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SUPERCONDUCTIVITY AND PERCOLATION IN Al-Ge FILMS*

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Résumé.- On a observé une double transition supraconductrice dans des films minces Al-Ge obtenus par coévaporation. Cette double transition est observée dans la transition résistive en fonction de la température et dans la caractéristique courant-tension. Une interprétation des résultats est proposée en termes de la théorie de percolation.

Abstract.- A double superconducting transition in co-evaporated Al-Ge films can be observed in both their resistance-temperature and current-voltage characteristics. An explanation is offered in terms of percolation theory.

Co-evaporated or co-sputtered metal-insulator mixtures are normally found to be in the form of metallic grains imbedded in an insulating matrix /1/. The size and shape of the grains depend on the metallic volume concentration, x , the rate of deposition, and the substrate temperature /2/.

If a single, isolated grain is large enough /3/ to have a superconducting transition at $T_{co}/4$, then mixtures with $x < x_c$ would be expected to have a double superconducting transition: an incomplete transition at T_{co} and a second transition at $T_{cj} < T_{co}$ due to Josephson tunnelling between the grains which makes the whole sample superconducting. x_c is the "critical" concentration for which the grains are no longer in metallic contact.

T_{cj} will be less than T_{co} when the Josephson coupling energy $n\hbar I_c(0)/2e$ of a grain to its nearest neighbors, where $I_c(0)$ is the $T=0$ critical current of one such isolated junction, is less than kT_{co} .

We have observed such a double transition in Al-Ge films with $x \approx 0.64$. The films were prepared by co-evaporation from two electron-beam guns onto room temperature glass slides at a combined rate of $\sim 50 \text{ Å/s}$. The deposition rate of each material was independently controlled by feedback from a separate quartz crystal thickness monitor which was previously calibrated by interferometry. Each slide contained nine samples with concentrations differing by $\sim 2\%$ due to their differing distances from the two sources. Electron microscope examination of similar concentrations evaporated onto SiO showed Al

spheres of very uniform diameter $\sim 200 \text{ Å}$ in a nearly random close-packed structure /5,6/.

Fig. 1 : Normalized resistance vs. temperature of three samples from one slide. $\square$, $\rho_n = 2.0 \times 10^{-4} \mu\Omega\text{-cm}$, $x=0.65$; $\circ$, $\rho_n = 3.0 \times 10^{-3} \mu\Omega\text{-cm}$, $x=0.68$; Δ , $\rho_n = 1.6 \times 10^{-3} \mu\Omega\text{-cm}$, $x=0.74$

Figure 1 shows the normalized resistance as a function of temperature for three samples from one slide. The double transition is clearly seen. As expected, T_{co} is nearly independent of x while T_{cj} decreases with increasing Ge concentration (decreasing x).

Figure 2 shows the current-voltage characteristic of one sample from the same slide as in figure 1. Two main transitions are again apparent.

However, the fact that the resistance falls to less than 30% of its value at T_{co} indicates that this first transition is not due to isolated grains alone. The resistivity of these samples is greater than $10^3 \mu\Omega\text{-cm}$, so the contribution of the resistance of the grains is almost negligible.

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Fig. 2 : Current-voltage characteristic at $T=1.52$ K for a sample with $x=0.78$ from the same slide as the samples in figure 1.

- a) complete characteristic with final slope equal to R_n .
 b) Increased current and voltage sensitivity showing the Josephson transition.

We therefore conclude that the transition at T_{co} includes a significant number of strongly coupled junctions as well. These superconducting clusters then "short out" a large percentage of the sample. What percentage of the volume must be contained by these clusters before they will interconnect and short out the whole sample is one of the principle questions of percolation theory /7/.

If we assume that the strongly coupled junctions are randomly distributed throughout the samples, then the answer is 15% /8/. That the whole volume of the sample is not superconducting at T_{cj} is supported by measurements of the critical current density below T_{cj} /9/. They show a much stronger dependence on temperature than is compatible with that

of identical Josephon junctions, thus indicating that even below T_{cj} more junctions become superconducting as T decreases.

If the data near T_{cj} from figure 1 is replotted on log-log paper, it is found that the resistance obeys a power law dependence $R \propto (T - T_{cj})^t$ with $t=0.7$. Straley has recently shown by a percolation-type calculation that the resistance of a superconductor-normal conductor mixture below the percolation threshold for the superconductor also obeys a power law $R \propto (x_c - x)^t$ with $t=0.7$.

We therefore propose that Al-Ge mixtures with Al concentrations near x_c and below T_{co} behave as percolation systems whose concentration of superconductor may be varied by both x and T .

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