NOTES

Properties of Epoxy-Modified YBCO Superconductors

Although new ceramic superconductors possess excellent critical transition temperatures, they have unacceptably low strength and toughness.[1-3] Both polymer (e.g., PMMA and epoxy) and metal (e.g., Au, Ag, and Sn) have been used quite successfully in reinforcing their strength and toughness.[4-9] Development of bulk ceramic–metal or ceramic–polymer composites is mainly aimed at improved mechanical properties that are essential at both the fabrication and application stages. However, choice of the metallic or polymeric phase should take into account its influence on the superconducting properties, i.e., without impairing both the electrical conduction and magnetic levitation.

In this article we describe the superconducting properties of epoxy-modified YBaCuO (123) composites. The influence of epoxy resin on the electrical and magnetic properties is discussed.

The 123 powder was made by solid-state reaction of the constituent oxides Y_2O_3, CuO, and BaO. Powders of Y_2O_3, CuO, and $BaCO_3$ were mechanically mixed in batches of 20 g using a mortar and pestle. The mixed powder was calcined at 930°C for 20 h, dry ground using a mortar and pestle, and then finally calcined at 940°C for another 20 h. After calcination, the powder was reground and pellets of about 3 mm in height were prepared by compaction in a 12.5 mm diameter steel die with a pressure of 150 MPa. The compacted pellets were then placed in alumina boats and sintered at 940°C in a flowing oxygen environment for 24 h and annealed at 600°C for 5 h. The phase composition of 123 powder and pellet was confirmed by x-ray analysis (XRD) using the Siemens D500 diffractometer.

The sintered pellets, P, ER0.5, ER5, and ER20, were subsequently impregnated for 0, 0.5, 5, and 20 min, respectively, in a bath of epoxy resin (DOW D.E.R. 353) mixed with stoichiometric amount (32.3 parts per hundred of resin by weight) of 4-4′ diamine-diphenyl-sulfone (DDS) as curing agent. The epoxy impregnated samples were then fully cured in an oven initially at 120°C for 16 h, followed by 4 h at 180°C.

Rectangular bars of 3 × 5 × 12 mm were dry-cut for d.c. resistivity and current density measurements. These were carried out in a home-made cryostat, from 77 K to room temperature, using the 2 × 2 probe technique. Electrical contact with the specimens was effected by means of symmetric loading applied through the high purity copper pins coated with silver-dag. This arrangement, with the current supplied from one face of the bar and the voltage measured on another surface, minimizes the contribution of surface resistance to the measured bulk resistance. A stabilized d.c. supply (Advance model PP7) and a digital microvolt meter (Keithley model 197) were used. The electrical resistances were measured at a constant current of 2 mA. The temperature was measured using a Digi-Temper thermocouple. The value of critical current (I_c) was obtained by measuring the d.c. current vs. voltage curve, with a criterion of 1 V per unit cross-sectional area to evaluate the critical current density (J_c).

The magnetic levitation behavior of the composites as a function of temperature was studied by floating a rare-earth magnet above the disc specimens. This experiment was aimed at ascertaining the direct correlation, if any, between Meissner effect and resistivity in the determination of T_c. If the correlation exits, the Meissner effect could offer a much simpler alternative for the measurement of T_c.

The electrical resistivity of pure and epoxy-impregnated samples (Figs. 1 and 2) showed that the T_c of 123 remained unchanged at 93 K, despite the presence of epoxy in the structure. This observation concords with results obtained for 123 samples modified with PMMA[4,10] and metals.[6-9] Resistivity results suggest that at temperatures above T_c, pure 123 behaved like a normal conductor but the epoxy-modified sample behaved like a semiconductor. The latter is evidenced by the decreasing resistance with increased temperature. This observation does not concur with the percolation threshold displayed by the PMMA or metal-modified samples[4-10] at temperatures above T_c. For instance, Chaim and Ezer[7] reported that YBCO/Sn composites sintered at 230°C exhibited a percolation threshold for electrical conductivity at 20 vol % Sn, with semiconducting and metallic behavior below and above it, respectively. Very similar percolation thresholds were reported for YBCO/Au[11] and YBCO/Ag.[12,13]

Preliminary results on the variation of voltage vs. current at 77 and 88 K (Figs. 3 and 4) suggest that the presence of epoxy acted as "weak-links" between grains and, thus, reduced the current-carrying capacity of 123. The I_c and J_c values for pure 123 were, respectively, 75 mA and 5×10^3 A/m^2 at 88 K, rising up to 560 mA and 3.7×10^4 A/m^2 at 77 K. The corresponding I_c and J_c values for epoxy-modified samples were 30 mA and 2×10^3 A/m^2, and 65 mA and 4.3×10^3 A/m^2, respectively. Presence of

