ELECTROPHYSICAL PROPERTIES OF THE CRYSTALS Bi₁₂SiO₂₀ IN THE ELECTRET STATE UNDOPED AND DOPED BY AI AND Ga IONS

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Relationships between the nonlinearity of current-voltage (I–V) and capacitance-voltage (C–V) characteristics of $\rm Bi_{12}SiO_{20}$ crystals, on the one hand, and their doping with Al and Ga ions, as well as their transition into the thermo- or photoelectret state, on the other hand, have been studied. The dependences of the non-linearity index and the characteristics of the I–V and C–V hysteresis loops on the polarization temperature and the energy of quanta of photoactivating illumination have been obtained. The evolution of hysteresis loops has been examined. The results obtained have been explained by involving such factors as the formation of Schottky barriers, confined electron injection from electrodes, and the mechanisms of bulk and quasidipole polarization which are responsible for the formation of thermo- and photoelectret states.

Study of current-voltage characteristics (CVCs) of semiconductors and insulators remains a challenging problem of solid-state physics. It is caused by the interest in CVC peculiarities (non-linearity of the S- or N-type, hysteresis, the dependence on external factors), the possibility to transit into low-resistance states, and electrophysical parameters of materials [1–9]. From the practical point of view, the CVC peculiarities are used in integrated and functional electronics, in order to fabricate integrated structures [5], photodetectors, electrophotographic devices, generators, signal transducers [3, 4], and so on.

Crystals of selenites $Bi_{12}MO_{20}$ (BMO), where M = Si, Ge, or Ti, are actual materials of functional electronics. They possess a unique combination of various properties (photorefractive, piezoelectric, acoustooptic, photoelectric, and so on) and demonstrate pronounced nonlinear effects which are used, in particular, in the devices for the recording, storing, and processing of optical information. To understand

the nature of these effects and to extend the range of their application, complex researches of BMO crystals are necessary. In a number of works, the non-linearity of CVCs of those compounds has been pointed out. However, the available body of experimental data is inconsistent and insufficient for understanding the nature of non-linear electrophysical properties. It has been discussed from the viewpoint of ther availability or absence of the injection of current carriers from electrodes, provided the band or hopping mechanism of current carrier transfer, and still remains debatable [10–18].

An assumption has been made that the peculiarities in the CVCs of selenites originate owing to the formation of an electret state [10]. In order to check this assumption, a complex research of the CVCs and the volt-farad characteristics (VFCs) of undoped $Bi_{12}SiO_{20}$ (BSO) crystals, as well as BSO crystals doped with Al (BSO:Al) and Ga (BSO:Ga) ions and transformed into the electret state, has been carried out in this work.

1. Experimental Technique

BSO crystals were grown up by the Czochralski method. The content of doping impurity in the crystals, according to the data of spectral emission analysis, amounted to 6×10^{-2} (Al) and 4×10^3 wt.% (Ga). Specimens were fabricated as polished bars $0.1 \times 0.1 \times 0.8$ cm³ in dimension. Pt-electrodes were deposited onto (001) planes 0.1×0.8 cm² in dimension by the method of cathode sputtering in vacuum. The CVCs and VFCs of BSO, BSO:Al, and BSO:Ga crystals in the thermoor photoelectret state (TES and PES, respectively)

were studied. The conditions of electret state formation were varied in the following limits: the polarization temperature $T_p = 300 \div 600$ K and the energy of light quanta that activate the photoelectret state $h\nu_p =$ $0.7 \div 3.4$ eV; at the same time, the voltage $U_p = 100$ V and the polarization time $\Delta t_p = 30$ min were constant.

