Physica C 235-240 (1994) 3091-3092
North-Holland

PHYSICA C

Anomalous magnetic field dependence of the critical current density in polycrystalline $YBa_2Cu_3O_7$

Shi Li[a], M. J. Darwin[a], J. Deak[a], D. Majer[b], P. Metcalf[a], E. Zeldov[b], and M. McElfresh[a]

[a] Physics Department, Purdue University, West Lafayette, IN 47907, USA.
[b] Physics Department, Weizmann Institute of Science, Rehovot 76100, Israel.

Magnetotransport as well as local and bulk magnetic measurements were made on polycrystalline samples of the same $YBa_2Cu_3O_7$ material making it possible to directly compare the various stages of flux penetration with the transport behavior. The bulk of the sample is screened up to the applied field value at which a feature is observed in the magnetization behavior. Above this field, flux penetrates between the grains and then at sufficiently high fields begins to penetrate into the grains. The critical current density J_c shows an anomalous hysteresis in the applied field H_a dependence. On the initial part of a $J_c(H_a)$ curve, J_c decreases rapidly but becomes nearly field independent when flux penetrates into grains. Upon decreasing H_a, J_c increases above the initial curve values.

An anomalous applied field (H_a) dependence of the critical current density J_c was shown to exist in polycrystalline $YBa_2Cu_3O_7$ (poly-YBCO).[1] Here the role of flux penetration is studied by combining the results of transport and magnetic measurements.

The field dependence of J_c was determined using a 2.5×10^{-7} V/cm criteria for a piece of poly-YBCO by measuring voltage as a function of current V(I) at a series of magnetic fields. The poly-YBCO material had an average grain size of 8 μm and a transition temperature $T_c = 90$ K. Shown in Fig. 1a is a plot of J_c as a function of applied field H_a at T = 78 K. Two different procedures were employed to measure $J_c(H_a)$. In one case (ZFC) the sample was cooled to the measuring temperature from above T_c in zero field, a field was then applied, and V(I) measured. This procedure was repeated for each point (H_a value) on the ZFC-V(I) curve in Fig. 1a. For decreasing H_a, the field was set to H = 600 Oe before decreasing to the H_a setpoint. For the second case (non-ZFC), the ZFC procedure was used only for the first data point with V(I) measurements at consecutive points made after merely changing the field.

The dependence of the bulk magnetization M on H_a was measured using a Quantum Design SQUID magnetometer on a sample of the same poly-YBCO material used in the transport measurements. Figure 1b is a plot of $M(H_a)$ at T = 78 K showing an unusual low field behavior with a distinctive extremum (peak) at $H_{peak} \sim 7$ Oe that is more evident in the inset. This peak is a result of complete screening of the bulk sample at low fields yielding to the penetration of flux between grains as H_a increases beyond H_{peak}. This interpretation was verified by employing samples with different geometries and observing that the value of the initial $M(H_a)$ slope was consistent with complete screening when the appropriate demagnetization correction was made for the particular geometry used. Further support can be found in Fig. 1c, which is $M(H_a)$ at T = 78 K for the same poly-YBCO material that has now been powdered and potted. The curves in Figs. 1b and 1c are nearly identical except for differences in the initial slope, shown in the insets of the figures. There is no peak observed for the powdered sample, however, its initial slope is the same as that of the bulk sample at fields just above H_{peak}. This slope is consistent with complete screening of the individual grains. In addition to the peak in the initial curve, as the field is cycled around a hysteresis loop a feature can be observed at H_a values that have the same magnitude as H_{peak}.

An AlGaAs/GaAs two-dimensional Hall sensor array was used to study the spatial dependence of the flux penetration. Plots of the normal component of the flux density $B_z(H_a)$ at the center of the sample are shown in Fig. 2, in which each curve corresponds

*The work at Purdue was supported by the Director of Energy Research, Office of Basic Energy Sciences through the Midwest Superconductivity Consortium (MISCON) DOE grant #DE-FG02-90ER45427.