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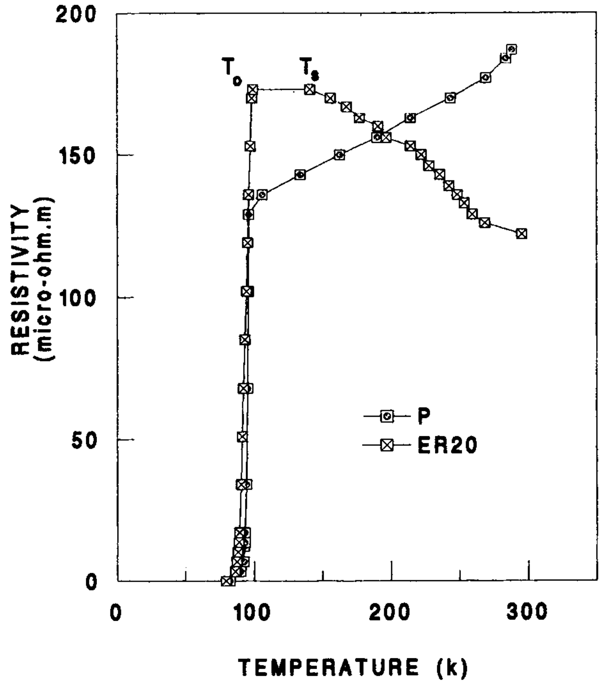

Figure 1 Variation of electrical resistivity vs. temperature for sample P and sample ER20.

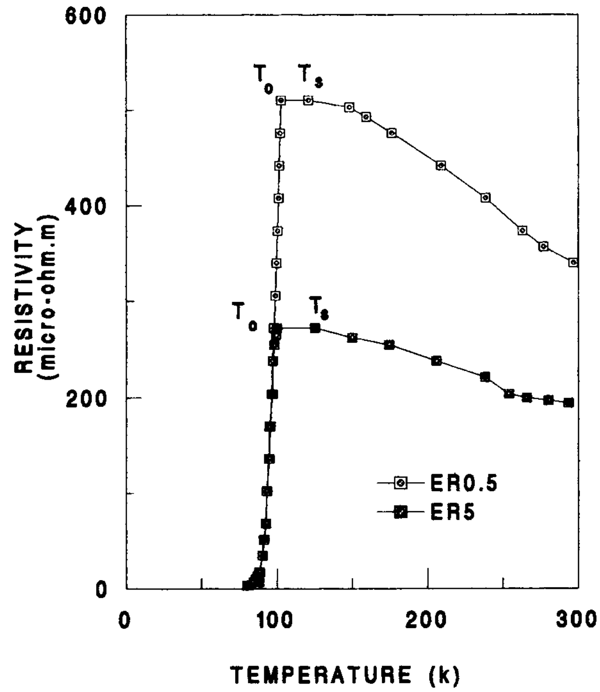

Figure 3 Variation of voltage vs. current at 77 and 88 K for sample P.

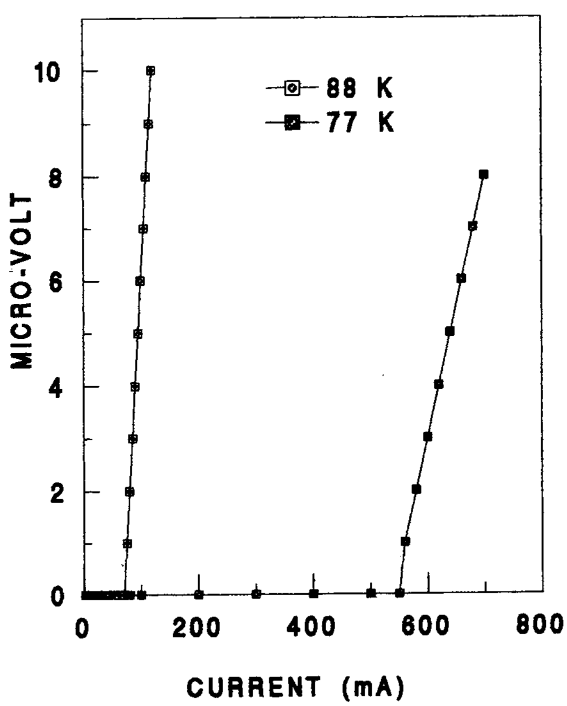

Figure 2 Variation of electrical resistivity vs. temperature for sample ER0.5 and sample ER5.

