SIMILARITY OF LONGITUDINAL AND TRANSVERSE CRITICAL CURRENTS IN SUPERCONDUCTING ALLOYS WITH RIGIDLY PINNED VORTEX LATTICE

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We have observed a similarity between the longitudinal ($\vec{j} \parallel \vec{H}$) and transverse ($\vec{j} \perp \vec{H}$) critical currents in superconducting alloys containing finely-dispersed non-superconducting inclusions capable of rigidly pinning the vortex lattice.

It is known [1] that in cold-deformed single-phase alloys, the longitudinal critical currents differ greatly from the transverse ones both in the character of the dependence on the magnetic field and in order of magnitude. This fact is attributed to the action of the Lorentz force, which is maximal when $\vec{H} \perp \vec{j}$ and tends to zero when $\vec{H} \parallel \vec{j}$ [2]. A different result should be expected in alloys with a rigidly pinned vortex lattice [3], where the Lorentz force is not produced and the possible anisotropy of j_cH should be connected only with the damagnetizing factor. To check on this assumption, we investigated the critical currents in alloys of niobium with titanium and zirconium, containing isotropically distributed inclusions of the ω or α phase [4]. The measurements of $j_{c\parallel}$ and $j_{c\perp}$ were made on the same samples. The composition and characteristics of the samples are given in the table.

The procedure of measuring the transverse currents did not differ from that described in [3]. To investigate the longitudinal currents, it was necessary to produce contacts that operated reliably in a strong magnetic field at sample current densities reaching 10^6 A/cm^2. This could be done by ultrasonic plating [4] with indium. A check has shown that the chosen plating regime did not change the superconducting properties of our samples. The investigated segment of wire, plated on the ends with indium, was placed in a copper holder, the construction of which excluded the possibility of displacement of the sample under the influence of the ponderomotive forces. A particular effort was made to keep the sample coaxial with the solenoid producing the magnetic field. The sample was provided with a brass shunt having a resistance 2×10^{-6} ohm at 4.2°K. At a superconducting wire diameter 0.11 mm, a

Sample No.	Composition, at.%	Dia., mm	Heat treatment
4v	Ti - 22 Nb	0.23	800°C - 1 hr, quenching, tempering 390°C - 1 hr
8	Ti - 22 Nb	0.11	Cold deformation, accompanied by decomposition of solid solution with precipitation of the α-phase
12	Zr - 20 Nb	0.22	800°C - 1 hr, quenching, tempering 350°C - 3 hr
2p	Ti - 36 Nb	0.17	Cold deformation of 99.975% without solid-solution decomposition

