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Photocurrent Domain Instability In High-Resistance Tunnel CdZnTe-Based Mis Structures

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Abstract. **The results of experimental studies of the photocurrent domain instability arising under illumination in high-resistance tunnel MTISTIM structures based on CdZnTe single crystals are presented. It is shown that the photocurrent domain instability is based on drift nonlinearity, i.e., the photostimulated spatial rearrangement of the electric field. It was found that, as in the classical Gunn diodes, the appearance of microwave oscillations of the photocurrent occurs at threshold values of external macro parameters, the change of which within certain limits provides a reversible change in the frequency of the oscillations up to 8 octaves. The results of experimental studies of the velocity–field dependence in CdZnTe, measured under spatially inhomogeneous distribution of the electric field in the volume of the MTISTIM structure, are presented. The threshold field of the oscillation occurrence and the maximum velocity of the majority carriers in CdZnTe single crystals are determined. Numerical estimates of the minimum irradiation power and carrier concentration necessary for the appearance of the photocurrent domain in the high-resistance MTISTIM structure of CdZnTe are presented. It is shown that due to the transverse electro-optical Pockels effect, the change in the domain field of the electro-optical characteristics of the semiconductor component of the diode allows the transfer of optical information from the controlling light flux $I_1(x,t)$ to the probe light flux $I_2(x, t)$, transmitted through the structure, i.e., to carry out high-frequency optical modulation of one light flux by another.**

Keywords: **photocurrent domain instability, photocurrent oscillations, threshold field, high-resistance tun-nel MTISTIM structure, photoelectric domain, electric current distribution**.

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Contents

1. INTRODUCTION

Recently, the studies related to the development of optically controlled active elements, based on which it is possible to create devices that provide the basic types of optical signal processing (modulation, switching, angular deviation, etc.) in the nanosecond and picosecond time scale have become particularly relevant [1-3].

One of the effects that can provide fast and "strong" changes in the electro-optical characteristics of the medium is the Gunn effect, which is based on the intervalley transfer of carriers. Theoretical estimates show that the time of intervalley transfer leading to the formation of strong field domains is $\sim 10^{-14}$ s, which potentially makes it possible to obtain changes in the electro-optical characteristics of the medium with characteristic times of $\sim 10^{-12}$–10^{-14} s [2,4].

The study of the light exposure effect on the parameters of Gunn diodes began almost

immediately with studies of the Gunn effect itself. The experimental results showed that illumination of planar di-odes leads to the control of the oscillation threshold field, the spectrum and intensity of the oscillations, the improvement of coherence, the change in the oscillation frequency, etc. In diodes based on high-resistance compensated single crystals of Ge(Au) GaAs(Cr), ZnTe-CdTe, the current-voltage characteristic (CVC) under illumination becomes N-shaped, and the formation of a section with negative differential photoconductivity (NDPC) on the CVC is accompanied by the appearance of low-frequency oscillations of photocurrent [5,6].

Later on, it was shown [7] that, depending on the backlight intensity, temperature, and other factors, one or another recombination nonlinearity is realized in such diodes, in which the transfer rate of the formed domains is limited by the time of carrier redistribution between the conduction band and the capture levels.

When studying the photoelectric properties of homogeneous high-resistance MTISTIM structures, where M is optically transparent metal electrodes, TI is tunnelthin insulator layers, S is a high-resistance semiconductor, it was found that the change in conductivity that occurs in such structures under illumination is accompanied by spatial changes in the distribution of electrical field $E(x)$ from uniform in the dark to sharply inhomogeneous under illumination. These changes are practically "inertialess" following the change in intensity. As a result, during illumination, the region of the "strong" electric field is spatially localized at the electrode opposite to the illuminated one, and the restoration of the initial dark field E_0 ($E_0 = V_0/L$) created by an external voltage source in the volume of the structure, after the termination of illumination occurs spontaneously during the drain of photoinduced charge to the external circuit [8].

