DEPENDENCE OF THE CRITICAL-CURRENT DENSITY ON THE GRAIN DIMENSION IN POLYCRYSTALLINE NIOBIUM

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An exponential dependence of the critical current density on the reciprocal of the grain dimension was obtained for polycrystalline niobium with grains ranging from 100 to 10 microns.

It is assumed that the grain boundaries in type-II superconductors in the mixed state can serve as pinning centers for the flux-line lattice (FLL) in materials having anisotropy of the superconducting properties [1].

To study the FLL pinning, one investigates the dependence of the critical current (j_c) on the grain dimension (d), since the latter determines the area of the intercrystallite surface, and by the same token the number (area) of the points of FLL pinning. Experimental data on the dependence of j_c on d are known only for Nb-Zr alloys [2] and for the compounds Nb_3Sn [3] and V_3Ga [4]. The results are conflicting and are difficult to compare.

Since niobium is an elementary type-II superconductor and is characterized by a noticeable anisotropy of the superconducting properties [5], it is useful to obtain information on the dependence of j_c on d.

The initial cold-drawn niobium wire of $\sim$ 1 mm diameter, of NVCh grade (99.3%), was annealed in oil-free vacuum of pressure not higher than 5×10^{-8} Torr. Variation of the temperature (800 — 1000°C) and of the annealing time (1 — 4 hr) yielded a series of samples with d from $\sim$ 10 to $\sim$ 550 μ. The grain dimension was determined from the average grain area obtained by the Saltykov method [6], the grain cross section being approximated by a regular hexagon.

After annealing, we measured the resistance R(293°K) at room temperature and the resistance R(4.2°K, 6 kOe) at 4.2°K and in a magnetic field H = 6 kOe. The ratio of the two resistances turned out to be approximately 30 for all samples. In addition, all the samples had the same upper critical field $H_{c2} \simeq 3.3$ kOe. These data indicate that the interstitial impurities had the same densities after different annealing regimes [7]. The effect of the dislocations was negligible, since their density in the recrystallized grains did not exceed 10^3 cm^{-2} [8].

Figure 1 shows the measured j_c as a function of H (in logarithmic scale) for different values of d. We see that decreasing d by one order of magnitude increases j_c by three orders (curves 1 — 6). Some samples in the series exhibited a peak effect. Curve 7 (d = 545 μ) corresponds in essence to a single-crystal sample, since d is commensurate with the sample diameter, and gives an idea of the j_c level ($\sim 10^2$ A/cm^2) determined by factors other than the grain boundaries, such as dislocations and others.

In fields weaker than H_{c2}, the j_c(H) curves are almost parallel, indicating that the j_c(d) retains the same form in the mixed state. The experimental results turned out to fit the linear relation log $j_c \sim 1/d$ at $H < H_c$. Figure 2 shows a typical plot of this relation for H = 2.9 kOe, with the line fitted by least squares.

Our experiments have thus shown that the relation $j_c \sim \exp(1/d)$ holds true for niobium in the range of d from $\sim$ 10 to $\sim$ 100 μ. By its definition, the quantity 1/d is proportional to

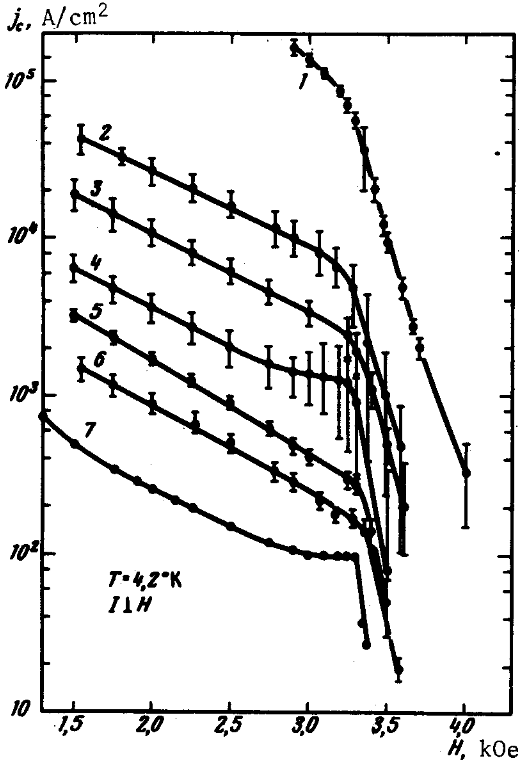

Fig. 1. Critical-current density vs. the external magnetic field for samples with grain dimensions (in microns) 11 (1), 17 (2), 24 (2), 42 (4), 73 (5), 107 (6), and 545 (7).

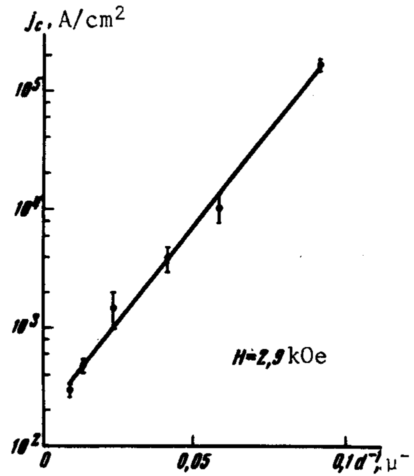

Fig. 2. Critical current density vs. the reciprocal grain dimension.

the area of the intercrystallite boundaries per unit volume, or to the number of FLL pinning points per unit flux line length, so that the dependence expected in accordance with [9] should be $j_c \sim 1d$. The experimentally obtained dependence, however, is much stronger, and its explanation calls for additional research.

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