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RESEARCH ARTICLE

ON THE EFFECT OF ELECTRIC FIELD ON PHOTOCONDUCTIVITY IN n-InSe SINGLE CRYSTALS

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Abstract

In a wide interval of change of the temperature (77÷400 K) and intensity (from extremely weak up to $2.5 \cdot 10^3$ V⁄cm) effect of galvanically applied external electric field on spectral distribution and lux-ampere characteristic of photoconductivity of n-InSe crystals with various (from ~ 10^2 to ~10^8 Ohm·cm) initial (at 77 K) specific resistance (ρ_{T0}).

It is established that contrary to low-resistance ($\rho_{T0} \leq 10^3$ Ohm·cm) crystals, in high-resistance ones ($\rho_{T0} > 10^4$ Ohm·cm) of this semiconductor in low temperature region (T ≤ 250 K) at strong electric fields key parameters and characteristics of the intrinsic photoconductivity changes with voltage.

It is supposed that found out at that dependence of parameters and characteristics of the intrinsic photoconductivity on external electric field is connected with spatial heterogeneity of the studied crystals and an electric ("injection") flattening of fluctuation of the potential relief of free energy zones in them.

INTRODUCTION

Indium selenide (n-InSe) possesses high photosensitivity in a wide range of the optical spectrum (0.35÷1.45 μm) [9] up to 350 K that makes it perspective material for optoelectronics [8]. In early works it was reported about induced by electric field impurity photoelectric phenomena [3, 4] and about dependence of photoconductivity kinetics on electric field [2] in n-InSe crystals. However effect of electric field on other characteristics and photoconductivity parameters in this semiconductor so far were not investigated.

For the purpose of revealing new features of electronic properties and possibilities of practical application of n-InSe in optoelectronics, in the given work we experimentally investigate effect of external electric field of different intensity on its photoconductivity.

2. Samples and experimental procedure

Investigated samples in the form of a plane-parallel plate were cleaved from homogeneous large n-InSe single crystal ingots of rhombohedral structure. Their geometrical dimensions did not exceed 0.30 mm and (5.00x3.00) mm^2 in directions along and perpendicular to "C" axes (perpendicular and along layers) of the crystal, accordingly. As a material for current contacts tin, indium, silver paste and aquadag were used. Samples with various structure (sandwich and planar) and geometry relative to direction of current flow (longitudinal and cross-section) were prepared.

Measurements were carried out at various temperatures (77÷400 K) in a wide range of change of wavelength (λ =0.30÷2.00 μm) and intensity (from extremely weak up to $5 \cdot 10^2$ Lx), intensity of electric field (from extremely weak up to intensity of switching [1]). Curves of spectral distribution (spectrum) and light (lux-current) characteristics (LAC) for studied samples with various initial (at 77 K in the dark) specific resistance (ρ_{T0} = $5\cdot10^2\div5\cdot10^7$ Ohm·cm). Before each measurement for the purpose of deleting the residual phenomena connected with prehistory of the sample samples were exposed to special temperature procedure [2].

3. Experimental results

On the basis of the carried out measurements following results have been established. At weak electric fields a spectrum and LAC of the intrinsic photoconductivity (a photoconductivity excited by light from fundamental absorption region), besides the temperature, appreciably depend also on ρ_{T0} value of studied sample. In low temperature region (T≤ 250 K) and weak light both the value of separate parameters and a course of characteristics (a spectrum and LAC) of the intrinsic photoconductivity for samples with various ρ_{T0} differ. Based on values of these distinctions, it is possible conditionally to divide n-InSe crystals into two groups – low-resistance ($\rho_{T0}\leq10^3$Ohm·cm) and high-resistance ($\rho_{T0}\geq10^4$Ohm·cm). Low-resistance crystals relatively poorly photosensitive, processes of the photo-response relaxation (establishment of stationary value at application of light and disappearance after the termination light exposure) have fast character (it is characterized by time constant $\tau\leq10^{-6}$ s), photoconductivity spectrum has no additional structure, and LAC obey to power law with an exponent $0 \leq \alpha \leq 1$. Contrary to low-resistance crystals, high-resistance ones possess considerably high photosensitivity, processes of a relaxation of the photoconductivity in them have slow character, after light termination high multiple residual photoconductivity is observed [5]. In initial (pre-linear) part of the LAX superliner site (where α sometimes reaches up to 6÷7) exists, the maximum and threshold frequency of the spectrum shifts to longer waves, the spectrum is expanded also owing to displacement of short-wave border to shorter wavelengths. On both branches of the spectrum (both on short-wave, and on long-wave) additional (weak) peaks in the form of a plateau occur, with growth of ρ_{T0} all this specificity of intrinsic photoconductivity amplifies, while with rise of the temperature and intensity of light they gradually disappear. For clearness, as an example on Fig. 1 characteristic curves of spectral distribution (Fig. 1, a) and LAC (Fig. 1, b) for most low-resistance (curve 1) and high-resistance crystals (curve 2) at 77 K are presented.