Further studies of the redistribution of electric fields in high-resistance tunnel MTISTIM structures based on compensated and "pure" p-CdTe(Cl) single crystals with a concentration of deep impurity levels $N_t > 10^{15}$ cm^{-3} and shallow impurity levels $N \sim 10^{12}$-10^{13} cm^{-3}, respectively, and n-CdTe(In) single crystals with $N_t \sim 10^{16}$ cm^{-3} have shown that the difference in electric fields formed during the illumination between the non-illuminated and illuminated electrodes in a number of structures can be significant [9]. Accordingly, it was to be expected that under the conditions of high applied voltages V_0 and high illumination intensities, an NDPC region could appear on the CVC of such structures.

The purpose of the work reported here was an experimental study of the excitation conditions for illumination of the Gunn oscillations of the photocurrent in high-resistance tunnel MTISTIM structures of CdZnTe.

2. MATERIALS AND METHODS

We investigated a batch of samples of homogeneous high-resistance tunnel MTISTIM structures based on undoped $Cd_{1-x}Zn_xTe$ ($x = 0.04$) single crystals with a concentration of deep impurity levels $N_t < 10^{13}$ cm^{-3}, resistivity $\varrho > 5 \cdot 10^8$ ohm×cm and the equilibrium bulk concentration of carriers $n_0 \sim 10^6$–10^8 cm^{-3}. The purity of the initial components Cd and ZnTe was no worse than $6N^{++}$. The prepared samples were rectangular parallelepipeds with different distances between the contacts L and the area of the illuminated surface S ~0.1−0.12 cm^2. Metallic Au or PT contacts were chemically deposited on opposite faces of single crystals containing tunnelthin oxide layers. According to ellipsometric measurements, the average thickness of the tunneling oxide layer d_{Ox} was ~10−15 nm.

The samples were illuminated from the side of the negative electrode by pump light pulses with quantum energies $h\nu \geq E_g$, where hν is the quantum energy, E_g is the band gap. The duration, amplitude and frequency of illuminating pulses of various shapes was regulated using an electronic power circuit. Samples were placed between optically transparent electrodes in a stage series-connected in the gap of the center core of the coaxial line. The photocurrent pulses and photocurrent oscillations generated at different powers of the illuminating pulses P_0 and the constant applied voltage V_0 were taken from the load resistance $R_l = 50$ ohm, connected in series with the sample, applied to the input of the oscilloscope and photographed. Based on the obtained images, the parameters of the oscillations were subsequently evaluated. The spatio-temporal characteristics of the electro-optical response generated in the sample under illumination were estimated using the characteristics of optical pulses recorded at the

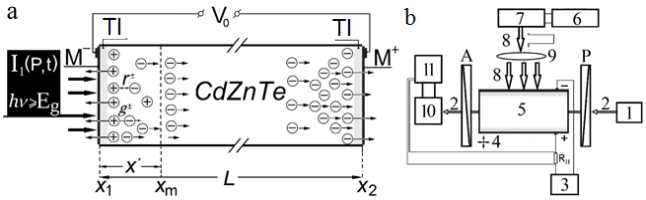

Fig. 1. *a – schematic diagram of the tunnel MTISTIM CdZnTe structure; b – schematic diagram of the experimental setup: 1 - power supply and source of probe light I_2, P - input polarizer, 2 - collimated beam of probe light I2, 3 - high voltage generator; 4 - micropositioner system, 5 - sample, 6 - electric pulse generator, 7 - electronic circuit of the pump light source, 7 - pulses of pump (controlling) light I_1, 9 - micro lens, A - analyzer, 10 - unit for recording optical pulses of probe light , 11 - oscilloscope.*

output of the sample, when it was probed by a narrow beam of non-photoactive light. A diagram of the MTISTIM structure and experimental setup is shown in **Fig. 1**a,b.

3. EXPERIMENTAL RESULTS

The band gap of the studied samples was determined experimentally from the optical absorption curves. According to measurements of several samples at room temperature, the band gap E_g was ~1.52±0.5 eV, and the absorption coefficient was α ~230÷250 cm^{-1}, which agrees well with Ref. [10]. The spectral distribution of photoconductivity obtained using selective spectral filters when the samples are illuminated with the same light fluxes (P ~1 mW) in the spectral range of ~640–1300 nm at a field strength of E_0 ~1.5 kV/cm is shown in **Fig. 2**. It

