing. This approach is original because hitherto unknown in the literature studies, where the TRG was used in combination with biomaterial.

In microbial and enzyme BFC can be used redox mediators, which carry out electron transfer from the biocatalyst to the electrode [38]. For some enzymes [39-42] is shown non-mediated bioelectrocatalysis. Substantially non-mediated/direct electron transfer depends on the type of enzyme immobilization method. Thus, the direct transfer of electrons has been described for *PQQ* (pyrroloquinoline) –dependent dehydrogenases as a part of enzyme biosensors and biofuel elements [43]. For the first time, the direct bioelectrocatalysis for a *PQQ*-dependent fructose dehydrogenase of *Gluconobacter* bacteria in the oxidation of fructose has been investigated in [40]. The fructose dehydrogenase enzyme was immobilized on the electrodes, made on the basis of carbon paste. The response to fructose was registered without addition of electron transport mediators. In the work [41] was found a direct non-mediated bioelectrocatalytic effect on a *PQQ*-dependent lactate dehydrogenase of *Gluconobacter sp. 33* on the gold electrode and electrodes, received by the dot-matrix printing. In the work [42] is represented an electrochemical cell, used as the working electrode a graphite core with an immobilized *PQQ*-dependent alcohol dehydrogenase (ADG) strain of *Gluconobacter sp. 33*. For this enzyme was observed a non-mediated electrochemical oxidation of ethyl alcohol. The ADG was immobilized on a graphite core by a cross-linking with glutaraldehyde. The maximum BFC voltage in the presence of ethanol at the opened circuit was 115 mV when using as the second electrode of a graphite core with inactive ADG. The three-electrode scheme was used for registration of the amperometric signal at +400 mV in relation to a reference electrode.

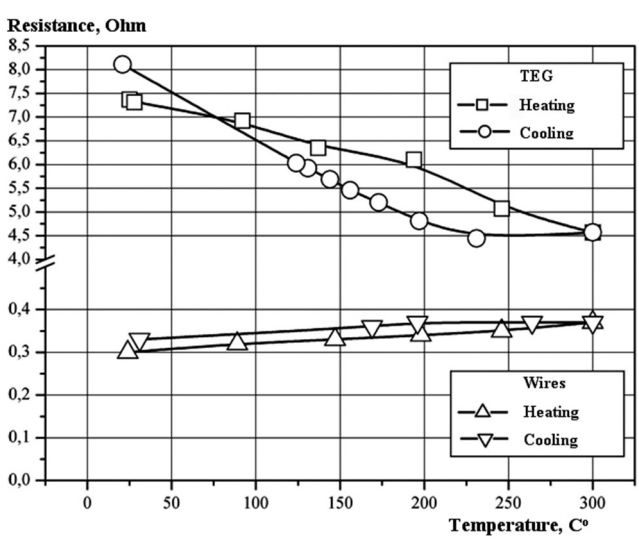

Fig. 5. *Comparative temperature conductivity dependence of the obtained sheet TEG material and material of lead wires.*

Also the non-mediated electron transfer was shown for such microorganisms as *Shewanella putrefaciens, Aeromonas hydrophila, Clostridium, Geobacter* [43]. Previously, it was found that bacteria of the genus *Geobacter* can perform the transfer of electrons to the graphite electrodes [44]. In the work [45] was demonstrated that *Geobacter sulfurreducens* can efficiently transfer electrons not only on graphite electrodes, but also when using as an anode of a gold electrode. On the anode was increased biofilm *G. sulfurreducens* and the reference electrode was the *Ag/AgCl*-electrode, where as an auxiliary electrode was used a graphite cloth. When using a gold electrode as the anode, the current density was 688 mA/m^2, and when using graphite cloth – 3147 mA/m^2.

The urgent task is to ascertain the possibility of using as an anode biocatalyst for BFC membrane fractions (MF) of microbial cells, containing a *PQQ*-dependent dehydrogenase. In a number of recent works was observed effect of direct electron transfer from a *PQQ*-dependent glucose dehydrogenase, immobilized onto multiwalled carbon nanotubes [46, 47, 48]. These data are the basis for the assumption that the use of biocomposite TRG/MF could provide a non-mediated catalysis of electrooxidation. The TRG has a high effective surface and, in this sense, is similar to nanotubes, on the other hand, the MF in fact are essentially membrane fragments, enriched with a *PQQ*-dependent dehydrogenases. As the test substrate was chosen an ethanol, which

effective oxidation of MF was shown in [47, 48]. We will note that unlike the expensive and complex techniques for receiving and purifying of enzymes, when receiving of MF is used a simpler procedure and, in this connection, the MF can be alternative to the use of enzymes in BFC.

3.1. Development and production of the bianode model

The *Gluconobacter oxydans* bacterial strain VKM B-1280 was received by the All-Russian Collection of Microorganisms of the IBPM RAS. The intact cells or their membrane fractions (MF were allocated in accordance with the procedure [47, 48] were immobilized by inclusion in gel of a chitosan on the TRG-electrode surface. For this purpose, on the electrode was applied 20 mcl of MF or intact cells, diluted twice with buffer solution. The electrode was dried at room temperature, it was applied 20 mcl of a 2% solution of chitosan in 1% acetic acid [49], and then it was dried at room temperature within 30 min.

The sinthesis of TRG was carried out on hydrosulphatic technology [36]. The process of TRG receiving included three main stages:

1) formation of intercalation connection (graphite hydrogensulphate) with stirring of low-ash graphite (GSM-1) within 30 min with a mixture of concentrated nitric and sulfuric acids at their ratio of 10:1 within thirty minutes. The graphite particles are modified with a mixture of sulfuric and nitric acids. This provided intercalation with the injection into the interlayer space of graphite particles of the intercalate molecules;

2) graphite interstitial compounds washing with water from the remains of acids to $pH \approx 6.8$ and subsequent drying of the oxidized graphite to a loose condition;

3) thermal expansion of the oxidized graphite at thermal shock of 800-900°C with receiving of TRG.

When heating of such powder, there is a destruction of the lamellar structure of graphite and transition to a layered-fibrous structure of expanded graphite. The received graphene-based TRG had a bulk density of $Pb = 16$ g/l. The elemental analysis showed that as an impurity the TRG comprises 0.5% of sulfur. By the method of raster electronic microscopy with the resolution up to 100 nanometers is observed a distinct layered-fibrous structure of the graphite material (Fig. 4).

The bulk density of expanded graphite powder can vary quite widely, depending on the mode of thermal expansion. The bulk density of TRG, which was determined by weighing of 15 ml after heating at temperatures of 200, 220, 250 (±5°*C*) within 10 minutes, was experimentally investigated. It was shown that with increase of heating temperatures of graphite particles, the values of bulk density of TRG decreased, and, according to heating temperatures, equaled to 116-113, 46-42, 36-33 g/l [36.]

Operating electrodes from TRG formed TRG by compacting of the powder at a pressure of 150 bars. The diameter of the measuring electrode was 12 mm, thickness – 0.2 mm. The cyclic voltamperograms were recorded using three-electrode circuit at a potential scanning rate of 3 mV/s. The reference electrode was a standard chlorine-silver electrode and the auxiliary electrode was a platinum plate of 1.8 cm^2. The chronopotencio metric measurements were performed by measuring of the potential of a stationary working electrode with respect to time of the reference electrode. Measurements were performed in the 30 mM solution of potassium-sodium phosphatic buffer (*pH* 6.0). The substrates were ethanol, glucose or acetaldehyde (DiaEm, Russia). The only one concentration of substrates was used in the operating electrolyte of 10 mM (if it isn't specified especially). In some experiments, as redox mediator was used 2,6-dichlorophenolindophenol at a concentration of 8 μM (DCPIP, Sigma-Aldrich). The measurements were performed on the galvanopotentsiostata VersaSTAT 4 (Ametek Inc.).

In the ethanol oxidation by an amperometric method was determined the MF respiratory activity. The MF immobilization was carried out by physical sorption onto glass fiber filters (GF/A type, Whatman, UK). For this purpose the MF suspension of 5 μl, containing biomass in concentration of 100 mg of crude weight/ml, were deposited on a filter and dried at room temperature within 20 min. The membrane with a bioreceptor of 3×3 mm^2 was fixed on the measuring surface of an oxygen electrode like Clark (Ingold, Germany). The respiratory activity of MF was caused by areas of the respiratory chain of the cellular membrane,

conjugated with clusters of *PQQ*-dependent dehydrogenases. The amperometric measurements were carried out in an open container of 2 ml. The Galvanostat-potentiostat IPC2L were used (LLC "Kronas", Russia), interfaced with a personal computer. For measurements in the measuring cell, containing buffer solution and oxygen electrode, the ethanol samples of 100 mcl were brought, containing various concentrations of the substrate. The recorded parameter was the maximum rate of a signal change (nA/s).

For receiving of images with a scanning electron microscope (SEM) on an electrode surface with cells and MF, a thin layer of gold was deposited. The deposition was carried out in a vacuum sputtering installation JFC-1100 (JEOL, Japan). The electron microscopic analysis of the samples was measured by SEM JSM-6510 LV (JEOL, Japan).

3.2. Electrophysical researches

During formation of the operating BFC electrode, it is necessary to carry out an immobilization of cellular material onto a surface of the volume electrode and as much as possible to fill its porous part. The view of whole cells of *G. oxydans* and MF, immobilized onto TRG, is given in **Fig. 6.1** and **6.2**, respectively; the images were received by means of SEM. The concentration of cells for immobilization was chosen such that they formed a monolayer with insignificant gleams. The scaly structure of TRG, pressed as a result of an electrode formation is visible in places of gleams (Fig. 6.1). The MF, being significantly smaller structures compared with cells, formed almost complete covering of the TRG-electrode (Fig. 6.2).

Since the bacterial membrane fractions of *G. oxydans* represent a fragment of the respiratory chain, for the characterization of their catalytic activity in the oxidation of ethanol was used the

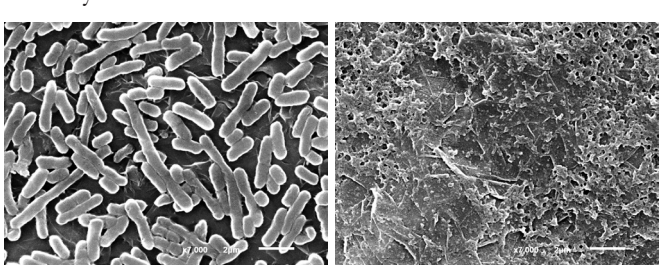

Fig. 6. *Whole cells of G. oxydans (6.1) and their MF (6.2) obtained by the scanning electronic microscopy. Immobilized biomaterial is covered with a layer of a hitozan.*

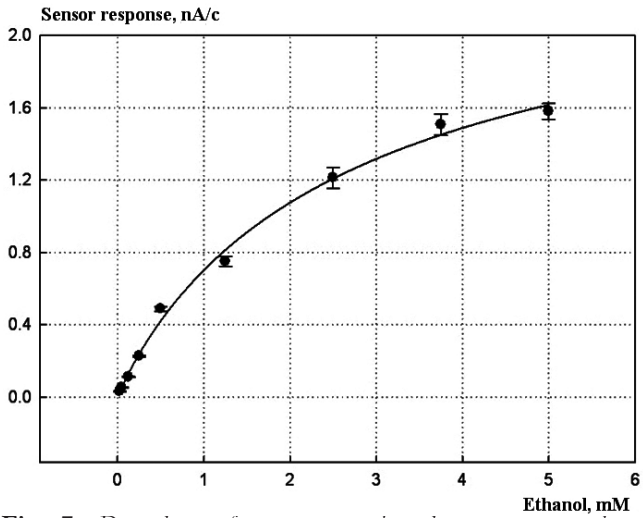

Fig. 7. *Dependence of an oxygen electrode response on ethanol concentration in presence of membrane fractions of G. oxydans bacteria.*

Clark-type oxygen electrode. From the dependence of the oxidation rate on the concentration of ethanol (**Fig. 7**) in the reactionary solution were calculated apparent K_M^{eff} (Michaelis's constant) and V^{eff}_m (the maximum reaction rate) values that were 2.8±0.7 mM and 2.5±0.3 nA/s, respectively.

The **Fig. 8** shows the dependences of potential on time, registered for the bioanode with immobilized MF by adding to the working electrolyte of ethanol, acetaldehyde or glucose. It is visible that after applying an ethanol in media, containing the measuring electrode, the stationary potential of the bioanode shifted to negative values of the potential. 1200 seconds later after the addition of ethanol the working electrode potential variation from a reference value was about 50 mV. This effect is an indication that the MF of *G. oxydans* bacteria contains the enzyme (a *PQQ*-dependent alcohol dehydrogenase), which

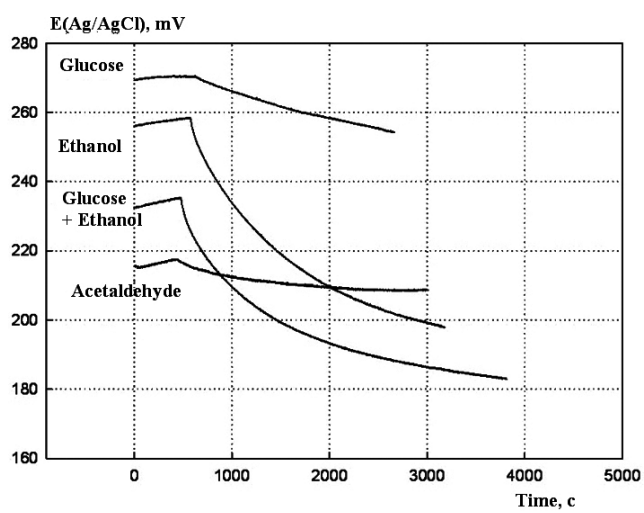

Fig. 8. *Dependences of stationary potentials from time for TEG-electrodes with immobilized by MF at addition in electrolyte of ethanol, acetaldehyde, glucose.*

catalyzes the electrooxidation of ethanol on the mechanism of non-mediated bioelectrocatalysis. After applying of acetaldehyde or glucose occurred only minor changes in the potential. The **Fig. 9** shows the dependence of the stationary potential of MF/TRG-electrode according to different concentrations of ethanol. The maximum value of the measured potential is achieved at an ethanol concentration of 10 mM in the operating electrolyte. The further increase in concentration didn't lead to an increase in potential change.

The cyclic voltamperogramma (CVA), registered by a measuring electrode with immobilized MF, are given in **Fig. 10**. It is seen that in the presence of ethanol, the anode current is increased compared with the control in the absence of a mediator. The observed increase in the anode current was not too considerable that may be associated with a relatively low concentration of electrocatalytically active points on the electrode surface. This may also be due to the low efficiency of electron transport between the electrode and biocatalyst.

Another pairing option of biochemical and electrochemical reactions is the mediator way. As the redox-mediator was used DCPIP, which is an effective electron acceptor in various biochemical processes. Furthermore, the standard redox-potential of the couple $DCPIP_{reduct}/DCPIP_{ox}$ is +0.217 V that allows to carry out the bio-electrochemical oxidation reaction of ethanol with relatively low values of the electrode potential under aerobic conditions. After adding of modified MF to the buffer solution of DCPIP and ethanol for the bioanode, the cathode

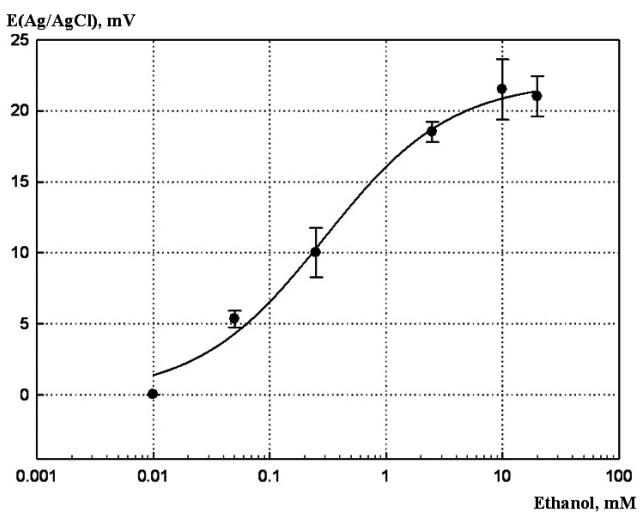

Fig. 9. *Change of stationary potential MF/TEG-electrode from concentration of ethanol in working buffer solution.*

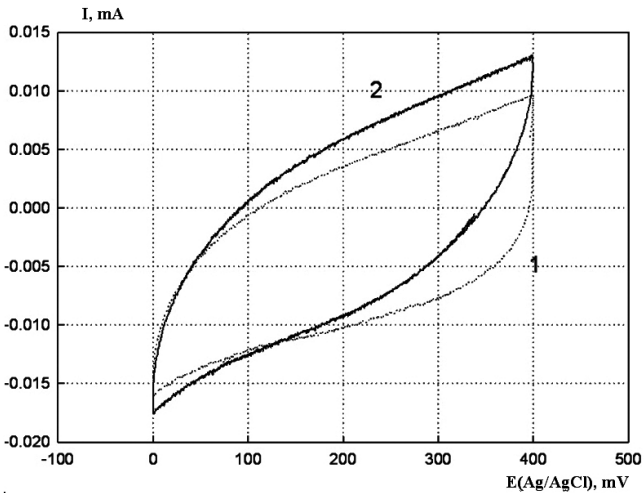

Fig. 10. *VAC are written down for TEG-electrode with immobilized MF in 30 mM potassium-sodium-phosphatic buffer solution, pH 6.0 (1) and in presence of 10 mM of ethanol (2).*

stationary potential change in the absence of substrate was 120 mV.

The **Fig. 11** shows the CVA for the bioanode with immobilized MF in buffer solution (control condition) and in a solution, containing ethanol and DCPIP. It is seen that in the presence of a redox mediator, on the cyclic voltammograms, starting with zero potential, there is a significant increase in the anode current in comparison with a control state, indicating on the mediated bioelectrocatalytic mechanism of the ethanol oxidation.

In the work was also used the bianode option on the basis of TRG with immobilized intact cells of *G. oxydans*. In the preliminary experiments, it was shown that in the absence of a mediator after adding of ethanol to the electrolyte solution there was no any changes of stationary potential of the bioanode.

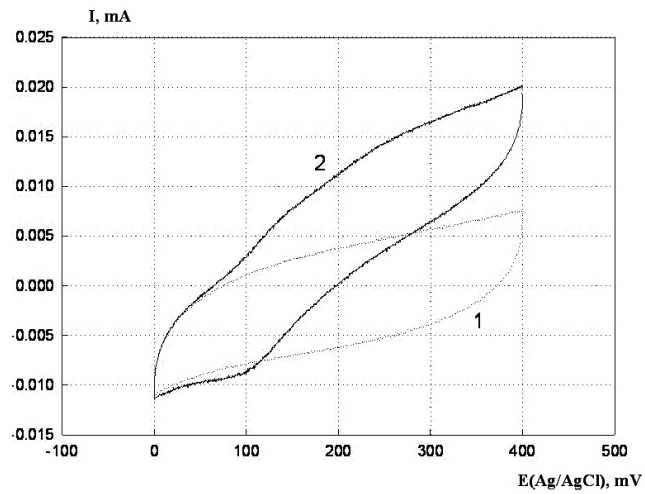

Fig. 11. *Voltamperometric characteristics (VAC) are written down for TEG-electrode with immobilized MF in 30 mM potassium-sodium-phosphatic buffer solution, pH 6.0 (1) and in presence of DHFIF (8 μM) and ethanol (10 mM) (2).*

This was due to the absence of a non-mediated electron transport from a donor-substrate (ethanol) on the electrode with immobilized intact cells. So, for enhancing of bioelectrochemical reaction of oxidation of ethanol, a redox mediator DCPIP was injected into the reaction system. After adding of redox mediator and ethanol into the reaction electrolyte, the change of the electrode potential was 160 mV from a reference value. The CVA, registered for bioanoda of TRG with immobilized intact cells in buffer solution and in the presence of a redox mediator and ethanol, are shown in **Fig. 12**.

