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POTENTIAL APPLICATIONS OF NbN COMPOSITES IN FUSION REACTOR MAGNETS*

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Recent projected requirements(1) for large scale fusion reactor magnets call for the development of advanced superconducting materials capable of producing peak magnetic fields in excess of 15 T with current densities in the windings in excess of 2×10^3 A/cm^2. These materials will be exposed to large stresses (up to 500 MPa) and neutron fluences as high as 10^{22} n/cm^2 over the lifetime of the conductor. The demonstrated strain and radiation tolerence of NbN together with excellent superconducting properties make it a promising candidate to be used in a superconducting composite capable of satisfying these requirements. Our program at Argonne is directed towards demonstrating a method of fabrication which is capable of achieving these goals. Tests will be conducted on moderate lengths of NbN superconducting composites to verify the ability to achieve large overall current densities in magnetic fields up to 20 T. High field applications of NbN are also being investigated by groups in Japan(3) and Germany.(4)

<u>Present Status</u>. NbN films are deposited on a variety of substrate materials using a d.c. hollow cathode magnetron sputtering gun (Varian S-gun). In this process Nb is sputtered in an Ar/N_2 gas mixture onto substrates held at a constant temperature of about 300 C. In the initial stages of the program, NbN films were deposited onto Al_2O_3 and Hastelloy B substrates.(2) The deposition conditions were systematically varied so as to determine the optimum conditions for producing NbN films with good high field properties. We can now produce NbN films up to several microns thick having J_c in excess of 3×10^4 A/cm^2 at 20 T

and 2.0 K. The upper critical field at 2.0 K of these films is about 27 T as determined by using the appropriate extrapolation, namely $J_c^{1/2} H^{1/4}$ vs. H.

Figure 1 shows J_c vs. H for one of our NbN films on a sapphire substrate at T = 4.2 K, together with comparable results from Refs. 3 and 4. For solenoidal applications of tape conductors, the film surface is parallel to the magnetic field near the bore where the fields are largest. For this reason it is imperative to make comparisons between materials using the parallel field orientation. In the case of films on round substrates, the J_c will be a suitable average of the parallel and perpendicular results. However, recent measurements of the critical field anisotropy in NbN films[5] show a strongly cusped dependence of H_{c2} vs. angle near the perpendicular direction. Therefore, the average J_c of a round conductor is likely to be close to the parallel field value, because only a small percentage of the film will be perpendicular to the applied field. Thus, for example, our somewhat low value of J_c for perpendicular field may be improved by careful alignment, but the usefulness is questionable. However, the $J_{c\perp}$ of Ref. 3 shows that NbN can potentially have a much higher J_c. The challenge is to obtain a microstructure and conductor geometry which exhibits such high J_c for the appropriate field orientations found in magnets.

Our experiments have produced several results which may form the basis for an understanding of the relationships between deposition conditions, microstructure, and superconducting properties. We have demonstrated that changes in Argon partial pressure (P_{Ar}) have a substantial effect on the superconducting properties of our films. These effects are summarized in Figure 2 where we show T_c, H_{c2} (4.2 K), and J_c (19 T, 4.2 K) vs. P_{Ar} for films deposited at 50 Å/sec. Although a clear physical understanding of these observations is not complete, the H_{c2} data are consistent with the increased resistivity measured on films produced at high Ar pressures. Also, the shape of the J_c data can be accounted for by the reduction of H_{c2} below the peak and T_c above the peak. Transverse TEM micrographs[6] show a large increase in the number of defects in films produced at higher Ar pressures but no change in the average grain diameters. Thus the intragrain defects may account for the higher resistivities observed.

We have recently extended our deposition technique to the production of short lengths ($\lesssim$ 10 cm) of NbN composite ribbons. These ribbons consist of several microns of NbN on one side of a 1/8" wide Hastelloy B type. The NbN film is overcoated with several microns of copper to provide thermal stability. The copper is deposited before breaking vacuum in order to minimize the contact resistance between the Cu and NbN layers. Such ribbons exhibit J_c values in the superconductor of up to 2.5×10^4 A/cm^2 at 20 T and 2.0 K.[7] These ribbons have only a small anisotropy in J_c between the parallel and perpendicular field orientations.

By continuously transporting a long ribbon beneath the target of our sputtering system we can produce moderate lengths (~ 1 m) of ribbon having a NbN film on one side. Our preliminary experiments maintained constant deposition conditions for several hours.

Future Directions. We plan J_c measurements on single layer coils wound from ~ 1 meter lengths of NbN ribbon to demonstrate that uniform homogeneous coatings can be produced.