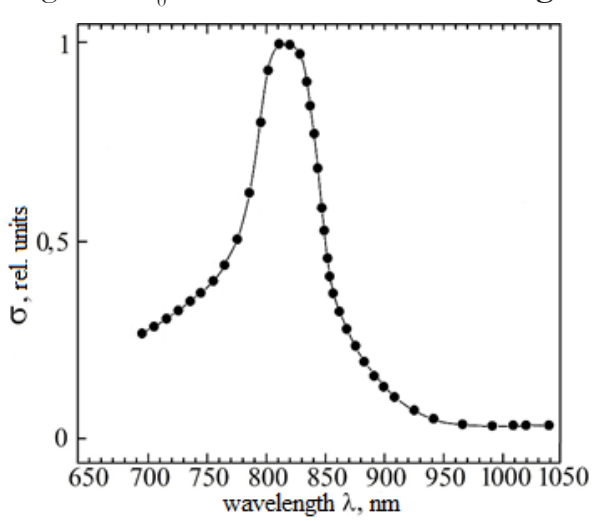

Fig. 2. *Spectral distribution of the photocurrent at the magnitude of the field E_0 = 1.5 kV/cm; T = 300 K.*

is seen that the photocurrent is maximal when the pump light has a wavelength of λ ~0.81÷0.82 μm and decreases sharply when the pump light is shifted to either the short-wavelength or long-wavelength part of the spectrum.

In the initial section, the dark CVCs of the samples are close to linear; up to fields E_0 ~3÷8 kV/cm, a section with a vertical increase in the dark current characterizing the transition from linear to quadratic dependence is not observed. In most samples, in the voltage range V_0 = 0÷800 *V*, the dark current increases by two to three orders of magnitude and does not exceed ~0.6-0.7 μA. At high bias voltages V_0, breakdown of samples occurs at fields E_0 ~13÷15 kV/cm, regardless of the polarity of the applied voltage.

At E_0 > 1÷2 kV/cm and low illumination intensities, the photocurrent increases linearly until saturation. With increasing illumination intensity, a deviation from linearity is observed, and at high illumination intensities, the CVC of the samples has a sublinear form, i.e., in the studied range of applied voltages, there is no carrier injection from the contacts.

Under illumination by light with a power of P_0 ~5–15 mW, a photocurrent appears in the samples, exceeding the dark one by approximately 3–4 orders of magnitude. At a field strength E_0 ~7–9 kV/cm and photocurrents exceeding ~3–10 mA, the CVCs of a number of samples show a spontaneous appearance of an *N*-type NDPC region, the formation of which leads to the formation of δ-shaped or triangular photocurrent oscillations that continue only during the light exposure. In long samples with *L* ~0.15–0.2 cm, with an increase in the illuminating pulse power P_0, the threshold field for the oscillation E_p significantly decreases and increases with a decrease in *L*.

The spectral range of illumination, in which the appearance of oscillations is observed in the samples, is close to the spectral distribution of the photocurrent. However, with the spectral shift of the illumination from the spectral region of intrinsic absorption to the short-wavelength region ($h\nu > E_g$) and especially to the long-wavelength region ($h\nu < E_g$), photocurrent oscillations occur at ever higher values of the external macroscopic parameters, i.e.,

the bias voltage V_0 and illumination power P_0. The occurrence of oscillations ceases when illuminated with light quanta with $\lambda > 0.88–0.9$ μm. In addition, a change in the shape, amplitude, frequency and coherence of the excited oscillations is observed during the spectral shift of the pump illumination.

A study of the kinetics of transients at different relations between the values of external macro parameters and different polarity of the applied voltage showed that:

- the time of photocurrent stabilization depends on the polarity of the applied voltage and is minimal at a positive potential on an non-illuminated electrode;
- in the presence of a natural oxide layer, the regime of the through photocurrent stabilizes at bias volt-ages V_0 ~1.5–3 V which increases with increasing thickness of the tunneling dielectric layer d_{Ox};
- a jump in the photocurrent at the leading edge of the photoresponse, preceding the establishment of a stationary photocurrent, is observed in most samples at low illumination powers ($P_0 \leq 1$ mW) and fields E_0 not exceeding 1.5–2 kV/cm, and the amplitude of the photocurrent jump rapidly decreases with increasing applied voltage;
- at the sub-threshold values of macroparameters, long-term relaxation and spikes of the photocurrent when the illumination is turned on and off are not observed in most samples;
- at any polarity of the applied voltage, an increase in the bias voltage and the power of the illuminating pulse leads to a decrease in the time of flight of carriers and the duration of the leading and trailing edges of the photocurrent pulse, and when the macro parameters are close to the threshold, the shape and time constant of the photo and electro-optical responses approach the duration and shape of the illuminating pulse;
- the NDPC segment appears at a certain power of the optical pulse P_p, below which the generation does not occur at any bias voltage.