Thus, the possibility of forming of the fuel cell's bioanode, based on thermoexpanded graphite and immobilized membrane fractions of *G. oxydans* bacteria, which are bioelectrocatalysts of oxidation reaction of ethanol, was demonstrated for a first time. The membrane fractions were immobilized onto the TRG-electrode, allow to perform non-mediated bioelectrocatalytic ethanol oxidation on the electrode, however, the process rate was low. The redox mediator 2,6-dihlorofenolindofenol significantly increases the rate of bio-electrochemical reactions, involving immobilized MF, and also allows an electrooxidation of ethanol using immobilized intact cells.

4. APPLICATION OF A GRAPHENE IN BIOFUEL ELEMENTS

Currently, a graphene (Gr) is the object of a great interest in various fields of science, including biology and biotechnology. The Gr is a two-dimensional nanomaterial, having high electrical conductivity and mechanical strength and a number of other properties, valuable in designing of electronic devices. It is found that Gr is well compatible with biomaterial that allows to use it in forming of biosensors and biofuel cells - devices, where the biocatalyst converts the energy of oxidation of organic substrates/biofuel into electric energy. The Gr can be used for the preparation of the high-structured electrode surfaces, which due to the high ratio of surface area to volume can produce an immobilization of a significant amount of the biocatalyst, that is, in principle, can result in a high output electric power of BFC. Taking into account that both subjects of Gr and of the BFC are intensively developed directions of researches now, in this work we consider the current state of the Gr use in BFC, where enzymes and microbial cells are used as a biomaterial. Actually, the question, on which researchers of various groups would like to get the answer, may be the following – whether is it really necessary to use Gr instead of the well-known and positively proved nanotubes or metalnanoparticles.

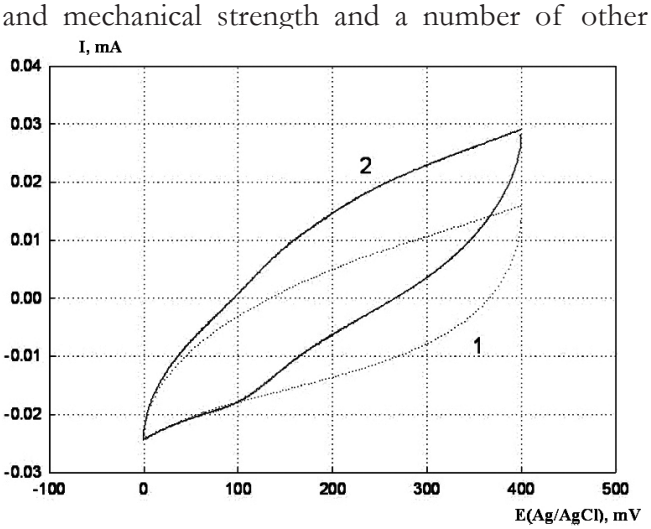

Fig. 12. *VAC registered for the TEG-electrode with immobilized intact cells in 30 mM potassium-sodium-phosphatic buffer solution, pH 6.0) - (1) and in presence of DHFIF (8 μM) and ethanol (10 mM) – (2).*

The graphene is the single layer of sp^2-carbon, consisting of the condensed six-membered rings. The material, consisting of two such layers, rather strongly differs in physical characteristics from a single-layer graphene, not to mention the bigger number of layers. An even greater difference is observed in "thick" scales.

For convenience, we use the following notations: Gr – graphene (without specifying the number of layers); Gra – graphite; HOPG – highly oriented pyrolytic graphite; nGra – nanosized graphite; PGra – penographite, ICGra – graphite's intercalation compounds, GraO – graphite oxide; 1sGraO – single-layered graphite oxide, mlGrO – multilayered graphite oxide, redGraO (RGO) – reduced graphite oxide (1 single-layer or multilayered); 1slGr – single-layered graphene, mlGr – multi-layered graphene (graphite plates with thickness of a few graphene layers), CMG – chemically modified graphene (graphene, containing substituents (*H, F* et al., and/or functional groups).

Physical properties of graphite

The free carbon in nature meets in two main types: diamond and graphite, and among synthetic types should be noted carbine, fullerenes, nanotubes, pyrolytic graphite, etc. A variety of modifications is caused by ability of carbon atom to accept tetrahedral sp^3 – (diamond), trigonal sp^2 – (graphite, graphene,

fullerenes, nanotubes) or linear *sp* – (carbyne) hybridization [50, 51].

The usual graphite is a tabular mass with a lot of metallic lusters, having various degrees of crystallinity and orderliness; individual particles can look almost as perfect crystals. The most frequently used in the laboratory graphite is a pyrolytic, which is received by decomposition of hydrocarbons on a graphite substrate at a temperature over 2000°*C*. To improve the regularity of the crystal is used the recrystallization, implying hot uniaxial pressing under a pressure of 300-500 kg/cm^2 at 3000°*C*. In this way, we receive samples of more than 10 mm thick and density of 2.27 g/cm^3, which is 99.95% of the theoretical density of graphite. The subsequent annealing of material at 3400-3500°C results in a highly oriented pyrolytic graphite.

Chemical properties of graphite

Graphite is quite inert under normal conditions. It is oxidized by atmospheric oxygen to *CO* at a temperature over 400°*C*, and to CO_2 - at temperature over 500°*C*. The temperature of the reaction beginning is higher, when the crystal structure of graphite is more perfect. Oxidation is accelerated in the presence of iron ions, sodium, copper and other metals, and slows in the presence of molecules of chlorine, phosphorus and boron compounds. Graphite hardly reacts with molecular nitrogen, with atomic at a usual temperature forms cyanogen C_2N_2. Halogens are being imbedded into the crystal lattice of graphite, giving interstitial compounds. With the majority of metals and their oxides graphite gives carbides. It with all alkaline metals, some halides, oxyfluorides, halogen oxides, oxides and sulfides of metals forms interstitial compounds with nitrides of metals at temperatures above 1000°*C* – solid solutions of nitrides and carbides, with borides and carbides – eutectic mixtures with melting temperatures of 1800-3200°*C*.

Covalent and intercalation compounds of graphite

Due to the layered structure, some atoms, ions and molecules can be imbedded into the interlayer space of graphite. The result are the so-called covalent compounds (CCGra) and intercalation compounds (ISGra) of graphite. The CCGra include fluoride graphite and graphite oxide – GraO. While formation of CCGra there is a partial transition of carbon atoms from sp^2- to sp^3-hybrid state and, as a result, a deformation of flat carbon grids [53].

So, the graphite oxide, which still saves developed reticular structure, is the most oxidized compound of graphite. Chemical methods of receiving of graphite oxide, based on the oxidation of graphite in concentrated acids (nitric acid, sulfuric acid) by such strong oxidants as $KMnO_4$, $KClO_3$, $(NH_4)_2S_2O_8$, MnO_2, etc. [54]. The lower rate of formation of graphite oxide in comparison with the rate of formation CCGra testifies numerous violations of the *C-C* bonds within each carbon hexagonal grid.

The carbon atoms in Gr are joined by sp^2 bonds in a hexagonal two-dimensional (2*D*) lattice. From the viewpoint of materials science, the single-layer Gr is a substance, furthermore, it is a separate molecule. From a chemical point of view, the single-layer Gr - a polymer.

Preparation of graphene and its analogs from the oxidized graphite

Due to not very successful initial attempts to receive graphene by direct dispersing of graphite, the dispersion of Gra derivatives, in which the interaction between the layers is reduced, appeared more promising. As such Gra derivatives are known GraO, CCGra and PGra. Most often the Gr is received using GraO. In turn, GraO opened in the 19th century, long before the discovery of the Gr, is received in three ways: 1)by the Brody's method [55], 2)the Shtaudenmayer's method [56] and 3)the Hammers's method [57]. All three methods include the step of processing of Gra with strong acids and oxidizers.

On the basis of GrO, which solubility (dispersibility) in water and other solvents is high, carried out the procedure of thin films coating with application potential in electronics. The oxidized Gr is an insulator, but its electronic characteristics can be controlled within certain limits by changing the degree of oxidation. Besides change of scales geometry, the properties of oxidized Gr are determined by the nature and ratio of oxygen-containing functional groups - carboxyl, hydroxyl or epoxy. The GraO, which still saves a developed grid structure, is the most oxidized compound of Gra. The lower rate of GraO, compared with the rate of CCGra formation, suggests numerous violations of the *C=C* bonds within each carbon hexagonal grid. The observations, made by scanning electron microscopy, showed that the GraO has a rough

surface with an average height of irregularities of 0.6 nm and amorphous structure due to the large amount of sp^3 *C-O* bonds [58].

Currently there is no single formula for GraO, since this compound is determined by the synthesis conditions and nature of the original graphite. The GraO often attribute a formula $C_8O_2(OH)_2$, where the oxygen is in the carboxyl, hydroxyl, ketonic, epoxy and other *O*-containing groups, which determine the acid-base properties of GraO and its hydrophilic [54]. The interlayered distance in GraO changes reversibly from 0.6 to 1.2 nm with increasing relative humidity of the product, which may indicate the formation of a grid of hydrogen bonds between the *O*-containing groups. The idealized structure of a single-layer GraO shown in **Fig. 13.**

A number of authors specify that homogeneous dispersions of GraO in water solutions and organic solvents can be received with simple processing of GraO by ultrasound (US) [60]. The hydrophilic GraO is dispersed in water with the maximum concentration of 3 mg/ml, forming brown and dark brown dispersions. The GraO dispersion in various organic solvents such as ethylene glycol, dimethylformamide (DMF), N-methylpyrrolidone, allows to receive a GraO concentration about 0.5 mg/ml [61].

The large number of functional groups, typically hydroxy and epoxy, allows to stabilize GraO skales in water. However, such functionalization destroys delocalized electrons π-system of graphene. The GraO actually becomes more insulating than a semimetal and this is its fundamental difference from graphene [62]. It is shown that under the action of powerful ultrasonic irradiation the GraO splits into fragments that subsequently formed by self-assembly fullerene and its analogs, carbon nanotubes and high-condensation products [63].

The chemical modification of the *O*-containing groups in GraO by various reagents (e.g., isocyanates) leads to the formation of the corresponding

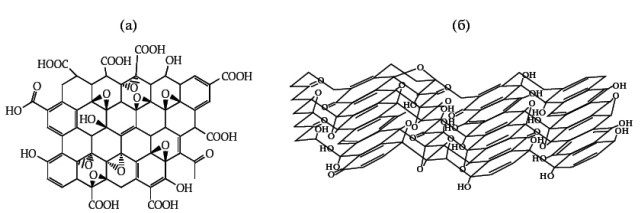

Fig. 13. *Graphite oxide structure: a) top view of idealized structure of one layer of GO, b) side view of model of single-layer GO* [59].

derivatives and increased concentrations of homogeneous dispersions in organic solvents [64].

Reduction of the oxidized graphene

For receiving of Gr from a single-layer GraO it is necessary to reduce the last – to remove the *O*-containing groups and to restore the system of *C=C* bonds. The process may be carried out at low temperature of about 180°*C* using as reducers such solvents as dimethylformamide, ethanol, butanol and others. The reaction progress is registered by a change in color of the dispersion. It is shown that the GraO can be effectively reduced by a simple long (more than 24 hours) heating at 220°*C* and even at 100°C in water or heating for 1 hour at 180°*C* in dimethylformamide [65].

To improve the solubility of reduced GraO, the product receiving is conducted in three stages: 1)reducing of oxygen group of GraO in $NaBH_4$ solution, 2)the reduced product is arylated by 2-sulfo aryldiazonium salt and 3)repeated performance of reduction with hydrazine to remove the remaining oxygen-containing groups. Such sulfonated reduced GraO is steady in water with a *pH* = 3-10 and concentration of 2 mg/ml. For the same purpose, it is possible to use, as shown in [66], some cellulose derivatives (sulfo, carboxymethyl or carboxypropyl derivatives).

In the work [67] as the reducing agent is proposed to use vitamin *C*, as well as a stabilizer – amino acids.

Experiments showed that the reduced GraO isn't equivalent to Gr; in other words, it isn't possible to fully reduce the GraO to Gr. Thus, the products, received in the reduction of GraO, contain substantial amounts of oxygen and, possibly, defects that destroy the delocalized π-system and significantly reduce the graphene electronic characteristics. From organic chemistry of aromatic compounds (to which single-layer Gr formally belongs), it is known that a number of *O*-containing groups are not reduced by the given above reducers. In confirmation of it, the calculations showed that reducing of less than 6.25% of Grao area is complicated in view of complexity of removal of hydroxyl groups. For these researches the GraO's model, containing hydroxyl and epoxy groups, was used and with nuclear relation *C/O* = 16 [68].

It would seem that thermal recovery methods are easier to execute, but they lead to the same results – the oxygen is retained in the final product [69].

At the same time, it is shown that the calcination of the samples of the reduced GraO [70] opens the possibility of a complete reducing of the grid of sp^2 bonds of six-membered rings. The GraO's reducing showed according to electron microscopy that the reduced GraO's scales consist of graphene islands, ranging in size from 1 to 6 nm, separated by a defective cluster, forming a flat area with quasiamorphous sp^2 *C-C* bonds; in addition, they contain large number of topological defects. On this basis, the following scenario of graphite redox was provided. Initially, during the oxidation locally are formed strongly oxidized areas, whereas 60% of the surface remains unchanged. After reducing the constant area remain unchanged, and the oxidized area reduced to sp^2-related grids, which, however, lose (not reduce) the original crystallinity (orderliness) of the graphene. In the structure of disordered areas are formed the so-called topological defects, so the reduced graphene is usually different from the single-layer graphene and in English literature usually denoted as RGO. The conductivity of the reduced graphene in 10 times or more lower than of the initial graphene [71].

In the work [72] by the method of atomic power microscopy was shown that the structure of reduced scales of graphene oxide differs significantly from the graphene, received by mechanical peeling. Being deposited on the smooth surface of highly oriented graphite, they have a non-flat globular morphology, indicating on the distortion of the carbon skeleton. Even more definitely the distortions of the structure were found in the work [73], where GraO's scales were reduced by three methods: aqueous hydrazine, under the action of the electron beam, or by heating at a temperature 300-600°*C*. In all cases, as the authors specify, were obtained a highly disordered graphene nanoscales. In the work [71] were studied the mechanical and electrical characteristics of the reduced scales of the suspended reduced GraO. It is shown that the mechanical properties (elasticity, flexibility) practically do not differ from single-layer graphene while electrical conductivity is significantly reduced and is at normal metallic conduction. In confirmation of it, it is shown that the local electrical properties of the reduced scales of GraO differ from properties of a single-layer graphene [74]. Thus, the presence of a large number of defects significantly reduces the electrical conductivity of these materials, however, makes them suitable as materials for stabilization of *Li* ions in supercondensers.

For identification of Gr are often used circular scattering spectroscopy [75] and atomic power microscopy [76], more rare – scanning tunneling microscopy [77].

4.1. The application of graphene materials for BFC electrodes

The one of the main problems of the industry development today consists in minimizing of financial costs and reducing the environmental load that accompany the overall growth of investments in production of food and energy. A promising way to solve the problem in the field of energy is to learn how to receive it via biocatalysis – isolated enzymes or microbial cells, which are biocatalysts, provide power generation in BFC devices [78].

Like the standard chemical element of the electric power – batteries, accumulators, etc., the BFC includes two electrodes, anode and cathode. The biocatalyst contains in the anode compartment, where are supplied substrates or fuel. The substrate is oxidized by anode biocatalyst, the released electrons flew on the anode surface. On the external circuit, the electrons move on other electrode – electrode, which also contains the biocatalyst, providing oxygen reduction [2].

The catalytic activity of the immobilized biomaterial is the most important factor, providing the generation of electrical energy in BFC. In this case, the question of its immobilization is also essential – on what material of an electrode the immobilization is made, what type of biomaterial is used, how the charge transfer to (from) the electrode(s) happens. The transfer of electrons to the anode and cathode can be done by two ways – by a carrier, i.e., mediator and by direct transfer (*DT*). The corresponding type and fixing of biomaterial, type of material of the anode and cathode can provide both mediate and *DT* of the electron to (from) the electrode(s). The *DT* allows to receive more effective BFC as thus the element structure becomes simpler, its internal resistance decreases, the use of additional connections as mediators isn't required. This moment is especially important and it should be noted that recently the considerable number of the conductive nanomaterials by means of which implementation of *DT* became possible,

was described. For the first time the *DT* was described for the laccase enzyme in 1979 [79]. After a while, the following step on use of nanoconductors was taken and fullerene was introduced into practice – a zero-dimensional material [80] and one-dimensional material – nanotubes [81].

After the described method of Gr preparation in the laboratory of A.Geym and K.Novoselov [81], the flow research was aimed at studying the possibility to use a two-dimensional structure for immobilization of the redox-enzymes. Immediately after it was shown that the Gr has high electronic conductivity and relatively easily produced, the stream of researches directed on attempts of its application for bioelectrodes construction considerably grew [83]. The Cr could be received mechanically by removal of the graphite layers or by chemical way – vapour-deposition method; graphene materials are received by chemical synthesis. The Gr oxides have high solubility in water, because it contains in the plane sites atoms of oxygen and hydroxyl (**Fig. 14**).

The Gr reducing can be carried out thermally, chemically or electrochemically, and in addition biologically, for example, by means of microorganisms [84]; the reduced Gr (GrR) should be distinguished from the "pure" Gr, received by synthesis. This is due to the fact that the procedure is also characterized both by a recovery process, and extent of purification of material [85].

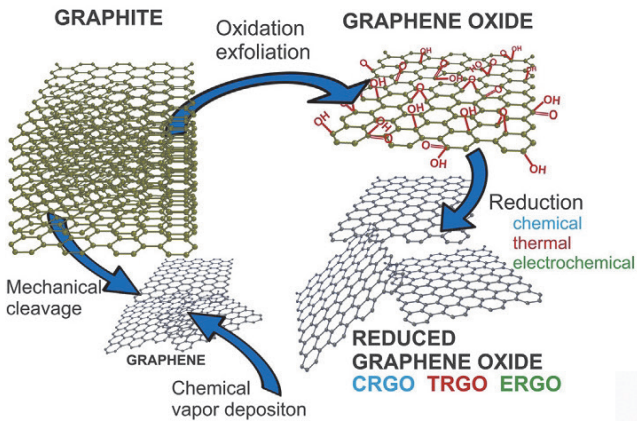

Fig. 14. *Schematic representation of methods obtaining G and GO (graphene oxide)* [84].

The first application progress was obtained by the use of Gr in the design of biosensors [86]; the data showed that Gr may be effectively used for interfacing with the biomaterial and actually opens the way to use it in the BFC. Nevertheless, it is quite surprising that were described only a little number of examples of the Gr use as a part of enzyme BFC. The joint use of microbial cells and Gr is studied more intensively; evidently, such situation is due to the fact that in general the total number of publications on microbial BFC is three times higher than on the enzymatic BFC.

