Spectra and kinetics of impurity photoconductivity of indium-doped solid solutions $Pb_{1-x}Ge_xTe$

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The spectra and kinetics of impurity photoconductivity (PC) in $Pb_{1-x}Ge_xTe$: In ($x = 0.08$–0.12) are investigated. At $T < 16$ K a negative PC is observed for $\hbar\omega \lesssim 0.1$ eV. The energies of optical ionization of levels are determined and they are compared with data from electrical measurements.

Many experimental and theoretical papers on the unusual photoelectrical phenomena in solid solutions based on PbTe doped with indium.[1–8] In spite of the high photosensitivity of doped specimens noted in Refs. 1 and 2, their PC spectra have not yet been investigated. In this work we studied directly the spectra and kinetics of impurity PC of high-resistance specimens of $Pb_{1-x}Ge_xTe$ doped with In.

Single crystals of $Pb_{1-x}Ge_xTe$ ($x = 0.08$–0.12) were grown by the method of sublimation and doped with indium (1 mol % InTe) during the growth process. The

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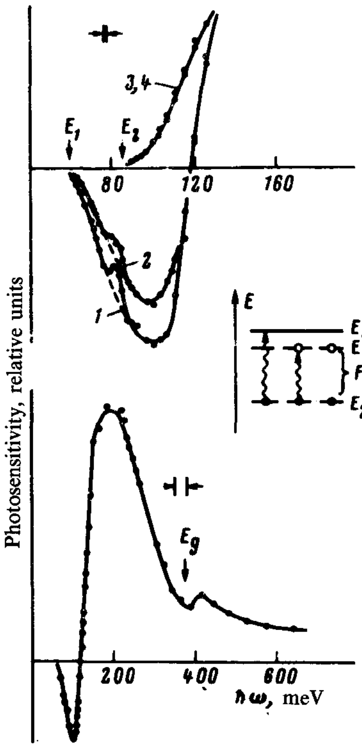

FIG. 1. Bottom: PC spectrum of $Pb_{0.88}Ge_{0.12}Te$ at 5 K. The width of the forbidden band E_g is determined from the spectrum of the photoelectric effect. Top: Long-wavelength part of the PC spectra of the same specimen at the following temperatures: 1) 5, 2) 12, 3) 23, and 4) 29 K.

PC spectra were investigated on a spectrometer with NaCl and KBr prisms with illumination of the specimen by a background with a temperature of 300 K.

The dark resistivity of the specimens depended exponentially on the temperature with activation energy 23–60 meV. Under the conditions of the background illumination, as the temperature decreased the resistance increased, passed through a maximum at $T \sim 30$ K, and then again decreased due to PC stimulated by the illumination. Figure 1 shows the PC spectrum of $Pb_{0.88}Ge_{0.12}Te$ at 5 K and, in greater detail, the long-wavelength part of the spectra at different temperatures. For quantum energies lower than E_g, strong impurity PC extending up to energies 60–85 meV is observed. Since the specimens are strongly doped with indium, it is natural to associate the impurity PC with the appearance of local In levels. At $T = 5$, the sign of the PC signal changes ["negative PC (NPC)] in the PC spectra of all specimens for $\hbar\omega < \hbar\omega_0$. This change is caused by the extinction of PC stimulated by the impurity background illumination. (The PC spectra coincided in cases when the radiation and background were incident on the specimen through the Ge and InSb windows cooled down to 5 K, in the last case the transmission limit lies at ~ 0.23 eV $< E_g$ $(Pb_{1-x}Ge_xTe) = 0.32$–0.38 eV.) The quantity $\hbar\omega_0$ was virtually independent of x and varied from 106 to 118 meV with an increase in the level of illumination and decrease of the thickness of the

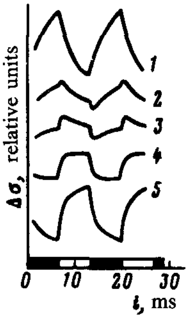

FIG. 2. Kinetics of the PC signal with excitation of a $Pb_{0.88}Ge_{0.12}Te$: In specimen by impurity light with energy 110.5 (1), 117.5 (2), 119 (3), 121 (4), and 123 (5) meV. $T = 5$ K.

specimen. At $T > 16$ K, NPC disappears and only positive PC is observed. The red boundary in the NPC spectrum depends weakly on x, varying from $E_1 = 69$ meV ($x = 0.08$) to 59 meV ($x = 0.12$). The position of the edge of positive PC does not depend on x and amounts to $E_2 = 85$ meV; an increase in x leads only to "smoothing" of the long-wavelength edge of the spectrum. The appreciable difference in the red boundaries E_1 and E_2 in PC spectra indicates the presence of two types of optical transitions in the system.

The latter is also confirmed by investigations of the spectral kinetics of PC (Fig. 2). When specimens are excited by light with $\hbar\omega < 100$ meV, a slow, "negative," nonexponential relaxation of the PC signal is observed. The shape of the PC signal changes sharply in the interval $\hbar\omega = 110$–123 meV; for $\hbar\omega > 123$ meV the positive PC signal rises and falls off with a characteristic time ~ 3 ms (5 K), which is independent of $\hbar\omega$, but decreases with increasing temperature or intensity of the illumination.

The impurity PC with a red boundary of about 85 meV, which leads to an increase in the electron density, is apparently related to photoionization of the In level. The appearance of long-wavelength NPC indicates the presence, aside from the ground level, of one more local level. There are several possible explanations for NPC. The most probable appears to us to be optical transitions between two local states of the impurity In, for which the degree of filling of the lower (recombination) level drops and the electrons excited by the background illumination begin to recombine more rapidly (insert in Fig. 1). In order for the NPC to be observed, the upper level must hold on to the excited carrier for a long enough period of time. The other possible explanation of NPC—the appearance of an acceptor level at a distance $\approx E_1$ from the edge of the valence band—appears to us to be less probable. Confirmation of this explanation could be the appearance of the PEM effect, which has not been observed, apparently because of the short lifetime of holes.

A rather sharp edge of the PC spectra, especially E_1, indicates that the electron-phonon interaction plays a small role in the formation of the spectrum. For this reason, it may be assumed that the optical and thermal ionization energies are nearly equal. If the scheme of electronic transitions shown in Fig. 1 is followed, then the lower level of In lies ~ 85 meV below the edge of the conduction band, the second level lies at a distance $E_3 = E_2 - E_1 \sim 15$–25 meV from the edge of the band, and the

Fermi level is located between them. The absence of PC in which the limiting energy coincides with the position of the Fermi level appears to support the model in Ref. 8; however the strong motion of the Fermi level with composition x with essentially constant E_2 and E_3 creates difficulties with the interpretation based on this model.

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