# Characteristics of transfer phenomena in $Pb_{0.78}Sn_{0.22}Te$ with a large indium content

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New phenomena were observed in $Pb_{0.78}Sn_{0.22}Te$ with a high concentration of indium at $T \lesssim 20$ K. These include very high photosensitivity and anomalous variation of mobility with temperature which are, evidently, associated with a phase transition.

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The hard solutions $Pb_{1-x}Sn_xTe$ and PbTe have recently become the subject of intensive studies. Of special interest is a change in their properties when doped with indium.[1-5]

In this article we report on preliminary results of investigations of the compound $Pb_{0.78}Sn_{0.22}Te$ doped, for the first time, with indium to 2.7 at%. Indium was injected into the original compound during diffusion from the gas phase.[6] Measurements were made on several tens of samples. Typical characteristics are presented for five of these.

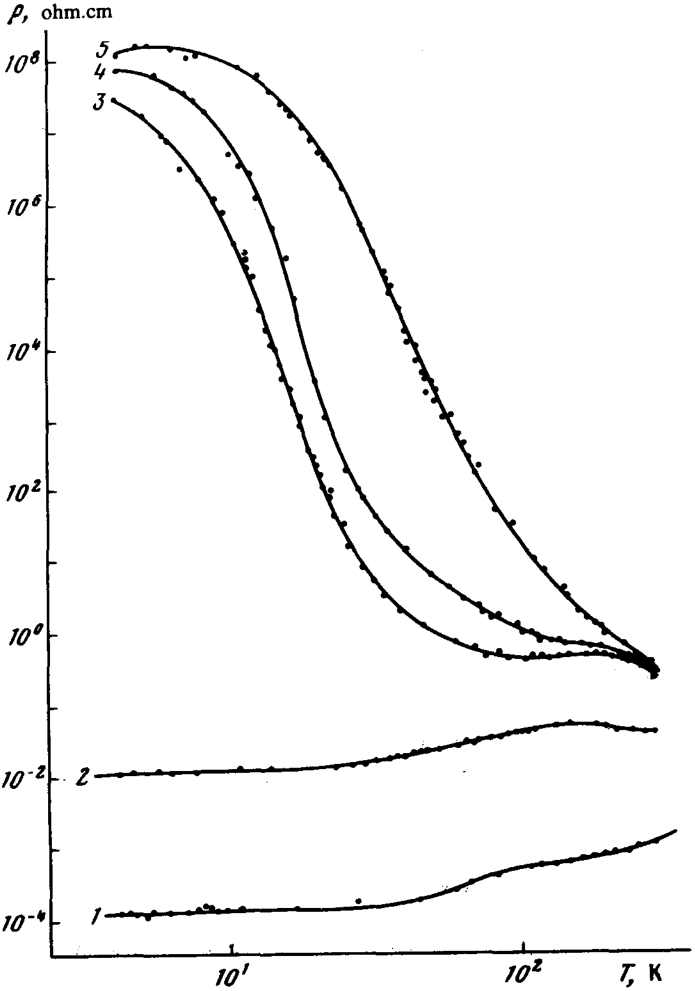

FIG. 1. Temperature functions of resistivity for In-doped $Pb_{0.78}Sn_{0.22}Te$ single crystals and films. Sample numbers correspond to curve numbers: 1—$C_{In}$ = 0.01 at%, *p*-type single crystal; 2—$C_{In}$ = 0.4 at%, *n*-type films; 3—$C_{In}$ = 0.74 at%, *n*-type single crystal; 4—$C_{In}$ = 0.97 at%, *n*-type single crystal; 5—$C_{In}$ = 2.7 at%, *n*-type film.

Figure 1 shows the temperature dependence of resistivity $\rho(T)$ for two groups of samples—with indium concentration $C_{In} \leqslant 0.4$ at% and $C_{In} > 0.7$ at%. Figure 1 show qualitative differences between the functions $\rho(T)$ for the two groups. Resistivity falls slightly when the temperature decreases from 300 to 4.2 K in samples with a lower In content (curves *1* and *2*), while it increases by 7–8 orders of magnitude in samples with a large In concentration (curves *3–5*).

We established in the course of measurements that samples with increased In concentrations are highly photosensitive at low temperatures. Thus, for instance, $\rho_T/\rho_C \gtrsim 10^{10}$ for sample 4 at $T = 4.2$ K, where $\rho_T$ is resistivity measured in the dark (point $B$ in Fig. 2) and $\rho_C$ (point $A$ in Fig. 2) is the resistivity of sample illuminated through the walls by 40-W incandescent lamp placed 10–20 cm from the sample. We failed to establish the longwave photosensitivity threshold, instead, we determined that it may be found at wavelengths $\lambda > 5\ \mu$m.