The dependences of the current I and the capacity Con the dc bias voltage U (CVCs and VFC, respectively) were measured. In the course of measurements, first, the voltage U was changed discretely with a step of ± 2 V; then, after making a pause $\triangle t = 20 \div 30$ s, which considerably exceeded the time of Maxwellian relaxation for selenites $\tau = 0.1$ s, the current was registered. The voltage was repeatedly increased and decreased with the change of its sign: we made forward scanning from 0 to 200 V and reverse scanning from 200 to 0 V to measure the positive-bias branches of CVCs and VFCs, and forward scanning from 0 to -200 V and reverse scanning from -200 to 0 V to measure the negativebias branches of CVCs and VFCs. Measurements were carried out at the temperature T = 300 K on the equipment (a V2-36 and a VK2-20 voltmeter, a V7-30 voltmeter-electrometer, an F-30 voltammeter, an E8-3 ac bridge) controlled by a microcomputer [19]. In addition, we used the probe method to study – under a microscope and with a step of about 30 μ m – the distribution of the voltage U_p across the thickness d of the specimen between electrodes.

2. Results and Their Discussion

Even the results obtained in the first cycle of measurements of non-polarized BSO crystals made it evident that the positive and negative branches of both curves I(U) and C(U) are nonlinear; they are asymmetric with respect to both vertical (I, C) and horizontal axes (U) and demonstrate a hysteresis, i.e. a non-equivalence of I and C values for forward (from -Uto +U) and reverse (from +U to -U) voltage scanning in the course of measurements. The phase transformation of crystals into the electret state is accompanied by the growth of the current through them and their capacity; the mentioned peculiarities in the CVC and the VFC become more pronounced at that (Fig. 1), so that they can be associated with the formation of the electret state which, according to work [19], occurs under the conditions of our experiments. It has been established in the previous works that the polarization conditions applied ensure the formation of a thermo- or photoelectret state in BSO crystals undoped and doped with Al and Ga ions [20,21]. This state, according to the

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Fig. 1. CVCs (panel *a*) and VFCs (panel *b*) of BSO crystals in the initial non-polarized state (curves 1 and 1') and a thermoelectret formed at $T_p = 325$ K (curves 2 and 2'). The arrows indicate the direction of a change of the voltage U (curves 1 and 2 correspond to forward scanning, curves 1' and 2' to reverse one)

modern concept [22], is governed by a spatially nonuniform redistribution of the polarization charge which remains to exist for a long time (much longer than τ) after the external electric field having been switched off. The existence of an electret state in BSO, BSO:Al, and BSO:Ga crystals, as well as its destruction, reveals itself, for instance, in the course of thermally stimulated depolarization [19–21].

Further researches showed that the peculiarities in the I(U) and C(U) curves (non-linearity, asymmetry, hysteresis) should be appended by the dependence of their shape on the sign of measuring voltage U, the numbers of measurement cycles with the voltage-sign reverse, the conditions of the TES and PES formation $(T_p, h\nu_p)$, and the nature of doping impurity (Al, Ga) (see Figs. 1–4).

2.1. CVCs

For the TES and PES of undoped BSO crystals, the positive and negative branches of CVCs measured in the course of the first forward scanning are exponential: $I \sim I_0 \exp(-U^*/U)$, where the value of the parameter U^* depends on the polarization conditions (Figs. 1, *a*; 2, *a*; and 3, *a*). Doping those crystals with Ga or Al changes the character of the CVC non-linearity of BSO:Ga and BSO:Al crystals in the case of forward scanning to the power-law one, $I \sim U^n$, with the power exponent *n* falling within the limits from 1.5 to 3 for different CVC sections (Fig. 3, inset *g*; Fig. 4, *b*). The reverse-scanning CVC profiles are power-law irrespective of doping; for these profiles, the values of the parameter *n* for positive



Fig. 2. CVCs (panels a and c) and VFCs (panels b and d) of BSO (panels a and b) and BSO:Ga (panels c and d) crystals in the thermoelectret state for the first (all panels, curves 1 and 1') and the second (all panels, curves 2 and 2') measurement cycle; the dependence Q(U) for BSO crystals (panel a, curves 3 and 3'). The arrows indicate the direction of a change of the voltage U (curves 1, 2, and 3 correspond to forward scanning, curves 1', 2', and 3' – to reverse one). The temperature of previous polarization $T_p = 370$ K

branches are higher than those for negative ones (asymmetric CVCs) in the BSO case and, practically, do not depend on the voltage U sign (symmetric CVCs) for doped crystals (Figs. 2, c; 3, c; 4, a).