Depending on the initial power of the illuminating pulse, two scenarios of initiating oscillation are observed. The first of them is realized at a small excess $P_0 \approx P_p$. In this case, the emergence of the domain is preceded by the formation in the near-contact region of the non-illuminated electrode or on the constant component of the photocurrent pulse of the photocurrent fluctuation, which is preserved while maintaining the macro parameters. Its transformation into a δ-shaped or triangular domain with a domain amplitude close to the amplitude of the photocurrent pulse occurs spontaneously when either of the macro parameters (or both at once) increases by a certain value ΔP or ΔV, which increase with a decrease in L. After the formation of a single domain, further increase in any of the macroparameters with a step ΔP or ΔV (provided that the other macroparameter retains its threshold value) leads to a sequential increase in the number of photocurrent oscillations, generated within the photocurrent pulse. The stabilization of the amplitude and shape of the photocurrent oscillations occurs after the formation of the second domain (**Fig. 3***a*).

The second scenario is realized when $P_0 > P_p$. In this case, the oscillation occurs spontaneously, and the frequency of photocurrent oscillations is determined by the power of the optical pulse (Fig. 3*d*). In this case, regardless of the scenario of oscillation occurrence, the maximum frequency of the oscillations is achieved at certain values $V_0 = V_{max}$ or $P_0 = P_{max}$, which differ from sample to sample. Then the oscillation frequency stabilizes and

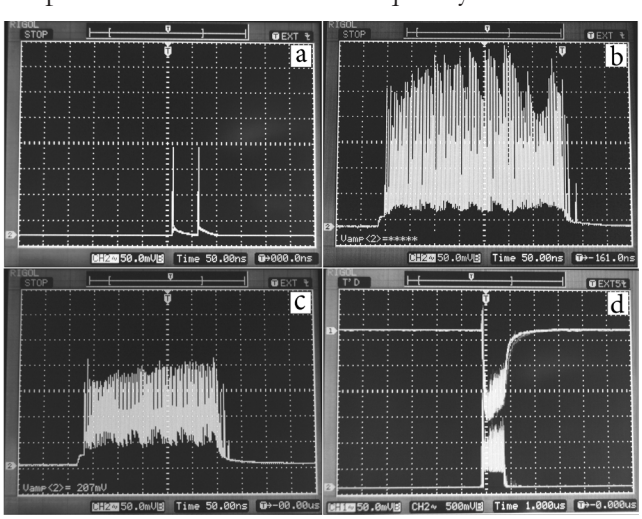

Fig. 3. *Oscillograms of photocurrent pulses generated at various values of external macroparameters: a – $P_0 \geq P_p$, $V_0 = V_p$; b – $P_0 \sim P_{max}$, $V_0 = V_p$; c - $P_0 \sim P_p$, $V_0 = V_{max}$; d - $P_0 >> P_p$, $V_0 \sim V_p$ where the upper trace is the optical pulses of the probe light, the lower trace is the fluctuation of the photocurrent. T = 300 K.*

remains constant, and a further significant increase in any of the macroparameters leads to breakdown of oscillation or to breakdown of the sample.

Accordingly, a decrease in any of the macroparameters in the range from V_{max} or P_{max} to their threshold values is accompanied by a decrease in the frequency of the oscillations and restoration of their shape. When fixing the values of the macroparameters in any interval of their increase or decrease, the oscillation frequency is stably preserved and is determined by the current values of the macroparameters. Changes in the generation frequency with a change in the optical pump pulse power and bias voltage are shown in Fig. 3*b,c*.

In the general case, the frequency of the oscillations is inversely proportional to the distance L between the contacts and weakly depends on the variable macroparameter and the excitation mode, although in some samples the maximum frequency may slightly vary. In most samples with L ~1.5–2 mm, when any of the macroparameters changes in the range of $V_p \div V_{max}$ or $P_p \div P_{max}$, the oscillation frequency changes in the range of 6–8 octaves. With decreasing L, the width of the oscillation band decreases and in samples with L ~100–300 μm does not exceed 2–3 octaves.