Biofuel elements on the basis of enzymes

The data on BFC, based on graphene and graphene-like materials in combination with enzymes and microbial cells are summarized in the **Table**,

Table

The configuration and characteristics of some BFE on the basis of a graphen and enzymes/microbic cells (according to the review [84])

Configuration and characteristics of some BFE on the basis of enzymes						
	Anode configuration	Cathode configuration	Open-circuit voltage, mV	Maximum specific power, μW/sm^3	Voltage at the maximum power, mV	Source
1	TMOS gel + CRGO + FM + GOx on Au plate	TMOS gel + CRGO + ABTS + BOD on Au plate	580	24.3	380	[33]/43
2	GCE/graphene nanoplatellets/ GOx/Nafion	TMOS gel + CRGO + ABTS + BOD on Au plate	≈550	58.0	220	[34]/44
3	Au plate/CRGO/FM + GOx/PPy	GCE/graphene nanoplatellets/Lac + BSA/Nafion	790	78.3	500	[35]/45
4	GCE/ERGO-MWCNTs/GOx/ Nafion	GCE/CRGO + Pt nanoparticles + Nafion	400	46	≈80	[37]/47
5	GCE/ER(GO + GOx)	GCE/MWCNT-ZnO/Lac	60	0.054	50	[36]/46
6	AuE/electrodeposited(GO + Co(OH)2 in CHI) + GOx	AuE/electrodeposited(GO/ Co(OH)2/CHI)/Lac	600	517	460	[38]/48
7	G/CNTs-COOH/GOx	G/CNTs-COOH/Lac + ABTS in solution	1200	2270	500	[39]/49

TMOS–tetramethoxysilane; FM–ferrocenemethanol; ABTS - 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid); BOD–bilirubin oxidase; PPy–polypyrrole; GCE–glassy carbon electrode; CHI - chitosan.

Table (continued)

The configuration and characteristics of some BFE on the basis of a graphen and enzymes/microbic cells (according to the review [84])

The configuration and characteristics of some microbic BTE						
	Anode configuration; mediator; carbon source	Cathode configuration/final acceptor of electrons; membrane	Open-circuit voltage, mV	Maximum specific power, μW/sm^3	Voltage at the maximum power, mV	Source
8	SSM/CRGO-PTFE; E. coli, (HNQ); glucose	Nafion CP/[Fe(CN)6]−3/-4	---	267	530	[107]/50
9	CP/CRGO/PEDOT; E. coli, (HNQ); glucose	PEM CP/[Fe(CN)6]−3/-4	≈700	87	430	[108]/51
10	CC/ERGO; P. Aeruginosa; glucose	Nafion CC/[Fe(CN)6]−3/-4	---	5.25	460	[109]/52
11	Vacuum-stripped G-CHI composite; P. Aeruginosa; glucose	Nafion CC/[Fe(CN)6]−3/-4	---	153	550	[110]/53
12	CP/GO nanoribbons; S. oneidensis MR-1; lactate	CMI7000 CP/[Fe(CN)6]−3/-4	---	3.4	---	[111]/54
13	CVD-grown G foam/PANI; S. oneidensis MR-1; lactate	PEM CC/[Fe(CN)6]−3/-4	≈700	77	200	[112]/55
14	CP/IL-rGO; S. oneidensis MR-1; lactate	Nafion CP/IL-rGO/[Fe(CN)6]−3/-4	---	60	160	[113]/56
15	Ni foam/TRGO; S. oneidensis MR-1; lactate	CMI 7000S NA/[Fe(CN)6]−3/-4	620	≈80	250	[114]/57
16	Graphite felt/GO/PPy; S. oneidensis MR-1; lactate	PEM CF/[Fe(CN)6]−3/-4	---	133	≈420	[115]/58
17	CP/G nanoribbons/PANI; S. oneidensis MR-1; lactate	Nafion CP/[Fe(CN)6]−3/-4	---	86	≈175	[116]/59
18	CP/GO nanoribbons; MBFC microbial consorcium; acetate	CMI7000 CP/[Fe(CN)6]−3/-4	≈740	32.6	≈530	[111]/54
19	CC/crumpled rGO-Nafion; anaerobic sludge; acetate	CMI7000 carbon brush/ [Fe(CN)6]−3/-4	≈660	3.6 Вт/м^3	400	[117]60
20	CC; anaerobic sludge; acetate	Nafion CC-BRGO/dis. O_2	390	32	200	[118]/61
21	SSM/PU sponge-G; sludge-based consorcium; glucose	AMI-7001 CC-Pt nano/dis. O_2	---	157	---	[119]/62
22	CC/bacterially reduced GO; anaerobic sludge; acetate	PEM CC-Pt nano/air cathode	≈600	191	300	[120]/63
23	CC/crumpled rGO; anaerobic sludge; acetateт	PEM carbon brush/ [Fe(CN)6]−3/-4	≈800	240	520	[121]/64
24	CC/ERGO/PANI; anaerobic sludge; acetate	Nafion CF/[Fe(CN)6]−3/-4	770	139	460	[122]/65
25	CP/RGO-PEI layers; anaerobic sludge; glucose	CMI7000 CP/[Fe(CN)6]−3/-4p	≈730	37	≈370	[123]/66

AC–activated carbon; CC–carbon cloth; CF–carbon felt; CP–carbon paper; CB–carbon black; PANI–polyaniline; N-G–N-doped graphene; HNQ–hydroxynaphthoquinone; FeTsPc - iron tetrasulfophthalocyanine; BRGO–bacterially reduced GO; SSM–stainless steel mesh; dis. O_2–O_2 dissolved in aqueous solution; PTFE–polytetrafluorethylene

which shows the basic constructive and operating characteristics of BFC structures. We will consider some details of the presented systems.

Direct and indirect with use of mediator electron transfer. There are many publications, describing features of catalytic reactions in systems on the basis of the glucose oxydas (GO), used as a model enzyme, and Gr. In 2009, were published the first works on the possibility of coupling of GO and Gr [87]; a year later appeared the publication on the use of GO and Gr, as part of BFC [88]. As the cathode catalyst mainly was used laccase. The GO contains flavin adenine dinucleotide, cofactor, surrounded by a protein and glycan structure, limiting the effectiveness of the exchange of electrons between the active point of the protein and surface of the electrode; thus, the structure of the enzyme forms a barrier for bioelectrode operating conditions. It should also be noted that even if the non-mediated electron transport is described for a biosensor, containing GO, it does not mean that the catalytic

current is associated with direct transfer between the electrode and cofactor. This effect may be the result of non-enzymatic reaction of hydrogen peroxide or oxygen, involved in the catalytic cycle of GO on the electrode surface [89]. On the other hand, the direct transfer is known for the cathode application of GO, when the current is generated in the process of FAD-cofactor reducing, which is then reoxisized by oxygen. Obviously, this case is not acceptable for the BFC functioning [84].

This situation is, of course, allows to design the biosensors, based on GO, but the principle is not applicable to formation of BFC for the following reasons: 1)GO more efficiently transfers the electrons to oxygen than the electrodes, which can be judged by the value of the constants of electron transfer; 2)the resulting from the reaction hydrogen peroxide is not suitable substrate. This reaction that competitive to oxygen, is the most important on the merits. It should be considered in a case when arises the question about the use of GO in BFC. Even in the case of direct, or more precisely, non-mediated electron transport between the electrode and GO, the mechanism can not be proved with absolute precision, therefore there is always a counterversion about reality of direct transfer of electrons. In this regard, it should be assumed that the direct anode electron exchange between GO and electrode is forbidden, and it is possible to use only mediated transfer (**Fig. 15**). Such reasonings are confirmed by an example of BFC, presented in the fifth position of the Table; the anod consisted of the GO enzyme, immobilized onto graphene oxide and glassy carbon electrode, the cathode represented by laccase, immobilized on multiwalled carbon nanotubes, modified with zinc oxide. BFC had open-circuit voltage of 60 mV,

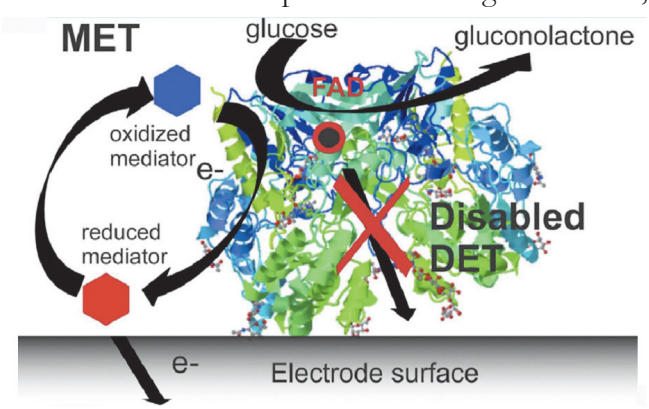

Fig. 15. *Electron transport caused by a mediator between FAD- dependent GOD and an electrode for a case when direct transfer is impossible. FAD-cofactor is designated of red and black circles* [84].

maximum specific power of 0.054 μW·cm^{-3} and voltage at the maximum power of 50 mV [83]. Such parameters in the given number of BFC are the smallest on value. However, the example of BFC, represented in the seventh position of the Table, contradicts the described scheme of the mechanism of GO functioning, since the parameters of BFC are the best of the submitted for enzyme BFC [87].

Graphene-based microbial biofuel cells

Despite the fact that the idea of electricity generation by oxidation of organic substrates with microbial biocatalyst was first formulated more than a hundred years ago [90], the decades were required in order to receive important results on microbial BFC. The task to provide effective electronic transport between an electrode surface and enzyme, localized in a microbic cell, was rather difficult. The challenge was not only to ensure the efficient transport of charge, but also to provide transport of the biocatalyst substrate; it was significantly harder for microbial cells than for an enzyme. As a result, the maximum power of BFC, based on enzymes, was higher than capacities of microbial BFC. In this regard, in the early 1980s, the main direction of research was the use of electron carriers – mediators [91]. At the same time, in two decades, there were reports about the possibility of non-mediated transport [93] and from that period, the study of microbial BFC gained new scope [94]. It was established that bacterial cells can have three main ways of electrons exchange with electrodes- via secreted mediators and with use of cytochromes and bacterial piles or nanowires (**Fig. 16**) [95-97].

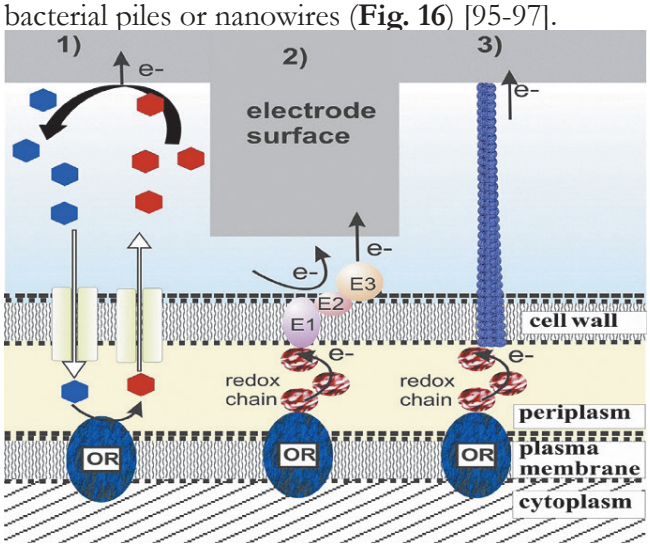

Fig. 16. *Schematic illustration of mechanism bacterial electrons exchange by means of 1) secreting mediators (at the left - an oxidized mediator, on the right - restored), 2) superficial cytochromes designated as E1-E3 and 3) bacterial pilis – nanowires or oxidoreductases* [84].

However, even in the presence of the specified assumptions, concerning mechanisms of an exchange, the further intensive studying of details was required. So, there was a question - whether is the transmission mechanism from one site of cytochrome to another or transfer is carried out on the conductivity mechanism in metals through π - π connected electrons in aromatic rings of amino acids [97]. Also it should be noted that the combination of three mechanisms of transfer for bacterial cells brings the difficulties in the unambiguous interpretation of the electron transfer process [98]. Regardless of the existing complexity of an explanation of transfer mechanisms, the discovery of *DT* effect of electrons near bacterial cells gave ample opportunities for BFC designing. These bacteria are called "ekzo-electrogen", i.e. capable independently to generate the electric power and containing nanosystems, which can be used for creation of a reagent-free microbic BFC. The BFC power on their basis reaches the power of many BFC on the basis of enzymes. However, on the base of data from the Table, it is possible to see that even use of graphene materials in microbic BFC doesn't allow to reach the best power values of BFC on the basis of enzymes. At the same time, the microbic BFC possess other positive qualities - for example, considerable higher operational stability, extraordinary wide range of substrate [99].

Now, the great attention when designing of microbic BFC, and including on the basis of ekzo-electrogen, paid to the application as a conductive nanomaterials (carbon nanotubes, carbon nanofibers and polymer, graphite particles) and conductive macrodimensional materials - carbon fabric, carbon paper, carbon felt. At the same time, despite the complex nature of the interaction with microbial cells, the frequency of Gr use in microbial BFC increases [84]. However, from the Table data can be seen that even when using the Gr in BFC, their parameters still recede, but in some cases considerably superior the BFC parameters, based on enzymes.

5. CONCLUSION

Thus, when considering various approaches, it may be noted that the current research in the field of BFC development are directed on studying of the properties of conductive nanomaterials to create electrodes, for the search of new schemes of nanomaterials use as electrodes, search for new enzymes and microbial cells, capable effectively to carry out an electron transfer using mechanism of mediated and direct bioelectrocatalysis. Graphene was among the carbon nanomaterials, both in biosensors and in BFC (biosensor technologies are precursors of BFC technologies, since the structure and function of BFC and electrochemical biosensors are very similar) [100].

The analysis of the available in the literature data on creation of BFC with new features suggests that one of tendencies is the development of small planar and volumetric BFC. For such systems will be required respectively small-sized electrodes - anode and cathode. Along with other known nanomaterials, the graphene materials have properties that enable their use in creation of BFC - so they have a high ratio "surface/volume", possess the high and controlled conductivity, high durability. The application in BFC of graphene materials extends the range of possibilities and allows us to develop a new generation of devices.

The obtained results allow to properly assess further ways of development of biofuel cells, including the creation of small BFC that can be effectively used in biorobotics, as well as in medical technology as implantable elements.

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PROGRAM-TARGET PLANNING AND MANAGEMENT THE CREATION OF COMPLEX TECHNICAL AND HUMAN-MACHINE SYSTEMS

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Abstract. **The paper reviews the development of methods of substantiation and selection of options when planning and management of human activities and development used in this process of technical means and organizational forms of planning and management. Provides the basic concepts of the program-target approach in planning and management of human activities. The main of these concepts is a program, the definition of which is given in the work. Discusses the basic principles of program-target planning and management the creation of complex technical and human-machine systems (CTS, HMS). Foremost among these principles is the end-to-end planning and management the creation of complex technical and human-machine systems life cycle. Describes the essence of decision making in end-to-end planning and management taking into account the uncertainties inherent in this process.**

Keywords: **planning, management, purpose, operation, program, mathematical model, uncertainties, decision making.**

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Contents

1. INTRPDUCTION

Planning and management of human activities in different branches took place at all times. That said methods of substantiation and selections of options of activities (decision making) have continuously developed, the technical means used in this process, as well as the formalization of organizational forms of planning and management.

In 1951 in the USA, the publisher of Massachusetts Institute of Technology published the first book in the world of Operations Research – Morse F.M., Kimball G.E. Methods of Operations Research. Cambridge, MA: Technology Press of MIT, New York, 1951, 158 p. In Russian language this book was published in the USSR in 1956. It described the statistical methods of assessment of efficiency of military operations with specific references and definition of quantitative basis for making the most effective decision by the leader of the military operation. Then the rapid development of operations research began in all developed countries. Currently Operations Research is a generalized name of the discipline, dealing with the development and application of mathematical methods, heuristic approaches and mathematical techniques to find optimal decisions in different branches of purposeful human activity. It includes: mathematical programming (linear, nonlinear, discrete, dynamic, stochastic); waiting theory; game theory; graph theory and mathematical methods of network planning; scheduling theory and combinatorial mathematics; inventory management, etc.

At the same time cybernetics as the science of control and communication in a living organism and machine began to explode (N. Wiener). At present, the objects of cybernetics are all managed systems. Each system is a plurality of interrelated elements able to perceive, remember and process information, and share it. Cybernetics studies the storage, transmission and processing of information, its use

for the control and regulation in complex dynamic systems. The most carrying weight theories, unifying by cybernetics, are: transmission of a signal theory, management theory, automata theory, synergetics, theory of algorithms, image discrimination theory, optimal control theory, theory of learning systems. Cybernetics became a theoretical basis of computer technology.

Electronics and computer technologies in its development has gone through several generations. Each generation of electronic computing machines (ECM) differed from the previous generation in element base, speedwork, outside dimensions, volume of operational and long-term memory, interface capabilities. The first electronic digital computer (EDC) was invented in the USA in 1946. Element base of the 1st generation of ECM, which were used in the 1950s were ordinary electron tubes. Technical means of this generation ECM occupied the room equal school sports hall. Speedwork, volumes of operational and long-term memory of these ECM were small. Information in the ECM were entered using punched cards, the results of the various calculations were printed on wide paper tape. Maintenance of such ECM required significant technical staff. Element base of the 2nd generation of ECM, which are widely used in the 1960s became semiconductors. In this regard speedwork, volumes of operational and long-term memory of ECM jumped very much. ECM of this generation used high-level programming languages and the principle of library programs. Further progress in the development of ECM occurred in connection with the advent of integrated circuits, which became the basis of the ECM element base (1970-ies). They were changed by the large-scale integrated circuits, and then – very-large-scale integrated circuits (3rd, 4th, 5th and next generation ECM). A new element base allowed to create ECM with a developed configuration of external devices; to increase significantly the volumes of operational and long-term memory; to implement multiprocessing; to create an advanced operating system that provides parallelism of operations; to create advanced tools for dialogue. Speedwork of supercomputers built on modern microprocessor element base reaches tens of petaflops (quadrillions floating point operations per second, flop/s - FLoating-point Operations Per Second). Such ECM can have actually unlimited necessary operational and long-term memory. And for all the technical devices of such super ECM is a small room enough. Background information in the digital and text form can be entered into the modern ECM using the alphanumeric keyboard or scanner. The results of processing this information can be outputted from the ECU via various classes of printers (laser, inkjet) in black and white as color. This information may also be displayed on the various classes of monitors (cathode ray tubes, liquid crystal). Recent advances in microelectronics have led to the creation not only of supercomputers, but ECM and such as your personal desktop, and mobile computers - laptops and tablets, which in its capabilities exceed the ECM 2nd generation.

2. BASIC PRINCIPLES OF PROGRAM-TARGET PLANNING AND MANAGEMENT

The main feature of the present time is the acceleration of scientific and technical progress, which is based on the full intensive development of fundamental research in basic, promising areas of natural and technical sciences, as well as the integration of science and industry. The essence of this integration is to unite on the basis of, firstly, modern methods and, secondly, the new organizational forms of planning and management of all stages and phases of the process of creation of new technics, starting from the emergence of a scientific idea and ending with its practical implementation. This new organizational form of planning and management of the creation of new techniques is program-target planning and management. It allows the creation of new machinery, surpassing the world level in the required timescale and with minimum expense for their development, production, assimilation and exploitation.

