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ABSTRACT

The importance of internal surface superconductivity with respect to resistive measurements is pointed out. Critical current density vs transverse magnetic field data are presented for a well-annealed 75Nb-25Zr alloy. A comparison of resistive critical field data so obtained is made with published ultrasonic, microwave and resistive transition data for cold-worked 75Nb-25Zr. It is suggested that the resistive critical field for the annealed alloy corresponds to the bulk upper critical field H_{c_2}.

During the last five years a large amount of resistive critical field (H_r) data has been compiled for various high-field solid-solution alloys. Anisotropy in H_r has been noted[1] or implied (compare Refs.2 and 3). This anisotropy, which is inconsistent with simple theoretical interpretations, has received little attention until recently.[4] Variation of H_r with microstructural modifications has been known for some time also,[5] yet its significance has not been widely recognized, partly because of skepticism concerning present knowledge of the effects of thermal treatment *per se* as opposed to the effects of compositional changes resulting from thermal treatments. It is important to point out that the H_r-anisotropy and the H_r-microstructure sensitivity are probably related to each other through a mutual dependence upon internal surface stabilized superconductivity above the bulk upper critical field H_{c_2}.

Resistive critical field is somewhat dependent upon the search-current density (J) used and the entire resistive transition is broad although in part these may be due to small composition variations which invariably occur in alloy ingots. Such composition variations are extremely difficult to eliminate entirely because diffusion does not occur readily at easily accessible temperatures. Even in heavily deformed alloys which are relatively homogeneous there is H_r dependence upon J and a broad resistive transition, indicating that these effects are also due to the nature of the cold-worked state. When, however, a severely cold-worked alloy is recrystallized, diffusion is enhanced and good compositional uniformity results. Furthermore, the resistive transition is sharpened considerably and the dependence of H_r on J is virtually eliminated for a range of search-current densities.

It has been shown that there is a limiting onset H_r for heavily cold-worked alloys,[3] and it appears that for well-annealed alloys there is a well-defined H_r which is probably the bulk upper critical field H_{c_2}. The latter has been demonstrated through a comparison of critical current density (J_c) vs transverse magnetic field, resistive transition and magnetization data for pure niobium.[6] Since the magnitude of J affects the determination of H_r, the choice of a single, arbitrary J will not allow the determination of H_{c_2} for all materials. Nevertheless, a complete J_c vs H curve along with suitable resistive transition curves does permit one to obtain H_{c_2} sin J_c falls abruptly (almost discontinuously) at H_{c_2} for well-annealed materials (Fig. 1). Conversely, the resistive transition occurs abruptly if a suitable value of J is used. Too high a value of J will give simply a critical current density point (for a resistive onset criterion), although a complete resistive transition will give an approximate value for H_{c_2}. Too low a value of J will give information about free-surface superconductivity, i.e., a tail on the J_c vs H curve which may extend as far as H_{c_3}. It is fortuitous that values of J useful in obtaining H_{c_2} are in the range 0.1 to above 100 amp/cm^2 where the onset H_r and the resistive transition curves are almost independent of variations in J or more than an order of magnitude for well-annealed materials.

Strong evidence that internal surface superconductivity is responsible for <u>apparent</u> bulk superconductivity (as determined resistively) up to magnetic fields above H_{c_2} is provided by comparisons of onset H_r for a wide variety of solid-solution alloys in both deformed and annealed conditions.[5,7] Invariably, the ratio H_r(cold-worked)/H_r(annealed) is within the limits 1.1 to 1.2 for transverse fields. It is significant that for 75Nb-25Zr the onset of the transition at 4.2°K as determined by an ultrasonic technique[8] (Fig. 2a) and by a microwave technique[4] (Fig. 2b) occurs rather near the H_r values for annealed 75Nb-25Zr (Fig. 2d), but significantly below the onset H_r value for cold-worked 75Nb-25Zr (Fig. 2c) which was interpreted as H_{c_2} in Ref. 4. The widths of the transitions determined by the former two methods are somewhat puzzling. They may be related to composition fluctuations or to internal surface superconductivity even though no anisotropy with field was observed. Similar experiments should be performed on recrystallized, homogeneous alloys. In such a case it is to be expected that the field-orientation anisotropy of H_r will disappear because any possible internal surface contributions to superconductive behavior will be greatly minimized and free-surface superconductivity should be easily recognizable (or easily inhibited) for the $J \| H$ case. Good microstructural control and analysis are necessary for a clear interpretation of the various possible transition fields.