The type of hysteresis is determined by the presence and the nature of doping impurity. For an undoped BSO, the current of reverse scanning exceeds that of the forward one (a "positive hysteresis" – Figs. 1, a; 2,a; 3,a), while, for doped crystals, the current of forward scanning is higher, as a rule, than that of the reverse one (a "negative hysteresis" – Figs. 2,c; 3,c; 4,a). However, a variation of formation conditions for the electret state can transform the negative hysteresis into a positive one (Fig. 4,a).

Repeating the measurement cycles resulted in a reduction of the area of CVC hysteresis loops, which determines the dissipation of the energy W in crystals. In general, the loops become more symmetric (Fig. 2, a and c).

The conditions of TES and PES formation considerably influence the CVC shape. For an undoped



Fig. 3. CVCs (panels a and c) and VFCs (panels b and d) of BSO (panels a and b) and BSO:Ga (panels c and d) crystals in the photoelectret state, induced by the action of red- (curves 1 and 1' in panels a, b, and d), green- (curves 2 and 2' in panels a, b, and d; curves 1 and 1' in panel c) and blue-light (curves 2 and 2' in panel c) illumination. $T_p = 370$ K. The arrows indicate the direction of a change of the voltage U (curves 1 and 2 correspond to forward scanning, curves 1' and 2' to reverse one). Dependences of the non-linearity index n on the energy of light quanta $h\nu_p$, used to form the PES, for the positive branches of CVCs (insets e and g) and VFCs (insets f and h)

BSO in the TES, the growth of the temperature T_p is accompanied by the increase of the exponent U^* for forward CVC scannings and the change of nonlinearity n for reverse ones. For BSO:Al crystals, the dependences $n(T_p)$ have maxima in the interval $T_p =$ $373 \div 420$ K for positive and minima for negative CVC branches (Fig. 4, b). As the temperature T_p grows, the areas confined by negative and positive CVC hysteresis loops change differently: there appears a maximum at $T_{\rm max} = 420$ K in the dependence $W(T_p)$ for positive hysteresis loops, whereas it monotonously falls down for negative ones (Fig. 5, b); moreover, after the polarization at $T_p = 375$ K, the hysteresis transforms from negative to positive.

For an undoped BSO in the PES, the exponent U^* for forward CVC scannings decreases with the increase of the light quantum energy $h\nu_p$ in the positive branches



Fig. 4. (a) CVCs of BSO:Al crystals in the thermoelectret state obtained after polarization at $T_p = 375$ (curves 1 and 1') and 475 K (curves 2 and 2'). The arrows indicate the direction of a change of the voltage U (curves 1 and 2 correspond to forward scanning, curves 1' and 2' to reverse one). (b) Dependences of the non-linearity index n of BSO:Al crystals on the temperature T_p for positive (curve 1) and negative (curve 2) CVC branches

and does not depend on $h\nu_p$ in the negative branches. The non-linearity parameter n is minimal at green illumination for reverse CVC scannings (Fig. 3, inset e). The spectral dependence $W(h\nu_p)$ has a strong and a weak maximum, which correspond to red and blue illumination, respectively, in the course of PES formation (the first cycles of measurements, Fig. 5, a). For BSO:Ga crystals in the PES, the parameter nincreases up to the saturation in the positive branches (Fig. 3, insert g), or, similarly to BSO, has a minimum in the negative branches. The dependences $W(h\nu_n)$ differ from one another by the absence of the weak maximum and the smearing of the intensive one (Fig. 5, a). However, the variation of $h\nu_p$ weakly affects the result of CVC scanning reversing, i.e. the residual hysteresis loops for the TES and PES are almost identical (Figs. 2, a and c).

