Critical magnetic fields of amorphous As_2Te_3 near the insulator-metal transition

I. V. Berman, N. B. Brandt, I. E. Kostyleva, S. K. Pavlov, V. I. Sidorov, and S. M. Chudinov
M. V. Lomonosov State University, Moscow

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The fields H_{c2} and the currents J_c have been measured near a pressure-induced insulator-metal transition in amorphous As_2Te_3. A superconductivity appears at a pressure $P \approx 70$ kbar; the value of T_c increases as the pressure is raised. The large values of $(dH_{c2}/dT)_{T_c} \approx 10$ kOe/K at low values of J_c indicate that the superconductivity is of a percolation nature.

1. Several amorphous chalcogenides of Ge and As undergo an Anderson insulator-metal transition when compressed.[1–3] For a-$Ge_{33}As_{12}Se_{55}$ and a-Ge_2Se_3, a linear extrapolation to zero of the activation energies E_a determined from the temperature dependence $R(T)$ at $P < 130$ kbar yields $P_c = 160$ kbar for the insulator-metal transition pressure for a-$Ge_{33}As_{12}Se_{55}$ and 180 kbar for a-Ge_2Se_3 (Refs. 2 and 3). At $P \approx P_c$, a superconductivity appears, with a critical temperature T_c which increases sharply with increasing P: $dT_c/dP \approx 0.1$ K/kbar for a-$Ge_{33}As_{12}Se_{55}$ and 0.05 K/kbar for a-Ge_2Se_3. The results found in Refs. 2 and 3 indicate that this superconductivity seems to arise in the immediate vicinity of the point at which E_a vanishes, i.e., when the Fermi level E_F crosses the mobility threshold E_c.

Questions which have remained unanswered, on the other hand, are the reason for the pronounced increase in T_c upon compression—this behavior is not characteristic of nontransition metals and their alloys—and the question of which side of the insulator-metal transition (the metal side or the insulator side) the superconductivity is observed on. The possibility that a superconductivity occurs in an insulating state with localized electrons in amorphous semiconductors was studied in Ref. 4. A characteristic feature of a "localized" superconductivity is the anomalous temperature dependence[5,6] of H_{c2}; this temperature dependence can be used to identify the nature of the superconductivity. The current-voltage characteristics $V(J)$ can also provide definite information about the nature of the superconductivity near the point of the insulator-metal transition.

2. In the present experiments we studied the resistance R as a function of T and T_c over the temperature range 300–0.06 K, and we studied the I-V characteristics and the curves of the critical fields, $H_{c2}(T)$, for amorphous As_2Te_3 at pressures up to 200 kbar. The pressure was applied by means of a VK-3 anvil and polycrystalline diamonds, by the technique described in Ref. 7. The resistance is measured by a four-contact method. The same sample is used for several measurements as the pressure is gradually increased or reduced; this approach improves the accuracy of the determination of the relative change in P and the resistivity ρ and makes it possible to study the reversibility of the observed effects. The ultralow temperatures are reached by means of a He^3-He^4 dissolution refrigerator. The curves of the critical fields are measured in a superconducting solenoid as the current in the sample flows perpendicular to the magnetic field H.

3. The value of R for a-As_2Te_3 at $T = 300$ K falls off smoothly upon compression. At $P \lesssim 100$ kbar, the curves of $R(T)$ are of a semiconductor nature. At $P \approx 70$ kbar, however, it is already possible to see a partial decrease in R in the temperature interval $0.06 < T < 0.6$ K, which is related to a transition of the sample to a superconducting state. When P is increased very slightly (by 1–2 kbar), the transition shifts up to T scale, and a progressively greater part of the sample goes superconducting. As P is raised further, the transition to superconductivity becomes complete, and the width of the transition decreases to 0.2–0.4 K. In the pressure interval 70–100 kbar, the value of T_c for a-As_2Te_3 increases upon compression with an anomalously large value $dT_c/dP = 0.2$ K/kbar and reaches a value of 7 K at $P = 100$ kbar. With a further compression, T_c increases more slowly, as can be seen in Fig. 1. Shown for comparison in the same figure are a plot of E_a versus P and the sole experimental value of T_c, measured in Ref. 8, at $P = 100$ kbar.

