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ANALYSIS OF CONTINUITY AND PROXIMITY EFFECT CONDUCTIVITY LIMITS IN "IN SITU" MULTIFILAMENTARY SUPERCONDUCTING WIRES

R. Roberge*, J.L. Fihey* and B. Schwartz*

IREQ, Institut de Recherche de l'Hydro-Québec, Varennes, Quebec JOL 3P0, Canada
* Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.
Department of Physics, Brooklyn College of the City University of New York, Brooklyn, N.Y, 11210, U.S.A.

Abstract.—We focus on the question of whether continuity or the proximity effect is the dominant factor for the high critical current in "in situ" materials. The analysis of the experiments indicate that proximity plays a role at low Nb concentration while continuity is the dominant factor for high Nb concentration.

1. INTRODUCTION.—The bronze or solid state diffusion process is now a well developed composite materials technology, but other techniques for the production of multifilamentary superconductors such as powder metallurgy /1,2/, infiltration /3/, and "in situ" /4/ show great promise. We discuss the superconducting properties of "in situ" materials and focus on the question of whether continuity or the proximity between the Nb filaments is the dominant factor for the high critical currents /5/.

2. ORIGIN OF SUPERCONDUCTIVITY.—The microstructure of a Cu-Nb alloy in the as-cast condition can be complex as illustrated in figure 1. In addition to a network of large (≈ 10 μm) niobium precipitates, a fine dispersion of niobium is evident on the copper subgrain boundaries. For an as-cast microstructure which did not show the fine subgrain precipitation seen in figure 1, a critical concentration of Nb in Cu for a sharp increase in Jc was observed earlier /4/. Hammond /6/ has also observed a similar critical concentration in multicomponent composite films of Cu-Nb,Sn. All three methods /1/ for describing the conductivity of a structure composed of materials with different conductivity distributed in a random fashion (Monte Carlo calculations, effective medium theory and percolation) predict a critical concentration for a sharp change in the conductivity with concentration.

Fig. 1: Microstructure of as-cast Cu-7 wt % Nb

In low concentrations (Nb < 8 wt %), if we have the fine subgrain precipitation, the specimen can exhibit superconductivity but the critical current density is very small (10 A/cm² or less). Superconductivity at low concentration has also been observed by Nagata et al. /8,9/.

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3. DEFORMATION PROCESS.- For concentrations below the threshold for continuity via percolation, the niobium is randomly dispersed in a matrix of copper. Following mechanical deformation the precipitates are elongated into filaments. The electrical resistivity at 4.2 K decreases rapidly with reduction in area (figure 2). If the measuring current is small (10 A/cm²) the resistivity is observed to decrease proportionally to $R^{-3}$, where $R$ is cross-section reduction ratio, and is in excellent agreement with the geometrical model proposed by Davidson, Beasley and Tinkham /10/ which gives $R^{-3}$. If the measuring current density is increased, $\rho$ increased rapidly, and if a criterion for $J_c$ of 1 $\mu$V/cm is used we can measure apparent critical current densities. However, these alloys are not superconductors.

If the niobium concentration is greater than the critical concentration from percolation theory, the critical current $I_c$ remains constant over a large range of cross-section reduction then decreases with a slope of $\approx R^{-1}$. The transition between constant and decreasing $I_c$ with $R$ is correlated metallographically to the region where the elongated Nb filaments become uniform in cross-section, not circular but of complex ribbon shape. Upon deformation /11/ the initial contact area between the Nb precipitates is presumed to remain nearly constant until all the elongated Nb particle cross-section has reached this contact area size. This model describes remarkably well the observed variation of $J_c$ with $R$, figure 3.

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If the proximity effect is the dominant conductivity process, we assume a network of discontinuous filaments which would become closer with deformation. Deutscher and DeGennes /12/ and McConnell /13/ form the basis for the following analysis. The equation for the critical current density for superconducting filaments gives:

$$J_{c}^{nS} = \left[1 - \frac{\tau}{\tau_{cS}}\right]^{2} \exp\left(-\frac{2d}{\xi_{n}}\right)$$  \hspace{1cm} (1)$$

where $d$ is filament spacing and $\xi_{n}$ the coherence length of the normal metal approximately 2000 Å. If the niobium precipitates are not in contact, the observed critical current density is due to the proximity effect. Equation (1) gives the variation of

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Fig. 2: $\rho$ at 4.2 K as a function of $R$ for different measuring current densities

Fig. 3: $J_c$ at 4.2 K as a function of $R$, our experimental results, proximity model, results of Nagata et al.
The effective $d(R)$ changes with $R$ as $d(R) = d/\sqrt{R}$. A very steep increase of $J_c$ with $R$ should be observed, figure 3. The initial slope should be 4. Experimentally we observe a slope of 1; the deformation model gives a slope of 1. Also shown in figure 3 is the low concentration Cu-Ga-V study where the proximity effect is the most likely conducting mechanism. These results are plotted in terms of $R$ (a conversion from their values of $d$ obtained from different heat treatments). The observed dependence of $J_c$ versus $R$ (or $d$) is as expected.

4. CONCLUSION.— The analysis of the experiments indicate that there is no dilemma between proximity or continuity, but that they are complementary; proximity occurs at low concentration and continuity is dominant at high concentration.

References

/2/ Battelle Columbus Laboratories, Progress Report BMI-X-687, Vol. 11
/7/ Kirkpatrick, S., Phys. Rev. Lett. 27 (1971) 1722
/13/ McConnell, R.D., Institut de Recherche de l'Hydro-Quebec n° 73-937-01.