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LEVITATION OF SUPERCONDUCTING COMPOSITES

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ABSTRACT

The inverse levitation of a high temperature superconductor-polymer composite consisting of powdered quench-melt-growth $Ba_2YCu_3O_{7-\delta}$ and cyanoacrylate is reported. Magnetic hysteresis loop measurements for the composite are compared to those measured for the bulk material prior to powdering. Differences in the flux pining capibility between the two material forms are small but significant.

INTRODUCTION

The recently developed polycrystalline $Ba_2YCu_3O_{7-\delta}$ high temperature superconductor made by the quench-melt-growth technique (QMG) possesses very effective mechanisms for pinning magnetic flux lines.[1,2] This material requires no external additive such as silver, and still posseses a very large critical current and displays a sizeable levitation effect. The source of flux pinning is attributed to the small non-superconducting Ba_2YCuO_5 phase which is trapped inside the QMG superconductor. The present investigation was initiated to study sample size effects on macroscopic properties and to determine the effectiveness of the QMG superconductor as a component in a superconductor-polymer composite.

EXPERIMENTS

A polycrystalline $Ba_2YCu_3O_{7-\delta}$ ($\delta \sim 0$) sample was prepared by the quench-melt-growth technique.[1,2] A large grain, 5 mm x 3 mm x 1 mm, was chosen from the sample and used for this study. The grain was split into two parts of equal weight. One part was set aside for comparison (hereafter referred to as the bulk sample). The other part was ground into powder using a mortar and pestle. The particle size of the powder was distributed from less than 1 μm to as large as 500 μm. The average size of the particles was estimated to be 70 μm. The powder was made into superconductor-polymer composite by infiltrating the powdered superconductor (80 weight percent) with an insulating liquid cyanoacrylate (20 weight percent). The composite was curred at abient temperature, (hereafter referred to as the composite sample). The volume of the composite sample was slightly larger than the bulk sample.

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Low alternating field (ac) susceptibility measurements were performed on both samples using a Hartskorn-type bridge operated at 0.5 Oe rms and at 1.68 kHz. Electrical resistivity of the bulk sample was measured using a standard four-probe dc technique. Magnetic hysteresis measurements were done at 77 K using a vibrating sample magnetometer after cooling the samples in zero applied field.

RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence for the electrical resistivity and the ac susceptibility of the bulk QMG $Ba_2YCu_3O_{7-\delta}$ sample. The data suggest that the bulk sample is of high quality. The ac susceptibility data indicates a large decrease in magnetic susceptibility on decreasing temperature at 92 K. This is consistent with the observed decrease in electrical resistivity . Both results indicate a transition width about 1 K. The ac susceptibility data also indicate the fraction of superconductor was near 100% for the bulk sample at 77K. (there are small fractions of non-superconducting Ba_2YCuO_5 and CuO.)

