Photoconductivity anisotropy of indium monoselenide at high optical excitation levels

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The photoconductivity anisotropy of indium monoselenide was investigated at high optical excitation levels, and a method for determining the height of the energy barrier in the parallel direction to the optical c axis is proposed.

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Because of a unique layered structure, the type $A^{III}B^{VI}$ semiconductor compounds have a high degree of mobility anisotropy caused by the energy barrier in the perpendicular direction to the layers (c axis). This property of the crystal is usually investigated by means of electrical measurements. This method, which is often unsuitable because of the high resistance of the examined compounds, cannot explain the nature of the barriers.

These difficulties can be eliminated, however, by using a high optical excitation level when it is possible to control the barrier height due to light doping up to degeneracy; this is the subject of the present paper. We used a ruby laser operating in the Q-switched mode ($\hbar\omega = 1.79$ eV, $t_{pul} = 5 \times 10^{-8}$ sec, $I_{max} \approx 10^{26}$ kV·cm^{-2} sec^{-1}), where quantum energy greatly exceeded the forbidden-band gap of the investigated n-InSe crystals ($E_g \approx 1.28$ eV) with a charge-carrier density of 10^{14} cm^{-3} at 300 K. The results of Hall measurements showed that the electrons dominate in the photoconductivity as a result of weak and strong illumination.

The lux-ampere characteristic (AC) of photoconductivity at a temperature of 300 K is shown in Fig. 1. Curves a and b correspond to the case when the applied electric field ϵ is directed parallel and perpendicular to the c axis.

A study of the photoconductivity kinetics showed that when the light intensity is I greater than $\sim 5 \times 10^{22}$ kV·cm^{-2} sec^{-1} a stationary density of nonequilibrium carriers is established in both cases during the light pulse (i.e., $t_{pul} > \tau$, where τ is the lifetime), and a $\Delta\sigma \sim I^{1/3}$ dependence is observed. Since surface recombination in the compounds is negligible,[1] this dependence makes it possible to assume that the band-band Auger recombination[2] is dominant in the recombination.

At $I \lesssim 5 \times 10^{22}$ kV·cm^{-2} sec^{-1} the stationary density cannot be established during the light pulse (i.e., $t_{pul} < \tau$) and the LAC is strongly dependent on the direction of the applied field. When $\epsilon \perp c$ (curve b), a $\Delta\sigma \sim I$ dependence is observed and when $\epsilon \| c$ (curve a) such linear dependence exists only to $I_1 \approx 10^{22}$ kV·cm^{-2} sec^{-1}. A stronger dependence, $\Delta\sigma \sim I^{2.5}$ is observed, in the range of intensity $I_1 \lesssim I \lesssim I_2 (I_2 \approx 3.5 \times 10^{22}$ kV·cm^{-2} sec^{-1}). Since the recombination in this region does not have a strong effect on the photoconductivity, the observed LAC peculiarity can be explained by the

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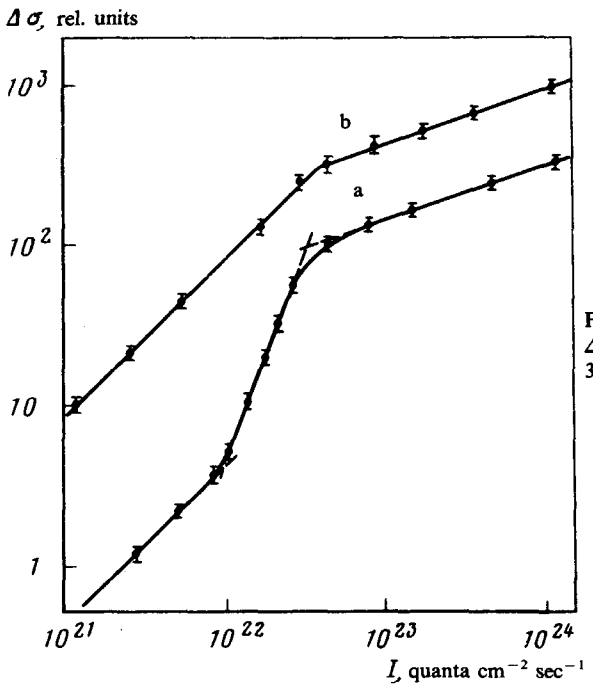

FIG. 1. Dependence of photoconductivity $\Delta\sigma$ on the light intensity of a ruby laser at 300 K: a—$\epsilon \| c$, b—$\epsilon \perp c$.

effect of the energy barrier on the mobility of nonequilibrium carriers. In fact the photocurrent is determined in the presence of the barrier by those carriers which are activated at the height of the equilibrium barrier ΔE_0. The nonequilibrium carrier density Δn increases with increasing excitation level, and the semiconductor begins to degenerate due to light doping after a certain density Δn, which is determined by the condition $\Delta n \approx N_c$ (N_c is the effective density of states), is reached.

A further increase of the excitation level causes the Fermi quasi level to shift within the bands, which in turn reduces the activation energy ΔE of the charge carriers. The photoconductivity in this case can be described as follows:

$$\Delta\sigma(I) = e\mu_0 \Delta n(I) e^{-\frac{\Delta E(I)}{kT}} = e\mu_0 \Delta n(I) e^{-\frac{\Delta E_0 - \xi_n(I)}{kT}}, \quad (1)$$

where μ_0 is the mobility in the absence of a barrier and XI ξ_n is the Fermi quasi level that was measured from the bottom of the conduction band.

The calculations show that Eq. 1 describes the LAC satisfactorily in this region. Since this region, according to Eq. (1), is determined by the condition $0 \lesssim \xi_n \lesssim \Delta E_0$, the photoconductivity LAC makes it possible to determine the equilibrium barrier height ΔE_0 by using the equation

$$\Delta E_0 = kT \ln\left[\frac{\Delta\sigma_2}{\Delta\sigma_1}\left(\frac{I_1}{I_2}\right)^a\right], \quad (2)$$

where $\Delta\sigma_1$ and $\Delta\sigma_2$ are the photoconductivities produced at I_1 and I_2, respectively, and α is the exponent of the dependence $\Delta n \sim I^{\alpha}$, which is equal to unity when $T_{\text{pul}} < \tau$. Estimates showed that $\Delta E_0 \approx 50$ meV. Since these barriers cannot be eliminated by shielding the nonequilibrium carriers up to degeneracy ($\Delta n \sim 10^{18}$ cm^{-3}), we can assume that they are not associated with nonuniform distribution of impurities or defects. In particular, as shown in Ref. 3, they may be caused by disordered packing that occurs in the layered materials.

In conclusion, we note that photoconductivity at high excitation levels can account for the anisotropy of other similar materials.

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