The experiments showed that in addition to changing the frequency characteristics, the growth of external macro parameters has a complex effect on the parameters of the oscillations. In particular, one of the manifestations of such an effect is associated with the shape and amplitude of the excited oscillations. Thus, in the majority of the samples studied, the amplitude and period of the formed oscillations successively decrease with the growth of any of the macroparameters, and their shape is successively transformed from δ-shaped to close to triangular or sinusoidal. However, a different situation is realized in a number of samples: with the growth of any macroparameter, up to P_{max} or V_{max}, the δ-shape and amplitude of the oscillations are preserved. In some samples, the formation of oscillations with a nanosecond and shorter leading edge length and domain amplitude close to the amplitude of the photocurrent pulse or exceeding it is observed. In addition, at high optical pump pulse powers, the formation of single "quasistatic" domains with the amplitude not exceeding 0.2 A is observed.

At the same time, although a somewhat lower generation frequency is achieved in some samples with P_{max} or V_{max}, nonetheless, samples in which the initial oscillation parameters are preserved are of significant applied interest, since oscillations of this form provide high-efficiency optical modulation of continuous light fluxes or switching of discrete short optical pulses [11].

Another influence of the growth of external macroparameters is associated with the period and modes of oscillation. Due to this effect, in a number of samples with increasing of any of the macroparameters, an aperiodic transit-time oscillation mode is implemented, in which the period between the oscillations sequentially decreases. With an increase in the macroparameters, a two-domain oscillation mode appears, which transitions into a three- or fourdomain mode as the macroparameter increases, with a close but different frequency of the generated oscillations; there is a spontaneous transition from δ-shaped domains to trapezoidal domains, etc. In addition, under exposure to light pulses of complex shape (sinusoidal, triangular, sawtooth, etc.), in such structures periodic or aperiodic photocurrent oscillation occurs, the envelope of which uniquely repeats the shape of the illuminating pulse [12].

The minimum duration of an optical pulse at which a single domain occurs in the structures exceeds two to three oscillation periods and depends on the power of the illuminating pulse.

4. DISCUSSION OF THE RESULTS

A comparison of the excitation conditions, oscillation conditions, and parameters of the photocur-rent domains with the results of similar studies shows that the formation of photocurrent oscillations in CdZnTe samples is not associated with a decrease in carrier mobility due to optical charge exchange of impurity levels, which is characteristic of recombination instability [7]. The high rate of domain trans-fer, the dependence of E_p on illumination intensity, the aperiodic transit-time oscillation mode, and the reversible dependence of the frequency of oscillations on external macroparameters, observed experimentally, indicate an unambiguous relationship between the formation of N-type NDPCs in

such structures and the photostimulated spatial rearrangement of the electric field, which so far has not been experimentally observed.

The results of experimental and theoretical studies of this effect are presented in Ref. [8], where, based on model concepts, it was shown that for low optical pump intensities and high tunnel transparency of the dielectric layer d_{Ox}, when the diffusion component of the photocurrent and the accumulation of mobile carriers at the non-illuminated electrode can be neglected, the stationary field distribu-tion profile $E(x)$ in the monopolar transport region has the form [8]:

$$E(x) = E_0 \left(\frac{x'}{L} \right)^{1/2}, \quad (1)$$

where $E_0 = \sqrt{\frac{8\pi JL}{\chi\mu}}$, L is the separation between the contacts, $x' = x_m - x_1$ is the width of the region of oscillation, separation and recombination of nonequilibrium photocarriers, x_1 is the initial coordinate, χ is the relative permittivity, μ is the mobility, J is the photocurrent density, determined by the relation [8]:

$$J = \frac{9}{32\pi} \frac{\chi\mu V^2}{L^3}. \quad (2)$$

Dependencies (1) and (2) are expressions known in the literature, discussed earlier in Ref. [13]. They correspond to the so-called "virtual cathode" approximation, from which the "infinitely weak field" draws the carriers off. Correspondingly, dependence (2) is a generalization of the known result for the case of the "photoelectric cathode", when the interband optical pumping is the carrier source. When a homogeneous high-resistance MTISTIM structure is illuminated, the role of such a source is played by a narrow contact layer near the illuminating electrode x', inside which photocarriers are generated, recombined, and separated.