2.2. VFCs

The VFC features for BSO crystals in the TES and PES are similar to those of CVC by the character of nonlinearity of the curves C(U) and I(U); the positiveness of the hysteresis; the shapes of the dependences $n(h\nu_p)$ and $n(T_p)$ (Figs. 1, *a* and *b*; Figs. 2, *a* and *b*; Figs. 3, *a* and *b*, insets *e* and *f*); the reduction of the area which determines the charge Q^* accumulated in crystals; as well as by acquiring a symmetric shape by VFC hysteresis loops, owing to the reverse of the bias voltage U (Figs. 2, *a* and *b*). Especially convincing is the analogy between the curves I(U) and the curves Q(U), where Q = CU, calculated from the VFCs (Fig. 2, *a*). Doping





Fig. 5. Dependences of the energy W and the charge Q^* , accumulated in BSO (curves 1 and 1' in panel a), BSO:Ga (curves 2 and 2' in panel a), and BSO:Al (panel b) crystals, on the energy of light quanta $h\nu_p$ (panel a), and the temperatures T_p for positive (curve 1 in panel b) and negative (curve 2 in panel b) hysteresis loops. (c) Temperature dependence of the dark conductivity σ of BSO (curve 1), BSO:Al (curve 2), and BSO:Ga (curve 3) crystals. (d) Voltage distributions across the BSO crystal thickness $U_p/U_{0p}(x/d)$ in the case of illuminating with red (curve 1), blue (curve 2), and white (curve 3) light. $T_p = 300$ K

BSO with Ga and Al changes the VFC shape and destroys this analogy: the curves C(U), in contrast to I(U), have now no saturation sections but pass through an intensive maximum; there appear the important discrepancies in the degree of their asymmetry; the dependences $n(h\nu_p)$ and $n(T_p)$ change their shape; but the negative character of hysteresis still remains untouched (Figs. 2, c and d; Figs. 3, c and d, insets g and h).

3. CVC Features and the Characteristic of Electret State

The CVC and VFC of BSO crystals undoped and doped with Al and Ga and transformed into the thermo- or photoelectret state, i.e. polarized, have not been studied before. However, we can point out some correlation between the CVC features obtained by us and those for non-polarized BMO crystals [10–18]. In both cases, the CVCs are nonlinear (exponential or power-law, with that or another set of nonlinear sections [10–18]), asymmetric [11, 13, 17], and exhibiting a hysteresis [14, 18]. The data on the CVC hysteresis in BMO are inconsistent; it can be both positive [14] and negative with symmetric hysteresis loops, the area of which diminishes as the measurement cycles are repeated [18].

The influence of Al ions does not correspond to our results as well; according to work [10], in the case of Bi₁₂TiO₂₀:Al crystals, it consists in the shift of nonlinear sections in the CVCs towards higher voltages rather than the variation of the non-linearity parameter. The CVC peculiarities of non-polarized BMO crystals are explained in different ways. Using an electron beam for the creation of an electron reservoir in the region near the surface of cathode which injects electrons, the authors of works [11–13] have demonstrated that the modification of the behavior of CVC sections - sublinear \rightarrow square-law \rightarrow a drastically growing current – with increase in the measured voltage can be described by the theory of space-charge-limited currents (SCLCs) [23]. In particular, the section where $I \sim U^2$ is associated with the Mott–Pekar law [23]

$$I = (9/8)\epsilon\epsilon_0\mu_{\rm eff}U^2/d_k^3,\tag{1}$$

where ϵ is the dielectric permittivity, $\epsilon_0 = 8.85 \times 10^{-12}$ F/m the dielectric constant, $\mu_{\rm eff}$ the effective mobility of electrons, and d_k the thickness of the interelectrode layer.