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FIGURE CAPTIONS

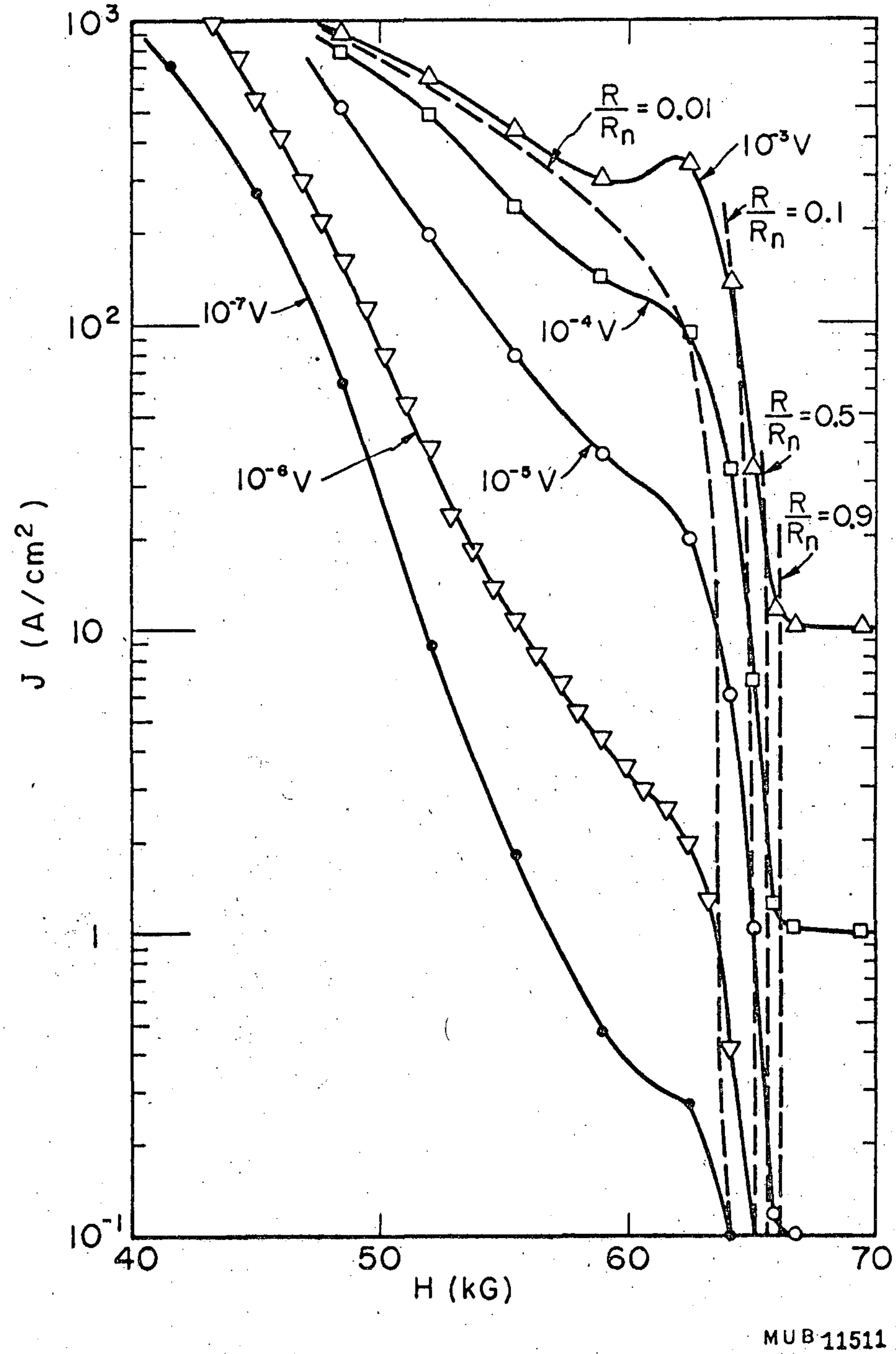
Fig. 1 Critical current density as a function of applied transverse magnetic field at 4.2°K for various voltage criteria with a 4 cm gauge length (solid lines) and for constant fractional restored resistance (broken lines): 75Nb-25Zr, 0.0254 cm diameter, annealed in high vacuum at 1450°C for 15 min.