It was shown [14–16] that the magnitude and coordinate dependences $E(x)$ obtained experimentally in MTISTIM structures based on high-resistance "pure" and compensated p-CdTe single crystals do not coincide with the results of theoretical calculations given in [17]. To the greatest extent, these differences relate to the contact areas, where the illuminated electrode has a more significant field decline than theoretical calculations, and the experimental values of the field near the non-illuminated electrode significantly exceed their calculated values and vary greatly with the coordinate [14]. Such differences were associated by the authors of Ref. [14] with the inadequacy of the model of the MSM structure with respect to the real MTISTIM structure, where the through photocurrent is accompanied by a partial accumulation of mobile carriers in the near-electrode regions. It was also shown there that in tunnel MTISTIM structures based on "pure" single crystals, the configuration of the mobile charge accumulated near the non-illuminated electrode determines the coordinate dependence $E(x)$. The latter, along with the dependence $J(I)$, has a sublinear form and can be approximated by the expression $E(x) = A \cdot x^n$, where A is a coefficient, n is the nonlinearity index, $n < 1$ [14].

Experiments on the nature of the distribution of electric fields in CdZnTe structures showed that, at comparable bias voltages and illumination intensities, the difference in electric fields achieved in such structures is greater than in similar structures of Ref. [14]; in the most perfect samples spatial changes of the field in the volume of the structure occur in shorter times. Moreover, at certain relations between the macroparameters, the CVCs of a number of samples show spontaneous formation of a descending N-type region, the occurrence of which is accompanied by the formation of photocurrent oscillations within the photocurrent pulse (Fig. 3*d*).

The steady-state distributions of the field $E(x)$, which are established when one of the macroparameters changes, are shown in **Fig. 4***a,b*. From the coordinate dependences $E(x)$ in Fig. 4*a* measured by the method [16], it follows that the stationary field distributions E(x) in the studied sample and the high-resistance MTISTIM structure based on a "pure" p-CdTe single crystal [14] qualitatively agree, i.e., in both cases under illumination the electric field decreases near the illuminated electrode and increases towards the non-illuminated one, reaching a maximum in its close proximity. However, at comparable bias voltages and power of the optical pump pulses, a stronger field difference between the illuminated and non-illuminated electrodes is formed in the CdZnTe structure.

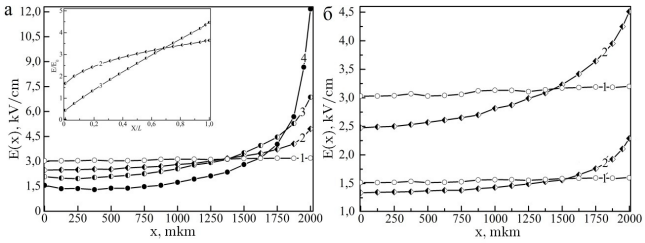

Fig. 4. *Steady-state distributions of electric field on MTISTIM CdZnTe structure: a - under the constant bias voltage V_0 = 601 V and illumination with light pulses of different power P: 1 - 0, 2 ~ 7.5 mW, 3 ~ 12.5 mW, 4 ~ 24.5 mW; the inset shows the coordinate dependences E(x) for the CdZnTe structure, calculated using the method [17] at the same values of the external macroparameters; b - under the constant pulsed pump power P_0 ~ 13 mW and different bias voltages V_0: 1 - 601 V, 1′ - 303 V, L ~ 2 mm, T = 300 K.*

At the same time, at high illumination intensities and fields E_0 ~ 4–6 kV/cm, the coordinate dependence $E(x)$ in the CdZnTe sample changes significantly: the region of the "strong" field is spatially localized in the narrow near-contact region of the non-illuminated electrode, occupying ~1/5–1/7 part of the sample, where it sharply increases with a positive curvature $d^2E/dx^2 > 0$ near the non-illuminated electrode and more weakly near the illuminated one, "sagging" inside the most part of the base. In this case, experiments show that in a number of samples studied, a slight increase in the field near the illuminated electrode may be absent, which is rather associated not with uncompensated impurity levels in the contact area of the illuminated electrode, but with asymmetric conditions for the passage though tunneling dielectric layers by carriers of different signs and the absence of injection from the contacts. In this case, the dependence $E(x)$ (curve 4 in Fig. 4*a*) can be approximated by the expression $E(x) \sim Ax^n$, where $n \sim 3.51$, which is in good agreement with the results of theoretical analysis, which in the diffusion-drift approximation predicts a superlinear dependence $E(x)$ in the region of monopolar transport, when the accumulation of charge in the near-contact region of the non-illuminated electrode cannot be neglected [8].

