Anomalous behavior of the electrical resistance of amorphous films Re–Ta–H in the superconducting transition in a magnetic field

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A sharp increase in the electrical resistance of amorphous Re–Ta–H films is observed during the superconducting transition in an external magnetic field.

The amorphous films 5–10 μm thick were obtained by ion-plasma deposition of the Re–Ta system[1,2] followed by electrolytic hydrogenation. The structure of the films was studied by an x-ray method and the composition was determined by Auger x-ray spectroscopy and photoelectronic spectroscopy.

The electrical resistance of the films was measured over the temperature interval 4.2–300 K in a perpendicular magnetic field of a superconducting solenoid with a field range of up to 12 kOe. The measuring current was no higher than 50 μA. The samples with a hydrogen content 7 at.% $\leqslant C \leqslant$ 14 at.% exhibited an electrical-resistance peak near T_c, while the electrical resistance remained nearly constant in the remaining temperature interval ($R_{\rm rem}/R_{300} \sim 1.03$). As the external magnetic field was increased, the electrical-resistance peak shifted toward lower temperatures, broadening its peak. The hysteresis was kept within 0.05 K. The critical temperature of the superconducting transition in a magnetic field was defined as the temperature of the electrical-resistance peak. The samples in which the effect was detected are given in Table I.

The temperature dependence of the relative electrical resistance ($R/R_{\rm rem}$) of the amorphous alloy $Re_{96}Ta_9H_{10}$, in which the maximum effect was detected, is shown in Fig. 1.

TABLE I. Influence on the composition of the Re–Ta–H films on the superconducting transition temperature T_c and on the effect: $\Delta R/R = (R_{\rm max} - R_{\rm rem})/(R_{\rm rem})$.

Composition	T_c, K	$\Delta R/R$, %
$Re_{84}Ta_9H_7$	7.29	10
$Re_{83}Ta_9H_8$	7.20	20
$Re_{81}Ta_9H_{10}$	7.08	126
$Re_{79}Ta_9H_{12}$	7.05	115
$Re_{77}Ta_9H_{14}$	7.05	33

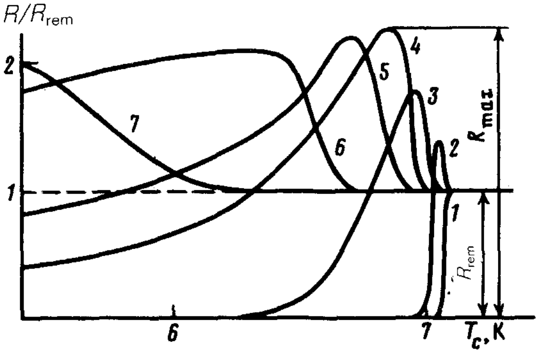

FIG. 1. Curves for the superconducting transition of the amorphous alloy in various magnetic fields. 1—$H = 0$; 2—$H = 300$ Oe; 3—$H = 1$ kOe; 4—$H = 2$ kOe; 5—$H = 4$ kOe; 6—$H = 8$ kOe; 7—$H = 12$ kOe.

In the absence of an external field ($T_c = 7.08$ K) the electrical resistance did not behave anomalously in the superconducting transition (see curve 1 in Fig. 1).

It is known that the electronic state density at the Fermi surface, which is calculated without allowance for the renormalization due to the electron-phonon interaction,[3] is

$$N(0) = \frac{\pi}{4k_B e\rho_{max}} \left(\frac{\partial H_c}{\partial T} \right)_{T_c} .$$

The plot of $N(0)$ as a function of the applied field is shown in Fig. 2. We see from this figure that the transition is primarily electronic in nature and that it is caused by the change in the electronic spectrum. Since $N(0) \sim n^{1/3}$ (n is the density of the conduction electrons), we can explain the observable anomaly qualitatively. We know that since the Fermi level of the crystalline Re ($T_c = 1.7$ K) lies near the minimum of the electronic state density,[4] the localized *d–d* bonds between the Re atoms in the crystal are covalent bonds. It was shown in Ref. 5 that amorphization of Re leads to breaking of covalent-type bonds and thus to an increase in n and hence in T_e. We assume that introduction of hydrogen increases the probability for the formation of covalent pairs. In a magnetic field an increase in the probability for the formation of

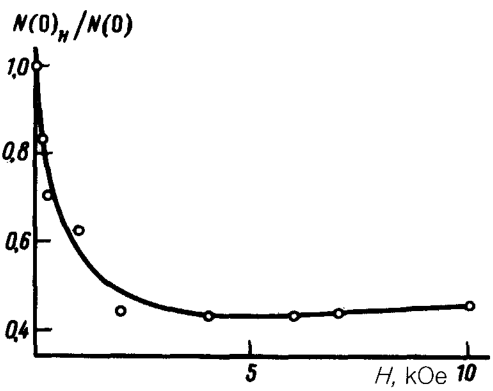

FIG. 2. Electronic state density $N(0)_H$ of the amorphous alloy $Re_{81}Ta_9H_{10}$ versus the applied field [normalized to $N(0)$ in the absence of a field].

covalent pairs may keep the superconductivity competitive, since covalent pairs in this case supplant the Cooper pairs. A decrease in the electron density leads to an increase in the electrical resistance. If the sharp decrease in $N(0)$ (see Fig. 2) is assumed to be caused by the transition, we can define the ratio $N(0)_H/N(0)$ as a measure of the relative change in the electron density ($n_H/n \sim 0.46$ for the alloy $Re_{91}Ta_9H_{10}$).

In summary, the coexistence of covalence and superconductivity is seen in the increase of the resistance due to the formation of covalent pairs upon the suppression of superconductivity in a magnetic field.

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