Two experiments were performed using the bulk and the composite samples. First a permanent magnet was used to test both the levitation and inverse levitation phenomena.[3] Figure 2 shows a photograph of the composite suspended below a small magnet. There appeared to be no qualitative difference in either the levitation or inverse levitation properties between the bulk and the composite samples.
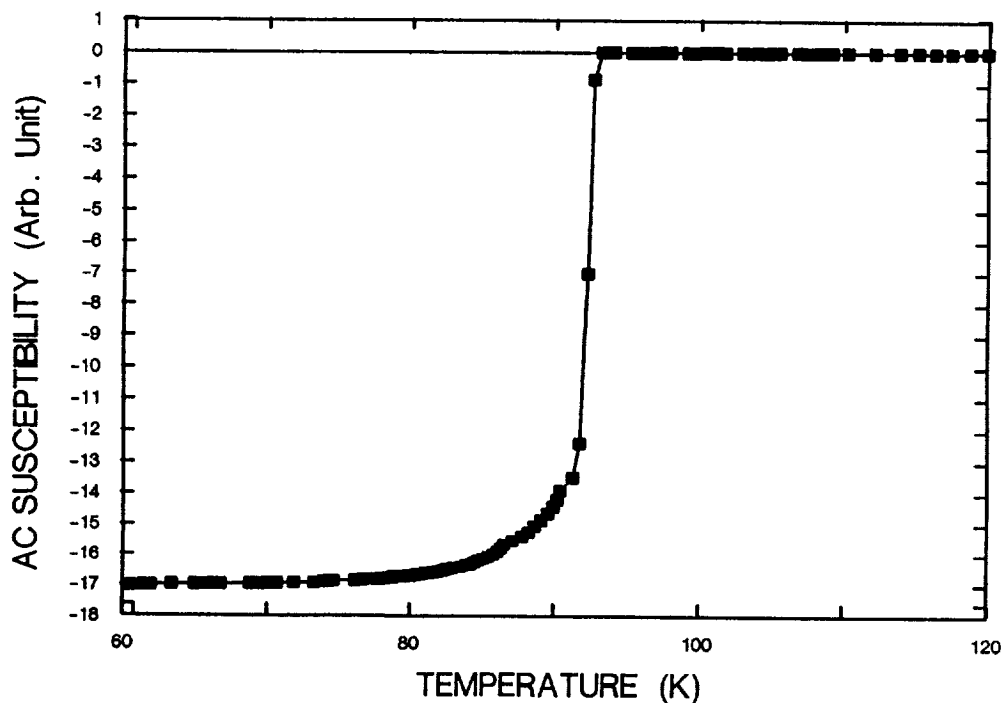

Figure 1a Magnetic susceptibility of the bulk QMG $Ba_2YCu_3O_{7-\delta}$ as a function of temperature.

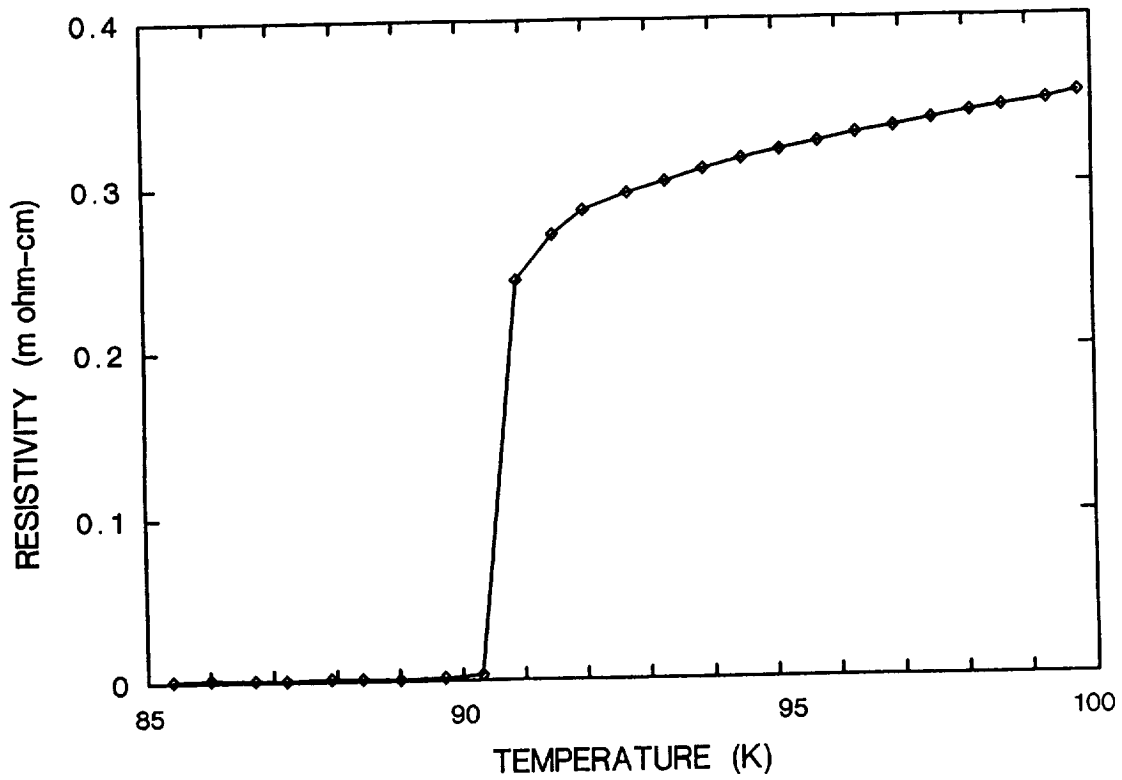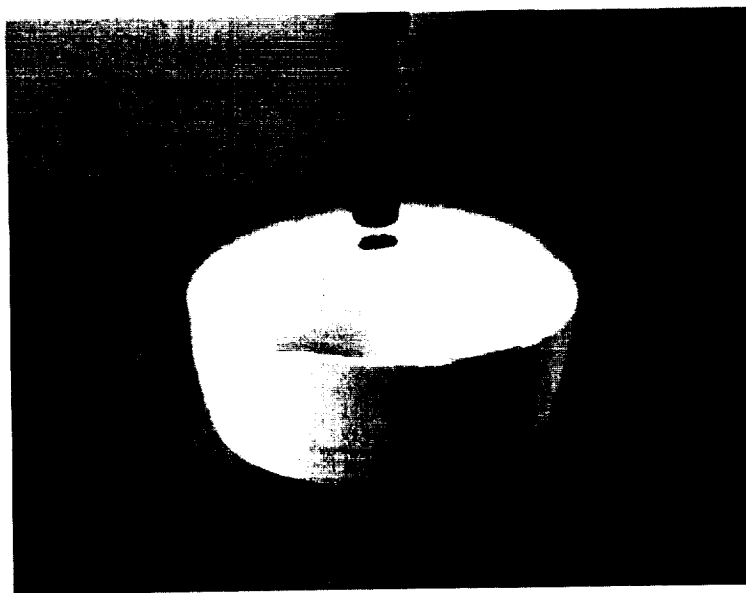Figure 1b Electrical resistivity of the bulk QMG $Ba_2YCu_3O_{7-\delta}$ as a function of temperature.

