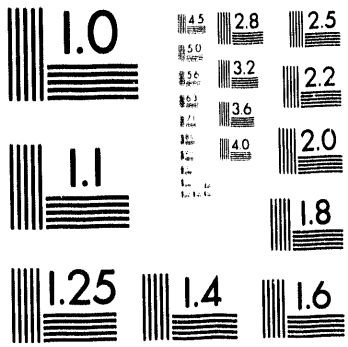
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2.8
2.5
5.0
3.2
2.2
5.6
3.6
2.0
4.0
1.1
1.8
1.25
1.4
1.6

1 of 1

Conf-930676--53

DISKS OF $YBa_2Cu_3O_7$ SHOCKED TO 10 GPa PRESSURES*

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The brittle superconducting oxide $YBa_2Cu_3O_7$ was shocked to 6.6 and 10.3 GPa without macroscopic fracture. The melt-textured disk-shaped specimen was preferentially oriented and was shock-compressed at an angle of about 30° from the effective c axis of this orthorhombic-phase specimen. Subsequent anneals of the 6.6 GPa specimen in oxygen at 890° C produced a magnetic hysteresis which is enhanced relative to the initial unshocked state, as expected for shock-induced defects.

Introduction

Bearings made from new high-transition-temperature (high-T_c) superconducting oxides are a possible application of these new superconductors. External magnetic fields are generated in such bearings by superconducting magnetic fluxoids which should be strongly pinned in the lattice to prevent dissipative losses. The purpose of a superconducting bearing is not to transport high currents and thus the problem of relatively small intergranular critical current density in polycrystalline oxide superconductors is minimized. However, intragranular critical current density needs to be increased by increasing the number and strength of flux-pinning sites within the lattice. In so doing, the magnetic field which can be generated and sustained by a bearing material is increased. High densities of lattice defects are induced in shock-compacted powders of $YBa_2Cu_3O_7$ and the dislocations

and stacking faults generated are effective in increasing flux-pinning energies and intragranular critical current densities.[1] However, an effective technique is needed to shock-induce lattice defects in high-T_c oxides which does not fracture the specimen. These defects should enhance flux-pinning energies and intragranular critical current density. In addition, the shocked superconducting material should have an enhanced magnetic moment caused by superconducting fluxoids which point in the same direction for maximum magnetic moment.

An attractive material to investigate is $YBa_2Cu_3O_7$, because of its excellent superconducting properties. An ideal form of $YBa_2Cu_3O_7$ to investigate is melt-textured material because it consists of large disk-shaped grains several mm across and several 10 μm thick, in which the c axis of the orthorhombic crystal structure is along the thin direction of each disk-shaped grain. Superconducting fluxoids point preferentially along the c axis. These grains are preferentially aligned in melt-textured $YBa_2Cu_3O_7$ such that their c axes point in a common direction normal to the plane of the specimen. Thus, melt-textured $YBa_2Cu_3O_7$ material has the crystallite arrangement needed for a high-T_c superconducting bearing.

Shocked Specimens

Our objective is to shock-induce lattice defects in a crystallographicaly aligned disk without fracture, at least on a macroscopic scale. In this way, an oriented shocked specimen can be annealed and its superconducting properties measured in a straight forward manner. The slip planes in $YBa_2Cu_3O_7$ are in the basal plane of the orthorhombic crystal structure.[2] Thus, shocking along the c axis normal to a disk-shaped single crystal is expected to fracture it into many small pieces, since no slip direction is available along the shock direction. Such fracture is what we observed by shocking a 1mmx1mmx20μm $YBa_2Cu_3O_7$ single crystal along the c axis while it was embedded in Ag powder.[3] According to Schmid's law the shear stress across the (001) plane and hence the dislocation density should be greatest in those grains oriented with the c axis at an angle of 45° with respect to the shock direction. A similar $YBa_2Cu_3O_7$ single crystal in Ag powder shocked at 45° from the basal plane broke into only a few pieces which were heavily defected.[4] Thus, controlling the orientation of a crystallographicaly oriented specimen with respect to the shock direction is an effective way to control fracture while shock-inducing defects.