Program-target planning and management for many years, is one of the most common and effective methods of state regulation of the economy, used in most developed countries. Among them are Canada, Japan, South Korea, Austria, Germany, France, Finland, the USA and others.

Attempts to use target-oriented approach in the national territorial planning took place as early as1920-1930. First software idea in the USSR were implemented in the GOELRO plan, developed in 1920. Issues were being resolved not just buildings of 30 regional power plants, and the whole set

of interrelated issues: increase fuel production, improvement or creation of its processing and transportation; industrial development; training of personnel; the creation of urban infrastructure, etc. Program-target approach has also found application in the creation of the Ural-Kuznetsk Combine, the development of the Khibiny mountains, building of a large industrial center of Komsomolsk-on-Amur and others. However, the level of methodological support of program-target planning and management at the time was very low.

The use of program-target planning and management on a new methodology basis with using the latest advances in the field of operations research, cybernetics and computer technology implemented in the USA R. McNamara in the mid-1960s to planning and management of development of weapons and military equipment (WME). Under his leadership the United States Department of Defence developed and implemented a system PPBS (Planning, Programming, Budgeting System). By 1966 the Pentagon started work in a new way and the American administration set the task of such transition before other Federal agencies. Principles of program-target planning and management were used for the preparation and implementation of space, military-strategic, territorial, scientific, technical and other programs and projects. American developments have brought to the conceptual framework of the program-target approach accurate structural and logical mathematical methods of partition the general scheme of the program into separate subgoals, problems, tasks by building tree of goals based on graph theory, assessing methods of the contribution to the achievement of the general goal, that allow optimally allocate the necessary resources for all elements of the program, methods of construction of organizational and management structures of goal's implementation etc.

In 1970-1990 target complex programs were widely used in the USSR as the most important constituent parts of the state long-term plans for economic and social development.

The current Russian budget is formed on the basis of targeted programmes. There were developed 39 state target-oriented program (STP). Programs covered in 2014 58,5% of the budget. As an example some STP: «Federal Space Program», «Development of civil aeronautical engineering», «Development of civil marine equipment», «Development of electronic component base and radioelectronics», «Housing», «Economic development in rural areas», «Development of Education» etc. Preparations are under way to the program start «Research and development on priority development fields of science and technology sector of Russia for 2014-2020».

From 1970 to the present time in our country is realized program-target planning and development management of WME [1]. The necessary controls and research institutions were created, organizational procedures, mathematical methods and models were developed, as well as relevant practical experience were gained. All this can be used in the implementation of program-target planning and management in the national economy.

At the heart of the planning and management of development WME is state defense order, representing the task for delivery of goods (WME, raw materials, materials, components, military stores etc.), execution of work (research and development, elimination of chemical weapons, building activity etc.), rendering services (repair, modernization of WME etc.) for federal needs in order to ensure the defense and security of the Russian Federation. State defense order is based on the «State Armaments Programme» for 10 years, which has a hierarchical structure corresponding to the structure of the armament system of the Armed Forces of RF. On the lower level of the «State Armaments Programme» are promising complexes (samples) WME, for each of which are specified military operational requirement, cost and timing of research and development, the volume of purchases by year planning period.

It follows from the foregoing that the main instrument of program-target planning and management is a program - a long-term planning document, combining purpose and objectives on terms of their achievements with the necessary tools and resources.

Before considering the basic principles of program-target approach to the planning and management, will focus on its basic concepts [1], related to the formalization of the organizational form of human activity, including planning and management.

Goal - the desired result of activities, achievable within a certain time interval.

Task – the desired result of activities characterized by a set of quantitative data or parameters and attainable for planned (specified) time interval [t_0, t_1]. Usually tasks are a concretization or detailed elaboration of goals from different sight angles. In general completion period of tasks is less, than the time for achieving goals.

Since the goal emerges as a more general category than the task, then we can assume that the goal is achieved by solving a number of tasks in connection with this problem can be ordered in relation to the goals.

Problem - a potential target (task), for which or is still not found an alternative to achieve it (the decision), or it is not possible to allocate resources to the search for alternatives and conducting an operation to achieve it (the decision), or both together.

Obviously in any sphere of activity are always more than can be goals and objectives. Analyzed and evaluated competing options to achieve a goal or solve the problem called alternatives of action or just alternatives.

A sequence of increasingly sophisticated in any sense of the goals we will call **direction of development.**

Operation – activity of the team, managed from a single center and aimed at achieving a goal or solution to the problem. Governing body of the operation has the ability to distribute the operation in accordance with the plan of operation all dedicated to the operation financial, human and material resources.

By the nature of behaviour there are two types of operations: terminal and continuing or developing.

Terminal operations ends the achievement of this goal finite time interval *T*, after which the resources can be used in other operations. Terminal operations include the creation of complex technical systems (CTS), human-machine systems (HMS), construction of facilities, buildings, new businesses, activities on disaster clean-up operations, etc. Terminal operations can form a sequence when the previous operation creates the preconditions for the implementation of the following with a more perfect in any sense of purpose, for example, the sequence of operations for space exploration (satellite launching, Laika in space, launching a man into space, long-distance flight of a man-in-space, joint flight of spacecrew, launching a man to the Moon, space-vehicle launching to Venus and Mars).

Developing operations – mass, serial production of goods and services, trade, learning processes in schools and universities, and so on. In this case, the goal of operations are periodically repeated for each year, quarter, month. The goals from period to period are becoming more and more perfect from any point of view. Thus, the developing operation associated with the implementation of the directions of development.

The results and timing of operations are usually probabilistic in nature. The operations aimed at achieving the goals, have a greater degree of uncertainty than operations, associated with the decision task. Any large scale operation can be represented as a multilevel hierarchical set of operations on a smaller scale. Moreover, the partitioning of operations is being done according the partitioning of the goal's (task) operation on a hierarchical set of sub-goals (sub-tasks). The partitioning is done to the level of tasks that are easy to take for elementary, i.e. those which are characterized by the only sustainable having no alternative method of solution.

Management and leadership of the governing body of the operation is called a sequence of commands, orders, signals, etc., that lead to a particular method of use or distribution of human and material resources, machinery, equipment, raw materials throughout the operation.

When managing the operation (activity) five successive steps take place: statement of goal; making a decision – a choice the best among many possible alternatives in accordance with the selected criterion (target function) [2, 3]; execution of the decision - the operation (operational control) and obtain the desired results; evaluation of results; recommendations for the future, which focuses mainly on improving the planning and operational management process.

Work – procedure, the result of which is material in nature, associated with the transformation of materials, energy, transportation of materials etc.

Work $x = (a, b, T)$ is characterized by:
– parameters vector $a = (a_1, a_2, \ldots)$, that determine the result of the work;
– resources vectorb = $(b_1, b_2, \ldots)$, equired to perform the work;
– time *T*, released to perform the work.

If the operation is to achieve a goal of large-

scale long enough, a plan of such an operation is called a program. In other words, the program - a comprehensive plan for a large-scale continuous operation. Or more precisely program – it is a comprehensive plan for long-term collective activities aimed at achieving the goal of large-scale or for the implementation of directions development.

In accordance with certain kinds of operations we have the types of programs too: terminal (the program «Apollo», programs for the construction of the Bratsk and Tyumen territorial industrial complexes, KAMAZ, BAM, etc.) and developing (development of the world's oceans, the energy of thermonuclear reactions, development of Non-chernozem zone, etc.).

The difference between the program and the long-term plan is that the program is focused on one goal, and long-term plan – on the department or organization whose activities are multi-purpose in nature. Long-term plan is formed from fragments of programs, the implementation of which involved the department or organization. In addition, long-term plan of some department or organization is multifunctional, i.e. consists of the individual plans, as the production plan, plan logistics, plan for labor and wages, financial plan, plan of capital construction, research and technological development plans etc.

In contrast to all of the functional plans the program has *complex character*, i.e. contains the full range of activities (works) to achieve the same goal or implementation of development directions. Therefore, the above definition of the program can be clarified.

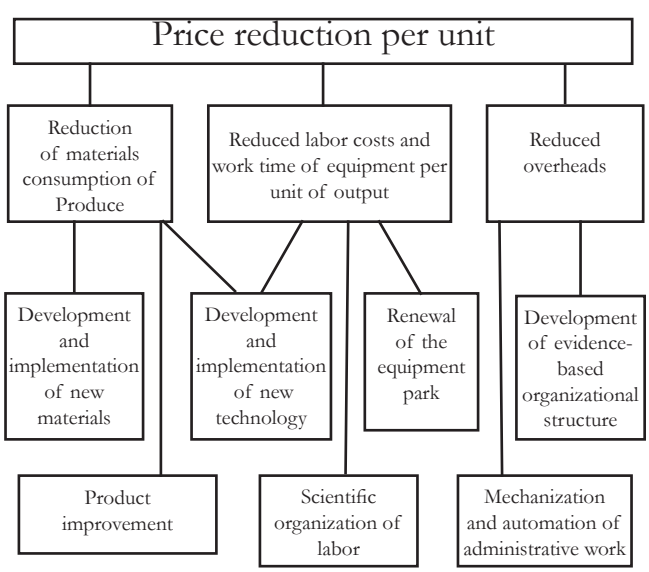

Fig. 1. *Structure of the program to reduce cost-per-unit in the industry sector or the company.*

Program – a long-term planning document, which contains a detailed over time, balanced on resources, compatible on executors and timing of the implementation, full set of socio-economic, organizational, economic, production, design, research and other activities aimed at achieving one goal or the implementation of development directions. The balance of resources means that there are no tasks, that are not resourced and that optimal from any point of view distribution of limited resources among the governing bodies of lower rank was conducted.

Implementation of the operation or implementation of the program can be shown by three types of graph-schemes or models.

1) Development of programs begins with the construction of the **graph goals and tasks,** which bears a name of **structure of the program**. The system of goals is hierarchical in nature due the fact that the overall goal of the operation is achieved only by the implementation of a hierarchical set of private operations of various ranks. In compiling the structure of the program is useful to set the weights p_j^i of goal's importance *j* inside each level *i*, for which there exist special methods. As a concrete example **Fig. 1** shows a three-level structure of the program to reduce the cost-per-unit in the industry sector or the company, which shows that the goals of of the lower level are the means (ways) to achieve the goals of the upper level.

2) The next graph-scheme – **information model**, which reflects the hierarchical structure of the organizational system that implements a given program, showing all the material and information flow between governments for various services, departments, production units etc.

3) And finally - **the network model** (**Fig. 2**), which gives an idea about the implementation of

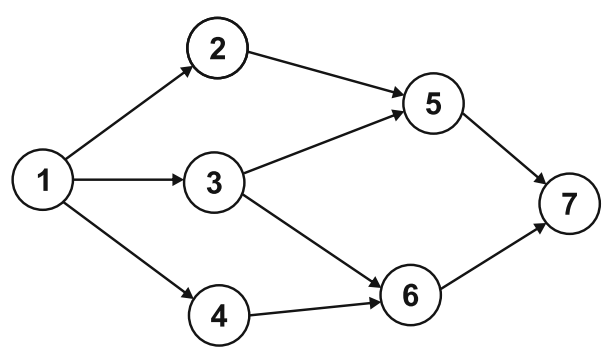

Fig. 2. *Network model.*

the program over time, reflecting the process of implementing a set of interrelated activities aimed at achieving the ultimate goal, and also allows to determine the importance of these characteristics of the considered process, its duration, complexity, cost, etc., based on accounting values of the relevant characteristics of individual works and the relationships between them [1, 4].

Programs to achieve certain goals, usually thought to **sliding**, i.e. with periodic adjustments, which gives them an adaptive character.

In the **structure** of any s**cientific and technical program** physically exist only complex technical and human-machine system (CTS, HMS). They ultimately determine the correctness of the taken decisions. Other higher levels are to some extent of conditional nature and their construction is necessary in the interests of further study plans of higher level.

In the process of scientific and technological progress is a change of some samples CTS (HMS) to others, more sophisticated. Consequently, one of the main and priority tasks of accelerating the pace of scientific and technological progress is the use of program-target planning and management of the establishment of CTS (HMS) to reduce the length of time from the appearance of a scientific idea to its wide practical implementation, and optimization of material, financial and human resources involved in this process.

3. END-TO-END PLANNING AND MANAGEMENT OF THE CREATION OF CTS (HMS)

Change one sample of CTS, HMS to the other, new lets talk about the life cycle of the sample CTS (HMS), about its birth and dying, i.e. decommissioning.

The life cycle (**Fig. 3**, LC) of some CTS or HMS, as usual, consists of the following stages or steps:

1) *Study intention*. At this stage, ideas on the implementation of the latest achievements of science and technology are born for meeting of CTS to the growing demands. There are determined desired operational and physical characteristics of perspective CTS, possible ways of its creation, are established the need for new technical solutions from the analysis of the **tree structure** CTS (**Fig. 4**) and the conditions for the realization of this tree. The result of the ending of stady intention is a technical task for realization of appropriate target research works (RW) indicating their purpose, timing, interaction of research institutions in conducting research.

2) *Realization of appropriate target RW* – fundamental, search and applied. One determines the ability to use particular scientific advances to improve the efficiency of the CTS, possible principles creation and establishing a new CTS are reviewed.

3) *Development of technical proposals or preliminary design*. From the analysis of possible options for a new CTS one determines the optimal way of its development, implementation and evaluation of the timing of realization and costs for all subsequent stages of LC. You must have some competitive technical proposals, if not the whole CTS, then at least its major subsystems, to choose the optimal way of developmental work at the stage of development of technical proposals. Competitive technical proposals usually are developed in parallel by different research and development organizations. If necessary, at the stage of development of technical proposals can be carried out more targeted research.

4) *Developmental work (DW)*. There are consistently developed conceptual, technical and working projects, the requirements for which are determined by the all-Union State Standard. The result is a working design documentation for production, assembly and erection of CTS, as well as the operation and maintenance documentation

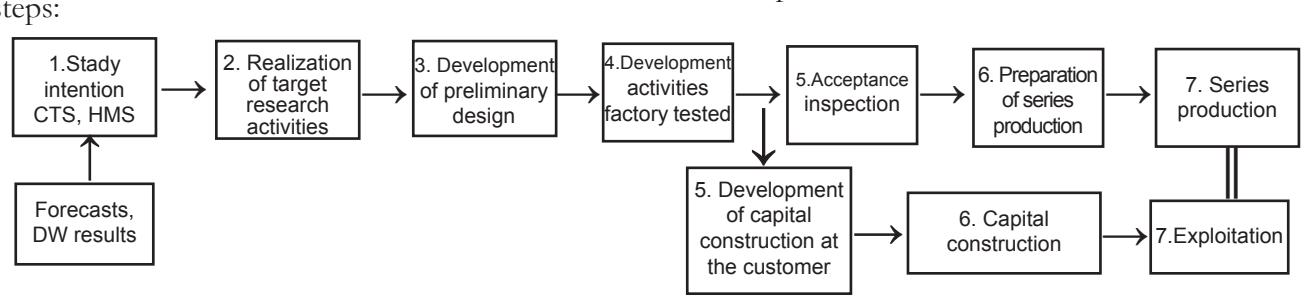

Fig. 3. *Life cycle CTS (HMS).*

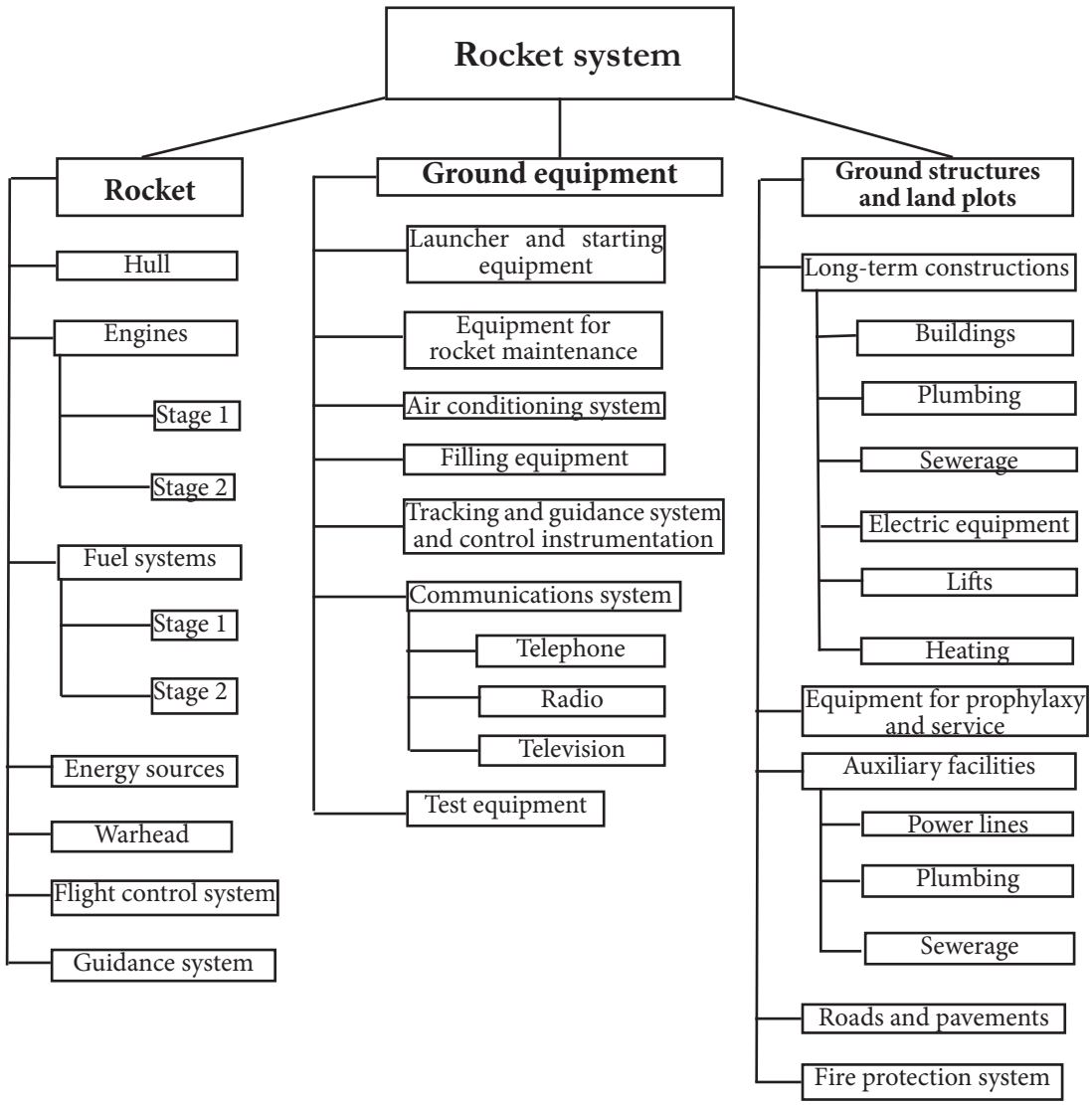

Fig. 4. *Tree structure rocket system.*

of CTS. This stage also includes the creation and production tests of the prototype CTS to test its performance, pre-checking the conformity of its basic parameters and requirements specification of design documentation.

5) *Acceptance inspection*. There are determined the CTS according to the technical task, the possibility of putting it into serial production. Simultaneously with the acceptance tests should be developed by the capital construction project for the customer.

6) *Productionisation and capital construction* of objects at the customer. Developing new production methods, tools, jigs and fixtures.

7) *Serial production and exploitation*. Part LC CTS (HMS) from elaboration of the plan to serial production is called the **Implementation Period**, and from the start of series production to decommissioning is called the **period of useful life** of CTS (HMS).