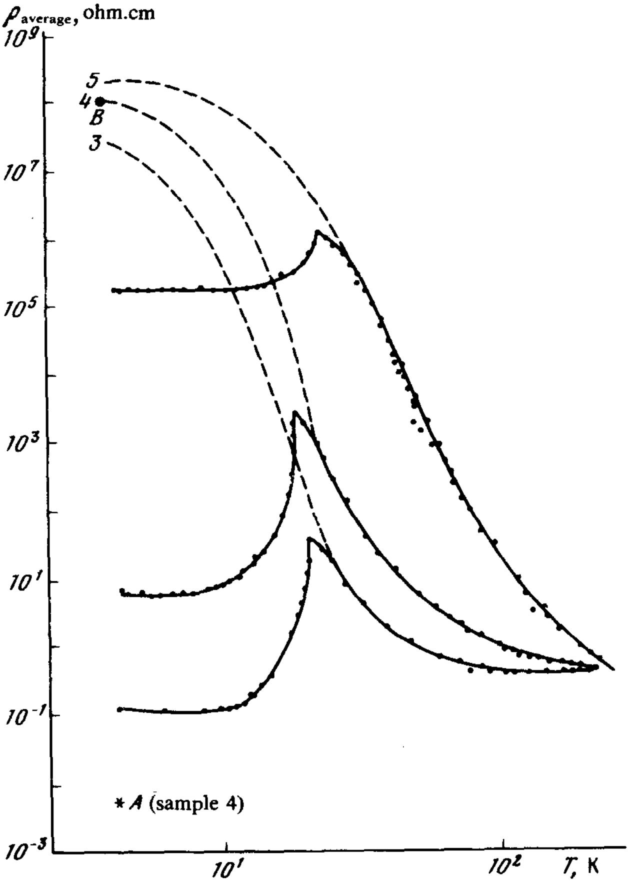

FIG. 2. Temperature functions of resistivity for sample 3–5 illuminated with white light. Dashed curves—without illumination.

The dependence of resistivity on the temperature at a constant illumination of samples by a white light of approximately the same intensity is shown in Fig. 2. A sharp resistivity maximum is observed at ~20 K. Above that temperature, $\rho_C(T)$ appears to follow the function $\rho_T(T)$ with which it subsequently converges, i.e., photosensitivity in this region is nonexistent. This type of temperature dependence is observed both for samples picked from various ingots and for films grown by the method of photostimulated epitaxy.

Photosensitivity of samples 3 and 4 is sufficiently high to permit temperature measurements with a total screening of the samples from the external radiation, including background radiation from components of a cryostat whose temperature is higher than that of a crystal. In these samples, a residual photoconductivity was observed[7]: samples retained a high conductivity long after the light was switched off. To return the samples to a high-resistance state required heating above 20 K and a subsequent cooling or application of an electric field with the intensity $E \geqslant E_{\min}$ ($E_{\min} \sim 40$ W/cm for sample 3).