For this reason, two dense melt-textured $YBa_2Cu_3O_7$ specimen disks 7.7 mm in diameter and 1.1 mm thick was embedded in a steel recovery capsule, which in turn was embedded in a steel fixture, and shocked to 6.6

and 10.3 GPa at an angle of 30° with respect to the average c-axis direction of $YBa_2Cu_3O_7$. A 6.5-m-long two-stage light-gas gun with a 20-mm-diameter bore was used to generate the shock wave by impact. The velocity of the lexan projectile was chosen to give the desired impact pressure in steel. The experiment is illustrated in Fig. 1; in this configuration the direction of shock propagation is 30° from the average c-axis direction of the disk-shaped $YBa_2Cu_3O_7$ specimen.

Results

Both impact pressures in an oriented melt-textured $YBa_2Cu_3O_7$ disk produced a one-piece specimen. The specimen shocked to 6.6 GPa was easily handled without breaking for post-shock annealing and SQUID magnetometer measurements; SQUID data was not obtained for the 10.3 GPa specimen. The shock pressure did not change the initial superconducting transition temperature of 92 K for the 6.6 GPa specimen, as measured by a SQUID magnetometer (Fig. 2). The field-cooled data at $4\pi M/H=-0.5$ for an applied field of 20 Oe are weakly affected by the shock. The zero-field-cooled data are sensitive to shock; at low temperature, for example, the SQUID signal is reduced by a factor of 2. However, a 24 hour anneal in oxygen at 890° C restores a major fraction of the SQUID signal. These data suggest that the high-pressure shock wave causes oxygen disorder and/or generates defects, the superconducting effects of which are improved by annealing in oxygen.

Magnetic moment induced in a specimen was measured as a function of applied magnetic field up to 40 kOe at 70 K. Magnetic hysteresis is the difference in magnetic moment induced on increasing and decreasing applied magnetic field. Magnetic hysteresis is sensitive to shock-induced changes in the microstructure of the material and to changes in critical current density. At an applied magnetic field of 1 kOe, annealing the specimen in oxygen was found to increase the magnetic hysteresis of the specimen. This means that the ability of the shocked and annealed specimen to act as a magnetic-bearing material is enhanced.

Magnetic hysteresis ΔM versus applied magnetic field was measured initially, after shocking (Fig. 1), and after heat treatments in oxygen at 890° C for various times, followed by 4 hours in oxygen at 450° after a slow cooldown from 890° C. The results for an applied field of 1 kOe are plotted in Fig. 3 as ΔM versus cummulative annealing time at 890° C. The specimen was annealed for a given time, removed, from the furnace, ΔM was measured with a SQUID, the specimen was annealed again at 890° C, and the process was repeated. The dashed baseline in Fig. 3 is the reference result for the unshocked specimen. At zero annealing time the

lower ΔM point is for the as-shocked specimen; the upper ΔM point corresponds to 10 minutes at 890° C. After a cummulative time of 15 hours, ΔM is enhanced over the starting value. An ehancement of about 15% is observed after a cummulative annealing time of 48 hours. For this specimen the enhancement in ΔM persists up to about 5 kOe although it decreases above 1 kOe.

These results show that the brittle oxide $YBa_2Cu_3O_7$ can be shocked to 6.6 and 10.3 GPa without macroscopic fracture, provided the disk-shaped specimen is in the preferentially oriented melt-textured form and is shock-compressed at an angle of about 30° from the effective c axis of this orthorhombic specimen. Subsequent anneals in oxygen at 890° C of the 6.6 GPa specimen produce a magnetic hysteresis which is enhanced relative to the initial unshocked state, as desired.

ACKNOWLEDGMENTS

This work was performed under the auspices of the U. S. Department of Energy. Work at Lawrence Livermore National Laboratory was performed under contract No. W-7405-ENG-48; work at Ames Laboratory, ISU was performed under contract No. W-7405-ENG-82. This work was performed with support from the High-T_c Pilot Center at Argonne National Laboratory.

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[1] S. T. Weir, W. J. Nellis, M. J. Kramer, C. L. Seaman, E. A. Early, and M. B. Maple, Appl. Phys. Lett. 56, pp. 2042-2044 (1990).

[2] M. J. Kramer, L. S. Chumbley, and R. W. McCallum, J. Mat. Sci. 25, pp.1978-1986 (1990).

[3] S. T. Weir, W. J. Nellis, Y. Dalichaouch, and M. B. Maple, unpublished (1990).