The main direction of improving the planning and management of the creation of CTS (HMS) is **end-to-end planning and management** of their life cycle, the essence of which is that the whole cycle of «research - production» is treated as a single process aimed at achieving the ultimate goal. End-to-end planning and management let reduce implementation period of CTS by eliminating gaps between the individual stages of LC, as well as the parallel execution of some works related to the different stages.

Individual stages of LC CTS can be characterized by **level of costs** *C*, necessary for their implementation. It should be noted that the **uncertainties** *H* in obtaining the desired results are very large in the early stages of LC and fall as far as

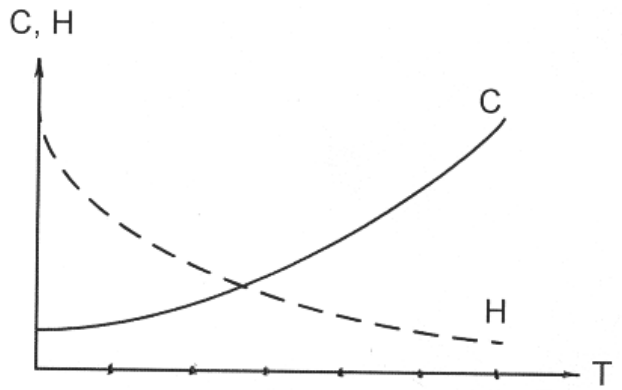

Fig. 5. *Level of costs.*

creating of CTS (**Fig. 5**). On the other hand, price of the work C, is relatively low in the early stages of LC of a new CTS, increases as the transition to later stages. Therefore, spending relatively little money on the early stages of LC, we significantly reduce the degree of uncertainty in the successful completion of the development and avoid large overhead costs that may arise in connection with setbacks and alterations in the stages of DW, testing and serial production.

The process of creating CTS (HMS) in view of their complexity, typically represent long-term operation. To implement end-to-end planning and management of the holding of each such operation must be preceded by the development of an appropriate program for creating CTS (HMS). In the initial stages of the life cycle CTS (HMS) to DW project, when the uncertainties in achieving the ultimate goals are great, this program is called the **target forecast**. As the reduction of uncertainties in the process of creating CTS (HMS) on the basis of the forecast target lifecycle is developed **end to end plan** of CTS (HMS).

The **target forecast** of CTS (HMS) lifecycle is a probabilistic judgment about the process of its creation. In the target forecast of lifecycle CTS (HMS) should be considered alternatives to achieve the ultimate goal for each of these options are set the expected cost of resources and time. The information contained in the target forecast of lifecycle CTS (HMS), has an orienting character. It is necessary to ensure focus during the early stages of the life cycle CTS (HMS).

In contrast to the target forecast **end to end plan** CTS (HMS), which covers all work on the creation of CTS (HMS), starting with R & d, has prescriptive character. It should contain only one best option of creating CTS (HMS) showing all the data on the CTS (HMS), the timing of creating CTS (HMS) and the necessary resources. End to end plans of CTS (HMS) provide a basis for quantitative calculations in the preparation of planning documents all higher levels and must contain the following required data: the purpose of CTS (HMS), its main characteristics, the timing of execution of certain works, information about the performers, the cost distribution by years, the volume of capital construction, the timing and volume of deliveries, as well as a comprehensive network model. As the proceeds set of interrelated works on the development, testing and production of CTS (HMS), as well as of capital construction end to end plan should be updated periodically as a result of the phase of decision-making [2].

When end to end planning and management of creation of CTS (HMS) in their life cycle disappears such lightly managed category as the introduction of scientific and technological achievements. Reification of knowledge will have planning character.

4. DECISION-MAKING WHEN END-TO-END PLANNING AND MANAGEMENT OF THE CREATION OF CTS (HMS)

The main point of the end to end planning and management of creation of CTS is **decision-making.** The essence of the decision-making is to compare several alternatives of action and selecting the best of them in accordance with the indicators. With various alternatives of action are associated different probabilities of success, and costs of various kinds of resources and time. These probabilities and costs can not always be accurately determined.

Depending on the availability of initial information solutions for end to end planning and management of creation of CTS may be taken in conditions of risk or certainty.

If for each alternative is known to what the final result it will bring, as well as the known amount of time and resources, the decision is made **under certainty.**

If for each alternative are known possible end result and the probability of its achievements as well as the probabilistic characteristics of time and resources, then we say that the decision is made **under risk**.

Uncertainties, which should be overcome when end to end planning and management of creation of CTS, can be divided into two groups - external and internal.

External uncertainties – uncertainties in the assessment of the true needs of CTS, as well as in the assessment of development environment, science, technology and economy, excluding the possibility a strict tasking of CTS creating in the early stages of LC. When deciding on the development of CTS these uncertainties will not be properly evaluated, it may be that the developing CTS will be ineffective or useless. As a result significant resources are lost, and most importantly - the time, the loss of which can not be recovered.

A major role in the assessment of external uncertainties in the end to end planning and management of creation of CTS should play a permanent system of military-political, demographic, scientific, technical and economic forecasting. On the basis of the forecast information provided by these systems, it is possible to correctly formulate the ultimate goal of CTS and get an estimate of its required amount.

Among the **internal uncertainties** of creation of CTS are technical and economic uncertainties.

Technical uncertainties associated with the assessment of opportunities and ways to create CTS with given specifications. These uncertainties are generated by the ambiguity of the structure of CTS. Multivariance structure of CTS in turn is caused by a variety of types of component elements and their parameters. Incorrect assessment of the technical uncertainties may result in termination of the development of CTS due to impracticability of initial requirements to it.

Overcoming technical uncertainties should be based on the use of various types of **system descriptions** of CTS, each of which represents a certain model of CTS, reflecting certain aspects of its construction and operation. The variety of system descriptions CTS can be reduced to four main: macroscopic, parametric, functional and morphological. The methodology for constructing these descriptions is given in the publication [5].

Economic uncertainties associated with the assessment of the duration of the individual stages of the LC and the costs of implementation.

Of great importance when deciding on the creation of advanced CTS plays the accuracy of determining the **duration of implementation period.** If the assessment specified duration will be too low compared to the actual, it can cause that created CTS will go into operation when it is already outmoded. In the best case the reduction in the duration of Implementation Period may result in termination of the development of the new CTS. It is very difficult to obtain a reliable estimate of the duration of the implementation period at the initial stages of LC CTS (study design, conducting targeted research). Often the error when estimating the duration of the implementation period until the beginning of the DW project are [1] from 2 to 5 years to decrease this duration.

It is difficult in the early stages of the LC also to give a reliable estimate of the total cost of creating of CTS. The cost is also usually underestimated The degree of divergence of the actual and estimated cost is directly related to the extent of scientific and technological change, embodied in the created CTS. If the CTS requires major technological shift, the error in the cost estimate are large, it is often the ratio of actual cost to estimated may reach 4. In that case, when a small scientific and technological shift is needed, the ratio is 1.1 – 2.0 [1]. These values can be used as constant factors in the calculation of the total cost of creating of CTS in the early stages of LC. Undertake a study also shown that estimates the cost of the work (activities, operations, actions) and necessary for their implementation time become more precise as we move from one stage LC CTS to another.

Thus, the uncertainties in the source data – an objective property of the environment in which decisions had to be made when the end to end planning and management of creation of CTS. It can be concluded about inexpediency of making a final decision on the establishment of some CTS if it is on one of the initial stages of LC. This means that after the completion of each stage of the LC should take a new decision on continuation of works on creation of CTS, and all the early decisions lose their effect if they do not coincide with the latter.

In consequence of reducing of uncertainties as we move from one stage LC to another decisions are taken when the end to end planning and management of creation of CTS after completion of the initial stages of LC **under risk**, after completion of the DW project and factory testing decisions are taken usually **under certainty**.

Decision to continue the work for creation of CTS after the completion of each regular stage LC should be taken at least on the following **parameters:**

W – effectiveness of CTS; P_{tch} – the probability of creating of CTS with given specifications; C_{rp} – cost of the remainder of the Implementation Period, to be able to start serial production of CTS; C_{sf} cost of the serial production of CTS; C_e – full cost of operation CTS in a unit of time (year, month, day); T_e – time of receipt of the CTS in operation; T_{ul} – duration of the period of useful life of CTS.

Let us examine briefly each of these indicators.

Obviously, CTS should first of all meets the specified requirements for efficiency W_e, i.e. the condition must be satisfied $W \geq W_e$. In the initial stages of LC, when the possibility of full-scale experiments is virtually eliminated, the value of the efficiency index W for each option of CTS can only be determined by a mathematical model of its operation or application that also allows to get depending on characterizing the influence of the structure and parameters of the CTS, nature of the relationship between the subsystems on its effectiveness for a given impact of the environment.

In practice, very often with the help of mathematical modeling is necessary to evaluate the effectiveness of different options CTS is not on one, but on several parameters. This may be due that in some cases creating CTS are multi-purpose, i.e. designed to solve a number of problems. The choice of the optimal variant of the CTS on two or more indicators in a rigorous mathematical statement is impossible, because any option, which is the optimal one performance indicator, as a rule, is not optimal for other indicators. In this case, it may be a compromise solution: preference is given to option, which, while not the best on any indicator, is acceptable in several indicators, i.e. rational variants of CTS are found and one of them is selected.

With the help of mathematical modeling operation (application) CTS assessment of its various options can be carried out not only in terms of efficiency, but also in terms of other properties: reliability, stability, noise immunity, etc. In this case, obviously, it is important that these properties were taken into account in the structure of the mathematical model.

Because of technical uncertainties exclude the possibility of selection after study design a single CTS creation's option, it is necessary to consider a wide range of alternatives and select the most probable of them as we move from one stage LC to another. On the basis of generalization of a number of research works [1, 2] it is possible to recommend the following target values of the indicator P_{tch} for selecting options for a new CTS after the appropriate stage of LC: development plan – 0.1-0.6; conducting of targeted research – 0.5-0.8; development of technical proposals – 0.7-0.95; DW project – 0.9-1.0; testing, capital construction, preparation of serial production – 1.0. Lower statutory value of the index P_{tch} consistent with CTS, the creation of which requires major technological shift, upper - CTS, which need a small scientific-technical shift. If for some options for creating a CTS is received, the station reserve fuel facility index value is less than the standard, this option is eliminated from consideration.

The essence of the use of indicators C_{rp}, C_{sf} and C_e is quite simple and is as follows. The calculated values of indicators of C_{rp} and C_{sf} must not exceed respectively allocations for research, development and production of CTS. Otherwise, the decision must be made for an additional appropriation or termination of the work on the creation of a new CTS. The value of the C_e is used when choosing one option from a number of possible equivalent on other indicators of CTS options. Preference is given to that option, which is cheaper to operate. The accuracy of determining the values of indicators C_{rp}, C_{sf} and C_e is low at the initial stages of LC CTS and is growing rapidly as we move from one stage to another.

The indicator T_e determines the time of receipt of CNS in operation. The value of the indicator T_e should not exceed the set time T_e for creation a new CTS. The value Te is easy to identify, if known, the duration of the remaining part of the implementation period of CTS.

And finally, a big factor in the decision to continue the work on the creation CTS plays duration of the useful life of T_{ul}. If it is too small, the feasibility of creation of CTS can be questioned. In assessing T_{ul} of creating CTS it is necessary to consider trends in the development of the type of equipment to which it relates, the development prospects of competing types of CTS and other factors. It should be noted that in each case the list of these indicators can be extended (the impact of

the new CTS on the development prospects of other CTS, extent of use when creating CTS of the latest achievements of science and technology in all design and technological solutions, etc.).

For each option of CTS value determination P_{tch}, the amount of work at each stage of LC, the timing of the individual steps, costs by stages can be carried out using a network model with deterministic and stochastic structure [1, 7, 8], which allows implementation of display processes set of interrelated works for creation of CTS. Knowing these figures is quite easy to obtain and values of C_{rp} and T_e.

The cost of serial production C_{sf}, the full cost of operation of the C_e and the duration of the period of useful life T_{ul} CTS in the early stages of LC, prior to DW, can only be determined by the methods of scientific, technical and techno-economic forecasting. At stages of DW and testing the value of C_{sf} can be determined under calculation, i.e. for each *i*-nd subsystem CTS finding costs expenditures connected with: basic materials $C_{bm,i}$, ready furnished parts $C_{fg,i}$, compensation $C_{p,i}$, overhead costs $C_{o,i}$, damage of defects $C_{d,i}$. As a result of summation of cost expenses on articles you can find the cost of serial production of CTS:

$$C_{sf} = \sum_{i=1}^{k} (C_{bm,i} + C_{fg,i} + C_{p,i} + C_{o,i} + C_{d,i}),$$

where *k* - number of subsystems CTS.

When forecasting or calculation of the total cost of of operating a single sample of CTS must be borne in mind that the value of C_e includes direct operating costs C_{dc}, related to the functioning of the CTS, storage costs C_k and the cost of maintaining staff C_s:

$$C_e = C_{dc} + C_k + C_s.$$

The value of C_{dc} includes the cost of technical support (all types of servicing, repairs, supply of spare parts), the cost of fuel and lubricants, the cost of maintenance of structures. The value of C_k consists of the cost of maintaining of resource base and costs of all kinds of works in storage CTS. The value of C_s includes salaries of staff, as well as the construction costs of residential buildings, etc.

Following the development of the technical proposals of the competing options of CTS, that meet all the above indicators, you need to choose one according on the criterion «**costs – effectiveness**». When choosing the optimal variant of CTS on this criterion of the three indicators *W, C* and T_e one is accepted as the main, and the other two are put into constraints. Here *C* – total price.

Following the development of technical proposals, and at all subsequent stages of the LC of those competing versions of the CTS that meet all the above indicators, you need to choose one according to the criterion of «**costs – effectiveness**». When choosing the optimal variant of CTS on this criterion of the three indicators *W, C* and T_e one is accepted as the main, and the other two are put into constraints. Here *C* – total price, which is defined as follows:

$$C = C_{rp} + nC_{sf} + nC_e,$$

where *n* – the value of the series.

Most often as the main indicator are taken effectiveness or cost. In the first case the task takes the meaning of optimization of CTS. Mathematically it is formulated as follows:

$$W \rightarrow max,\ C \leq \hat{C},\ T_e \leq T_{ee},$$

where $\hat{C}$ – a given limit value, the total cost of *C*.

In the second case the task takes the meaning of optimization of the allocation of resources and has the form:

$$C \rightarrow min,\ W \geq W_e,\ T_e \leq T_{ee}.$$

However, in some critical situations in the first place there is the time of being of the new CTS in operation. The mathematical formulation of this problem has the form:

$$T_e \rightarrow min,\ W \geq W_e,\ C \leq \hat{C}.$$

Since the establishment and functioning of CTS occurs in conditions of a large number of uncertainties or actions of a large number of random factors, then these indicators should be treated as random variables, which can be characterized by the laws of their distribution or other probabilistic characteristics. When deciding on the further continuation of works on creation of CTS after the next stage of LC (up to DW inclusive) as indicators of C_{rp}, C_{sf}, C_e, T_e and T_{ul} are choosing their average values (mathematical expectations). In assessing the effectiveness of CTS, if the result of its operation is a random event, as an indicator of the effectiveness of *W* is selected probability of accomplishment of this event. If the result of the functioning of CTS is some random variable, as an indicator of the efficiency of *W* take the average value (mathematical expectation) of value.

5. CONCLUSION

The constant growth of socio-economic development of our country in the world today can provide only an accelerated transition to the high-quality production. The solution to this problem can be carried out on the basis of program-target planning and management creation of new machinery, with or surpassing the world level, in the required timescale and with minimum expense for their development, production, assimilation and exploitation. Program-target planning and management is one of the most common and effective methods of state regulation of the economy. Its main principle is end-to-end planning and management of the creation of CTS (HMS) along its life cycle to reduce the length of time from the appearance of a scientific idea to its practical implementation and optimization of material, financial and human resources involved in this process. This article should allow a deeper understanding of the main provisions of the program-target planning and management and to use them in practical activity.

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ABIOGENESIS TRANSITION FROM THE ATMOSPHERE INTO THE HYDROSPHERE: FROM VESICLES TO PROTOCELLS

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Abstract. **Presented probable variant of stage transition of abiogenesis from the atmosphere into the hydrosphere - the transition of abiogenic organics from planetary autoclave of near-surface oxygen-free atmosphere into hydrosphere of a cooling planet and development of abiogenesis in the hydrosphere before its completion with the emergence of protocells. Herewith, the hydrocarbon droplets of atmospheric aerosol - the main sources of energy of formation of organic matter in the primitive atmosphere, when dissolved in an turbulent aqueous medium transformed into vesicles - centres of development of primitive energy metabolism and flowing homeostasis, inherited from drops. Interaction of viral world, which appeared in the atmospheric period of abiogenesis, with the world of lipid vesicles ensured the development in them of mechanisms initially anaerobic and then aerobic external and internal energy metabolism. Herewith an important role in the metabolism of vesicles played the selection compounds by type of symmetry. This selection narrowed the range of compounds involved in the internal metabolism of vesicles and provide optimal occurrence of appropriate mechanisms of developments of nascent cellular world**

Keywords: **abiogenesis, atmosphere, hydrocarbon nanodroplets, autonomous energy source, metabolism, homeostasis, primary separation, lipids, vesicles, viruses, molecular symmetry.**

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Contents

1. INTRODUCTION

The subject of this paper is the abiogenesis final stage, start of which is the transition of the "prelife" from the atmosphere into hydrosphere of the planet when it cools, finish is the first appearance of the archaic cells. Prior to that stage the germs of life have gone a long way of the evolutionary development from nonequilibrium aerosol organic systems – the hydrocarbon nanodroplets [1] - the first sustainable confined sources of free energy in the first subvital zone of the planet - in the planetary autoclave of

near-surface oxygen-free atmosphere, to form a sufficiently rich set of structures and mechanisms "prelife". Along with organics captured during accretion of the planet from the protoplanetary cloud appeared and developed own organics, conditions of forming of which seem to be quite sufficient. This conditions are the temperature and the required values pressure, saturating of near-ground layers of the atmosphere with water vapor and minerals, the turbulence of these layers, energy of natural sources - Sun, heat, radioactivity and, finally, autonomous sources – world of hydrocarbon drips that ensures abiogenesis by energy. The initial stage of abiogenesis in oxygen-free atmosphere with a predominance of methane, carbon monoxide and ammonia in the near-surface dense dust layer with vapors and suspensions of minerals - natural catalysts is characterized the synthesis of the simplest hydrocarbons. This are amino acids up to the chain peptides and ribozymes (first organic catalysts), nucleotide and their chains up to RNA polynucleotides, lipids, archaic macroergs finally viruses. Was formed mechanisms of primitive metabolism - the exchange of matter and energy with the environment and the flowing homeostasis - maintaining the stability of the elements and variables (temperature, pH, etc.) in the flowing interaction with the environment. When condensation with water vapor, this organics passed into the aquatic environment of the formed hydrosphere planet.