Also it is established that parameters and characteristics of the intrinsic photoconductivity of low-resistance crystals, under the conditions considered by us do not depend on electric field. However in high-resistance crystals at low temperatures (T) and weak light (Φ), at voltages (U) corresponding to non-linear part of the static the current-voltage characteristics (CVC) where appreciable injection through current contacts in the sample takes place begins to appear dependence of parameters and characteristics of the intrinsic photoconductivity on electric field (E). At identical values E, T and Φ with growth of ρ_{T0} effect of the electric field on photoconductivity becomes more appreciable, and with growth of Φ and increase T it is weakened and at last wholly disappears (parameters and characteristics of photoconductivity of high-resistance crystals almost coincide with those in low-resistance crystals).

On Fig. 2 characteristic curves of spectral distribution (Fig. 2, a) and LAC (Fig. 2, b) for low-resistance (curve 1) and high-resistance (curves 2-4 and 2-6, accordingly) crystals at various intensities of the external electric field.

The measurements carried out by us showed that effect of the electric field on photoconductivity in n-InSe crystals more strongly manifests at $U \geq U_{TFL}$, where U_{TFL} - value of electric voltage at which a full filling of traps in a mode of the space-charge limited currents (SCLC) [10] occurs. In addition, measurements carried out on samples with various current contacts, as well as with various structure and measurement geometry unequivocally testify that in the found out dependence of the intrinsic photoconductivity on external electric field in the investigated semiconductor the defining role plays also injection, since in a case non-galvanic effect of the external electric field on the sample dependence of the photoconductivity on electric field is not observed.

It has appeared that under optimal conditions depending on value of ρ_{T0}, under the effect of the electric field the exponent of pre-linear part of LAC changes in 7÷1 limits, the spectrum maximum shifts from 1.10 to 0.95 μm, the photoconductivity spectrum contracts from 0.30÷1.45 to 0.35÷1.25 μm and its both branches almost smooth out (additional weak-defined maxima on these branches disappear). Effect of the external electric field on intrinsic photoconductivity more strongly manifest itself in those crystals in which also effect of photo-memory is considerable [5].

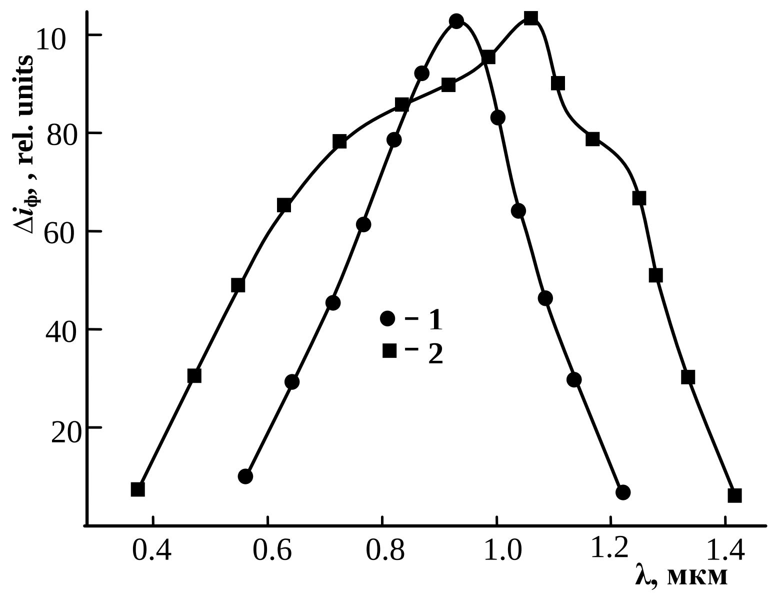
Discussion of the results

Going to discussion of the received experimental results, first of all, it is necessary to notice that the dependences of photoconductivity found out by us on the external electric voltage in n-InSe crystals are not connected with a warming up of free charge carriers by electric field [7] and/or other effects of strong electric field [6]. These dependences cannot be also consequence only changes of interaction of free charge carriers with any dot centers (capture centers, trapping levels, recombination centers, etc.) [11]. In favor of this conclusion unequivocally testify such weighty experimental facts as absence of dependence of photoconductivity on electric field at non-galvanic effect of the electric field with intensities up to ~10^5 V/cm, low (not sufficient for an electric warming up) values of mobility of free charge carriers ($\mu \leq 10$ $cm^2/V \cdot s$) in high-resistance crystals (in which dependence of photoconductivity on external electric field is observed), memory character of the found out changes (after the termination of the effect of strong electric field sometimes duration of the time for restoration of the initial condition of parameters and characteristics reaches few seconds which considerably exceed time constant, characteristic for carrier-dot centre processes [7]).