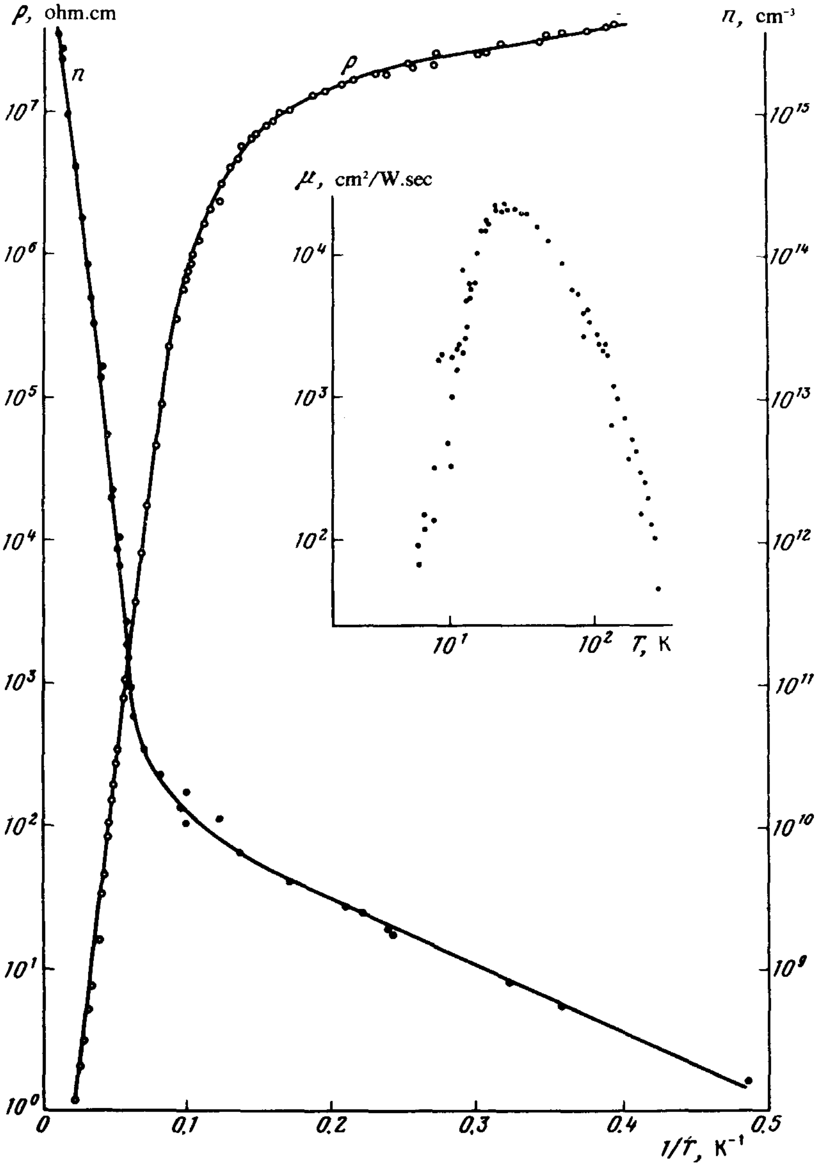

FIG. 3. Temperature functions of resistivity, electron concentration, and electron mobility for sample 3.

The occurrence of photosensitivity and its sharp increase with decreasing temperature below 20 K also coincides with changes in the activation energy and mobility, as seen from the temperature functions $\rho = f(1/T)$, electron concentration $n = f(1/T)$, and mobility $\mu = f(T)$, all shown in Fig. 3 for sample 3. Below 20 K, the absolute values of $\rho$ and $n$ may vary somewhat from experiment to experiment; however, their dependence on the temperature always remains the same.

The function $\mu(T)$—shown as an inset in Fig. 3—has a well-defined maximum. With the temperature decreasing from 20 to ~8 K, the mobility varies (decreases by more than two orders) as $\mu \sim T^6$, a fact which cannot be explained in terms of impurity scattering. At higher temperatures $\mu \sim T^{-3}$ a fact that may be attributed to optical phonon scattering.

A comparison of the functions $\rho(1/T)$ and $n(1/T)$ shows that an increase in the resistance in the temperature range $300 > T > 20$ K depends on a decrease in the electron concentration. The temperature dependence of the Hall constant reveals the presence of deep levels with activation energies of 14, 19, and 30 MeV for the samples 3,4 and 5, respectively, with the corresponding indium concentrations of 0.74, 0.97 and 2.7 at%.

The special features of the galvanomagnetic and photoelectric properties of the compound in question are cearly associted with the occurrence of a phase transition in the compound at $T < 20$ K. The existence at this temperature of a phase transition in compounds with a similar composition was also predicted on the basis of observed changes in the permittivity,[8] susceptibility,[9] and mobility.[4]

[1] V.I. Kaĭdanov, R.B. Mel'nik, and I.A. Chernik, Fiz. Tekh. Poluprovodn. 7, 759 (1973) [Sov. Phys. Semicond. 7, 522 (1973)].

[2] I.A. Drabkin, B.A. Efimova, G.F. Zakharyugina *et al.*, ibid. 7, 794 (1973) [7, 545 (1973)].

[3] A.N. Weis, V.I. Kaĭdanov, Yu. I. Ravich *et al.*, ibid. **10**, 104 (1976) [**10**, 62 (1976)].

[4] K.I. Geĭman, I.A. Drabkin, A.V. Matveenko *et al.*, ibid. **11**, 846 (1977) [**11**, 499 (1977)].

[5] B.A. Akimov, N.B. Brandt, L.I. Ryabova, and S.M. Chudinov, Suppl. au J. de Physique, Fasc. 8, C-6 (1978); C6-1079; Fiz. Tekh. Poluprovodn. **11**, 1077 (1977) [Sov. Phys. Semicond. **11**, 637 (1977)].

[6] O.V. Aleksandrov, G.A. Kalyuzhnaya, K.V. Kisileva, and N.I. Strogankova, Izv. AN SSSR, Ser. Neorg. materialy **14**, 1277 (1978).

[7] M.K. Sheĭkman and A. Ya. Shik, Fiz. Tekh. Poluprovodn. **10**, 209 (1976) [Sov. Phys. Semicond. **10**, 128 (1976)].

[8] Yu. A. Bratashevskiĭ, V.D. Prozorovskiĭ, and Yu. S. Kharionovskiĭ, ibid. **9**, 1612 (1975) [**9**, 1064 (1975)].

[9] V.M. Baginskiĭ, R.O. Kikodze, G.V. Lashkarec *et al.*, Fiz. Tverd. Tela **19**, 588 (1977) [Sov. Phys. Solid State **19**, 338 (1977)].