[4] S. T. Weir, W. J. Nellis, C. L. Seaman, E. A. Early, M. B. Maple, M. J. Kramer, Y. Syono, M. Kikuchi, P. C. McCandless, and W. F. Brocious, Shock-Wave and High-Strain-Rate Phenomena in Materials, New York: Dekker Press,1992, pp.795-808.

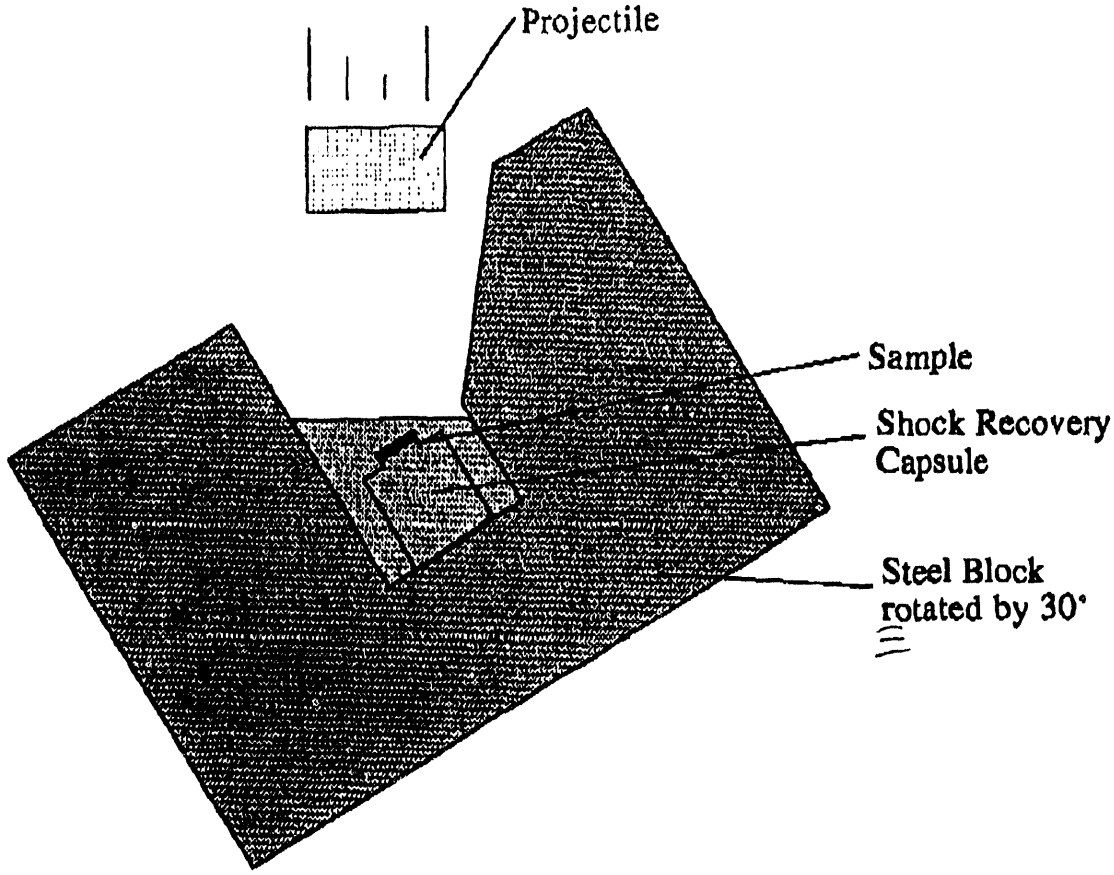
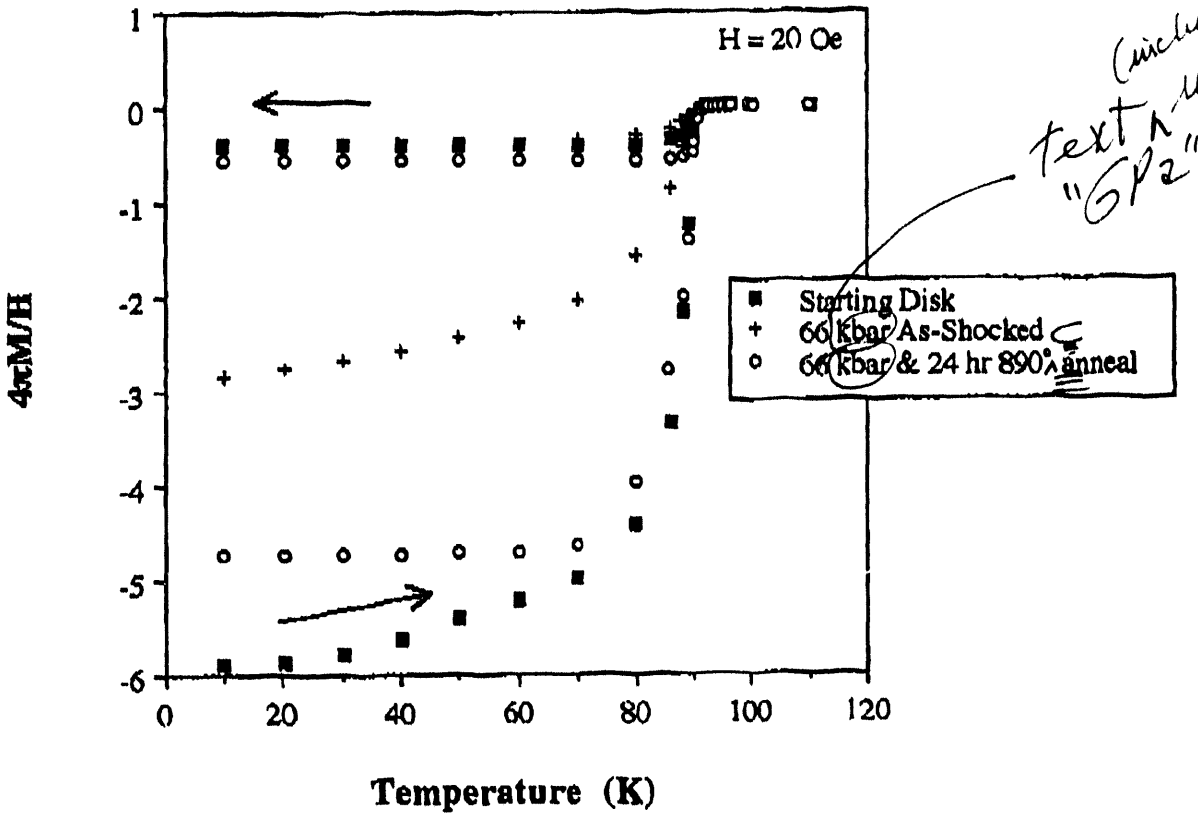