Fig. 2a Ultrasonic transition for 75Nb-25Zr;[8]

2b Microwave transition for cold-worked 75Nb-25Zr;[4]

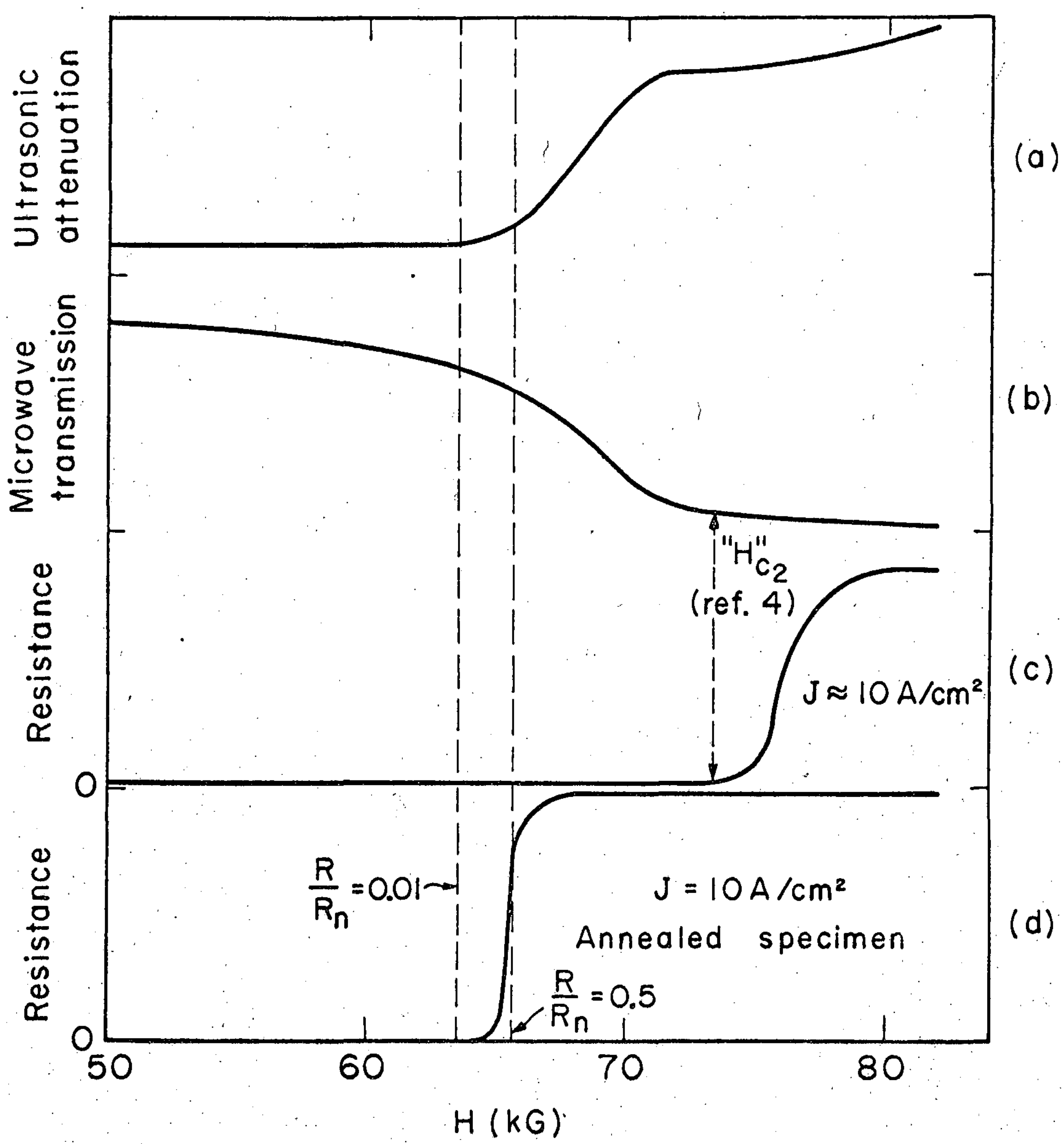
2c Resistive transition for cold-worked 75Nb-25Zr;[4]

2d Resistive transition for annealed 75Nb-25Zr: H_r indicated for 1% and 50% ($H_r = H_{c_2}$) resistance restored (all at 4.2°K).



10^3
10^2
10
1
10^{-1}
J (A/cm²)
40
50
60
70
H (kG)
$\frac{R}{R_n}$ = 0.01
10^{-3}V
$\frac{R}{R_n}$ = 0.1
10^{-7}V
10^{-4}V
$\frac{R}{R_n}$ = 0.5
10^{-6}V
10^{-5}V
$\frac{R}{R_n}$ = 0.9
MUB 11511

Fig. 1.



Ultrasonic attenuation
(a)
Microwave transmission
(b)
"H_{c_2}"
(ref. 4)
Resistance
(c)
J ≈ 10 A/cm²
0
$\frac{R}{R_n}$ = 0.01
J = 10 A/cm²
Annealed specimen
Resistance
(d)
$\frac{R}{R_n}$ = 0.5
0
50
60
70
80
H (kG)
MUB-11512

Fig. 2.