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SHOCK-INDUCED DEFECTS AND FLUX PINNING IN $YBa_2Cu_3O_{7-\delta}$ + Ag COMPOSITES

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SHOCK-INDUCED DEFECTS AND FLUX PINNING IN $YBa_2Cu_3O_{7-\delta}$ + Ag COMPOSITES

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A composite specimen of $YBa_2Cu_3O_{7-\delta}$ and silver was fabricated by shock-compacting to 167 kbar a mixture of $YBa_2Cu_3O_{7-\delta}$ powder and 30 % vol. silver powder. The recovered sample was then studied with TEM, and the amount of magnetic flux pinning exhibited by the $YBa_2Cu_3O_{7-\delta}$ component was determined with a SQUID magnetometer. We find that the shock process resulted in a large increase in the flux pinning energy of the sample. This result is significant because higher pinning energies imply higher intragranular critical currents.

1. INTRODUCTION

The application of high-temperature superconductors to practical devices has been hindered by the relatively low critical currents which can presently be obtained in bulk specimens. Critical currents in high-temperature superconductors appear to be severely limited by the large amount of thermally-activated magnetic flux creep found in these materials[1,2]. Flux creep effects are very large in high-temperature superconductors because the characteristic magnetic flux pinning energies are an order of magnitude smaller and desired operating temperatures are 20 times larger in high-temperature superconductors than in conventional superconductors. As a result, the thermal activation energies for flux bundle hopping are very low.

Since crystalline defects are known to act as pinning sites for flux lines, the problem of increasing effective pinning energies and reducing flux creep effects can be viewed as a materials-processing problem, with different processing methods yielding specimens having very different critical currents. We report here on the effects of shock-compaction [3,4] on the defect structure of $YBa_2Cu_3O_{7-\delta}$, and on the influence of this defect structure on the flux pinning energy of shocked $YBa_2Cu_3O_{7-\delta}$. This processing method has several promising features. First, since the shock-pulse lastis only about 1 μsec, the heating associated with the shock is localized primarily on the particle surfaces, which then undergo thermal quenching at rates up to 10^9 °K/sec [5]. Shock-processing thus enables the surfaces of the powder particles to be heated and bonded together while keeping the particle interiors relatively cool and stable. Shock-processing also appears to enhance the sintering of ceramic powders and lowers the temperatures and pressures required for hot-pressing[6]. Finally, shock-processing introduces shock-induced defects which show some promise of significantly increasing the effective flux pinning energies of high-temperature superconductors.

2. SAMPLE FABRICATION

Our shock-compacted sample was fabricated by driving a 167 kbar shock wave through $YBa_2Cu_3O_{7-\delta}$ powder (28-45 mm diameter powder particles) mixed with 30 volume percent silver powder (20-30 mm dia. particles). The silver powder here serves as a ductile, conducting binder for the brittle $YBa_2Cu_3O_{7-\delta}$. In a practical application, the silver would also offer a conducting path for an electric current should the superconducting component be quenched for some reason. To generate the shock wave, a light gas gun was used to fire a 5 g, 20 mm diameter plastic projectile at 2.74 km/sec at the powder mixture, which was held in a copper capsule. The total mass of the powder mixture in the capsule was 186 mg [4].

X-ray and SQUID magnetometer studies of the compacted specimen reveal that the superconducting properties of the starting powder are largely retained, although optical microscopy indicates that there is a substantial reduction in the characteristic grain size from about 10 µm to 1 µm as a result of shock-induced cracking and fracturing.

In the as-shocked state current was conducted through the silver below the T_c of the oxide. Resintering the specimen in oxygen at 890 °C for 50 hours produced a 300 A/cm^2 transport critical current density at 77 °K.

3. TEM STUDIES

TEM studies on foils obtained from the as-shocked 167 kbar specimen reveal that the shock process resulted in a very high density of twin boundaries in the orthorhombic phase regions of the $YBa_2Cu_3O_{7-\delta}$. A very large number of 001 dislocations was also observed in the orthorhombic phase regions (Fig. 1), the density of these dislocations being several orders of magnitude higher than normally present in sintered $YBa_2Cu_3O_{7-\delta}$ samples.

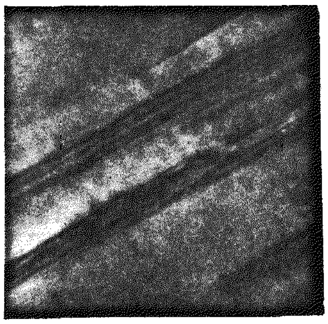

FIGURE 1
TEM Micrograph Showing 001 Dislocations in the Shocked $YBa_2Cu_3O_{7-d}$ Sample

The tetragonal phase of $YBa_2Cu_3O_{7-\delta}$, which is non-superconducting, was also observed in the as-shocked specimen. This phase was not present in our sample before shocking, and appears to result from re-crystallization of the $YBa_2Cu_3O_{7-\delta}$ at the surfaces of the powder particles, due to the considerable heat generated there during the shock process. The failure of the as-shocked compact to conduct a supercurrent is presumably due to a surface layer of this shock-induced tetragonal phase on the $YBa_2Cu_3O_{7-\delta}$ powder particles. As noted in the previous section, re-sintering the sample in oxygen yields a sample which does carry a supercurrent.

To gain a better understanding of the effects of re-sintering on our sample, a TEM study is currently being performed on a specimen which had been re-sintered after shocking. Preliminary results indicate that re-sintering causes the 001 dislocations to be replaced by stacking faults.