Projectile
Sample
Shock Recovery Capsule
Steel Block rotated by 30°

Fig. 1



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text uses "GP2"

Fig. 2

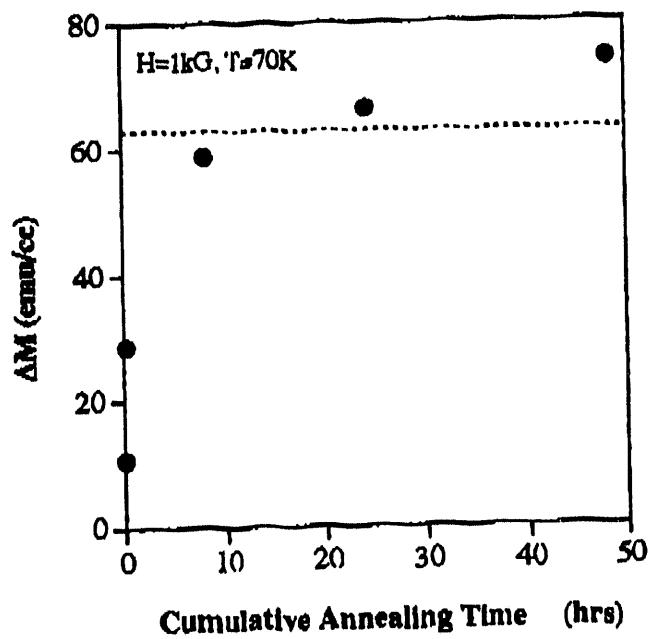
H=1kG, T=70K
ΔM (emu/cc)
80
60
40
20
0
0
10
20
30
40
50
Cumulative Annealing Time (hrs)

Fig. 3

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