High-Capacity Superconducting Current Leads of \( \text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x} \)

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We have fabricated and measured a high-capacity superconducting current lead composed of a \( \text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x} \) cylinder, 20 cm long and 0.9 cm² cross section. A steady-state, d.c., critical current of 225 A at a temperature of 77 K was measured in this sample, using a voltage criterion of \( 2 \times 10^{-7} \) V/cm (\( \rho = 8 \times 10^{-10} \) ohm-cm). This current was limited by the current-induced, self magnetic field. To our knowledge this is the largest d.c. critical current so far reported in a \( \text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x} \) sample and demonstrates the possibility of using high-temperature superconducting HTS materials for current leads to low-temperature superconducting LTS magnets or in power distribution systems.

KEY WORDS: Current leads; \( \text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x} \); high-current capacity.

1. INTRODUCTION

One of the most promising near-term applications of high-temperature superconducting HTS materials is for current leads to low-temperature superconducting LTS magnets or in cryogenic power distribution systems. Such applications do not require particularly high critical current densities but they do require high currents. Current leads must carry high currents, but they are not required to be flexible and there is no requirement to operate in high magnetic fields since the leads can be shielded from external fields. The purpose of the experiment reported here is to demonstrate the capability of \( \text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x} \) to carry large d.c. supercurrents through a large cross section rather than large current densities in small area samples. The 225 A of supercurrent passed through the sample at 77 K is sufficient to warrant continued development of these applications, but the engineering design of such leads would be greatly eased by improvement of the superconducting critical current in modest magnetic fields.

2. SAMPLE AND EXPERIMENTAL SETUP

The sample was fabricated in the shape of a cylinder with outer diameter of 1.6 cm, inner diameter of 1.2 cm, and length of 20 cm. This shape was chosen to provide a 0.9 cm² cross section for current flow in such a manner as to reduce the current-induced self magnetic field which varies as \( 1/r \), where \( r \) is the distance from the cylindrical axis. The length of the sample was chosen to provide a critical current measurement with sufficient sensitivity to be meaningful in an engineering sense, i.e., resistivities at critical current several orders of magnitude less than cryogenic copper.

The sample was prepared by viscous processing techniques [1]. This technique is described in Ref. 1. Briefly, \( \text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x} \) was prepared by mixing \( \text{Y}_2\text{O}_3 \), \( \text{BaCO}_3 \), and \( \text{CuO} \) powders, calcining at 900°C for 10 h, and then grinding the calcined material in a vibro-energy mill in ethanol. The powder was dried in a rotary evaporator. The powder was then processed using nonaqueous solvents and polymers, and the tube was extruded by means of a cross-head extruder. The tube was sintered in flowing oxygen at 920°C and cooled at 400°C at 1°C/min. The sample was annealed at 400°C and then ramped at 60°C at 1°C/min and removed.

One of the major concerns in this experiment was the proper attachment of the normal current leads to the HTS sample. At these high currents, large contact resistances can limit the observed critical current. To lessen this problem, we baked on (700°C for 1 h in flowing oxygen) gold contacts at each end.

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of the cylinder covering an area of approximately 10 cm² at each end. This area was subsequently "tinned" with a eutectic In–Ga solder. Concentric, coaxial normal current leads were made from 1.9 cm wide, tinned copper braids. This braid was flared to surround the ends of the HTS sample and completely covered the pretinned area. This braid was then wrapped tightly with copper wire to hold it firmly in place while more In–Ga solder was added. The entire sample lead arrangement was gently heated (180°C) to ensure uniform bonding. The contact resistance of these leads was found to be less than 10⁻³ ohms. Figure 1 shows a schematic of the sample and lead arrangement.

Voltage leads were attached to the HTS cylinder, 10 cm apart and 4 cm from the current leads, in order to conduct four terminal current–voltage measurements on the HTS sample. These leads were attached with silver paint.

Two current lead schemes were used in order to vary the current-induced self field at the surface of the sample. The induced tangential field is given by the equation

\[ B_s = \mu I / 2 \pi a \]

where \( \mu \) is the permeability and \( I \) is the current flowing parallel to the cylindrical axis, inside the radius \( a \) of the sample. This surface field would normally be maximum at the outer surface of the cylindrical sample and zero at its inner surface.

However, in the configuration represented schematically in Fig. 1a, the return current flows up the center of the hollow cylindrical HTS sample; therefore, the field will be maximum at the inner surface and zero at the outer surface as well as zero for all distances greater than \( a_{\text{outer}} \). In this arrangement self fields from one lead would not effect the current flowing in other nearby current leads, should multiple leads be needed for a given application.

In the configuration shown in Fig. 1b, only half of the current flows up the center of the HTS cylinder, while the other half of the current flows around the outside of the cylinder. In this configuration, the self field at the inner surface will be half that of configuration 1a and the field at the outer surface is now half the value of the field which would have been induced if no current had been passed through the center of the cylinder. The third concentric lead, surrounding the HTS cylinder, carries the other half of the current flowing in the HTS sample and ensures that the external self field effects from this lead arrangement is also zero.

3. RESULTS

The sample was immersed in liquid nitrogen and the d.c. current was varied linearly at a rate of typically 25 A/min or less from zero to a current corresponding to a measurement voltage of about 300 μV (30 μV/cm), and then swept back to zero current at the same rate. The voltage was continuously recorded on an X–Y recorder. The \( I-V \) curve was found to be reproducible and nonhysteretic. Figure 2 shows some of the \( I-V \) curves taken on this sample as a function of magnetic field applied parallel to the cylindrical axis. The criterion for defining \( I_c \) was the point of first deflection from the zero voltage line which corresponded to a d.c. voltage criteria of 2 × 10⁻⁷ V/cm.

The current–voltage curves can be used to characterize the abruptness of the \( J_c(H) \) transition. Using the empirical relation

\[ V \sim I^n \]

to fit the data, one can extract \( n \) values for the transition, as had been done previously for both composite LTS wires [2,3] and HTS rods [4,5]. Figure 3 shows the results of our determination of \( n \) as a function of \( H \). The sharpest transitions occur in low magnetic fields, where \( n \) exceeds 30. At higher fields the \( n \) values become markedly lower as the transition broadens, dropping to a value of 3.5 at 50 mT. This