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HIGH FIELD PROPERTIES OF NbN RIBBON CONDUCTORS*

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ABSTRACT

In this paper we report the first high field measurements on ribbon conductors composed of NbN and Cu deposited onto Hastelloy ribbons. These ribbons are 5 to 8 cm long, 1/8" wide, and have several microns of NbN, covered with several microns of Cu, deposited onto one side. Such samples have a $T_c \sim 14.5$ K, H_{c2} (2.0 K) $\sim$ 26 T in the parallel direction and J_c (20 T, 2.0 K) up to 3×10^4 A/cm^2.

A recent mirror fusion reactor study outlined the need for a superconducting solenoid capable of operating in the 20-24 T range. Presently, there are no commercially available superconductors with properties suitable for magnets in this range. In a program aimed at developing such a conductor, we have produced NbN films with high field properties which could satisfy this requirement. In this paper, we report the first high-field measurements on short lengths of practical ribbon conductors based on NbN. These reproducible high-field properties coupled with the demonstrated strain and radiation tolerance of NbN make it an ideal candidate for reducing the size and cost of the next generation of fusion reactor magnets.

Recently, the high field properties of thin film NbN deposited onto sapphire and Hastelloy were reported.[1] These films, deposited by d.c. reactive magnetron sputtering, were used to optimize the high field properties of NbN films. The details of this process will be reported elsewhere. In order to study the more practical aspects of our films, we have begun fabricating 1/8" wide conductors consisting of several microns of NbN deposited onto 0.002" thick Hastelloy ribbons overcoated with several microns of copper using a thermal evaporator. These ribbons are 5-7 cm long and, at present, have NbN and Cu deposited onto one side only.

Using the high-field facilities available at the Francis Bitter National Magnet Laboratory** the critical current density (J_c) has been measured as a function of applied field, for both the parallel and perpendicular directions, at two temperatures (4.2 and 2.0 K). In Figure 1, we show J_c vs. H for one of these ribbons for both the parallel and perpendicular directions. The 1 μV/cm criterion, is used to define J_c.