However, studying the Me-BMO-Me structures, where Me stands for metal contacts made of Ag, Al, or In, brought the authors of work [10] to a conclusion that the CVC non-linearity is caused by the formation of Schottky barriers at the contacts. According to the diffusion theory of rectification at such barriers, the inverse current looks like [10, 24]

$$I = -2e\mu_{\rm eff} n_s [(n_{0/2}\epsilon\epsilon_0) \times$$

$$\times (\Delta \phi + eU)/kT)^{0.5} [\exp(-eU/kT) - 1],$$
 (2)

where e is the electron charge; $n_s = f(U,T)$ and n_0 are the concentrations of electrons from the conduction band at the Me–BSO interface and in the specimen bulk, respectively; and $\Delta \phi$ is the contact potential difference. The analysis of expression (2) gives ohmic, sublinear, and superlinear sections in the CVC for different relations among $\Delta \phi$, eU, and kT.

Additional arguments in favor of the models with contacts, which either block or inject electrons, can be provided by the VFC C(U). Since the VFCs of BMO crystals have not been studied earlier, we considered the VFCs of SrTiO₃ (STO) and Sr_{0.5}Ba_{0.5}TiO₃ (STBO) crystals [25–27]. For these crystals, the C(U)-curves are characterized by a dome-shaped profile with a maximum, which can be shifted with respect to the axis C, and a hysteresis. The characteristics of the hysteresis are the relative variation $\Delta C/C_0$ of the output capacity C_0 , where $\Delta C = [C(0) - C_0]$ and C(0) is the capacity after the cycle action of the bias voltage U, the voltage U_i which determines the VFC maximum, and the sign of ΔC , which indicates "negative" ($\Delta C < 0$) or "positive" ($\Delta C > 0$) hysteresis. According to the results of work [25], the dome-shaped CVC at $U_i = 0$ corresponds to either a uniform distribution of space charge (SC) or its absence (if $\Delta C/C_0 \leq 10^{-2}$). The shift of the maximum of the C(U) curves with respect to the coordinate origin by $\pm U_i$ evidences for a non-uniform distribution of the SC. The negative hysteresis at $U_i = 0$ and $U_i \neq 0$ is caused by injection of electrons in the course of VFC measurements. The positive hysteresis points at the absence of injection. In this case, the shift of the maximum of the C(U)-curves can be a result of the non-uniform SC distribution in the crystal at the stage of its preparation for experiment.

We would like to point out a certain analogy between the VFCs of BSO:Ga crystals in the TES and PES (Figs. 2,d and 3,d) and the VFCs of non-polarized ferroelectric crystals STO and STBO. In both cases, the dependences C(U) are dome-shaped, with a maximum shifted to $U_i = +(10 \div 20)$ V; they demonstrate a negative hysteresis with the magnitude $\Delta C/C_0 \leq 0.5$; and they vary with a reduction of $\Delta C/C_0 \leq 0.5$ owing to the reverse of the bias voltage U. Taking all that into account, we may suppose that, in BSO:Ga crystals, injection of electrons occurs from Pt-electrodes.

However, the VFCs for the PES and TES of BSO crystals look differently: the curves C(U) have branches turned upwards (for the first measurement run); they pass through a minimum at $U_{i \min} = -(5 \div 10)$, shifted with respect to the *C*-axis; and the hysteresis is positive. After several cycles of bias-voltage change, the shape of hysteresis loops in the VFCs for crystals in the TES becomes symmetric – "the moth wings" (see Figs. 2, *b* and 3, *b*). Such a shape of the C(U)-curves cannot stem from the electron injection; more probably, it points at the fact that the application of bias voltage gives rise to the reorientation of the internal electret field which is governed by the non-

linearity of the dielectric permittivity $\epsilon(U)$, similarly to the reorientation of domains in ferroelectrics.