If at the beginning of evolutionary transformations of such systems polynucleotides are only used as a depot (warehouse) archaic macroergs, then by the time of the transition abiogenic organics into the aquatic environment have developed mechanisms of matrix reproduction of complex compounds, including polynucleotides themselves in multicomponent reactions. Significant, apparently crucial role in these mechanisms played (and play up to the present time in cells) lipids - light (several hundred Daltons), linear molecules of relatively small size (about 1 nm), synthesized on hydrocarbon droplets and to partially or completely covered them surface. Flowing homeostasis of lipid massa provides the convergence to it of all the reactants into the reaction zone. Processes of lipid metabolism have lead to a shift of the lipid mass together with the her associates and their complexes to a convoluted chains of amino acids - to the primitive proteins - enzymes, that perform catalysis of decomposition reactions energy-intensive lipid [2]. The energy of this decay can be used in the synthesis reactions of other compounds, including archaic polynucleotides and macroergs. On this basis, on the surface of lipids began to pile up and operate mechanisms of forming organelles (plastids, vacuoles, ribosomes, vesicles, tubular structures, etc.), that provide an interface of reactions of the matrix reproduction of complex compounds and replication of polynucleotides.

The pinnacle of the evolution development of atmospheric phase "prelife" was the appearance of the first virus-like bodies and, finally, of primitive viruses [2]. Combinatorics of peptide compounds, feedbacks between the matrix reproduction and replication of primary information polynucleotides in a symbiotic relationship with local sources of free energy, that utilize the stocks of atmospheric hydrocarbonic raw, all of this made an emergence of viruses at this stage inevitable. Because metabolism drops was open, their surface structures - the compounds and their complexes, including with polynucleotides, were able to as go to the gas medium well as come back at the drops surface, providing reproduction of compounds. For rapid evolutionary development of the first viruses in the gaseous medium formed the ideal conditions: the open metabolism of drops have guaranteed the energy basis, and frequent mutations of the information parts in an aggressive and highly turbulent medium of the then atmosphere provide a flow of new information.

2. "ACTIVE" LIPID FILMS AND VESICLES

The result of the transition of the atmospheric organics into the aquatic environment, which appeared on the cooling surface of planet by condensation of water vapor (along with endogenous - mantle [3] and exogenous - meteorites [4] and ice rains [5] - the sources of primary hydrosphere), became "a primary soup ", whereof wrote A.I. Oparin [6]. Autonomous sources of free energy - "active" hydrocarbon droplets, archaic enzymes and lipids on their surfaces at the transition from atmosphere to aqueous medium completely or partially lost of their lipidic shells, as schematically shown in **Fig. 1**.

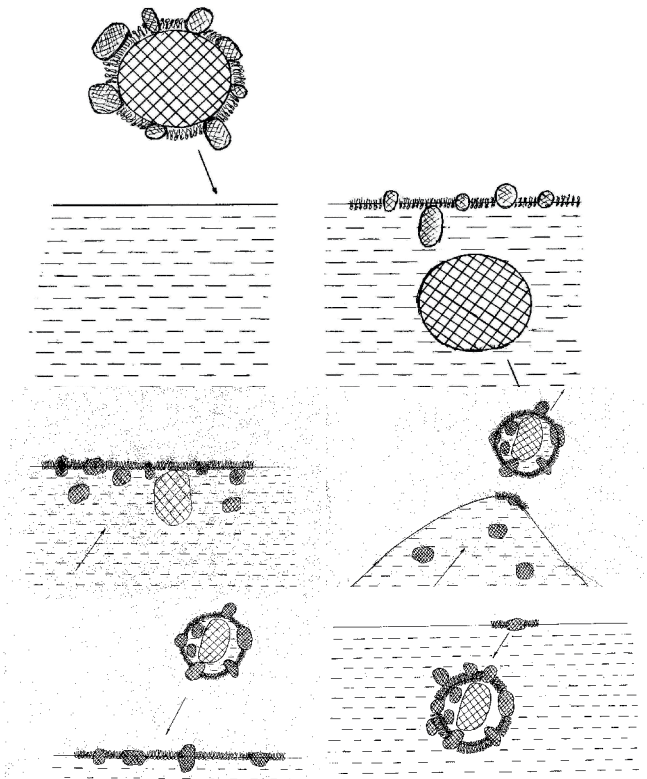

Fig. 1. *The lipid shells of hydrocarbon droplets in an aqueous medium.*

On the water surface are the single-layer lipid films with embedded and their associated archaic enzymes. Due to the strong turbulence at the phase boundary between atmosphere and water surface of these films were formed vesicles[1], just as it is done in laboratories by sonication. Some of the films and vesicles in the new conditions of water medium have inherited from hydrocarbon droplets the mechanisms of metabolism. It is important to note that the metabolism of vesicles could be both external and internal, and some of them had got and that and other at the same time. In turn, only some of the viruses are able to interact with these structures in the new environment, more dense than water vapor. For emerging living world this situation can be described as a catastrophe, bifurcation. Compared to the lifetime of our Galaxy the transition time "prelife" in the aquatic environment looks as a moment, and compared with the appearance and development of our civilization - almost an eternity.

Abiogenesis had continued to evolve in the new environment. The lipid films on the aqueous surface and the lipid vesicles in thicker of aqueous medium "replaced" as sources of free energy the hydrocarbon droplets atmospheric aerosol. The carbon-containing compounds energy of decay on the surface of films and vesicles provides a synthesis of all of the abiogenic organics - polynucleotides, archaic viruses, enzymes and macroergs. Hydrolysis of macroergs largely complemented the energy for synthesis of compounds involved in flow metabolism of open systems in an aqueous medium.

Note that such anoxic synthesis of macroergs in conjunction with enzymatic disintegration of compounds (including enzymes themselves), independent of presence of macroergs in reaction zone, is used and at present, not only in red blood cells, but also and in all cells in quiescent. The presence of such ways of obtaining macroergs in addition to the main energy-dependent processes for their synthesis, provides the cells in quiescent the concentration stability of these compounds, including and ATP.

3. METABOLISM OPEN SYSTEMS AS THE PREDECESSOR OF THE PROTOCELLS ACTIVITY AND FISSION

The question of occurrence in the cells mechanisms of their fission seems unsolvable if to approach this problem under the assumption that these mechanisms division formed in the cells themselves and, most importantly, for them. The situation is different if we assume that these mechanisms began to take shape for the reproduction of viruses in the period of abiogenesis in an aqueous medium, and then inherited by cells for mitotic activity.

Abiogenesis in the gas and aqueous medium lasted parallel many millions (if not billions) of years under the leading (in the transformation of organic matter) role of viruses, that evolving in atmosphere more quickly. Was formed new feedbacks between viruses of both media and local sources of free energy. In the aqueous environment surrounding the energy sources (lipid vesicles and films), and in vesicles appeared a sufficient quantity of macroergs for replication of information pieces and bodies viruses.

Alongside with the concentration macroergs non equally important factor is to maintain in the aqueous medium the reaction zone of acidity, optimal for multicomponent reactions metabolism. Intensification of oxidative processes in which

[1]Vesicle - cavity bubble (lat. vesica - bubble) to 100 nm in diameter, in a lipid shell with an aqueous solution of nucleotides.

used oxygen of water molecules inevitably led to acidification of reaction zone, changing the rate of metabolic reactions, reducing the power of sources. In process of the aqueous medium acidification the reaction zone was shifted further away from the surface of the lipid films and vesicles, where are mainly generate free energy with the release of ions H +, contributing to the primary reactions of rapid synthesis of the biologically active small compounds, for example, short peptides, whose the non-ribosomal synthesis can be carried out quickly and does not require high energy expenditure [7]. Such compounds known and currently, and molecular mechanisms act in the present-day cells and in the internal environment of multicellular organisms.

Implementation of these ways to improve molecular mechanisms metabolism and of strengthening on this basis of energy generation led to the emergence of new structures that could later be used after the upgrade in cells and for other purposes. So, the chains reactions alkalizing of cytoplasm were needed for the organization of a cyclic mode of activity cell [8] and the complex oscillating regimes of acidification and alkalization in the background of natural acidification of the cytoplasm during mitosis [9].

Let us explain the last statement. Since modern complex processes of cellular metabolism requires energy, then, if there is competition between the two major groups of primary energy-dependent processes for macroerg ATP (meaning the group that involved in the synthesis of ATP and the group that in this is not involved) the maximum possible efficiency work of each can be achieved by disseminate their action in time. Herewith the systemically important factors are typically the changes of acidity and concentration macroergs. Basic methods and means of implementing such a time diversity of processes are mentioned above. So in the activity mode of modern cells are for this used the cyclic changes of pH and concentrations of the main macroerg in the cytoplasm [8]. At mitosis the changes of this parameter have more complex character, however, achieved by the same means. With the accumulation in the depot of energy-consuming and plastically material, enough to power a few cell divisions, a signal is generated to start mobilizing of depot material. In parallel, this same signal generates the increased of alkalizing processes of cytoplasmic before neutral values, causing the cell "reminisces" the condition of their first evolutionary predecessors. To the extent of uptake of energy-intensive substrates the acidification of the cytoplasm naturally grows from neutral values. Precisely this determines the sequence of switching and completing all the processes of fission [9]. Molecular mechanisms of automatic activation and regulation of alkalizing and acidifying the cytoplasm during mitosis are formed ("are grow") in considered evolutionary period out of archaic cycle of the precursor cells metabolism. So cyclic changes the length of fibers spindle, caused by the change dominance of processes of their growth and decay, as well as the change of value affinity chromosomes to their ends of the at the equator, defining processes of the "shake-up" and "recognition" by chromosomes "own" thread can be explained by the superposition of the archaic cycle on mitotic cycle in phase of the monotonic rise acidification of the cytoplasm during mitosis [9].

We should also mention the possibility of appearing in the period under review another phenomenon: the emergence of the tubular structures of lipids, which departs from the surface of vesicles into surrounding aqueous environment. Such structures are could to appear in the case of temporary dominance of lipids synthesis over their decay as an macroergs by the steady intensification of energy metabolism and pH fluctuations of adjacent aquatic environment. Since the replication of information parts of viruses occurred also due to the decay energy of lipids, their indicated tubular structures could be used as a depot of this peculiar macroerg.

In concluding this section, we note that the level of acidity and concentration of macroergs in the aquatic environment and their natural variations in open systems that generate energy, in the period under review proved to be useful for the reproduction of increasingly sophisticated viruses. Accordingly, appeared new tools and molecular mechanisms that have ensured for this the optimum conditions and have given a start to the formation of the mitotic apparatus and means of cyclic acidification-alkalinization modes of processes the cell metabolism. The formation

of such mechanisms began at the considered abiogenesis stage in the processes of reproduction and evolutionary development of viral world, long before the appearance of first cells and the final formation of the living world

4. EVOLUTION OF THE WORLD VESICLES, APPEARANCE OF PRECURSOR CELLS AND THEIR ORGANELLS

A previous sections have been devoted to the consideration of evolutionary development of external metabolism of lipidic films and vesicles. His openness for interaction with viruses ensures rapid development of the viral world and, accordingly, equally rapid complication of metabolic structures that provide energetic support of evolutionary changes. Behind the scenes is still the fate of structures that "are trapped" into the vesicles. We emphasize "trapped", because the lipid films and vesicles of that time were by dynamic structures. Recall that the organics exchange of aqueous medium with the atmosphere was continued, although its intensity gradually was falling. From films were appearing new vesicles. They were seizing the organics, the source of which - a films which were broking by the shear flows. And the "membranes" of vesicles, who died under the dominance of decay of lipids (the analog cell death by way of necrosis). Vesicles could be combined into larger individuals in random collisions and merging. Their contents were combined. The internal environment of vesicles have enriched with new structural elements, useful for her metabolism. This happened in the flow (replacement, substitution) of composition vesicle. Thus at indirect interacting with viruses, internal metabolism of vesicles could develop. However, the criteria for peculiar selecting and securing of new information (in according to EM Galimov new compounds [10]) were slightly different than for external metabolism. External metabolism developed in cooperation with viruses. This interaction was the leading factor in this development. Development of external metabolism was progressive, with the proviso that the development of virus was also progressive and the representation of viruses was increased in nature. Outdoor metabolism provided the viruses the pick new information. Internal metabolism was developed using structures that confer resistance to the harmful effects of turbulent water environment. These two processes were parallel. This interaction of two metabolic systems with each other and with the viruses prepared and implemented the preconditions for the emergence of the first precursors of organelles and cells.

Indeed, the vesicles with their primitive outer and inner metabolism remind us the mitochondria, which act in oxygen-free environment of the primitive ocean, the whole mass of water which can be identified with "the cytoplasm" planetary scale. Isolation of metabolic structures was casual, but widespread. This determined the inevitable emergence of bubbles with a lipid envelope, which from the incomplete enzymatic pool is not capable of generating energy at its outer side. Among them were a vesicles, whose internal metabolism can provide the energy of the replication of captured polynucleotides and the reproduction of other compounds. Such vesicles with good reason can be attributed to the ancestors of the first cells, and a vesicles that have external and internal metabolism, can be attributed to their predecessors of energy organelles.

5. SELECTION OF COMPOUNDS BY THE TYPE OF SYMMETRY

One of the most characteristic processes inherent to abiogenesis - the vesicle contents formation by selection available having at that time of organic compounds by the chirality - the type of symmetry of the molecules with respect to their optical activity (right or leftrotatory the plane of polarization of light). All biota is chiral, unlike nonbiological organics. For instance, all the amino acids can be in relation to the plane of polarization of the incident light only the left rotatory (and exactly they are the parts of protein), and sugar - only dextrorotatory (the parts of RNA and DNA). Questions, how they have been selected and whether it contributed to the emergence of the first cells remain unanswered.

One option of answer is possible in the context of the necessary "benefit" for the nascent cellular world. Selection entering into the vesicles compounds by the type of symmetry substantially has reduced the time (had to select from a much smaller number of elements) in the formation in the vesicles the

structures and mechanisms that distinguish the first cells from its predecessors.

Possible following mechanism of this selection. Chiral element macromolecule (usually an asymmetric carbon atom is) influences the structure of the electron density of its atoms so that the dipole moment (multipole of first-order) molecule is oriented in the direction of its low electron density, i.e. the minimum of the cross-sectional of linear molecule. Such a molecule in the field membrane, directed inwardly of vesicle, too is orienting her dipole moment to inside, and encounters a little resistance to the her small cross-section. Whereas for the achiral molecule her dipole moment (if any) is not orientated oneself toward the low electron density, i.e. the minimum cross-sectional area of the molecule. And resistance to her movement in the field membrane is insurmountable.

For example, a chirally dextrorotatory D-glucose (as deployed in a linear conformation) has a dipole moment that faces to the carbonyl positive end with a minimum electron density i.e. with a minimum cross-section. While on her negative pole the group CH2OH oriented perpendicular to the axis of the molecule, ie, here her cross-section is maximized. But in membrane her field orients the "acute" end the glucose molecule inward vesicle. The resistance to her movement inward is minimum, and the membrane is permeable to such a molecule. In experiments with whole blood and erythrocytic mass, dilute by physical solution, previously[2] we have shown that D-glucose accumulates in the cytoplasm, and the larger, more the potential difference set at erythrocyte membranes.

Likewise occurred, apparently the filling of vesicle contents with compounds of defined chirality, i.e. selection of compounds by the type of symmetry.

6. APPEARANCE OF THE FIRST PROTOCELLS

We have shown above, in the period under review are ripe conditions for the emergence of the first cells. Their predecessors - "active" vesicles already possessed primitive genome and energy metabolism that can provide energy not only for replicate their data connections, but also for the reproduction of most of the compounds of their internal environment. In the selection process their resistance to aggressive environmental influences increased. A cyclic metabolism (archaic cycle) was forming, which ensure the achievement of their maximum capacity with help of the alternating interchange of energy-dependent processes. Herewith a leading backbone factor of innovation action in vesicles (other than energetics) became the acidity of their internal environment. With regard to the membrane vesicles, balance velocities of synthesis and degradation (expenditure) of their lipids observed only accidental and for a short time. Further was following inevitably the ruin of vesicle through the path to necrosis or apoptosis. This fact was accelerating the testing of individual vesicles on the stability at the initial stage of the cell world forming. It was rather helpful than harmful for the evolutionary transformations. However, with the growth of energy metabolism capacity, such mismatching of the velocities of synthesis and breakdown of lipids became brake for evolutionary development. Intensification of deposition of lipidic mass outside and inside the vesicles, including in the form of tubular structures, additional membranes and other structures that include lipids, was reducing significantly the probability of their ruin through the path to necrosis or apoptosis. To this also contributed the emergence of the depositing of energy-intensive substrate, which assimilated inside the vesicles, and was the most represented in the environment. Innovations largely decreased danger of a ruin of vesicles. In addition, some types of such structures of depositing became fulfil protective function. This also strengthens stability of vesicles to destructive influence of environment.

In the final stages of becoming of cellular world, such depots were ready to provide energy and materials for mitotic activity. However, the progressive movement of elements of the arising cells world towards the increasing complexity of their structures, and first of all information parts was starting significantly hindered. The fact that the intensification of the internal energetic metabolism (general line of development of living world) inevitably led to an increasing acidification of the internal environment of the vesicles. A situation shaped, similar to the one that was discussed above at competition for energy of two groups

[2]In 80-90th years these experiments were initiated and started by Andrei Agasievich Charakhch'yan (FIAN USSR).

of metabolism processes. At this time we are talking about competition for energy of replication processes increasingly complex information molecules and processes of reproduction of all other compounds involved in the metabolism [11]. Recall that this is the end result of interaction of open, and then internal metabolism of vesicles with viruses. Upon acidification of the medium compared with the waters of the archaic ocean the viral bodies lose affinity for information parts, freeing them for their replication and their reproduction at the expense of energy of external metabolism. The internal environment of the vesicles with a functioning energy metabolism was always been acidified. Therefore, at the initial stage of evolution constraints for reproduction genetic material within such vesicles was not. At the beginning, information molecules replicate by a relatively weak acidification of the internal environment, and then, at a significant acidification starts reproduction of connections of enzymatic base. Such a procedure has found its consolidation in the archaic cycle. However, as the evolutionary development of energy metabolism, which characterized by further intensification of oxidative processes, the increasing complexity of the genome and the growth of information pieces to be replicated, more rapid acidification of the internal environment prevented the completion of replication. In addition, the archaic cycle acidification-alkalinization increasingly shifted to the acidic side, exacerbating competition for energy in reproduction of connections between the genome and the pool of enzymes that were in the past a viral bodies. Separation of archaic cycle into the cycle metabolic activity and mitotic cycle has removed this difficulty. This became possible after the emergence of new means of regulating the activity of enzymes that serve the depot of the plastic and energy-intensive materials, and enzymes responsible for alkalinization of internal environment of vesicles. With the growth of depot and accumulation material therein, sufficient to allow the mitotic activity, using these new means was generated a signal, which provided, firstly, a rapid and deep (to neutral pH indicator values) alkalinization of internal environment of vesicles and secondly, the start of mobilization with subsequent utilization of the material depot. Herewith the system "reminisces" the traversed evolutionary path by reproducing its major milestones (Haeckel's law than not?), only in reverse order. Such a deep alkalinization of internal environment caused assembly of genetic material and former viral bodies into a single structure (later chromosome), as it was before after leaving of the reproduced parts of the virus from acidified zone external metabolism of vesicles into a neutral aqueous medium of archaic ocean. Further association of the said assembly with lipids of inner side of a membrane corresponds to a passed stage of the interaction of polynucleotides with lipid layers era "began of began" prior to the viruses with open metabolism of "active" hydrocarbon droplets. Naturally, the subsequent acidification of the internal environment of vesicles, associated with the beginning of recycling material depot, at first launched a replication of data connections, and then, with increasing acidity of the medium, the reproduction of other compounds involved in metabolism. Do not dwell on the analysis of the mass of errors associated with development in the processes of evolutionary transformation of specific mechanisms to regulate the speeds and depth of acidification of the internal environment. Note that exactly such mechanisms using acidification of medium as a key factor in their action, eventually, provided not only the completeness of the doubling of all the compounds involved in the internal metabolism, but division of vesicles into two parts with a full value metabolism, i.e. their transformation into the first cells.

