

Strain-induced correlation of self-localized states in $\text{Pb}_{1-x}\text{Sn}_x\text{Te}(\text{In})$

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As the In concentration $\text{Pb}_{1-x}\text{Sn}_x\text{Te}(\text{In})$ is raised above $C_{\text{In}} \sim 2$ at.%, the lifetime of the nonequilibrium electrons is observed to decrease sharply, as does the critical field for photoconductivity quenching. The kinetics of the photoconductivity at $C_{\text{In}} \gtrsim 2$ at.% and $T < 20$ K suggests a correlated change in the structure of impurity centers.

1. According to the present understanding,^{1,2} the capture of an electron to a self-localized state in $\text{Pb}_{1-x}\text{Sn}_x\text{Te}(\text{In})$ (and certain other materials³) or the ejection of an electron from such a state is accompanied by a local change in the lattice structure (a pronounced displacement of the atoms) around the impurity center. As a result, a barrier arises between the localized and delocalized electron states and causes a “retarded” photoconductivity at $T < 20$ K. The previous theoretical and experimental research on this question (see the bibliographies in Refs. 1 and 2) has dealt with the situation in which the distance between the impurity centers is so large that the interaction of centers through their strain fields can be ignored. On the other hand, as the concentration of such centers is raised, we would expect that the interaction between these centers would become so strong that the changes in the charge states of the centers would become correlated, since a change in the structure of one of the centers would raise the probability for structural changes at others. The properties of the corresponding samples would naturally change in a qualitative way. In this letter we report a study of the changes in the photoconductivity kinetics of n -type $\text{Pb}_{0.75}\text{Sn}_{0.25}\text{Te}(\text{In})$ alloys as the concentration of the impurity, C_{In} , is raised to 2.6 at.% (the solubility of In in this alloys is estimated to be 5–7 at.%).

2. Single crystals were grown by zone sublimation and also from a molten solution by the moving-heater method. The doping with indium was carried out during the synthesis. The ion concentration was determined by spark mass spectrometry. Samples $0.5 \times 0.9 \times 5$ mm in size were placed in a shielded metal vacuum chamber cooled with liquid helium. As the source of the IR light we used a Joule-heated carbon resistor. The sample temperature (T) and the temperature of the heat source (T^*) were monitored with thermocouples. Let us look at the experimental results.

3. In the alloys with $C_{In} \gtrsim 0.5$ at.% (the sample designations used below are numerically equal to C_{In} in at.%), the dark ($T = T^*$) resistivity ρ_T increases with decreasing temperature to $\rho_T \gtrsim 10^6 \Omega \cdot \text{cm}$ at $T < 10$ K, since at $x \cong 0.25$ the local level^{1,2} ϵ_i stabilizes the Fermi level, which lies in the energy gap. When the IR light is turned on, the resistance of the samples decreases by several orders of magnitude. The illuminated resistance (R_i) and the dark resistance (R_d) are sharply different at $T < T_c$. For alloys with $C_{In} \gtrsim 0.5$ at.% we have $T_c \sim 19$ – 22 K, while for the alloy 2.6 we have $T_c \cong 15.2$ K. The steady-state values of R_i increase monotonically with increasing C_{In} at a fixed $T^* = 25$ K: from $10^{-1} \Omega$ for the alloy 0.5 to $10^6 \Omega$ for the alloy 2.6. This effect is equivalent to a decrease in the impurity-photoconductivity signal.

The decrease in the photoconductivity with increasing C_{In} could not be a consequence of a decrease in the number of electrically active centers, since the electron density reaches $5 \times 10^{16} \text{ cm}^{-3}$ as the L bands move closer together under pressure in the metallic phase of the alloys. The changes in the illumination-current and spectral characteristics of the photoconductivity can also be ruled out as governing factors, since R_i falls off by more than an order of magnitude as T^* is raised to 100 K ($T \sim 4.3$ K). At sample thicknesses $d > k^{-1}$ the photoconductivity is independent of the absorption coefficient k . The only remaining cause of a decrease in the photoconductivity is thus a decrease in the lifetime of the photoexcited electrons.

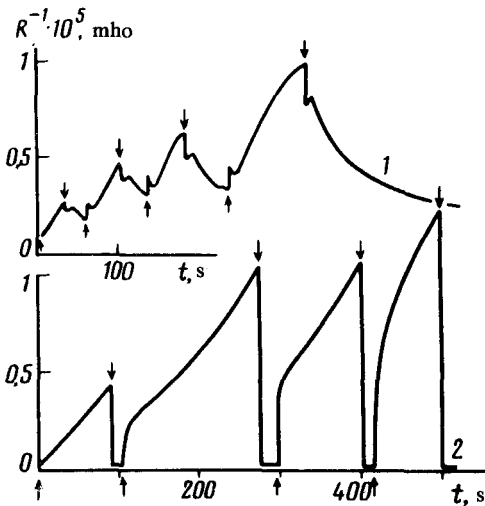


FIG. 1. Kinetics of the rise and decay of the photoconductivity signal in samples 0.6 (curve 1) and 2.3 (curve 2). The arrows show the times at which the illumination is turned in (\downarrow) and off (\uparrow). $T^* = 12.3$ K, $T = 4.2$ K.