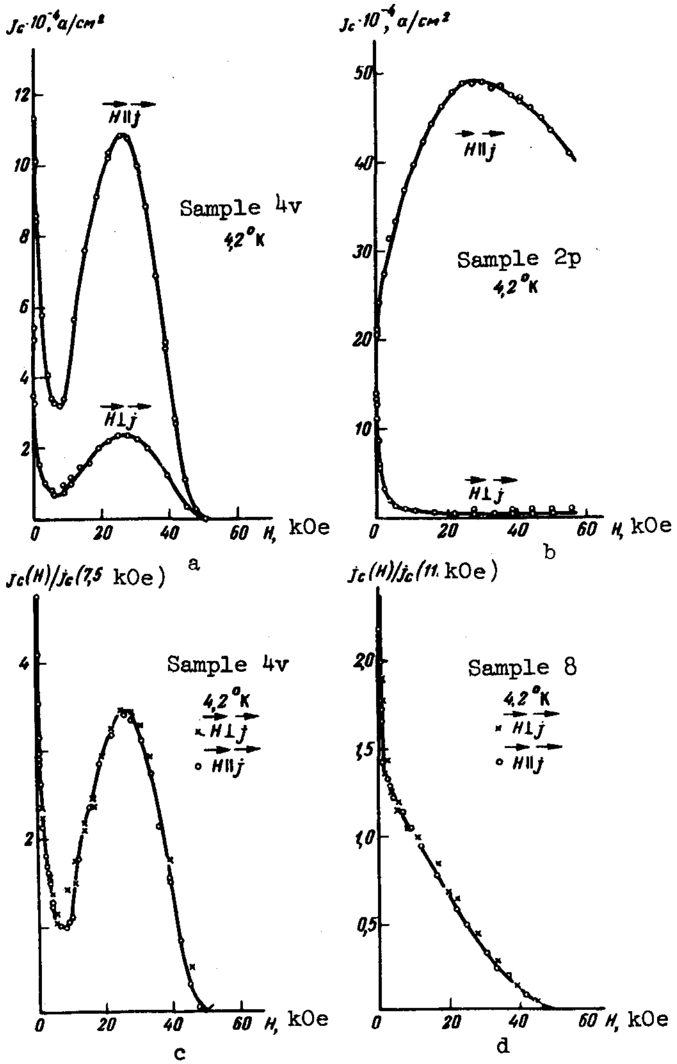

Fig. 1

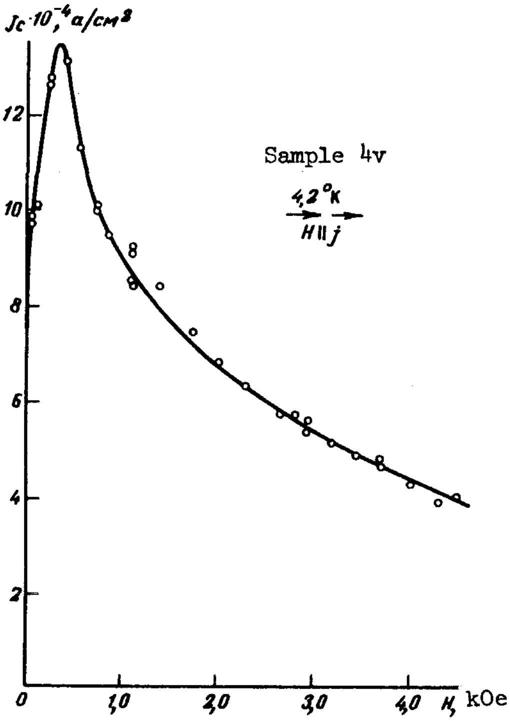

Fig. 3

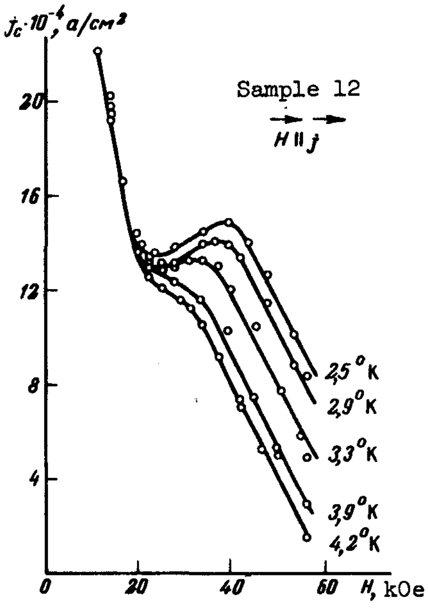

Fig. 2

Fig. 1. Density of critical current vs. external magnetic field: a, b - current density in absolute units; c, d - current density in relative units. The data on the samples are listed in the table.

Fig. 2. Longitudinal critical current density of sample 12 vs. external magnetic field at various temperatures.

Fig. 3. Peak in $j_{c\parallel}(H)$ curve, observed in weak magnetic fields; sample 4v.

current 100 A, and an external magnetic field intensity 55 kOe the contact resistance did not exceed 2×10^{-8} ohm. The transition from the superconducting to the normal state was revealed by the jump of resistance across the shunt.

The results are shown in Figs. 1 - 3. From a comparison of Figs. 1a and 1b we see that the critical currents of samples containing non-superconducting inclusions (Fig. 1a) and single-phase cold-deformed samples (Fig. 1b) behave quite differently. When the magnetic field increases, the longitudinal critical current of the single-phase sample (Fig. 1b) increases, forming a characteristic dome, in full agreement with [1], while the transverse current drops to a plateau. The ratio $j_{c\parallel}/j_{c\perp}$ reaches 80. In the two-phase sample (Fig. 1a) the longitudinal and transverse currents vary in the same manner with the magnetic field, and the maximum value of $j_{c\parallel}/j_{c\perp}$ does not exceed 5. The similarity between the critical currents in samples with nonsuperconducting inclusions is shown more clearly in Figs. 1c and 1d, from which it follows that if the plots of the transverse and longitudinal currents are made to coincide at one point, then they coincide at all other points. This means that the dependence of $j_{c\parallel}/j_{c\perp}$ on the magnetic field intensity in alloys with a rigidly pinned vortex lattice is described by the same equations. Figures 1c and 1d show two types of dependence, with and without a peak on the $j_c(H)$ curve. The peak corresponds to "breakdown" of the superconductivity of the inclusions, and is observed when the dimensions of the inclusions are close to the coherence length. If the inclusions are strongly enriched with titanium or zirconium, and if their average linear dimension exceeds the dimension of the superconducting pair, then the breakdown field vanishes and the peak disappears (Fig. 1d).