The studies of electret state in BSO crystals evidence for a substantial contribution made by quasidipole mechanisms of polarization [19]. This contribution dominates in comparison with that of bulk-charge polarization, following the reduction of electroconductivity σ . The temperature dependences of the equilibrium dark conductivity $\sigma(T)$ make it evident that $\sigma \approx 10^{-13}$, 10^{-7} , and $10^{-6} \ \Omega^{-1} \text{cm}^{-1}$ for BSO, BSO: Ga, and BSO:Al crystals, respectively, at room temperature (Fig. 5, c), and the photoconductivity $\sigma^{\rm ph}$ of BSO in the visible range of the spectrum is 2 to 4 orders of magnitude higher than those of BSO:Ga and BSO:Al [28]. Note that the difference of the σ -values for undoped and doped BSO crystals correlates with the difference of the areas of the first hysteresis loops (Fig. 2), and the availability of maxima in the spectral dependence $\sigma^{\rm ph}(h\nu)$ for BSO in the red and blue spectral ranges with the maxima of spectral dependences $W(h\nu_n)$ and $Q(h\nu_n)$ (Fig. 4,a).

For the further analysis of the results, the conditions on contacts have also to be taken into account. According to work [29], the work function is $A_1 = 4.5$ eV for BSO crystals and $A_2 = 5.6$ eV for Pt-electrodes. That is, $A_1 \ll A_2$, and Schottky barriers should appear at Pt– BSO contacts. The quantity A_1 depends simultaneously both on the type and the concentration of impurity [29]; therefore, an opportunity for the ratio between A_1 and A_2 to change in the case of doped crystals is not excluded, which means a possibility for electrons to be injected from Pt-electrodes.

Our experiments showed that the transformation of crystals into the TES or the PES is associated with the conditions on contacts. The transformation is accompanied by the emergence of a spatially non-uniform distribution of the polarization voltage $U_p/U_{0p}(x/d)$ (where $U_p(x/d)$ is the distribution of polarization voltage across the specimen thickness and U_{0p} is the external voltage applied between the cathode and the anode), which is typical of barrier contacts (illumination by red and blue light). In this case, if BSO crystals are illuminated with blue light, the intensity of voltage jumps U_p/U_{0p} near the contacts diminishes and the photoconductivity of those crystals increases. A substantial growth of $\sigma^{\rm ph}$ in BSO crystals induced by their illumination with highly intensive white light, or an enhancement of the dark σ in BSO:Ga and BSO:Al crystals, brings the distribution $U_n/U_{0n}(x/d)$ closer to linear, i.e. the Schottky barriers disappear (Fig. 4, d). A nonlinear coordinate dependence of the local photoconductivity $\sigma^{\rm ph}$ between the cathode and the anode, obtained in work [5], testifies in favor of the existence of Schottky barriers at the contacts between an In, Ag, or nichrome electrode and a B₁₂GeO₂₀ crystal. The inhomogeneity of the $U_p/U_{0p}(x/d)$ -distribution means the inhomogeneity of the bulk-charge one, with the bulk charge being accumulated on traps; in this case, if there is no injection, the electroneutrality is kept preserved (BSO), otherwise, a monoelectret (BSO:Ga) is formed.

The formation of the electret state is accompanied by the appearance of the electret field $E_{\rm el}$. If the field $E_{\rm el}$ and the external measuring field $E_{\rm ex}$ are directed opposite to each other, they compensate contact fields E_k – also counter-directed to each other – at Schottky barriers near the opposite surfaces of specimens with Pt-electrodes. In this case, the CVCs are close to exponential (Figs. 1, a, 2, a, and 3, a), which are typical of Schottky barriers connected in forward direction, and can be described by the expression

$$I = I_s[\exp(eU/kT) - 1], \tag{3}$$

where the factor I_s changes insignificantly with the variation of U. The change of the polarity of an external voltage brings about the situation, where the electret, $E_{\rm el}$, and the external, $E_{\rm ex}$, fields are directed in the same direction, so that they suppress the field E_k of only one Schottky barrier. In this case, the CVC is described by expression (2) for the reverse connection of such barriers. In general, the first cycle of measurements produced asymmetric CVCs (Figs. 1, a, 2, a, and 3, a). An excess of the reverse-CVC-scanning current over the forward-CVC-scanning one is caused by the increase of the electret charge magnitude. After the measuring-voltage sign has been changed (together with the field strength which is directed opposite to the electret field) and the voltage amplitude started to grow, the electret state becomes partially destroyed. The repeated alteration of the voltage sign ultimately destroys the electret state; the dependences $I \sim f(U)$ become power-law and more symmetric with respect to the current axis, they are described as the CVCs of Schottky barriers with reverse connection; the area of hysteresis loops (the dissipation energy W) decreases (Fig. 2, a).