Let us explain the last statement. With the gradual acidification of the medium changes the ability of compounds to associating with lipids. Some of them are accumulated on the inner surface of the membrane, while others can go into the aqueous environment. Changing the number of organics on lipids entails not only a change in internal energy of the membrane, but may accompanied and by changes in the shape of the vesicle. In the process of evolutionary selection were chosen corresponding compounds, synthesized in vesicles, and the mode of acidification of the internal environment, which provided the appearance of the constrictions and the collapse of dividing vesicles into two parts. In this way, in our opinion, formed from vesicles the first cells with anaerobic archaic metabolism, already capable, albeit with errors, reproduce oneself entirely. They gave rise to the development

of cells, which form in the cytoplasm the depot of energy-intensive material necessary for division. These first cells having only the rudiments of the cytoskeleton could not adequately withstand the aggressive action of the water element and were perishing. Their contents turned out to the common heritage of the emerging living world. However, the speed of their reproduction at abundance of energy-intensive and plastic material (transition of organic from the atmosphere into the aqueous medium is not over), eventually had higher the rate of their ruin. "First-burning" of cells was held, was launched development of anaerobes, and not with a single cell, which could perish along with the offspring, but in mass quantity, that eliminates accidental.

7. FINAL STAGE OF ABIOGENESIS

This stage is characterize not only by the further development of oxygen-free metabolism of first cells and "active" vesicles, but also and by new phenomenon - the emergence of photosynthesis. In the period under review the development of abiogenesis in the aquatic environment inside and outside the vesicles with developed metabolism there were complex compounds that can store energy (eg macroergs) and transmit it to other compounds. Among them were also sensitive to sunlight, able to garner the energy and use it directly for the synthesis, or transmit it to other compounds. The atmosphere became more and more transparent that was conducive to photosynthesis. Formation free energy sources through the use of sunlight is made possible at a certain stage of cooling the Earth's surface, including water mediums. Such processes proceeded as in open aqueous medium, and within the vesicles, so how organics transition from the atmosphere into the aqueous medium is not yet ended and was continued the isolation of material of aqueous medium in vesicles by capturing necessary compounds at the closure of the lipid membranes. The latter circumstance in the future became a defining moment in the transformation of such vesicles in predecessors of proplastids and themselves plastids, in which occur general processes of metabolism.

An most important consequence of the emergence and rapid accumulation of vesicles, in metabolism of which was dominated the photosynthetic processes by the synthesis from carbon dioxide the carbon-containing compounds, became yield oxygen. Only after its accumulation in the atmosphere in sufficient amount became possible forming the aerobic metabolism in first cells.

It is believed that this accumulation of oxygen in the atmosphere is determined by the activities of prokaryotes with their ability to photosynthesize. In our analysis of the first in this case were the evolutionary precursors of plastids - vesicles with metabolism based on photosynthesis, because, in our opinion, prokaryotes else did not exist, because their predecessors - the vesicles with an external depot of the power-consuming and plastic material else has not "learned" to share.

Further development (complication) of vesicles was going in two main directions: in interacting with world of viruses and in interacting with each other. In a symbiotic information interaction with complicated world of viruses arosed the structures which provide for vesicles, firstly, greater stability in the turbulent environment, and, secondly, formation of energy metabolism, based on the use free oxygen in the oxidation processes. Of course, it is impossible to achieve absolute stability, so they are after their ruin "shared" by their content with new vesicles, since the phase of organics isolation was not over yet. Furthermore, the vesicles may adhere to each other, combining their contents.

One of the important factors that determined the further development of the living world became the ability to capture other vesicles or even cells at the formation of large vesicles. Huge biomass of all living organisms of the planet Earth originated from carbon-containing compounds, and passed, in our opinion, the vesicular stage. Therefore, the surface layers of the archaic ocean were filled mostly with vesicles with such density that such a possibility has been provided and a very long time. A detailed analysis of the separation processes of the developing biological material allows us to trace the sequence of formation of all major branches of cells: animal, plant and fungi, as well as prokaryotes. As part of a short article it is impossible to elaborate on such material. We note only that this approach

finds its solution is also in the problem of initial accumulation of oxygen in the atmosphere as a consequence of long-term domination of vesicles with energetic metabolism on the base of photosynthesis. Grips at its birth by large vesicles of archaic cells with "active" vesicles and without them became the beginning of the formation of all types of cells. We emphasize that the specified "action" had the planetary scale, not as a separate act of "creation." Nature used the separation in time competing for energy and materials processes of formation of cellular structures (organelles) and the cells themselves of the above types. Precursors of mitochondria and nuclei (perhaps archaic cells) were formed and included in the structure of animal cells at a time when the oxygen pressure does not exceed 2 mm Hg. This is evidenced by homeostasis of the oxygen level in the cytoplasm of animal cells. In process of its grows in the aquatic environment, the predecessors of plastids have began gradually to displace predecessors mitochondria. Period from the beginning of this displacing to its completion - formation time of the fungal cells. At the final stage is setting a complete domination of predecessors plastid and are formed plant cells by the above scheme. Since the plastides and plant cells have been formed in the last turn, they included the achievements of previous stages of formation of the living world. On the one hand, the structural elements of precursors and the cells themselves and plants and fungi began more resistant to aggressive environment. Many elements and mechanisms of mitotic activity were "borrowed" from animal cells. On the other hand, they could not provide cytokinesis proper division of plant cells and fungal cells into two equivalent parts. Formation of the original fission mechanisms of these cells was carried out by the same principles of selection, that and of animal cells. With the accumulation in the depot of energy-intensive and plastic materials signal is forming for the start of its utilization, which is triggered by the achievement of a size sufficient to provision of energy of several cellular divisions. When reaching a certain level of acidification of the cytoplasm the material constriction or septum in prokaryotic cell and preprophase band and cell plate in the plant cells spontaneously is collected in these structures on the principle of minimum free energy of structure. The assembly of elements and material, as well as the order of percolation of processes during mitosis eventually became performed automatically, and the driving factor, as in the animal cell, became the cytoplasm acidification.

8. CONCLUSION

Formation of the complex and diverse mechanisms of cell activity and its reproduction began in an aqueous medium long before the appearance of the first cells in considered by us phase of abiogenesis in processes of interaction of the viral world with the world of lipid vesicles having initially anaerobic and, with the development, aerobic external and internal energetic metabolism. Leading link, a provider of new information, necessary for the evolutionary development of the living world were viruses. Short lifetime of vesicles due to the ongoing their birth inevitably was accompanied by the seizure with the water of the biological material that has provided a new flow of information as a necessary condition for the growth of populations of viruses and stability for the vesicles.

It is shown that the maximum possible power of groups metabolic processes competing for macroergs in vesicles was achieved thanks to the breeding of these groups in time. Means of this breeding becam the natural acidification of the internal environment by the synthesis macroergs, and the forcible her alkalinization by the their utilization for the needs of cell activity. Cyclical regimes of vesicles metabolism (and subsequently cells) were formed by selection of enzyme on activity of the catalysis of synthesis by higher values pH, than catalysis of utilisation macroergs. The essential role in the appearance of the cells played selection of compounds by the type of symmetry (chirality) which extremely narrow the range of compounds that can participate in the internal metabolism of vesicles. This, in turn, ensured a successful search by trial and error of the respective forms of the compounds and mechanisms in reserved time for the nascent cellular world from the beginning of the transition of organics from the atmosphere to the

surface of the planet and to completion of this transition.

At the initial stage of this period developed the anaerobic metabolism of vesicles. The logical conclusion of this development was the emergence of the first simplest anaerobic cells without chromosomes and nucleus (prokaryotes) that could reproduce itself.

Formation and development in some, else small part of vesicles and cells-anaerobes of the metabolism on the base of photosynthesis, provide gradual accumulation in the atmosphere of oxygen. This to ensure the formation and development in vesicles and first cells in addition to anaerobic energetic metabolism, that already existing, aerobic metabolism, which gave rise to the development of simplest (prokaryotic) cells aerobes.

One of the important factors that determined the development of the living world was the ability to capture by the formation of large vesicles other vesicles or even cells. To the moment of achievement in an atmosphere of oxygen partial pressure of 2 mm Hg, the captured "active" vesicles with preserved of the cyclicity of its aerobic metabolism gradually turned into the mitochondria, and cell-anaerobes - into the kernels, that can double their genetic material during mitosis than was launched start of the formation and evolutionary development of animal cells.

With further accumulation of oxygen in the aquatic environment has steadily increased the proportion of vesicles with the metabolism based on photosynthesis. Into such vesicles inevitably get elements of anaerobic and aerobic metabolisms. The isolation of these vesicles together with the vesicles-aerobic and anaerobic cells in the composition of a large vesicles gave rise to the formation and development of fungal cells. Captured vesicles transform into plastids and mitochondria, and cell - into nucleus.

Vesicles with complex metabolism comprising photosynthesis and utilisation of energy-intensive substrates by aerobic and anaerobic manner, in process of the accumulation of oxygen in the aqueous medium is practically superseded all other vesicles. Grips and the inclusion of such vesicles along with anaerobic cells as part of larger vesicles by the above given scheme, gave a start to the formation and development of plant cells. In these nascent cells there were no conditions for the formation of mitochondria, and the plastids were somewhat different from the plastid of fungal cell by versatility of their metabolism. So naturally turned out that many of the basic plant metabolic processes occur in plastids and in animals, these same processes are in the cytoplasm.

So ended the stage of abiogenesis - gradual complication inorganic substances before the biopolymers (nucleic acids, proteins, and others.), which are inherent in the basic properties of living things - metabolism, replication, flow homeostasis and selection of compounds on the type of symmetry, and the emergence of protocells - of descendants of hydrocarbonic aerosol of primary the atmosphere and of vesicles of the primary ocean.

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ELENA F. SHEKA

(TO 80 ANNIVERSARY OF BIRTH)

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November 20, 2014 marked the 80th anniversary of Elena Feodorovna Sheka, Doctor of Physical and Mathematical Sciences, Professor, Head of the Laboratory for Computational Nanotechnology of the Department of Theoretical Physics and Mechanics of the Peoples' Friendship University of Russia, a renowned expert in the field of experimental and computational spectroscopy of molecular crystals and quantum chemical modeling of nanoscale systems .

Elena F. was born in 1934 in Kiev, in the family of employees: Father Feodor Mikhailovich Dubovtsev - employee of the general service department of the Central Committee of the Communist Party of Ukraine, Valentina Emelyanovna mother - a housewife. Father went missing in the first months of the Great Patriotic War; Elena Feodorovna with her mother survived the occupation of Ukraine in the countryside and in 1945 returned to Kiev. After graduating the school number 65 with a gold medal in 1952, Elena F. entered the Physics Department of Shevchenko' Kiev State University. In the third year, EF Sheka is allocated to the chair of optics, headed at the time by Prof. A.A. Shishlovskiy. Here, under the guidance of Prof. Shishlovskiy she performs a diploma work devoted to the study of the luminescence of impurity centers in alkali halide crystals. After graduation in 1957, Elena Feodorovna is left on the chair, where she began her career as a laboratory assistant, then a senior laboratory one. In 1958 Elena F. enrolled in the graduate school of the Institute of Physics, Academy of Sciences of the UkrSSR, where, under the leadership of Acad. A.F. Prikhot'ko is engaged in low-temperature spectroscopy of molecular crystals. The results obtained were the basis of her PhD thesis "Exciton spectra of naphthalene crystal" that was defended in Moscow, at Lebedev' Physical Institute, Academy of Sciences of the USSR in 1962. She works at the Institute of Physics, Academy of Sciences of the Ukrainian SSR as junior researcher and then senior one until 1966. In 1966 Elena F. moved to Chernogolovka, Moscow region and hold the senior researcher position of the Institute of Solid State Physics, Academy of Sciences of the USSR. Here, in the Laboratory of Optics and Spectroscopy, led by her husband - the winner of the Lenin Prize, Prof. Vladimir L'vovich Broude – she continues to study exciton states of molecular crystals and starts a new research line - the study of phonon spectra of molecular and liquid crystals using inelastic scattering of thermal neutrons. In 1972, in Lebedev' Physical Institute, Academy of Sciences of the USSR she defended her doctoral thesis "Exciton spectra of molecular crystals." Soon Elena F. - head of the Laboratory of Optics and Spectroscopy of the Institute of Solid State Physics, Academy of Sciences of the USSR. At the same time she began teaching activities: Elena Fedorovna - associate professor since 1978 and full professor since 1985 at the Department of Solid State Physics, Faculty of General and Applied Physics, Moscow Institute of Physics and Technology in Dolgoprudny, Moscow region. Since 1986 to the present time Elena F. – full professor of the Department of General Physics, and then the Department of Theoretical Physics and Mechanics of the People's Friendship University of Russia, Moscow and the head of the Laboratory of Computational Nanotechnology. Under her leadership, nine PhD and one doctoral theses were defended.

Elena F. Sheka - author of over 300 scientific papers and four books on excitonics of molecular crystals, phonon spectra of molecular crystals (inelastic neutron scattering experiment and calculation), the electron-phonon interaction and vibronic spectra of molecular crystals, phase transitions in molecular

solids with liquid-crystal behavior (vibrational spectroscopy and neutron diffraction), vibrational spectroscopy of nanoparticles, quantum-chemical modeling of nanoscale systems, applied quantum chemistry and computational nanotechnology.

Among the most significant scientific results of Elena Feodorovna - the first direct evidence of Davydov' splitting of exciton absorption bands in molecular crystals (1961), the first direct calculation of the exciton bands of the anthracene crystal (1964), the first evidence of the Rashba effect (delocalization of the impurity states near the exciton band of crystal - 1961 in the absorption and 1984 in luminescence), the manifestation of two-particle vibronic states in the absorption spectra of molecular crystals (1966), the first direct measurement and calculation of dispersion and density of states of phonons of naphthalene and anthracene crystals (1978-1982); the discovery of metastable liquid crystalline phases in the solid molecular solids (1984), of technological polymorphism of silica nanoparticles (1992), and of the STM-tip stimulated graft oligomerization reaction on the surface of diamond-like films (1995); the prediction of magnetism of clean surfaces of silicon crystal (1997, confirmed experimentally in 1999) and of magnetic nature of the ground state of silicon fullerenes (2001); the development of parallel codes of quantum-chemical calculations for multiprocessor supercomputers as the basis of computational nanotechnology (2001); the revealing of peculiarities of the electronic structure of fullerenes (2004-2007) and carbon nanotubes (2007) caused by odd-electron nature of the systems; the classification of types of donor-acceptor complexes based on fullerenes (2004); the explanation of nanostructured magnetism of polymerized fullerenes (2005); the suggestion of a computational algorithm of fullerenes polyderivatives (2006) and chemically modified nanotubes (2007); the disclosure of the leading role of the donor-acceptor interaction in fullerene oligomerization (2007) and of clustering of fullerene molecules in dilute solutions as reasons for the amplification of spectral and nonlinear optical properties of solutions (2008); the explanation of the molecular nature of magnetism of nanostructured graphene (2009); the establishment of molecular theory graphene (2013); the development of the basic concepts of theoretical chemical physics of graphene.

A wide range of scientific contacts is inherent to the working style of Elena Feodorovna. Among the latter there are occasionally interrupted cooperation with the Frank Laboratory of Neutron Physics, JINR (Dubna) from 1976 to the present; cooperation with the Laue-Langevin Institute (France) in 1976-85; tight contacts with the Solid State Institute of the Central Physical Institute of Hungary in 1976-85 years, the contract with the Institute of Physical and Chemical Research (RIKEN) in Japan, 1997-99; the collaboration with the Technical University of Delft (1999-2001). Led by EF Sheka, the Laboratory of Computational Nanotechnology was a collective member of nanoscience projects of the European Research Foundation in 1999-2000 and NWO project with the Technical University of Delft (Netherlands), 1999-2001; the cooperation with the Institute of Problems of Chemical Physics, from 2004 to the present time; the cooperation with the Ioffe Physical-Technical Institute RAS (St. Petersburg).

E.F. Sheka is a member of the Russian Nanotechnology Society, the American Chemical Society, and the European Society of Computational Methods in Science and Industry. She is the regional representative of Russia in the International Society of Theoretical Chemical Physics. The results obtained have also received recognition in the form of numerous grants.

E.F. Sheka was awarded by the medal "Honored Worker of Higher Professional Education", diplomas of the People's Friendship University of Russia.

E.F. Sheka - member of the editorial boards of several international journals, including "Molecular Crystals and Liquid Crystals" (CRC Press; Taylor & Francis Group.) and "Journal of Nanoparticle Research" (Springer), co-editor of "International Journal of Nanomaterials, Nanotechnology and Nanomedicine "(Peertechz Publ.). She took part in the work of more than 250 national and international conferences. Elena F. is the soul and motor of Moscow Workshop "Graphene: Molecules and Crystals" regularly operated over two years under the guidance of Prof. S.P. Gubin.

High scientific erudition, a fantastic working capacity, integrity and responsibility brought to EF Sheka a deserved prestige and wide recognition of the scientific community.

Friends, colleagues and students sincerely congratulate Elena Feodorovna Sheka with a glorious jubilee and wish her good health, good luck and success in research and teaching.

Editorial Board of RENSIT of the Department of Problems of Radioelectronics, Nanoscale Physics and Information Technology RANS heartily joins these wishes to its good acquainted and always wished author.

Edition

ROSTISLAV V. BELYAEV

(TO 80 ANNIVERSARY OF BIRTH)

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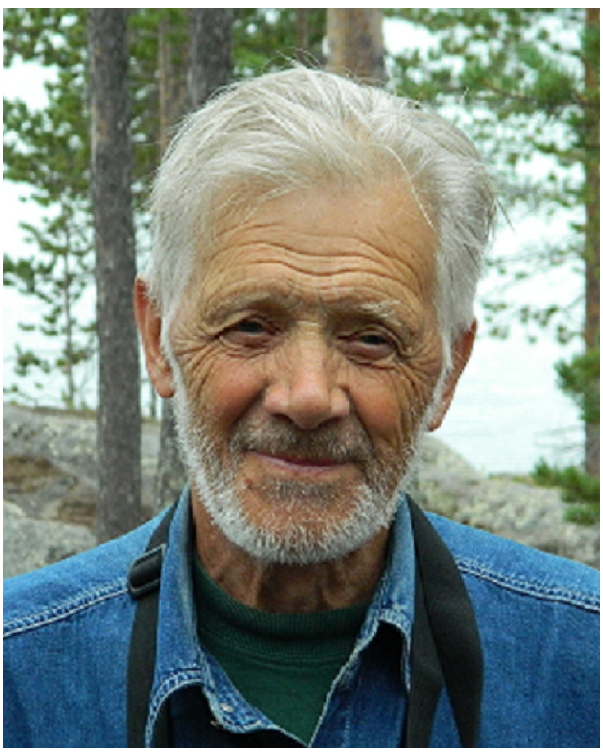

September 1, 2014 was 80 years old Rostislav Vladimirovich Belyaev, Candidate of Physical and Mathematical Sciences, Senior Researcher, Laboratory of Physical Foundations of nanocomposite materials for the Information Technology Division of the physical foundations of nanoelectronics VA Kotelnikov Institute of Radio Engineering and Electronics Russian Academy of Sciences, Corresponding Member of the Russian Academy of Natural Sciences, a renowned expert in the field of generation of microwave noise oscillations and processing of wideband signals based on dynamic chaos.