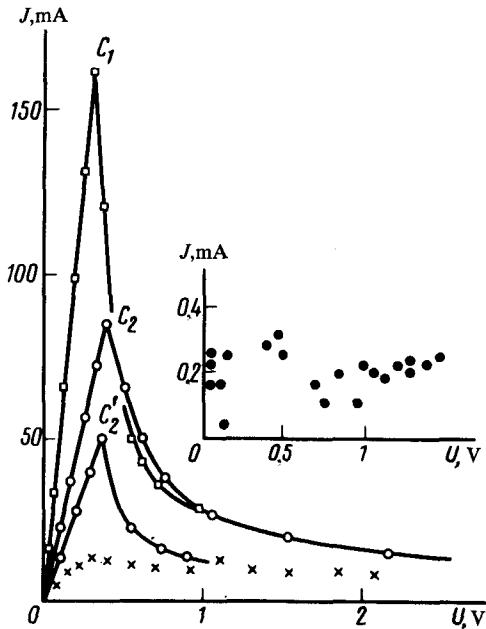


FIG. 2. Family of I-V characteristics of $\text{Pb}_{0.75}\text{Sn}_{0.25}\text{Te}(\text{In})$ alloys with various values of C_{In} : \blacksquare —0.6; \circ —0.8; \times —2.3; \bullet —2.6. For the curve with the point C_2' we have $T^* = 16$ K, while for the others we have $T^* = 21$ K. In the inset, $T^* = 70$ K.

4. The kinetics of the photoconductivity decay in fields $E \sim 1$ V/cm at $T = 4.2$ K is determined by the value of C_{In} : In the alloys 0.6 and 0.8 a relatively rapid initial rise in the photoconductivity signal (curve 1 in Fig. 1) is followed by a relaxation over several hours, while in the alloys 2.3 and 2.6 the decay of the photoconductivity is of the nature of an abrupt cutoff (curve 2 in Fig. 1). A repeated application of the IR illumination in the latter case leads to a faster initial rise of the conductivity. In an effort to determine the reasons for the cutoff of the photoconductivity we studied the static I-V characteristics of the alloys. Taking into account the possible appearance of high-resistivity domains in fields $E_k \sim 8$ V/cm due to a Gunn instability, we plotted the results as the voltage across the entire sample, U , vs the current J (Fig. 2). The illuminated branches of the curves, with maxima C , are described by the thermal theory⁵ for the samples with $C_{\text{In}} < 2$ at.%. It follows from these results that the maximum photoconductivity current falls off by ~ 3 orders of magnitude with increasing C_{In} , and at $C_{\text{In}} \geq 2$ at.% the shape of the I-V characteristics changes qualitatively. The crosses in Fig. 2 show the maximum measured currents, while the steady states are actually described by a set of scattered points (see the inset), which demonstrate that the system consists of nonequivalent disordered regions. The cutoff voltage for sample 2.3 is 10 mV, while at $C_{\text{In}} < 1$ at.% the kinetics of the photoconductivity decay is independent of U up to 5 V. The low values of U of course do not rule out high local fields E in the sample.

5. The decrease in the photoconductivity in the alloys with high values of C_{In}

cannot be due to a more pronounced inhomogeneity of the system. In the samples studied the electron mobility is the same as the band mobility: at $T \sim 10$ K, $\mu \sim 2 \times 10^5$ cm²/(V·s). Even if we assume a pronounced perturbation of the edge of the conduction band, the recombining electrons and charges centers could not accumulate in the same regions, as occurs in the case of a "contravariant" band modulation,⁶ since there is no conductivity involving a stabilizing local level. The inhomogeneity of the Pb_{1-x}Sn_xTe(In) alloys might be due to the deliberate addition of impurities with a low solubility (Cd, Zn) or the introduction of a small amount of In, with the necessary condition for stabilization of the position of the Fermi level not being satisfied. Study of the kinetics of the photoconductivity shows that the lifetime of the nonequilibrium electrons in these systems is some undetermined long time: $\tau > 10^5$ s.

6. The most natural way to explain these results is to assume a strain-induced correlation of impurity centers in accordance with the theory of Refs. 1-3. When this correlation prevails, a change in the structure of one of the centers causes changes in the structure of several of the neighboring centers in a time determined by the sound velocity. The number of such neighbors increases with increasing C_{In} , so that the effective lifetime of the photoconductivity decreases. Finally, at high C_{In} , the system may decay into several nonequivalent regions of macroscopic size, either spontaneously or in response to some small random perturbation. The conductivity of such a structure under conditions such that the impurity centers are undergoing photoionization could result only from the formation of some conducting cluster. The cutoff of the photoconductivity is equivalent to the breakup of this cluster. Repeated illumination restores the conductivity (curve 2 in Fig. 1).

We would like to point out in conclusion that the spontaneous delocalization might be exploited to amplify a sound pulse propagating through the system if the peak value of the pulse exceeded the strain threshold required for delocalization.

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