Figure 2 Inverse levitation of a QMG $Ba_2YCu_3O_{7-\delta}$ superconductor/polymer composite.

Figure 3 shows a comparison of the magnetic hystersis loops for the bulk QMG $Ba_2YCu_3O_{7-\delta}$ and the composite sample. A loop for a typical sintered $Ba_2YCu_3O_{7-\delta}$ sample is also included for comparison. The loop for the bulk and the composite are similar, both possesing a large remanent magnetization and a large amount of enclosed area. This indicates a significant amount of magnetic flux pinning. It also indicates that powdering the bulk QMG $Ba_2YCu_3O_{7-\delta}$ sample and isolating each particle in the polymer does not destroy the inherent flux pinning capibility of the superconductor. The small differences which are apparent in the hysteresis loops for these two forms of samples, are likely caused by differences in sample shape, size and texture. These parameters were not controlled in the present study. However, both of these hysteresis loops are significantly different from that typical of a sintered sample, which has little flux pinning capibility.
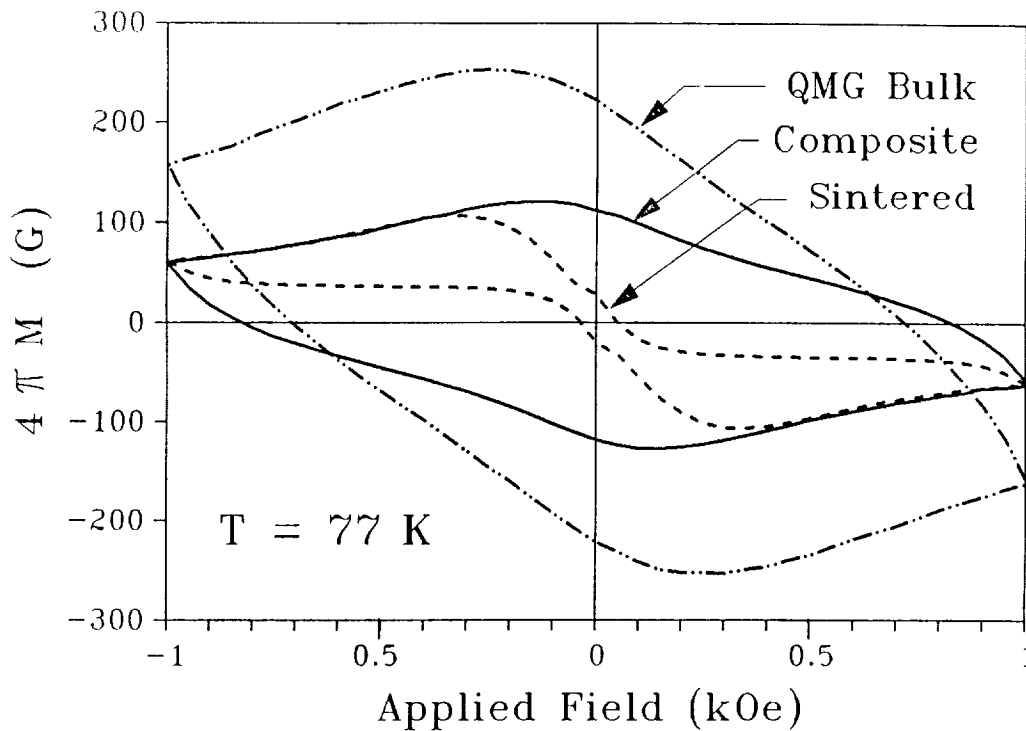