Another effect on the coordinate dependence $E(x)$ is exerted by a change in the bias voltage at a constant optical pump power. From the stationary distributions $E(x)$ measured in the same sample at different bias voltages V_0 and illumination with a fixed-power light pulse (Fig. 4*b*), it follows that a decrease (increase) in the magnitude of the applied voltage V_0 leads to a decrease (increase) in the value of the field E_0, by the magnitude of the changing voltage, while the coordinate field changes due to the monopolar mobile charge of the photocarriers change little. In other words, in such structures, the threshold field strength E_p is determined by the combination of the field E0 created by the external voltage source V_0 and the field E_1 created by the photoinduced space charge [8]:

$$E_p = E_0 + E_1. \quad (3)$$

It follows from Eq. (3) that the appearance of oscillation in such structures can be achieved with various relations between the values of external macro parameters. This feature leads to the fact that after the formation of the domain, changes in any of the macroparameters leads to a change in the frequency of the oscillations, which is observed in the experiment.

At the same time, the results of studies concerning the domain instabilities in high-resistance CdZnTe are not found in the literature. Therefore, along with the measurement of E_p in several CdZnTe samples, the velocity-field dependence $\upsilon(E)$ was measured. The measurement of the velocity of carriers under the conditions of inhomogeneous field $E = E(x)$ was carried out using the technique [9], which is based on scanning the sample from one electrode to another with a narrow beam of probe light that causes no photoactive absorption and measuring the transit time of carriers and the spatio-temporal and amplitude characteristics of the pulses of the probe light beam at each scanning step under illumination the sample with short light pulses under constant applied voltage. This approach allows calculating at each step the field value in the MDTPTDM structure and the carrier transit time corresponding to this value for any polarity of the applied voltage and any coordinate dependence $E(x)$.

Measurement of the dependence $\upsilon(E)$ in samples with different L showed that although the carrier velocity varies from sample to sample in the range υ ~0.7–1.25·10^7 cm/s, the maximum carrier velocity is reached at threshold fields E_p ~12.5–13.3 kV/

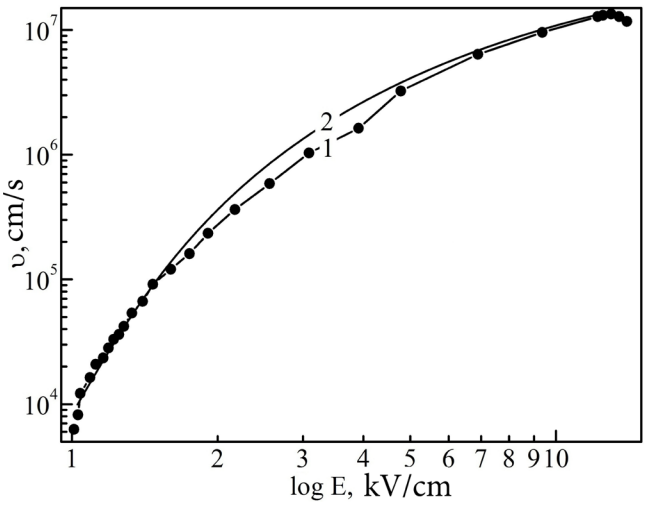

Fig. 5. *Dependence of the electron drift velocity υ on the electric field strength E(x) in CdZnTe: 1 - experiment, 2 - calculation; L = 2 mm, T = 300 K.*

cm, after which on the curve $\upsilon(E)$ a falling section is observed (**Fig. 5**).