4. FLUX-PINNING ENERGIES

The purpose of our study was to determine how shock-processing affects the flux pinning energy and, thus, the intrinsic critical current of $YBa_2Cu_3O_{7-\delta}$. In order to do this, we performed magnetic flux relaxation experiments with a SQUID magnetometer on our shock-compacted sample over a wide range of temperatures. Our flux relaxation experiments consisted of cooling the sample in a zero field to a desired temperature below T_c, turning on a 10 kOe field, and then making repeated measurements of the sample's magnetic moment over a period of one or two hours. Figure 2 shows a typical flux relaxation plot obtained from the as-compacted specimen at a temperature of 10 °K.

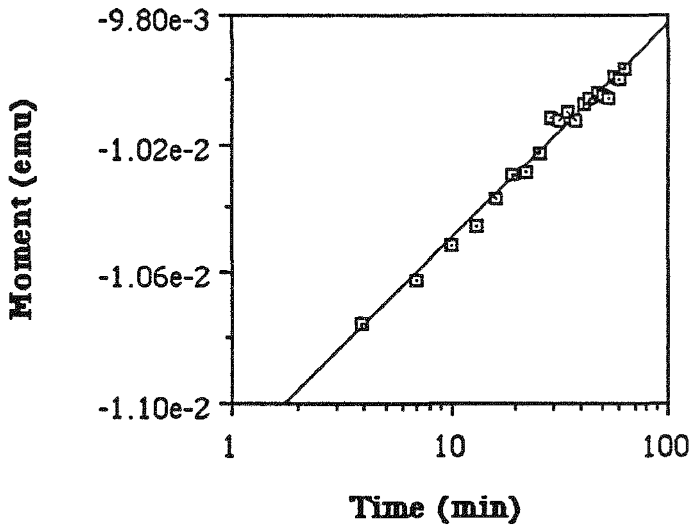

FIGURE 2
Flux Relaxation Data on a Y_{123} - Ag as-shocked composite at 10 K. The data is fitted to a logarithmic curve $M=A_1\log(t)+A_2$, where A_1 and A_2 are fitting parameters.

The magnetic moment relaxes at a logarithmic rate and this relaxation rate is related to the flux pinning energy U_o by the equation[7]

$$\frac{dM}{d\ln(t)} = \frac{r\,J_c}{3}\frac{kT}{U_o}$$

where M is the magnetization of the sample, r is the grain radius, J_c is the intrinsic critical current, and T is the temperature. Since the product rJ_c can be easily determined from magnetic hysteresis data[8] by the formula

$$\Delta M = \frac{2}{3}\frac{r\,J_c}{c}$$

the flux pinning energy can be entirely determined from SQUID experiments.

Table I lists the pinning energies obtained at various temperatures for the starting $YBa_2Cu_3O_{7-\delta}$ powder, the shock-compacted specimen, and the re-sintered specimen.

Table I
Pinning energies for starting powder, shock-compacted sample, and resintered sample as a function of temperature. All energies are in eV.

T (°K)	Powder	Shock-Compacted	Resintered
70	0.021	0.050	0.040
60	0.034	0.046	0.048
50	0.042	0.054	0.045
40	0.037	0.026	0.069
30	0.021	0.031	0.052
20	0.019	0.038	0.019
10	0.009	0.024	0.008

4. DISCUSSION

The results listed in Table I show a significant increase in the flux pinning energy as a result of shock-processing; over the temperature range 10-70 K, the pinning energies for the shocked specimen average about 70% higher than the pinning energies of the starting powder. This large increase in flux pinning energy is apparently due to the large numbers of shock-induced twins and 001 dislocations formed during shock compaction, these defects acting as pinning sites for magnetic flux lines.

Our preliminary TEM analysis of our re-sintered sample indicates that considerable numbers of defects remain in the shocked sample after re-sintering. Indeed, Table I shows that although re-sintering the compacted sample decreases the pinning energies somewhat from the as-shocked state, probably because this step anneals out some of the shock-induced defects responsible for the increased pinning, the pinning energies still remain considerably higher than those of the starting powder over a wide range of temperatures.

The shock-compaction process, then, appears to be a promising one for fabricating high-Tc materials for the transport of superconducting currents. In future studies we expect to further explore in further detail the types of defects formed during shock-compaction, how re-sintering affects these defects, and how these defects affect magnetic flux pinning and, hence, intragranular critical currents.

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1 A. Khurana, *Physics Today*, 17 (March, 1989)

2 J. Mannhart, P. Chaudhari, D. Dimos, C.C. Tsuei, and T.R. McGuire, Phys. Rev. Lett. **61**, 2476 (1988).

3 W.J. Nellis and L.D. Woolf, MRS Bulletin **14**, 63 (1989).

4 W.J. Nellis, C.L. Seaman, M.B. Maple, E.A. Early, J.B. Holt, M. Kamegai, G.S. Smith, D.G. Hinks, and D. Dabrowski, "Shock-Compaction of $YBa_2Cu_3O_{7-x}$ and $HoBa_2Cu_3O_{7-x}$ Powders in a Metal Matrix", to be published by the Metallurgical Society (1989).

5 V.F. Neterenko and A.V. Muzykantov, Soviet Combustion, Explosion, and Shock Waves **21**, 240 (1985).

6 O.R. Bergman and J. Barrington, Journal of the American Ceramic Society **49**, 502 (1966).

7 M.R. Beasley, R. Labusch, and W.W. Webb, Phys. Rev. **181**, 682 (1969).

8 C.P. Bean, Rev. Mod. Phys. **36**, 31 (1964).