The effect of indium impurities on the photoluminescence of $Pb_{1-x}Sn_xTe$ at high excitation levels

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(Submitted 11 June 1980)
Pis'ma Zh. Eksp. Teor. Fiz **32**, No. 2, 132–135 (20 July 1980)

We have discovered that at high excitation levels in $Pb_{1-x}Sn_xTe$:In there is a wide, x-independent band in the photoluminescence spectrum with an energy at the maximum that substantially exceeds E_g ($\hbar\omega^* \approx 230$ meV at 80 K). We discuss the possibility that the excited levels of the indium impurity have an effect on the occurence of this band.

PACS numbers: 78.55.Hx, 81.15.Ef, 61.70.Tm

Both the first communication on PbTe:In (Ref. 1) and a number of subsequent papers (Refs. 2–6) describe unusual properites of $Pb_{1-x}Sn_xTe$:In which are manifested in galvanomagnetic effects and transient photoconductivity at low temperatures. In this letter we present the results of an investigation of the photoluminescence spectra of $Pb_{1-x}Sn_xTe$:In at high excitation levels for temperatures between 20 and 180 K.

Epitaxial films of $Pb_{1-x}Sn_xTe$ ($x = 0$–0.22) were obtained by instantaneous ba-

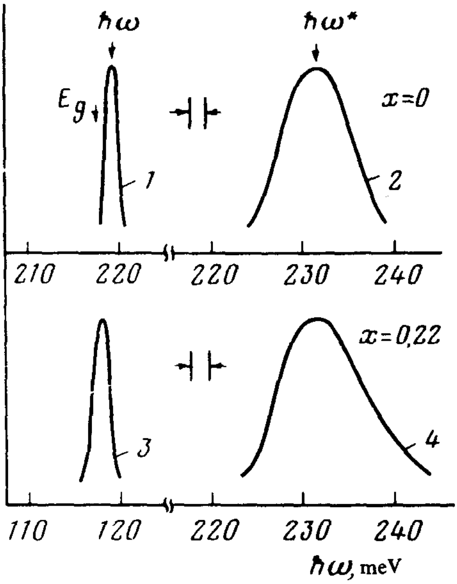

FIG. 1. Photoluminscence spectra of $Pb_{1-x}Sn_xTe$ for samples with (2, 4) and without (1, 3) indium impurities; the solid lines indicate $T = 87$ K; indium content 0.1%.

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cuum evaporation onto a substrate of BaF_2 (Ref. 2) and doped with In (0.005–0.2 at.%). The parameter x was fixed by the ratio of the components during the growing process. The photoluminescence was investigated for excitation by a neodymium laser ($\hbar\omega_{\text{exc}} = 1.17$ eV, $W = 10^5$–10^6 W/cm^2) by the method described in Refs. 7 and 8 , using $Cd_{1-x}Hg_xTe$ and Ge:Au photodetectors.

Figure 1 shows the luminescence spectra of indium-doped and undoped samples. In all twelve of the indium-doped samples a spectral band with a maximum at $\hbar\omega^* \approx 230$ meV (80 K) was observed. The position of the maximum was almost independent of x, but it was shifted upward by 5 or 6 meV as the indium content was increased. When the temperature was raised above ~50 K, the band shifted by approximately the width of the band gap E_g, with $\partial(\hbar\omega^*)/\partial T \approx 0.6$ meV/K. The band width was $\lesssim 12$ meV at 80 K. Sometimes this band was distorted by absorption of ambient radiation. In the samples without indium impurities the position of the maximum $\hbar\omega$ changed regularly with composition; the photoluminescence line was located 3 to 10 meV above E_g and corresponded to a narrow stimulated-emmission line.