In addition, a new sputtering system consisting of two opposed 5" Varian S-guns is almost complete. The vacuum chamber is designed to work with differentially pumped dynamic seals through which indefinitely long lengths of substrate material can pass continuously. However, initial experiments will concentrate on the properties of NbN sputtered onto a variety of fiber materials having a round cross section diameter up to 25 μm. Substrate materials showing the greatest promise would be coated in longer lengths in a process similar to that used for carbon fibers.[4] Such coated fibers can be combined to emulate conventional multifilamentary conductors, which, when compared to sputtered tape conductors, may achieve higher overall J_c's, greatly improved flux jump stability, and reduced a.c. losses. Also, round conductors can be conveniently bundled and transposed to produce composites capable of carrying the high currents necessary for large magnet applications. These experiments will be conducted in collaboration with the High Field Magnet Group at Livermore and Materials Concepts Inc., Columbus, Ohio.

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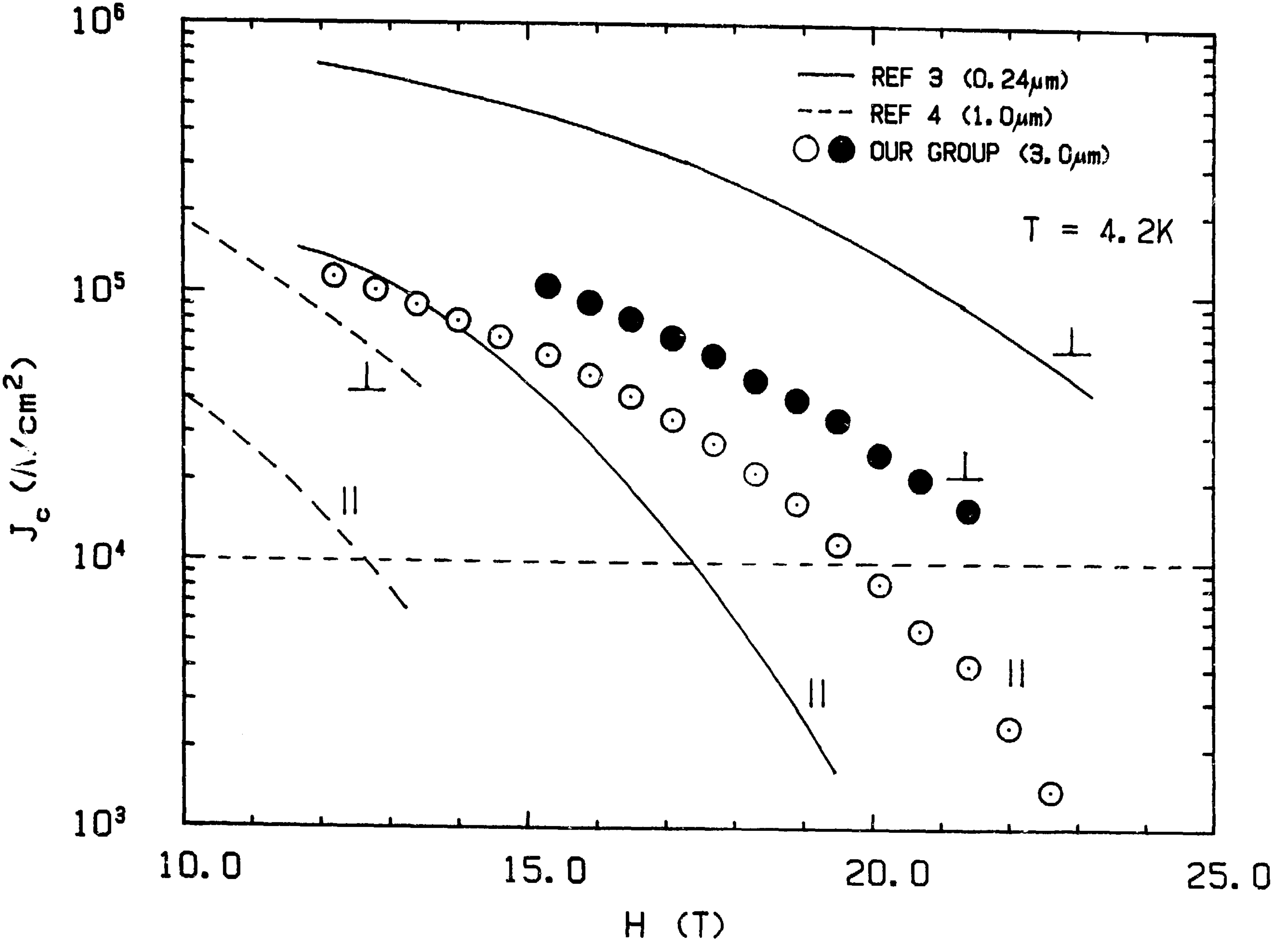
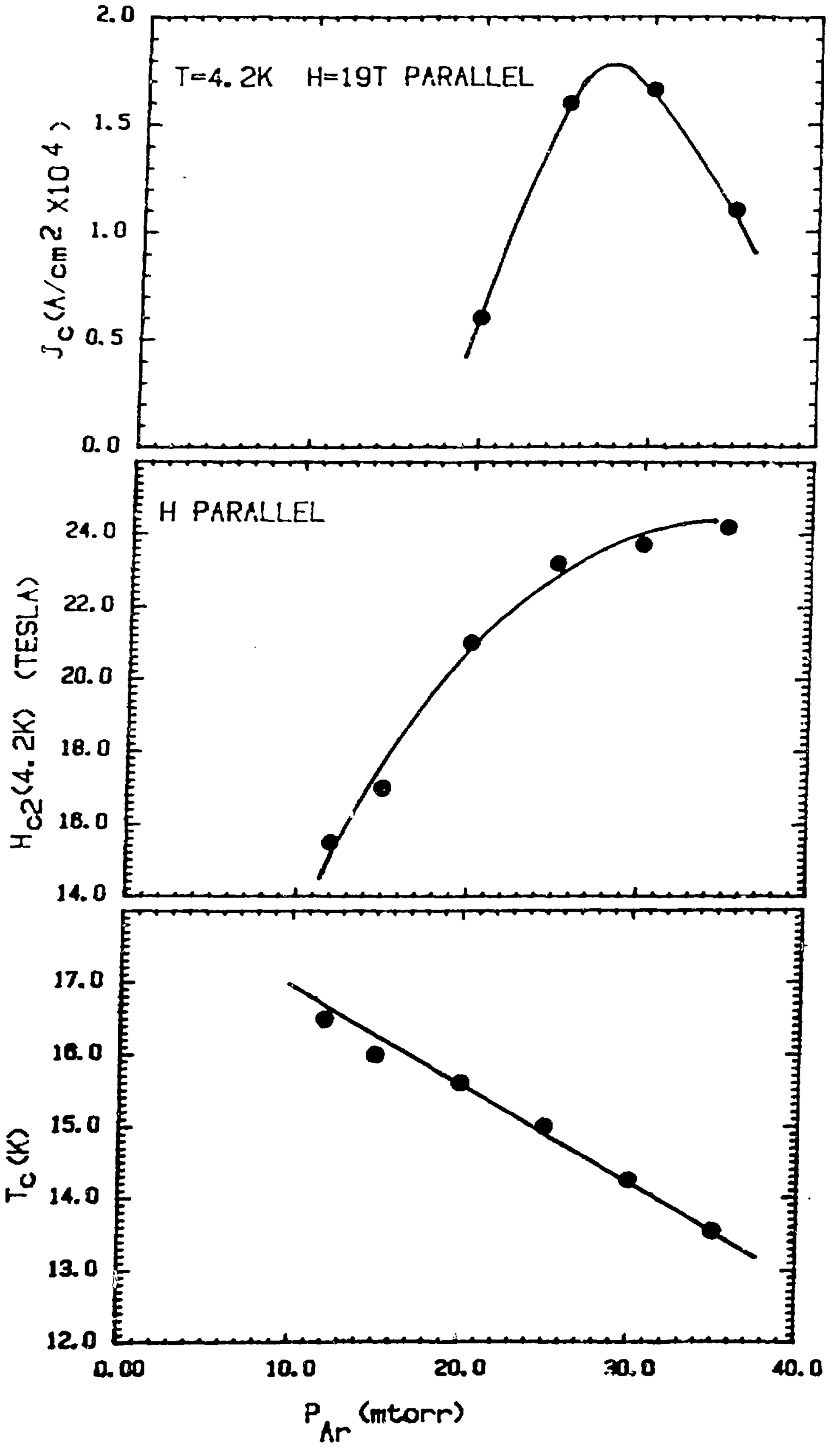


REF 3 (0.24μm)
REF 4 (1.0μm)
OUR GROUP (3.0μm)
T = 4.2K
⊥
||
⊥
||
⊥
||
10^6
10^5
10^4
10^3
J_c (A/cm^2)
10.0
15.0
20.0
25.0
H (T)



T=4.2K H=19T PARALLEL
J_c (A/cm^2 X10^4)
2.0
1.5
1.0
0.5
0.0
H PARALLEL
H_{c2}(4.2K) (TESLA)
24.0
22.0
20.0
18.0
16.0
14.0
T_c (K)
17.0
16.0
15.0
14.0
13.0
12.0
0.00
10.0
20.0
30.0
40.0
P_{Ar} (mtorr)