Critical Current in YBa$_2$Cu$_3$O$_7$ Ceramics

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Measurements of critical currents using a four-point direct current (dc) method and an alternating magnetic field method have been performed on several superconducting YBa$_2$Cu$_3$O$_7$ ceramics at 77 K. In the presence of a constant magnetic field, the critical currents obtained with the alternating field method are several orders of magnitude larger than the critical currents measured by the dc method. Also, we observed a minimum in the dc critical current as a function of applied transverse magnetic field. Several authors have suggested that these ceramics behave as individual superconducting grains coupled by Josephson junctions. In this paper, we explain the two observations above using that model.

1. INTRODUCTION

Since the discovery$^1$ of YBa$_2$Cu$_3$O$_7$, a great deal of attention has focused on the current carrying capacity of this compound. This property will determine the usefulness of this compound for a variety of applications. Cava et al.$^{2,3}$ measured the critical current density, $J_c$, using the standard four-point contact technique on a bulk sample which was necked down to a cross-sectional area of 0.2 mm$^2$. In these types of measurements, the contact resistance is usually of the order of one ohm, and this leads to significant heating if the measuring current exceeds one ampere. Even with this limitation, they were able to obtain values of $J_c$ as high as 1000 A/cm$^2$ at 77 K.

From measurements of the field inside a hollow superconducting cylinder against an applied external field, the total supercurrent carried by the cylinder has been obtained.$^3$ Assuming that the current density is uniform

$^*$This paper reports the use of the lowest cross-section for the measurement of the critical current density to date.
throughout the cylinder thickness the critical current density can be determined as a function of magnetic field.

The results from the methods outlined above can all be affected by the surface quality of the sample. During the micromachining required to reduce the cross-section of the sample for direct current measurements, the surface of the sample may be damaged. This may also happen in the special casting methods used to produce hollow cylinders to measure the shielding current. If this occurs, then the measured critical current density, which is an average over the whole sample, will be adversely affected.

Estimates of $J_c$ have also been obtained from measurements of magnetization against magnetic field. This avoids completely the problem of electrical contact with the sample. However, this method relies on a model of the response of type II superconductors to the application of an external field. The Bean model predicts that the critical current is given by

$$J_c = \frac{30M}{R}$$

where $R$ is the radius of the cylindrical sample and $M$ is the magnetization hysteresis at a given field.

In this paper, we report on measurements of critical current density of bulk samples of YBa$_2$Cu$_3$O$_7$. These measurements were obtained using two methods, a conventional four-point dc method and an induction method. This induction (ac) method has been previously used by Campbell to determine the critical current density as a function of position inside cylindrical samples of conventional type II superconductors. The results from this method are not affected by defects at the surface of the samples.

2. SAMPLE PREPARATION

Y$_2$O$_3$, Ba(NO$_3$_)$_2$, and CuO powders were ground and mixed in the appropriate stoichiometric amounts, then calcined according to the schedules in Table 1. After calcination, the resulting cake was analyzed by ICP spectroscopy for Y, Ba, and Cu. The cakes were approximately stoichiometric (Table 2).

<table>
<thead>
<tr>
<th>TABLE I</th>
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<tbody>
<tr>
<td>Calcining Schedule</td>
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<table>
<thead>
<tr>
<th>Schedule</th>
<th>Details</th>
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<tbody>
<tr>
<td>Y19</td>
<td>50°C/hr to 425°C, 5°C/hr to 460°C, 50°C/hr to 585°C, 10°C/hr to 625°C, 50°C/hr to 900°C, hold 24 hrs, air cool.</td>
</tr>
<tr>
<td>Y34</td>
<td>200°C/hr to 610°C, hold 2 hrs, 100°C/hr to 840°C, hold 12 hrs, furnace cool.</td>
</tr>
<tr>
<td>Y47</td>
<td>200°C/hr to 620°C, hold 2 hrs, 25°C/hr to 875°C, hold 16 hrs, furnace cool.</td>
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