Detection of the effect of external electric voltage on photoconductivity in materials just possessing photo-memory property (in those crystals which are partially-disordered [5] and non-equilibrium electronic properties are well described on the basis of two-barrier energy model of the semiconductor [12], having in free bands recombination and drift barriers), under conditions of high injection through current contacts, in the region of weak light intensity and low temperatures unequivocally testify that thus a principal cause of difference of the basic characteristics of photoconductivity (LAC and a spectrum) for low-resistance and high-resistance crystals is spatial heterogeneity (partial disordering) of the high-resistance crystals. Owing to what in them besides direct inter-band, under certain conditions takes place also inter-band excitation of the intrinsic photoconductivity facilitated by tunneling through recombination barriers. Apparently that particular component of photoconductivity causes displacement of a maximum and long-wave limit of its spectrum to shorter wavelengths, and arisen in near-surface layer recombination barriers lead, first, to spectrum expansion to longer waves, secondly, to occurrence additional weak defined maximum on a short-wave branch of the spectrum. Within a framework of this model it is supposed that at higher galvanically applied external voltages where considerable injection through current contacts takes place, the injected carriers partially compensating volume charges on borders of recombination barriers, reduce their effect on photoconductivity and at such voltages high-resistance crystals on the photoelectric properties come nearer to low-resistance ones. Therefore with growth of U the exponent on pre-linear part of LAC gradually decreases, the photoconductivity spectrum is narrowed, its maximum shifts to short-wave side, and additional peaks on its both shoulders disappear. In favor of the offered model testifies also dependences of the spectrum and LAC of photoconductivity on value of initial specific resistance, on effect of the electric field on them in the investigated high-resistance crystals at low temperatures and weak light intensities. Most likely, at high temperatures and high light intensities the electric flattening of free bands (an electric flattening of the free band potential fluctuation) is replaced by a temperature or light flattening.

Signatures to drawings

Fig. 1, a. Spectral distribution of the intrinsic photoconductivity in n-InSe crystals with various initial specific resistances.



ρ_{TO}, Ohm·cm: 1 - $5{\cdot}10^2$; 2 - $5{\cdot}10^7$; T = 77 K; E = 50 V⁄cm; $\Phi = 0.1\Phi_м$

Fig. 1, b. Light (lux-ampere) characteristic of the intrinsic photoconductivity in n-InSe crystals.
T = 77 K; E = 50 V/cm; $\lambda = \lambda_m$

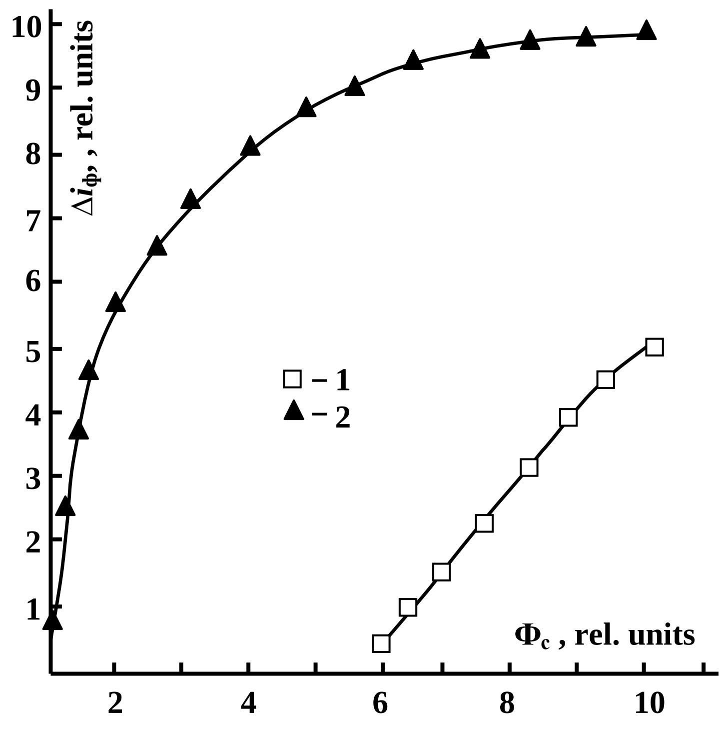


Fig. 2, a. Spectral distribution of the intrinsic photoconductivity of low-resistance (curve 1) and high-resistance n-InSe crystals (curves 2-4) at various intensities of electric field.
T = 77 K; $\Phi = 0.1\Phi_m$; E, V⁄cm: 1, 2 - 50; 3 - 800; 4 - 1500.