The possibility of detecting the Gunn effect was theoretically analyzed earlier in [18], where, based on the results of Ref. [19], an expression is given that allows estimation of the carrier concentration necessary for the appearance of Gunn oscillations in a high-resistance semiconductor:

$$n > -\frac{2.09\varepsilon}{Lq\frac{1}{v}\left|\frac{dv}{dE}\right|}, \quad (4)$$

where E is the magnitude of the electric field strength, n is the concentration of electrons in the semiconductor before the beginning of domain formation, ε is the permittivity, q is the charge of electron, L is the separation between the contacts, υ is the absolute value of the electron drift velocity, $d\upsilon/dE$ is the differential mobility, which is negative due to the intervalley transitions of hot electrons.

It was also shown there that the generation due to electrical injection of carriers from a contact into a high-resistance n^+-n-n^+ structure is not possible, because at certain bias voltages V_0', the current mode limited by the spatial charge is replaced by the current mode limited by the emission ability of the cathode contact n^+-n, and the field strength remains constant regardless of the further growth of V_0'. However, in an illuminated high-resistance tunnel MTISTIM structure, these restrictions are removed, because after the establishment of the nonequilibrium depletion regime, the rate of generation of nonequilibrium photocarriers in such structures is proportional to the illumination intensity [20], and an increase in the photoinduced mobile charge leads to an increase in the field in one of the regions of the structure. As a result, due to nonequilibrium carriers Δn under illumination it becomes possible to provide the carrier concentration n and the field strength E_p necessary for the occurrence of oscillation. In addition, consequently, this leads to the fact that, firstly, the oscillation without illumination in such structures cannot occur at any bias voltages, and, secondly, due to this mechanism, an unambiguous relationship between the duration of oscillation and the duration of the pump light pulse.

Using the oscillograms of photocurrent pulses shown in Fig. 3a, one can estimate the initial carrier concentration n at which stable oscillation occurs in the CdZnTe structure. It should be noted that, taking Eq. (3) into account, the value of the threshold field E_p was determined at values of external macroparameters close to the threshold.

Then for a sample of CdZnTe, assuming for estimate $L = 4.61\cdot10^{-2}$ cm, ε = 10.3 (1 MHz) [21], $E_p \sim 1.28\cdot10^4$ V/cm, $q = 1.6\cdot10^{-19}$ C, $E_0 \sim 8.7$ kV/cm, $\upsilon \sim 9\cdot10^5$ cm/s, $\left|d\upsilon/dE\right| \sim 70.3$ $cm^2V^{-1}s^{-1}$, the initial concentration of carriers n amounts to $\sim 3.5\cdot10^{12}$ $см^{-3}$, and the parameter $nL \sim 1.61\cdot10^{11}$ cm^{-2} [4].

For the mean current photosensitivity $S_i \sim 0.75$ A/W and the reflection coefficient $R \sim 0.3$-0.35, the light power, at which the oscillation arises, is ~7–9 mW, which agrees well with the experimental data.

From the oscillograms (Fig. 3 b,c) it follows that changing any of the macroparameters within the range from P_p to P_{max} at $V_0 = V_p$ or from V_p to V_{max} at $P_0 = P_p$ results in the practically similar maximal frequency of oscillation fmax, increasing from $f_1 \sim 19.6$ MHz to $f_m \sim 260$ MHz under the growth of the optical pump power from P_p to P_{max} with the step $\Delta P \sim 1$ mW and the bias voltage from V_p to V_{max} with the step $\Delta V \sim 5.2$ V.

5. CONCLUSIONS

This paper presents the results of experimental studies of a new type of domain instability, which is based on drift nonlinearity – the photostimulated

spatial restructuring of the electric field. It is experimentally shown that in a high-resistance tunnel MIS structure, this physical mechanism leads to a significant deviation from equilibrium of its main macroparameter, the electric field, which becomes unstable at certain values of the macroparameters and jumps from the stationary nonuniform distribution throughout the entire MTISTIM structure to a new, but also steady state, in which it becomes narrowly localized and periodically moves from one electrode to another.

Accordingly, in MTISTIM structures based on electro-optical crystals, changing the electro-optical characteristics of the medium by the domain field makes it possible, due to the transverse electro-optical Pockels effect, to transfer optical information from the controlling light beam $I_1(x, t)$ to another light beam $I_2(x, t)$, which is transmitted through the structure, i.e. to carry out high-frequency optical modulation of one light flux by another.

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