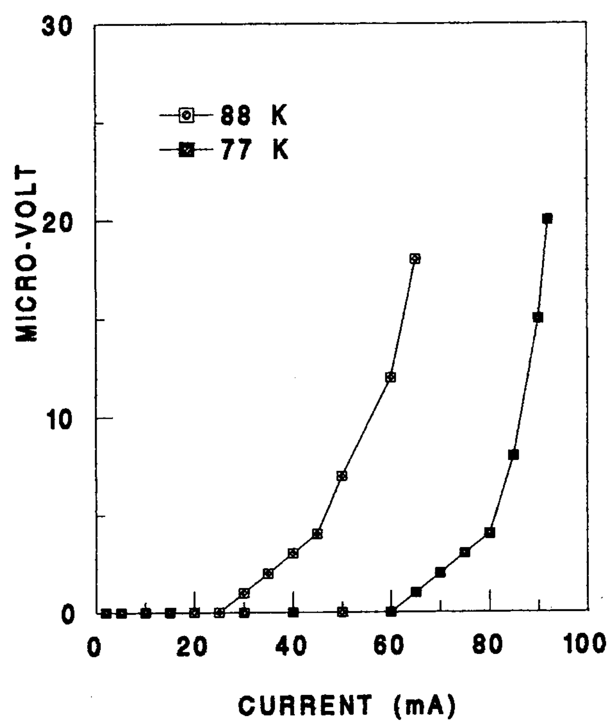

Figure 4 Variation of voltage vs. current at 77 and 88 K for sample ER20.

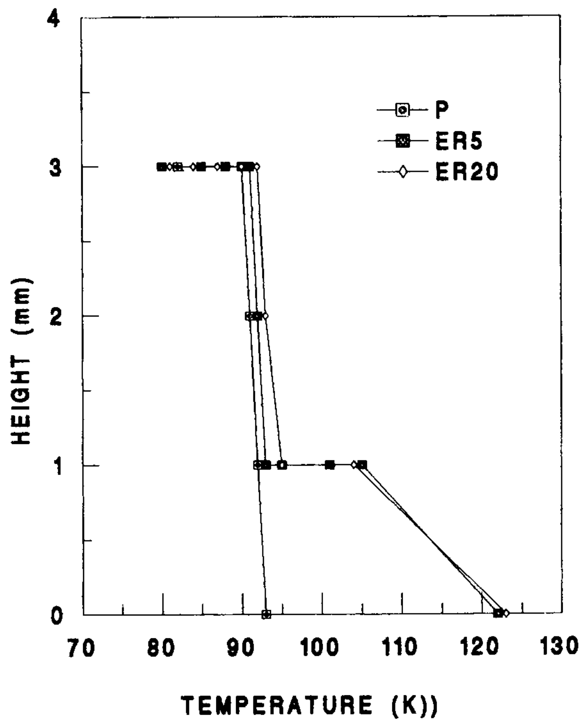

Figure 5 Variation of levitation height vs. temperature for pure and epoxy-modified 123 samples.

more epoxy did not appear to reduce further the value of I_c and J_c.

All epoxy-modified samples appeared to be capable of displaying the Meissner effect for much longer and higher temperature (Fig. 5). The diamagnetic shielding property improved in the presence of epoxy but did not become weakened with epoxy content, as was the case for YBCO/Sn composites.[7] In pure-123, the Meissner effect disappeared soon after the temperature approached the onset of superconductivity (T_o). In contrast, this effect continued in epoxy-modified samples until the temperatures warmed up to T_s (see Figs. 1 and 2). The resistivity appeared to remain unchanged in the temperature region ranging from T_o to T_s. This range increased with impregnation time and reached a saturation value after 10 min. It appears that the presence of epoxy resin enabled the display of superconductivity to stabilize for higher temperatures. This may be attributed to a high specific heat of epoxy, which acts as "heat-sink," thus allowing less energy available for breaking up the Cooper electron pairs. It follows that the display of superconductivity should persist at higher temperatures. Alternatively, the presence of epoxy may serve as "pinning sites" for the stabilization of magnetic vortices created within the superconductor. This helps in the minimization of flux-creep that is common in high T_c superconductors and the concomitant stabilization of flux fields or prolonged display of Meissner effect, as indicated in Figure 5.

In summary, the presence of epoxy did not affect the T_c and the Meissner effect but reduced the current carring capacity. Above T_c, the epoxy transformed 123 into a semiconductor, although a percolation threshold was not evident, and increased the temperature range for the onset of superconductivity and diamagnetic shielding.

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