PHOTOCONDUCTIVITY OF INDIUM MONOSELENIDE CRYSTALS IN STRONG ELECTRIC FIELDS

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The influence of an external constant electric field on the spectral distribution and lux-ampere characteristic of the photoconductivity of indium monoselenide crystals with different (from ~$2\cdot10^3$ to $2\cdot10^6$ Ohm·cm) initial resistivity (ρ_0) at 77K is studied in the temperature range of 77-350 K at the electric field intensities from the extremely weak up to ~$2.5\cdot10^3$ V/cm

It has been established that for the crystals of this semiconductor in the region T <250 K at electric fields corresponding to the superlinear portion of the static current-voltage characteristic the main parameters and characteristics of the photoconductivity depend on the electric field intensity. It is supposed that found out at that dependence of parameters and characteristics of the photoconductivity on electric field is connected with spatial heterogeneity of the studied crystals and an electric flattening of the potential relief of the fluctuation of free energy zones in them.

Keywords: photoconductivity, single crystal, contact material, electric field, spectrum, light characteristic, injection, current-voltage characteristic.
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1. INTRODUCTION

Indium monoselenide (InSe) single crystals possesses high photosensitivity in a wide range of the optical spectrum (0.35÷1.45 μm) [1] up to 350K that makes it perspective material for optoelectronics [2]. Although this semiconductor photoconductivity is studied for a long time [3-6], but not paid due attention to its dependence on the electric field. Proceeding from this, in this work we experimentally investigated the photoconductivity of indium monoselenide crystals in strong electric fields.

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, which were grown by a modified Bridgman method [7]. Their geometrical dimensions did not exceed 0.30mm 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 temperatures 77÷350K in the range of change of wavelength λ=0.30÷2.00 μm and intensity $\Phi \leq 5\cdot10^2$ Lx). Intensity of electric field was changed from extremely weak up to intensity of switching [8]. Curves of spectral distribution (spectrum) and light characteristics (LC) for studied samples with various initial (at 77 K in the dark) specific resistance (ρ_0=$2\cdot10^3$-$2\cdot10^6$ Ohm·cm). Before each measurement for the purpose of deleting the residual phenomena connected with prehistory of the samples, samples were exposed to special temperature procedure [9].

3. EXPERIMENTAL RESULTS

On the basis of the carried out by us measurements it is established that at weak electric fields a spectrum and LC 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 the temperature region $T \leq 250$ K and weak light both the value of separate parameters and a course of characteristics (a spectrum and LC) 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 ($\rho_0 \leq 10^3$ Ohm·cm) and high-resistance ($\rho_0 \geq 10^4$ 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 characterised by time constant $\tau \leq 10^{-6}$ s), photoconductivity spectrum has no additional structure, LC obey to power law with an exponent $0 \leq \alpha \leq 1$, the parameters and characteristics of the intrinsic photoconductivity under the conditions considered by us do not depend on the electric field.

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 [9]. In initial part of the LC superlinear site (where α sometimes reaches up to 6÷7) exists, the maximum and threshold frequency of

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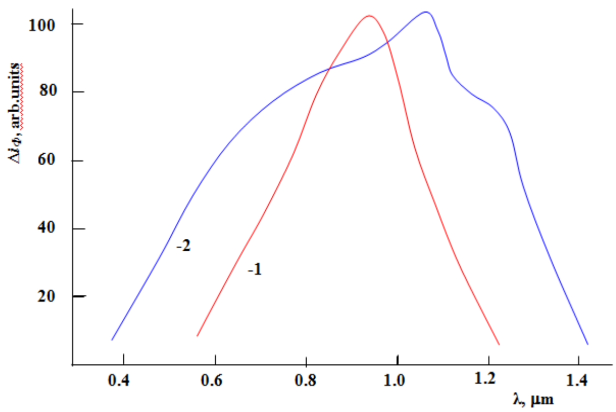
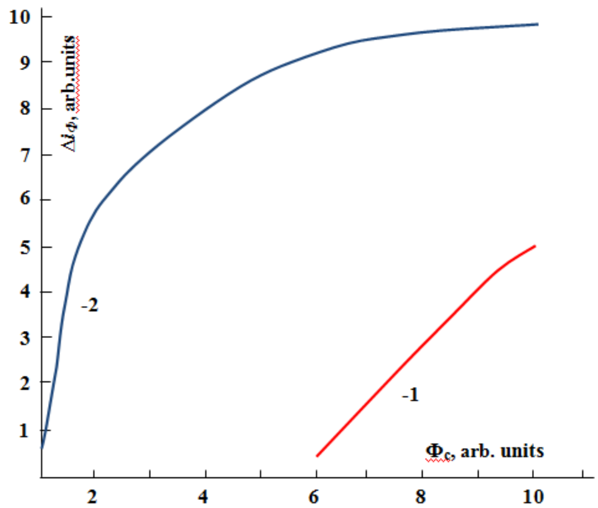
the spectrum shifts to longer waves, the spectrum is expanded also owing to displacement of short-wave border to shorter wavelengths. On both branches of the spectrum (both on short-wave, and on long-wave) additional peaks occur, with growth of ρ_{T0} all this specificity of intrinsic photoconductivity amplifies, and with rise of the temperature and intensity of light they gradually disappear (Fig. 1).