Figure 2 shows the change in the spectra for one of the $Pb_{1-x}Sn_xTe$:In films as the temperature was raised. At low temperatures both low-energy stimulated-emission

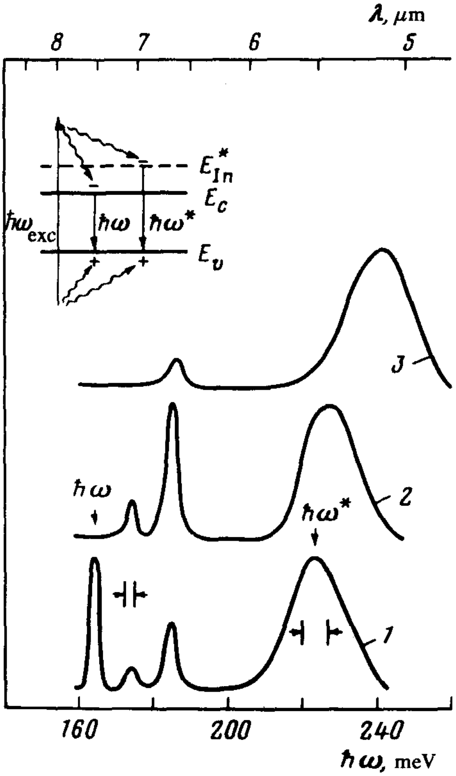

FIG. 2. Change in photoluminescence spectra of $Pb_{1-x}Sn_xTe$:In as the temperature is increased ($x \approx 0.22$, 0.1% In). The inset shows the energy diagram of the electronic transitions.

lines $\hbar\omega^*$ were observed simultaneously. The stimulated-emission lines behaved like laser modes, falling off with increasing T in proportion to the difference between the energy of the mode and the gap energy E_g. The relative intensity of the modes depended strongly on the level of excitation. Figure 3 shows the temperature dependence of the position of the lines. The $\hbar\omega^*$ band in the samples containing indium were dominant above ~90 K and were observed all the way up to ~180 K.

Particular attention should be paid to the wide spectral interval in which the luminescence band was observed: more than 70 meV for the sample shown in Figs. 2 and 3, i.e., more than half the gap width E_g. This suggests that hot carriers take part in the radiative recombination under these conditions of excitation. In experiments on the electroluminescence of $Pb_{1-x}Sn_xTe$:In in heterojunctions,[9] no spectra of this type were reported.

Our results can be explained by the existence of a quasilocal energy level at the indium impurity, E^*_{In}, located above the edge of the conduction band (inset in Fig. 2). This level differs from the ground-state level of indium, which is responsible for the galvanomagnetic effects in $Pb_{1-x}Sn_xTe$:In. The laser-excited hot electrons do not have time to thermalize before being captured by indium atoms and recombining with holes. These holes can be either free or localized at the indium atoms. Some of the

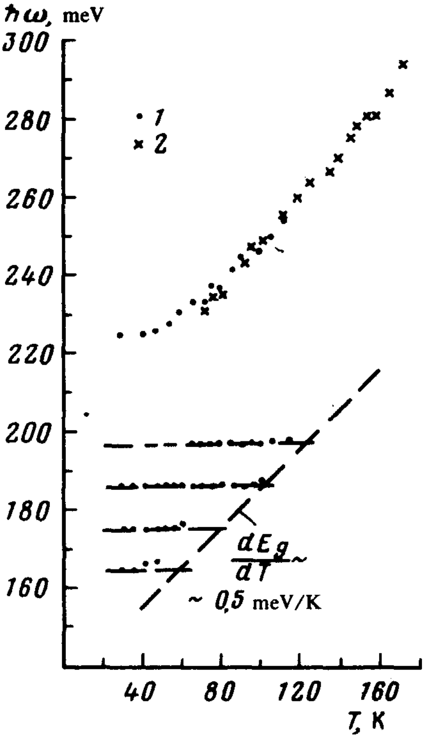

FIG. 3. Temperature dependence of the position of the spectral maxima of $Pb_{1-x}Sn_xTe$:In. 1—0.15 In, 2—0.2% In; $x \approx 0.22$.

electrons from the conduction band recombine immediately with holes, causing a fringe band. Such a situation is possible if the time required for equilibrium between the indium states and the band is substantially longer than the time for recombination from these states. In our experiments, the decay time of the luminescence was limited instrumentally and was $\lesssim 10^{-7}$ sec.

The optical transitions that are observed can in principle be explained by models variously featuring the recombination of electron-hole pairs at In^{2+} atoms, electron at In^{3+} ions, and holes at In^{+} ions. The composition independence of the $\hbar\omega^*$ band, its temperature dependence, and the ambiguity of the information on the charge state of the indium impurity in equilibrium make it difficult to interpret these transitions definitively in terms of one of these models.

The authors wish to thank I. A. Drabkin, N. B. Brandt, B. A. Akimov, and L. I. Ryabova for helpful discussions.

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