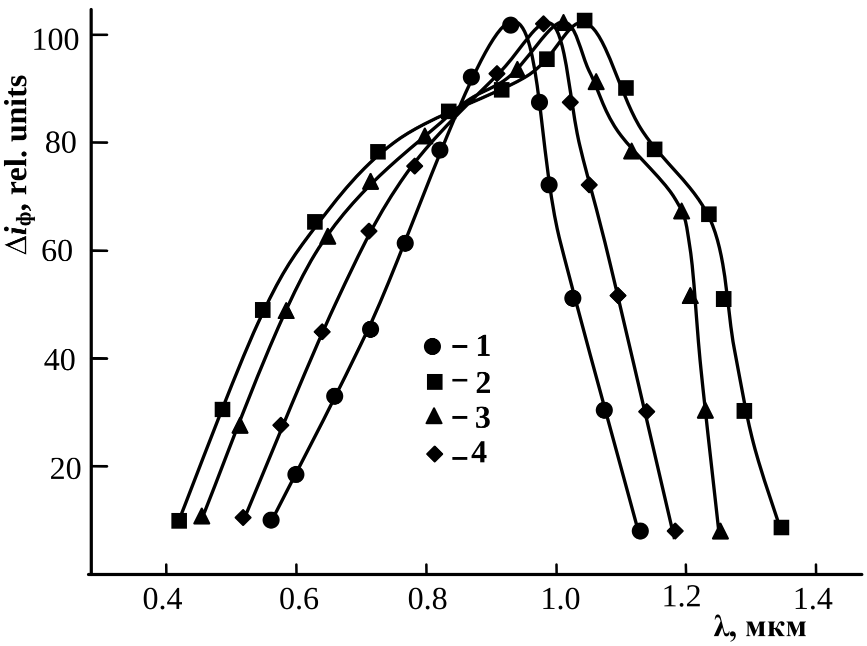
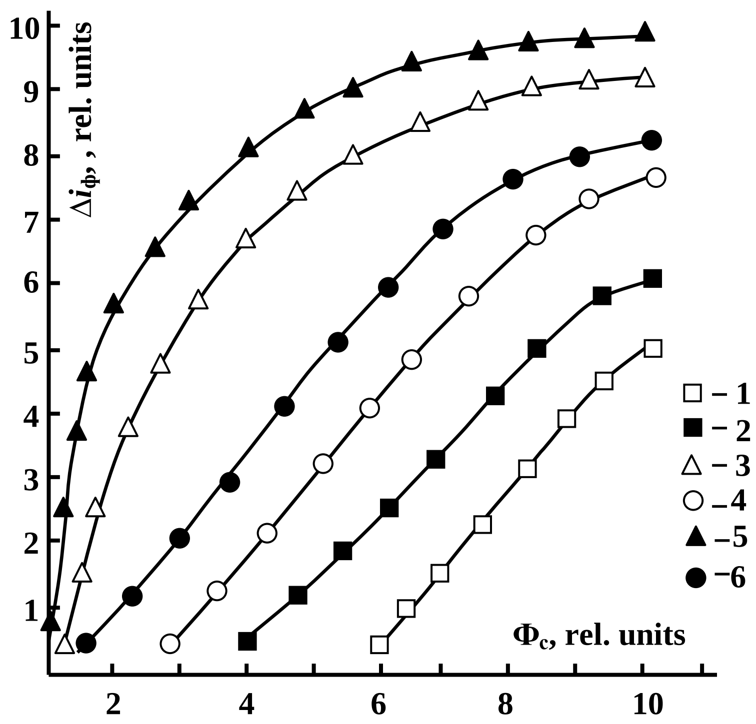


Fig. 2, b. Light (lux-ampere) characteristic of the intrinsic photoconductivity of low-resistance (curve 1) and high-resistance n-InSe crystals (curves 2-4) at various intensities of electric field.



T = 77 K; $\lambda = \lambda_m$
E, V⁄cm: 1, 2 - 50; 3 - 800; 4 - 1500.

Conclusion

Thus, it is possible to conclude that effect of galvanically applied external electric field on photoconductivity of high-resistance n-InSe crystals is not connected with electric warming up of the charge carriers and/or other effects of a strong field, and directly associated with spatial heterogeneity of samples of these crystals and electric flattening of free band potential fluctuation at high injection levels through current contacts.

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