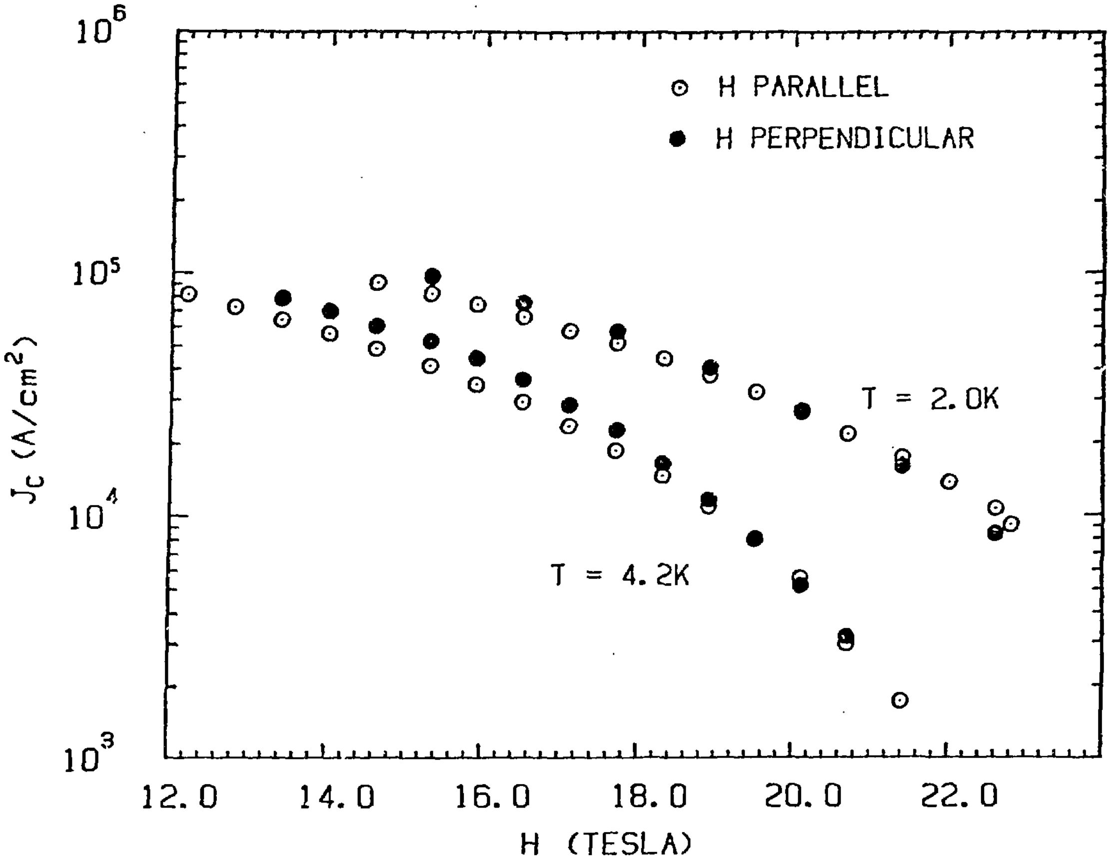

Fig. 1. Critical current density (J_c) vs. applied magnetic field (H) for one NbN ribbon conductor. The data are at T = 4.2 and 2.0 K, with the field orientation both parallel and perpendicular to the film surface.

This corresponds to an effective resistivity of about 10^{-10} Ω-cm.

Several features, common to all of our NbN samples, with important consequences for the feasibility of producing a practical conductor, are: 1) The ribbons have J_c well in excess of 1×10^4 A/cm^2 at 20 T and 2.0 K (the highest value is 3.0×10^4 A/cm^2); 2) we are able to deposit substantial thicknesses of NbN onto the Hastelloy ribbons without experiencing bonding problems (~ 17 to 20 μm); 3) we are able to deposit up to 5 μm of Cu onto these ribbons; 4) the J_c of the ribbons in the perpendicular direction is always higher than in the parallel direction; and 5) the J_c of the ribbons is the same as that measured for patterned NbN on sapphire with a Cu coating, implying that the NbN is not degraded at the edges of the ribbon.

The measured properties of our ribbons can be used to estimate the properties of a more practical conductor design. For example, a 1 cm wide ribbon with 15 μm of NbN and 5 μm of Cu deposited onto both sides, having a J_c for the NbN alone of 3.0×10^4 A/cm^2 at 20 T and 2.0 K (our best ribbon) has an overall J_c, including Cu and Hastelloy, in excess of 1×10^4 A/cm^2 at 20 T and 2.0 K. This value is well above the value (3.5×10^3 A/cm^2) set by Hoard et al.[2] in designing a 20 T magnet operating at 1.8 K. A conductor of this configuration would carry 100 A at 20 T. A cable of 10 to 20 ribbons, possibly with internal cooling, has the potential to satisfy the current requirements of large fusion magnet designs. Also, the higher J_c in the perpendicular direction should reduce the stability problems associated with the perpendicular field component at the ends of tape-wound solenoids.

The substantial increase in J_c obtained by operating at 2.0 K appears to be almost entirely due to an increase in H_{c2}, thus indicating the potential additional gains which could be achieved by increasing H_{c2} by means other than temperature. For example, the addition of appropriate third elements, such as C or Ti. It has been shown that such additions increase T_c of NbN, but, very little work has been done on their effect on H_{c2}. One of our immediate goals is to investigate the high field properties of Nb(Ti)N and Nb(C)N compounds formed by reactive sputtering from Nb(Ti) and Nb(C) targets. Another goal is to fabricate continuous lengths of NbN ribbon conductor (~ 20-70 cm) for more extensive testing of their high-field properties and suitability as practical superconducting materials. A new system designed to simultaneously deposit NbN onto both sides of moving ribbon substrates is being constructed and the results on materials produced in this system will be reported in the future.

To summarize, we have succeeded in producing short lengths of ribbon conductor based on NbN, coated with Cu, which have excellent high field superconducting properties ($J_c = 1.5\text{-}3.0 \times 10^4$ A/cm^2 at 20 T and 2.0 K) and have potential as conductors for the next generation of superconducting magnets for fusion reactors. Future work will involve attempts to increase H_{c2} of these materials together with the fabrication of longer lengths for more relevant testing.

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