Figure 2 shows curves of the critical fields of a-As_2Te_3. We see that a-As_2Te_3 is a hard superconductor. The value of $(dH_{c2}/dT)_{T_c}$ is 10 kOe/K and, in a first approximation, constant over the pressure range 80–100 kbar. As the pressure is raised above 100 kbar, the value of $(dH_{c2}/dT)_{T_c}$ begins to fall off, and at $P = 110$ kbar we have $(dH_{c2}/dT)_{T_c} \approx 6.5$ kOe/K. At pressures corresponding to $T_c = 2$ K ($P = 80$ kbar),

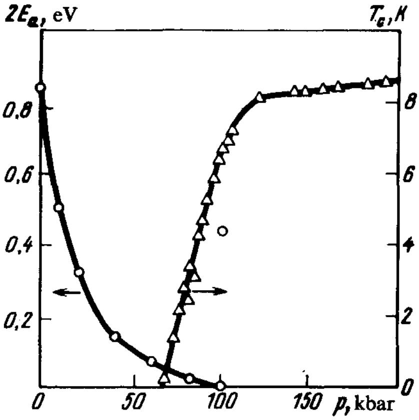

FIG. 1. Pressure dependence of $2E_a$ (scale at the left) and T_c (scale at the right) in a-As_2Te_3. △—Data from the present study; ○—data from Ref. 8.

the shape of the $H_{c2}(T)$ curves is nearly the same as that in the GLAG theory. The ratio

$$-\frac{H_{c2}(0)}{(dH_{c2}/dT)_{T_c}},$$

calculated from the value found for $H_{c2}(0)$ by extrapolation (the dashed line in Fig. 2) is close to the value of 0.69 predicted by that theory. This circumstance means that

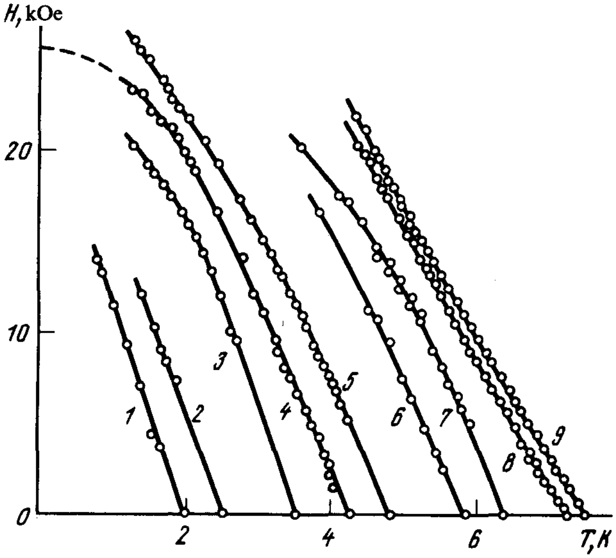

FIG. 2. Critical magnetic field of a-As_2Te_3 at various pressures P: 1—77 kbar; 2—80; 3—86; 4—88; 5—90; 6—94; 7—98; 8—108; 9—110 kbar.

we can use the relation

$$N(E_F) = \frac{1}{8ec\hbar\rho} (dH_{c2}/dT)_{T_c} \tag{1}$$

to estimate the change in the electron-state density at the Fermi level, $N(E_F)$, caused by the pressure. A calculation of $N(E_F)$ from (1) and the values found for ρ and $(dH_{c2}/dT)_{T_c}$ shows that as the pressure is raised from 80 to 110 kbar, the value of $N(E_F)$ increases from 0.2×10^{34} to 0.8×10^{34} states/(cm^3·erg·spin).

There are no structural features in the *I-V* characteristics near the insulator-metal transition. The critical field at the corresponding pressures is unusually low for a hard superconductor, 10–100 A/cm^2.

4. The data from these experiments on the appearance of a superconductivity in a-As_2Te_3 at the extremely low temperatures reached in these experiments support the suggestion that the onset of superconductivity and the change in T_c upon compression are related to a change in the relative positions of E_F and E_c. The low values of J_c in this pressure range and monotonic behavior of V as a function of J indicate that the onset of the superconductivity is of a percolation nature. The superconductivity occurs in the metal phase of a-As_2Te_3 at least at pressures above $P\approx 80$ kbar, and there is apparently a weak localization. In most of the theoretical papers[5,9,10] the decrease in T_c as E_F approaches E_c from the metal side of the metal-insulator transition has been attributed to an increase in the effective Coulomb repulsion because of a weakening of electron diffusion. The significant increase observed[1)] in $N(E_F)$ at a pressure above that corresponding to the insulator-metal transition indicates that the increase in T_c as E_F moves away from E_c is due to not only a change in Coulomb pseudopotential but also an increase in $N(E_F)$, apparently caused by an increase in the number of delocalized electrons.

[1)] *A calculation of $N(E_F)$ from the expression given here may lead to underestimates of $N(E_F)$ near the localization threshold.*[5]

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