a)

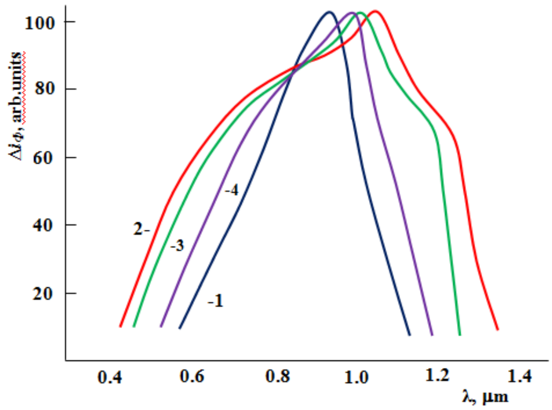


b)

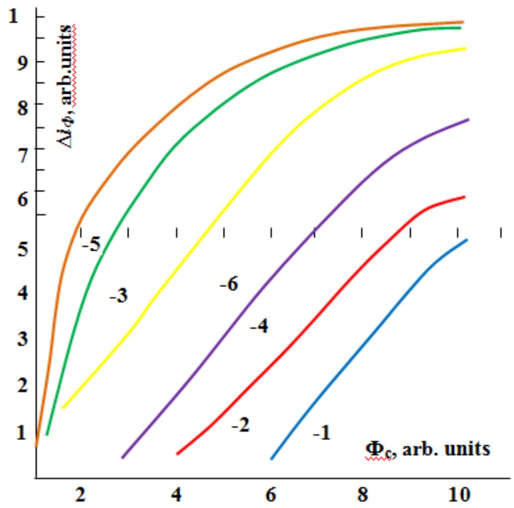
Fig. 1. Spectral distribution (a) and light (lux-ampere) characteristic (b) of the photoconductivity in n-InSe crystals with different initial specific resistance (ρ_O) at weak electric fields. ρ_O, Ohm·cm: 1 - 2·10^3; 2 - 2·10^6; *T*=77 K;б: λ= λ_M; E =50 V⁄cm; *a:* Φ=0.1Φ_M, *b:* λ= λ_M .

However in high-resistance crystals in the region of low temperatures and weak illuminations 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). With growth of ρ_0 effect of the electric field on photoconductivity becomes more appreciable, and with growth of Φ and increase of *T* it is weakened and at last wholly disappears.

On Fig.2 characteristic curves of spectral distribution (a) and lux-ampere characteristics (b) for n-InSe crystals with different initial specific resistances (ρ_O) at different E are shown.



a)



b)

Fig. 2. Spectral distribution (a) and light (lux-ampere) characteristic (b) of the photoconductivity of n-InSe crystals with different initial specific resistance (ρ_O) at various intensities of the electric field. *T*=77 K; ρ_O, Ohm·cm: 1 - 2·10^3; 2, 3, 4 - 2·10^6; Φ=0.1;Φ_M; E, V⁄cm: 1, 2 – 50; 3 – 800; 4 – 1500.

It is established that effect of the electric field on photoconductivity in n-InSe crystals more strongly manifests at U≥U_{TFL}, where U_{TFL} – the 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 defining role plays also an 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_0, under the effect of the electric field the exponent of pre-linear part of LC changes in

7÷1 limits, the spectrum maximum shifts from 1.10 to 0.95μm, the photoconductivity spectrum narrows from 0.30÷1.45 to 0.35÷1.25 μm and additional maxima on it are not observed. 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 [9].

4. 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 [11] and/or other effects of strong electric field [12]. 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.) [13]. 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 ~10^4 V/cm, low (far from sufficient for warming up) values of mobility of free charge carriers ($\mu \leq 10$ cm^2/V·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 [13]).

Detection of the effect of external electric voltage on photoconductivity in materials just possessing photo-memory property (in those crystals which are partially-disordered [9] and non-equilibrium electronic properties are well described on the basis of two-barrier energy model of the semiconductor [14], having recombination and drift barriers in free bands), 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 for low-resistance and high-resistance crystals is 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 assisted by tunneling through recombination barriers. Apparently it is this 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 LC gradually decreases, the photoconductivity spectrum narrows, its maximum shifts to short-wave side, and additional peaks on its both shoulders disappear. In favor of the offered model testify also dependences of the spectrum and LC of photoconductivity on ρ_0, detecting their dependence on electric field intensity only at low T and Φ. Most likely, at high T and Φ an electric flattening of the free band potential fluctuation is replaced by a temperature or light flattening.

5. CONCLUSION

Thus, it is possible to conclude that effect of galvanically applied external electric field of high intensity 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, but is directly due to the partial disorder of these crystals and an electric flattening of free band potential fluctuation at high injection levels through current contacts.

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