A comparison of the results for $j_{c\parallel}(T)$, shown in Fig. 2, with the corresponding data for $j_{c\perp}(T)$ (Fig. 1c [5]) shows that the similarity of $j_{c\parallel}$ and $j_{c\perp}$ appears not only in their dependence on the magnetic field intensity, but also in the temperature dependence.

As to the difference between the absolute values of $j_{c\parallel}$ and $j_{c\perp}$ (Fig. 1a), it can be explained in the following manner. In the limiting case of weak magnetic fields ($H < H_{c1}$), the intensity of the magnetic field on the surface of a cylindrical cylinder can at $\vec{H} \perp \vec{j}$ be twice the value of the unperturbed external field. In strong magnetic fields ($H \sim H_{c2}$), the field on the surface equals the external field. Thus, on moving from H_{c1} to H_{c2}, the maximum field on the surface changes from 2H to H. On the other hand, when $\vec{H} \parallel \vec{j}$ we have $H_{surf} \equiv H$. If we take into account also the fact that j_c decreases rapidly with increasing H, and that the nonsuperconducting inclusions are oriented in a definite manner relative to the wire axis [6], then the difference between the absolute values of the longitudinal and transverse currents becomes understandable.

In conclusion we point out the narrow and steep peak on the $j_{c\parallel}(H)$ curve, observed in weak magnetic fields on all the samples with nonsuperconducting inclusions. This peak, which is represented in Fig. 3, is apparently connected with the filling of the cross section of the sample by current [7]. The local current density decreases with the magnetic field, and the area filled with the current at first increases. The combination of the two opposing tendencies leads to the appearance of the maximum.

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SPACE-CHARGE-LIMITED TUNNEL CURRENT IN Al-Al_2O_3-Al JUNCTIONS

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In [1 - 4] they reported observation of negative-resistance sections on the current-voltage characteristics of Me-D-Me tunnel junctions, including Al-Al_2O_3-Al junctions. The appearance of a negative-resistance section is attributed in [1] to the process of a pn junction in the dielectric film.

We observed negative-resistance regions in the tunnel characteristics of Al-Al_2O_3-Al junctions at bias voltages of both polarities. The conductivity curve $g(U) = di/dU(U)$ has an almost symmetrical w-shaped form with a deep trough at $U = 0$ (Fig. 1). The bias voltages U_1, U_2, U'_1, and U'_2, corresponding to the extrema on the current-voltage characteristic, equal 0.052, 0212, -0.155, and -0.213 V, respectively. Positive bias corresponds to positive voltage applied to the upper electrode of the tunnel junction. The plot of g(U) for the

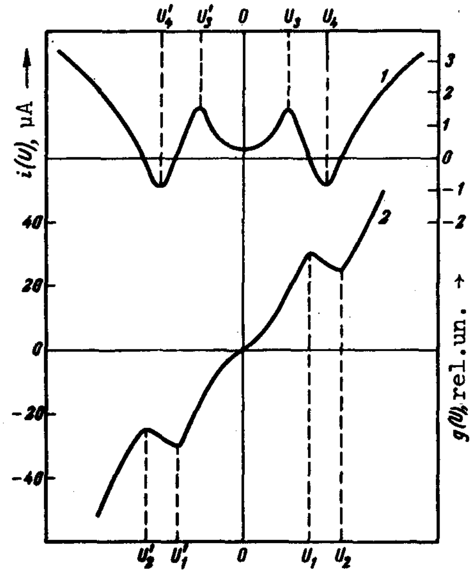

Fig. 1. Plots of tunnel current i(U) (1) and tunnel conductivity g(U) (2) of Al-Al_2O_3-Al tunnel junction.