Figure 3   Comparison of the magnetic hystersis loops for the bulk QMG $Ba_2YCu_3O_{7-\delta}$, the composite and a sintered sample.

In the case of the inverse levitation effect, the balance of forces can be written as[3]

$$M(H)[dH/dz]_{-z_o} = g \qquad <1>$$

where M(H) is magnetization per unit volume. dH/dz is the field gradient where the sample is located and g is the acceleration of gravity. Equation <1> requires positive non-zero value for M(H) in the first quadrant of the hysteresis loop for the inverse levitation to be possible.

Figure 3 shows that the powdering of a bulk sample only has a limited effect on reducing M(H) in this quadrant. The particle size effect on M(H) may be estimated from the field dependence of the magnetization of a superconductor. From Bean's model[4] we have

$$J_c = Km/a \qquad <2>$$

or equivalently,

$$m = J_c a/K \qquad <3>$$

where m is the vertical width of the hysteresis loop, Jc is the critical current for the superconductor, a is the particle diameter and K is a constant depending on the geometry of sample. For a given material the Jc is fixed for the tempeature of measurement, and m will depend on the size of sample through the parameters a anf K. If we take a cubic bulk sample of magnitization m_b cut into n^3 equal cubic particles, the magnetization of each particle will be on the order of $m_n = m_b/n$. The total magnetization per unit volume achievable by the n^3 particles is thus reduced by a factor of n, whereas the volume of each particle has been reduced by a factor of n^3. This simple analysis suggests that the reduction of the magnetic moment is much slower than the reduction of the volume of particles. For the simple study here, the change of total magnetic moment from the bulk sample to the composite sample is much smaller than the factor 1/n, suggesting that that either the bulk sample meight be somewhat granular in nature or the geometric factor K is not the same for the bulk sample and the composite sample, or a combination of both. Obviously, the use of composites for levitation must be weighed against many other factors, such as sample size, synthesis method and engineering designs.

It is also noted that the particle size effect is reflected in the shape of the hysteresis loop. The loop for the composite sample is not identical to that of the bulk. The composite loop appears to reach a saturation at a lower field that of bulk. While the penetration of the field occurs at a higher field for the bulk sample. Consequently, upon the application of field, the composite which is composed of smaller superconducting particles will begin to lose its superconductivity before the bulk $Ba_2YCu_3O_{7-\delta}$ does. However, for some practical application involving levitation using superconducting materials, this reduced performance at high fields may not be a critical factor.

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SECTION 2:
FLUX DYNAMICS