Rostislav Vladimirovich was born in 1934 in the city of Astrakhan. His father, VI Belyaev, a surgeon, graduated from Astrakhan Medical Institute. He died in 1939 at age 30 from an incurable disease. Paternal grandfather - IA Belyaev was born in 1885 in the Kaluga province, graduated in 1914, the Medical Faculty of the University of Emperor Nicholas in Saratov. Was called up for military service, was awarded the Order of St. Stanislaus 2 and 3rd degree, the Order of St. Anne 3rd degree. Since 1915, worked at the Department of Ophthalmology of the Imperial University of Nicholas, from 1923 to 1933. headed the Eye Clinic of Astrakhan Medical Institute at the rank of professor, from 1933 to 1944. headed the Department of Ophthalmology at Saratov State Medical Institute. Mom graduated from Astrakhan Medical Institute and worked all her life pediatrician. Her parents were military, but by her husband mother - entrepreneurs.

After graduating in 1952, high school, RV Belyaev enters the Moscow Institute of Physics and Technology in the 1st specialty - Electronics (faculties then MIPT not yet exist). In the process of learning takes place in the MIPT basic practice and training on leading electronics industry of the USSR Research Institute "Istok" Fryazino Moscow region. Thesis at the end of training devoted to the study of field emission properties of rare-earth elements, under the supervision of Ph.D. BS Kulvarskoy performs in the newly established in Moscow on the initiative of academician AI Berg Institute of Radio Engineering and Electronics, Academy of Sciences of the USSR (1953, in the building of the Faculty of Physics, Moscow State University, migrated to the Lenin Hills).

After graduation RV Belyaev in 1958 distributed in IRE USSR Academy of Sciences for the post of junior researcher, where the Department of Electronics, headed by Corresponding Member of the USSR Academy of Sciences DV Zernov, engaged in the development and study of electron-beam systems with flat beam for automatic coding signals. In 1971, during the reorganization of the structure of RV Belyaev transferred to the laboratory headed by VYa Kislov, and thus changes the direction of the work performed.

The main themes of future activities RV Belyaev associated with developing area generating chaotic oscillations with a level greater than the noise floor systems, that is due to the properties of nonlinearity and delay effects, implemented in particular in systems with feedback delay feedback:

- research and development in the field of microwave generation broadband noise oscillations in plasma;
- research and the creation of electron-wave microwave devices;
- research and creation of a noise signal generator of the microwave range on the basis of solid state semiconductor devices.

Further, due to the transition from analog to digital, RV Belyaev conducted research algorithms of pseudo-numeric (integer) sequences and their properties:

- development of digital broadband information technologies based on dynamic chaos for processing, transmission, storage and protection of information;
- development and application of research methods of fractal analysis of complex wideband signals.

The thesis is an RV Belyaev the title of Ph.D., completed in 1986, is devoted to the study of excitation noise oscillations in generators on the avalanche-transit diodes (ATDG). It is known that these oscillators are excited into oscillation, which together with the spectrum of the harmonic components comprises a continuous component with a level exceeding the feedback fluctuations of the avalanche current. In some cases, increasing operating current ATDG leads to the excitation of noise fluctuations without isolation of the harmonic components. Studies on simple models of self-oscillating systems such as the Van der Pol has shown that under certain conditions, even in such systems can be implemented modes of the complex nature of the oscillations. In order to identify the nature of the excitation of anomalous noise regulations in ATDG experimentally investigated such generators on simple systems that allow a controlled excite one-, two- and three-mode oscillation. It is shown that in these systems when the current ATDG modes implemented with the spectra vary according to the complexity of sequential scenarios generated oscillations typical for a large class of dynamical systems studied simple models. These results demonstrate the dynamic nature of the excitation of abnormal noise oscillations in such generators, although fluctuations of the avalanche current in such generators will undoubtedly affect the level of their appearance, but they are not the direct cause of the chaos, it is - in the complex dynamics of the diode-oscillating circuit. These results have practical application in the creation of practical systems generating wideband noise signals ATDG based on a power level comparable to the level of the oscillation generating ordered.

RV Belyaev, together with Institute staff developed, implemented and studied in the form of digital circuits forming algorithms broadband noise signal, which have found practical application in real-world applications.

Together with other members of the Institute, he repeatedly took part in field work and trials in various parts of the country from Kamchatka to Astrakhan, from Voronezh to Sevastopol.

Since 1958 to the present time Rostislav Belyaev - employee IRE RAS, from 1971 to 1986. - Junior Researcher, from 1989 to present - Senior Researcher, from 2007 to 2010. Acting Head of laboratory.

The scientific results RV Belyaev published in 65 articles in various journals and presented at 42 national and international conferences. Has 4 inventor's certificates.

RV Belyaev - conferee of several international and national conferences, schools systems with chaotic oscillations. Is responsible executor of the decree of the government, as well as on numerous grants RFBR and ISTC. Rostislav Vladimirovich - member Russian Scientific and Technical Society of Popov Radio Engineering, Electronics and Communication since its inception in 1991, corresponding member of the Russian Academy of Natural Sciences (2001) in the Department of Radio Electronics problems, nanoscale physics and information technology.

RV Belyaev since 2009 - Executive Secretary of scientific journal "RadioElectronics. Nanosystems. Information Technology "(RENSIT).

In 1997 he was awarded the honorary title of Veteran of Labor; he was awarded the medal "In commemoration of the 850th anniversary of Moscow", the badge "Honorary Radio Operator" the Ministry of Radio of Russian Federation.

Rostislav Vladimirovich - a tireless traveler and experienced water tourists, traveled the country and outcome of Far North - Kola Peninsula, Ural Mountains, Putoran, Kamchatka, tributaries of Pechora, Ob, Yenisei (Lower and Stony Tunguska), Lena, to the South - Lake Baikal, Issyk Kul, Tuva - the origins of the Yenisei region near border with Mongolia. Herewith he is actively promoting this lifestyle among employees, pulling them into their dizzying projects.

Life Rostislav Vladimirovich - a living history IRE, he - where need heavier laborious work, creating soil in which grew all important results of collective. Its reliability, natural intelligence, politeness, courtesy, responsiveness, high scientific erudition, amazing performance, devotion to work, integrity and responsibility - priceless gift to the his collaborators.

Friends, colleagues and students sincerely congratulate Rostislav Vladimirovich BELYAEV with a glorious jubilee and wish him good health, good luck and success in scientific activities for the benefit of laboratory and the Institute!

Editorial Board of RENSIT of Department problems Radioelectronics, Nanoscale Physics and Information Technology RANS heartily joins these wishes.

Edition

GRAFENIKA [GRAPHENICS] RUSSIAN GUBIN'S SEMINAR (MOSCOW)

Elena Yu. Buslaeva

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Russian Seminar "GRAPHENE: MOLECULE AND CRYSTAL (material, physics, chemistry, electronics, photonics, biomedical applications)" under the direction of prof. SP Gubin operates from November 2011. Seminar sessions are held once a month, mainly in the boardroom VNIIAlmaz in Gilyarovskogo str., 65 (metro station "Rizhskaya"). The seminar is supported by LLC "AkKoLab" and the VNIIAlmaz. Programms of seminars are available at http://www.akkolab.ru.

The seminar organizers see it as a discussion platform to discuss new ideas and concepts, review the results and the exchange of experience of researchers in the booming grafenika - an interdisciplinary field of modern science. Anticipated publication of an annual compendium of seminar materials, creating Programs of research in this area with possible access to financing. The seminar was attended by officials from various scientific institutions of Moscow - Kurnakov Institute of General and Inorganic Chemistry RAS, Nesmeyanov Institute of Organoelement Compounds of RAS, Semenov Institute of Chemical Physics RAS, Kotel'nikov Institute of Radio Engineering and Electronics RAS, National Research Centre "Kurchatov Institute", Moscow State University Department of Chemistry, Moscow Institute of Physics and Technology, National Research Nuclear University "MEPhI", People's Friendship University of Russia, LLC "AkKoLab", Open Joint Stock Company (JSC) "VNII ALMAZ", LLC "Karbonlayt", JSC NIIgrafit and others, as well as invited members of scientific institutions in Russia, Commonwealth of Independent States (CIS) and foreign countries. The audience for each session - about fifty participants. In the four- hour meeting with a break heard and discussed the 3-4 reports, news review and submitted poster presentations.

The journal RENSIT is published semi-annual reports of this seminar: list of reports indicating affiliated authors and submitted abstracts.

Keywords: nanometer level combined probe and optical techniques, graphite oxide, thermal decomposition, gaseous products, carbon chains, ballistic electron transport, spin-orbit coupling, resistive switching, tin and antimony sulfides, reduced graphene oxide, sodium-ion batteries

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NINETEENTH SEMINAR, 09.10.2014

1. **Golberg DV** (DrSci Phys&Math, prof., NIMS (Japan), MIS&S).

Studies of graphene at the nanometer level combined probe and optical techniques.

2. **Kryazhev YuG** (DrSci Chem, prof), Trenikhin MV, Likholobov VA (DrSci Chem, prof, Member-corr RAS, IHCP RAS).

The composition of the gaseous products of thermal decomposition of the graphite oxide. Due to the structure.

TWENTEENTH SEMINAR, 27.11.14

1. **D'yachkov PN** (Dr Sci.Chem), Zaluev VA (Kurnakov IGIC RAS)

Simulation of ballistic electron transport and spin-orbit coupling in carbon chains.

2. **Kapitonova OO** (Grad. student, Lomonosov MSU, Chem Faculti).

Formation of nanostructures based on graphene oxide with resistive switching.

TWENTY-FIRST SEMINAR, 25.12.2014

1. **Prikhodchenko PV** (Dr Sci Chem., Kurnakov IGIC RAS).

Composite materials based on tin and antimony sulfides and reduced graphene oxide - promising anode materials for sodium-ion batteries.

2. **Gubin SP** (Dr Sci Chem., Kurnakov IGIC RAS).

Summing up "graphene" year: achievements, programs, projects, conferences etc.

EUROPEAN PROGRAMME ON GRAPHENE

Sergey P. Gubin, Elena Yu. Buslaeva

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Abstract. **Journal of Carbon (2015, 85: 450-451) announced the publication of a special issue about of researches funded by the European Science Foundation program EuroGRAPHENE (2010-2013), as well as the ten-year program GRAPHENE-FLAGSHIP 2013. By the publishing of this material, Editorial RENSIT hopes to attract the attention of Russian research groups to the program the GRAPHENE-FLAGSHIP with the prospect of integration into its work. Editorial looks forward to discussing this issue in the upcoming September this year the first Russian conference on graphene in Novosibirsk.**

Keywords: **graphene, 2D-materials, nanoribbons and nanodots, fundamental properties, applied researches, electronic devices based on graphene, the European Science Foundation, Eurografen program and Graphene Flagship, integration**

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Ten years ago, a revolution began that has taken the solid state physics and materials science communities by storm: the discovery of how to prepare and process graphene, the first of a large family of monoatomic, 2-dimensional materials. This discovery, and the subsequent analysis of this material led to amazing discoveries at a fundamental level, such as the presence of massless charge carriers in graphene, whose behavior is governed by quantum electrodynamics. Geim and Novoselov were awarded the Nobel Prize in Physics 2010 for these discoveries in a material that is "all surface and no bulk". The unusual physical properties of this material – strength, high carrier mobility, etc. – have also raised hopes that a new era in materials science applications has dawned, in electronic devices in particular, but also in other fields. Ten years and tens of thousands of publications later, the struggle to fully understand graphene's physical properties either as a free-standing entity or in contact with other materials, and the race to potential applications shows no sign of slowing down. Moreover, the prospect of combining graphene with other truly 2D materials such as hexagonal boron nitride or single/multilayers of transition metal chalcogenides offers the prospect of creating a new class of 2-dimensional composite structures that may bring new functionalities in electronic data processing and storage devices, to name only one possible application.

Graphene's properties were first discovered in Europe, by Geim and Novoselov at the University of Manchester. Immediately afterwards, research on graphene flourished worldwide and many countries, such as South Korea or Singapore, rapidly established strong research activities in this field, both in academic and industrial labs, launching ambitious research programs on graphene. In Europe, one of the first coordinated efforts on graphene was initiated by the European Science Foundation, which in 2009 launched the EuroGRAPHENE program.

EuroGRAPHENE was conceived in mid-2008 as the first multinational European initiative to study various aspects of graphene from a fundamental as well as applications-oriented point of view, and started operation at the end of 2010. Within seven collaborative research projects, 43 principal investigators and associated partners, EuroGRAPHENE addressed graphene-related issues, from graphene-organic transistors and optoelectronic devices through graphene– ferromagnetic junctions to spin-entangled states in hybrid graphene systems. Work within these projects was funded by the national research funding agencies from 2010 through 2014, and the contents of the EuroGRAPHENE program across national and institutional boundaries was discussed at several large meetings and numerous small workshops. Intense collaborations have emerged from the EuroGRAPHENE program and continue to be active beyond its conclusion.

This special issue of CARBON contains scientific papers resulting from work within EuroGRAPHENE's projects. This is only a small selection among the many publications that have emerged and are still in the process of being submitted from those projects; moreover, in line with the main audience of CARBON, many papers in this volume deal with specific aspects of graphene research, e.g. the preparation and processing of different kinds of graphene. The ensemble of these

articles reflects the enormous variety of scientific fields where graphene can play a role, from physics to chemistry, surface science, nanotechnology and more.

Among the topics covered in this volume, silicon carbide as the singly most important substrate for high quality epitaxial growth plays a major role. Apart from the ubiquitous growth on the hexagonal silicon-terminated SiC(0001) surface, the growth of single and bilayer graphene has been performed on nonpolar surfaces of hexagonal SiC as well as on the polar cubic (100) surface. Intercalation of gases (e.g. hydrogen) and metals has been a very active subfield of graphene research, and a few representative studies appear in this volume. Interest has also concentrated on precursors to graphene preparation, such as graphene oxide and its photo-induced or electrochemical reduction. The improvement of organic and inorganic composites using graphene oxide, as example to improve battery storage capacity or photochemical water-splitting are other examples in this volume, investigated from an applications-oriented viewpoint. The property of graphene nanoribbons is another exciting topic in graphene research, since these are thought to be the solution to one of graphene's basic problems in electronic switching applications – the absence of a sizeable fundamental band gap.

Overall, these papers highlight one of the most exiting features of graphene research, i.e. the strong intermixing of fundamental science and enormous technological interest. Graphene nanoribbons and nanodots, for example, are an ideal playground to study the optical and electronic properties of graphene using theory and modelling; on the other side, they can give a key to the highly desired production of graphene-based transistors. Graphene growth on SiC is a fascinating problem of surface science on one side; on the other, achieving a complete control of this physical process would allow to obtain graphene of the highest quality on non-conductive substrates.

This dual interest is present also if we focus on graphene chemistry. Graphene oxide (GO) is a "strange" chemical object, whose exact structure is still far from being completely understood, and controlled. Once an underdog in the graphene community, it is now the most processable and tunable among the 2D materials, and is used to produce highly performing sensors, batteries or composites, as some papers of this issue demonstrate.

The EuroGRAPHENE program ended in 2013, and was rated as "highly successful" by an external review panel of experts. Citing their words:

"EuroGRAPHENE has created and helped in shaping a closely collaborating community of researchers in graphene science and technology in Europe. This community has grown about ten times since the start of the program. Projects benefitted from the complimentary expertise of partners in different countries and from interactions between theory and experiments. Overall, the total number of publications, around 300, is impressive."

However, in our opinion, the most important result of EuroGRAPHENE initiative was not only the large number of publications (including nine patents) obtained. The program has served as a model for a larger collaboration encompassing many European nations. A main criticism raised was the relative short time-span of the program funding – only 3 years. In 2013, after a tough selection process, the European commission decided to launch another project on graphene, the "GRAPHENE Flagship" (http://graphene-flagship.eu/) – much more ambitious, larger and longer than anything ever tried before. This cooperation involves about 140 research groups throughout Europe, is planned to last for ten years, and dedicated to transforming the scientific revolution of graphene into real, useful technology. The EuroGRAPHENE program initiated by the European Science Foundation can be rightfully seen as the forerunner to the GRAPHENE Flagship, having demonstrated by the feasibility of such a cooperation that, even under stiff international competition, European research can be at the forefront in the field, developing new ways to grow and process this fascinating material, and use it in different applications fields.

With this special issue, we want to give a glimpse of what EuroGRAPHENE participants have worked and continue to work on, and a panoramic view of the research lines generated from that first, seminal European research project on graphene.

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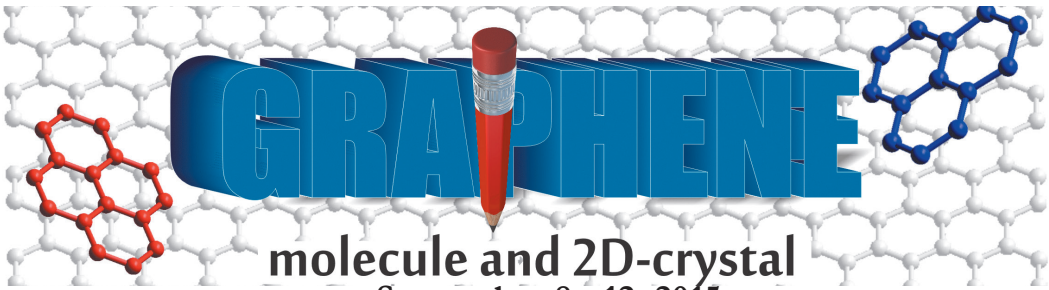
First Russian Conference



September 8 - 12, 2015
Russian Federation, 630090 Novosibirsk
http://niic.nsc.ru/conferences/graphene

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GM2dC'2015 - brand of the new Russian conference "Graphene – a molecule and 2D-crystal", the first conference in Russia devoted to the results and prospects of research on graphene and related materials. Conference is purposely interdisciplinary, as the problem itself. One of the conference objectives is to develop a common language (terminology) in the discussion of the unique properties of graphene for professionals from various fields of science, a single view of the prospects in this direction.

Conference language is Russian

GMC SUGGESTED TOPICS

- Graphene - the composition, structure, plies, types of defects
- Identification and characterization of graphene samples on different origin (CR, XRD, AFM, TEM, SEM); metrology
- Methods of prepapration and perspectives of graphene production
- The physical properties of graphene: conductivity, thermal conductivity etc.
- Physics of graphene: electronic structure, quantum electrodynamics, plasmonics etc.
- Electronic devices and devices based on graphene, carbon nanoelectronics
- Chemistry of graphene: hydrogenation, fluorination, oxidation, functionalization
- Graphene oxide - structure, properties, chemistry
- Electrochemistry of graphene, supercapacitors and Li-ion batteries
- Graphene and catalysis
- Graphene in biomedical researches
- Graphene in the enviroment; ecology; toxicity
- Oder 2D-objects, electronic structure, physical properties; sandwiches

IMPORTANT DATES

Registration and abstract submission deadline	**May**	**01, 2015**
Acceptance notification	**May**	**30, 2015**
Payment of registration fee deadline	**Juli**	**15, 2015**
Conference program	**August**	**20, 2015**
Full paper submission in journal RENSIT	**September**	**08, 2015**

VENUE

House of Scientists, Academgorodok, Novosibirsk.

ACCOMMODATION OF PARTICIPANTS

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