The non-linearity of VFCs is also explained by the conditions at blocking contacts, taking the formation of TES and PES into account. In a polarized BSO crystal, the electret (polarization) charge $Q_{\rm el}$ is mainly formed owing to quasidipole polarization [19]. If the external bias field E_d is directed in parallel with the electret field $E_{\rm el}$, there occurs a non-uniform redistribution of

the space charge, which corresponds to the increase of the capacity C. The change of the bias-voltage polarity (to -U) results in a reduction of the field in the crystal $E = E_d - E_{\rm el}$, i.e. leads to the larger smearing of the bulk charge and to the reduction of the capacity C caused by this charge. Nevertheless, the further increase of E_d stimulates the charge growth again. It can be explained by the contribution of quasidipole polarization, with the reorientation of quasidipoles along the direction of the bias field E_d .

In the course of following measurement cycles, by altering the polarity of the bias voltage, we obtained symmetric VFCs (Fig. 2,b). If, due to either doping or the conditions of formation of the electret state, the relation between work functions A_1 and A_2 in BSO:Al and BSO:Ga crystals, respectively, changed to $A_1 > A_2$, the CVC peculiarities can be explained in the framework of the SCLC theory. At the polarization stage, owing to the injection of electrons into highresistance crystal specimens, a monoelectret state is formed. In the first cycle of measurements, asymmetric CVCs are obtained (Figs. 2, c, 3, c, and 4, a).

For various magnitudes and polarities of the bias voltage, it will either compensate or strengthen the field of the injected charge; this circumstance gives rise to asymmetric VFC loops (Figs. 2, d and 3, d). After several measurement cycles, the CVCs become more linear, owing to the fact that the injected charge quits the crystals. The VFCs also signal about the disappearance of the bulk charge from specimens. For BSO:Al crystals, the change of the hysteresis character from negative to positive and the reduction of the non-linearity parameter value from n = 2 to n < 1, which accompanies the growth of the polarization temperature T_p (Fig. 4,b), can be explained as the transformation of the type of Pt-BSO:Al contacts from blocking to injecting ones.

Thus, the features obtained in CVCs and VFCs originates from the conditions of the formation of TES and PES and the relations between the work function values for BSO crystals and metal electrodes. Doping BMO changes the conditions of the formation of TES and PES in BSO:Al and BSO:Ga crystals, owing to the variation of the dark and photoconductivity values, the modification of the ratio between the contributions of bulk-charge and quasidipole polarizations, and the change of the type of Pt–crystal contacts from blocking to injecting.

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ЕЛЕКТРОФІЗИЧНІ ВЛАСТИВОСТІ НЕЛЕГОВАНИХ ТА ЛЕГОВАНИХ ІОНАМИ Al I Ga КРИСТАЛІВ $\rm Bi_{12}SiO_{20}$ В ЕЛЕКТРЕТНОМУ СТАНІ

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Резюме

Досліджено зв'язок нелінійності вольт-амперних (ВАХ) і вольт-фарадних характеристик (ВФХ) кристалів Ві₁₂SiO₂₀ з їхнім легуванням іонами Al, Ga та переведенням до термо- і фотоелектретного стану. Отримано залежності показника нелінійності і характеристик петель гістерезису ВАХ і ВФХ від температури поляризації та енергії квантів світла, що фотоактивують поляризацію. Вивчено еволюцію петель гістерезису. При інтерпретації результатів враховано бар'єри Шотткі, обмежену інжекцію з електродів, механізми об'ємно-зарядової і квазідипольної поляризації, відповідальної за формування термо- і фотоелектретних станів.