Avalanche-like processes induced in $Pb_{1-x}Sn_xTe(In)$ alloys by strong electric fields

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We have observed an avalanche-like breakdown in the dielectric state of $Pb_{1-x}Sn_xTe(In)$ alloys at helium temperatures. This breakdown, which occurs after a time t_d following the imposition of a strong electric field, leaves the alloy in a new stationary state with a falling volt-ampere characteristic. The lag time t_d depends on the strength of the electric field and can reach ~ 1 hour.

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1. We have investigated the voltage-current characteristics (VACs) of indium-doped (~ 0.5 at. %) single crystals $Pb_{0.75}Sn_{0.25}Te$ alloys in static and pulsed electric fields with strengths up to 200 V/cm and at temperatures in the range 4.2–40 K. The above composition corresponds to a dielectric state of the alloys with a thermal activation energy $\epsilon_A^T \approx 20$ meV and a high resistivity $\rho \sim 10^6$ Ω·cm at $T = 4.2$ K.

The measurements were made in a cooled, airtight metal chamber, which almost totally shielded the sample from external radiation. There was provision for IR illumination of the sample by means of a carbon resistance heater placed in the chamber. For the static-field measurements, the sample was connected in series with a power pack and a load resistance R_L. The power pack was an electronic system with a fast (~ 1 μsec) switching time from constant-voltage to constant-current operation as the total resistance of the circuit falls below a set level. The current and voltage contacts were applied to the samples with an In + 1%Au + 4% Ag alloy.

2. The static-field studies revealed a new, decreasing branch of the voltage-current characteristics $Pb_{1-x}Sn_xTe(In)$ alloys. A typical VAC for $Pb_{0.75}Sn_{0.25}Te(In)$ is shown in Fig. 1 (the dimensions of the sample were $5 \times 0.8 \times 0.8$ mm). At the original temperature of the sample (and the thermostatic chamber) the current density j as a function of E for $E \gtrsim 0.2$ V/cm is highly nonlinear (curve I; curve I′ is the same curve on a larger scale). As E is increased to $E_K = 70$ V/cm, which in certain limits depends on the rate $\partial E/\partial t$ at which the field is turned on (in Fig. 1, $\partial E/\partial t = 1$ V/cm·sec), there is an avalanche-like growth in the circuit current (path LM in Fig. 1, $R_L = 0$). If E is

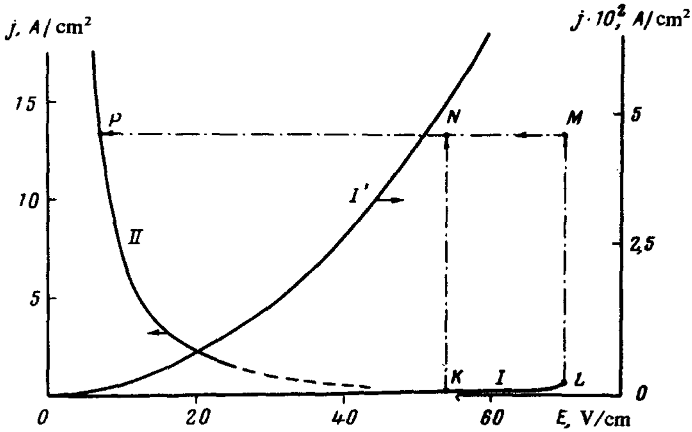

FIG. 1. The two branches of the volt-ampere characteristic of the alloy $Pb_{0.75}Sn_{0.25}Te(In)$ (see text).

held constant during this process, the crystal is heated by a strong current ($j > 100$ A/cm^2) and is shattered (at point L the temperature of the sample is ~ 5 K). When the power pack is operated in the switching mode (limiting the current at the level MNP in Fig. 1), the voltage across the sample falls off sharply, and the system goes over to a new time-independent state characterized by a continuous decrease in VAC (branch II). Under the conditions of the experiment, at large values of j (~ 15 A/cm^2) the alloy was heated to ~ 30 K. In the weak-current region (branch II, dashed curve) the VAC is unstable for any mode of operation of the power pack and for any R_L: for $E < E_K$ the VAC breaks from branch II over to branch I.

The system can also be transfered to branch II at fields that are rather high (30–60 V/cm) but lower than E_K by means of a short period (~ 30 sec) of heating with a temperature pulse of amplitude $T \gtrsim 15$ K or with a pulse of IR radiation produced by a carbon resistor, which is located at a distance of 100 mm from the sample, at a temperature $T^* \gtrsim 20$ K (path KNP, $R_L = 0$). The Hall coefficient R depends strongly on both j and H. The quantity $1/eRc$ measured in weak fields $H \lesssim 1$ kOe varies over the range 2×10^{13} to 3×10^{16} cm^{-3} as j is changed from 2 to 20 A/cm^2. For any value of j the Hall coefficient decreases by a factor of 5 to 10 as H is increased in the interval $1 \lesssim H \lesssim 60$ kOe.

Measurements made on samples with several voltage contacts show that on branch II the field E is distributed uniformly over the length of the sample; this does not preclude the formation of a current pinch in the sample. As the temperature of the thermostat containing the sample is increased in the range $15 \lesssim T_H \lesssim 40$ K, the VAC becomes a continuous S-shaped curve.

3. To study the dynamics of the breakdown we measured the VAC in pulsed electric fields. A typical family of VAC's for the alloy $Pb_{0.75}Sn_{0.25}Te(In)$ is shown in Fig. 2 (sample dimensions $2.5 \times 0.2 \times 0.3$ mm). The pulse duration t_p was varied from 10 μsec to 10 sec. The values of E and j were taken from the decay of the measuring pulses. It can be seen from the data shown that the breakdown time t_b is 1–5 msec. For

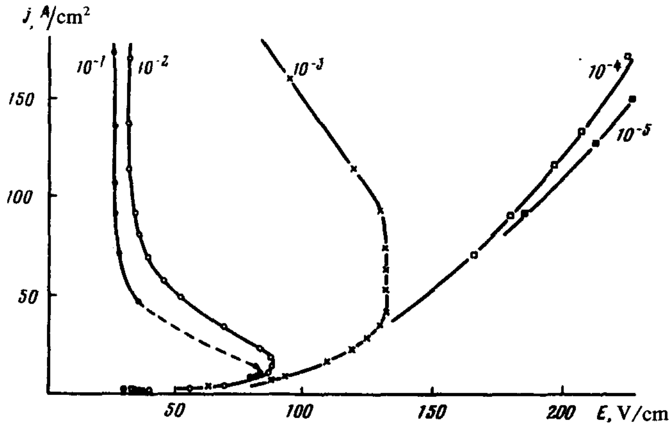

FIG. 2. Family of volt-ampere characteristics of $Pb_{0.75}Sn_{0.25}Te(In)$ during pulsed operation at $T_H = 4.2$ K (the numbers by the curves give the duration of the measuring pulses in seconds).

$t_p \gtrsim 1$ sec the VAC is similar to the static one. It was established that breakdown occurs at a time t_d after the field is turned on (typical shapes of the current and voltage pulses are shown schematically in the inset in Fig. 3. The time t_d depends strongly on the field strength and can reach ~ 1 hour (for $t_d \gtrsim 10$ sec, static fields were used in the measurements). The delayed breakdown process is illustrated in Fig. 3, which shows

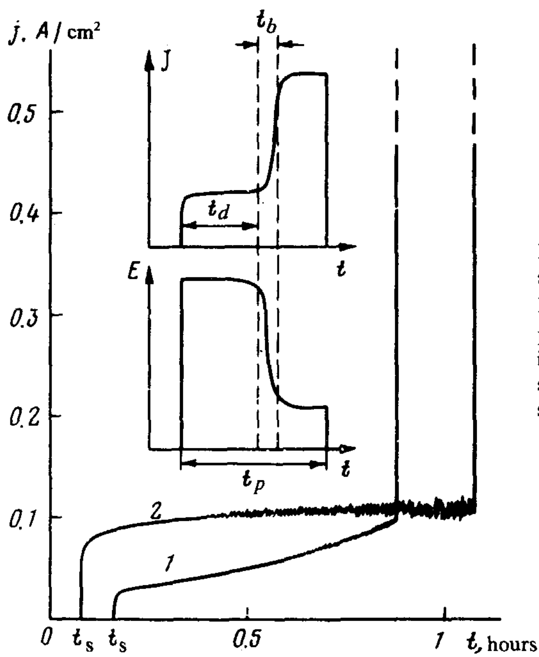

FIG. 3. Time dependence of current through sample for $Pb_{0.75}Sn_{0.25}Te + 0.5$ at. %In (1) and $Pb_{0.80}Sn_{0.2}Te$ with high indium content (2) in the presence of a strong electric field (see text). The inset shows schematically the shape of the measuring pulses of current and voltage used in constructing the pulsed volt-ampere characteristics.

the time dependence of the current density through a $Pb_{0.75}Sn_{0.25}Te(In)$ sample at $T_H = 4.2$ K (curve I; a field $E = 60$ V/cm is turned on at instant t_s). After the field is turned on, the current, fluctuating weakly, grows slowly with time right up to the instant of breakdown. The lag time t_d falls from ~ 1 hour to ~ 200 msec when E is increased from 60 to 70 V/cm (the fall off is approximately linear in the scale $\ln t_d - E$).

4. It was established that in the dielectric state of $Pb_{1-x}Sn_xTe$ alloys, either doped (~ 0.5 at %) with Al ($x = 0.20$), Cd ($x = 0.20$) or Ga ($x = 0$) or containing a high ($\gtrsim 1$ at. %) indium content ($0.20 \lesssim x \lesssim 0.23$), transitions to a state with a decreasing VAC are also possible in strong electric fields; the decreasing VAC is characterized by the same values of the product $jE \approx 40$–60 W/cm^3 for samples with dimensions of $5 \times 0.8 \times 0.8$ mm. Curve 2 in Fig. 3 illustrates the process of delayed breakdown in the dielectric state of a $Pb_{0.80}Sn_{0.20}Te$ alloy with a high indium content at $E = 70$ V/cm and $T_H = 4.2$ K. In the $Pb_{1-x}Sn_xTe$ alloys doped with Al and Cd, the delayed-breakdown effect was not observed.

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