SSDI 0921-4534(94)02111-2

to a different maximum H_a value (H_a^{max}). The sample was zero field cooled for each curve. The behavior is completely reversible for H_a^{max} = 5 Oe, whereas the behavior is irreversible for H_a^{max} = 10 Oe. For the larger fields shown in Fig. 2, the curves show irreversibility with all curves returning to the same remanent value. More detailed Hall array studies have shown that irreversible behavior sets in above the peak.

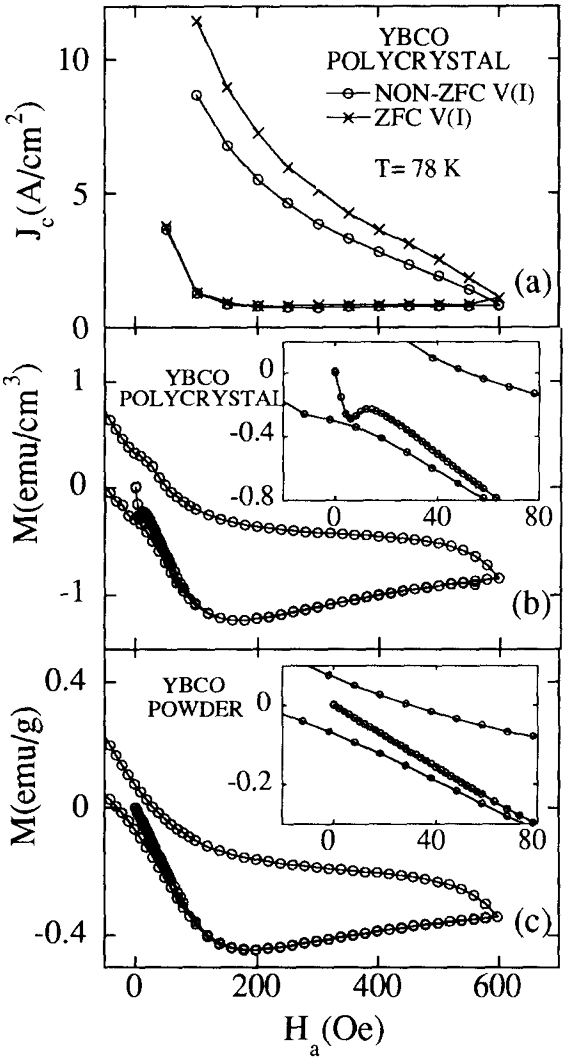

Figure 1. Comparison of the applied field H_a dependence of (a) the critical current density J_c determined by transport, (b) the magnetization of the same bulk sample, and (c) the magnetization of the sample after powdering.

A portion of the $B_z(H_a)$ curve at the higher fields shown in Fig. 2 appears reversible. This corresponds to both the second linear region in Fig. 1b and the initial slope of Fig. 1c and appears to be the screening regime of the individual grains. At sufficiently high fields the $M(H_a)$ curves are no longer linear and the remanent B_z value becomes significantly larger than those presented in Fig. 2. This appears to be the regime in which flux penetrates into the individual grains.

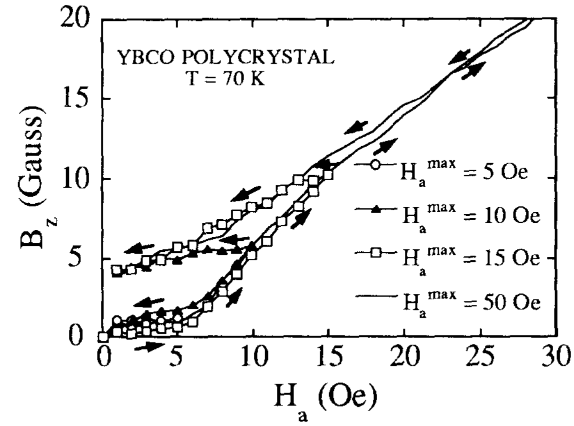

Figure 2. Dependence of the local magnetic flux density B_z on the maximum applied field H_a^{max} when B_z is measured with a Hall sensor array element positioned at the center of a bulk sample.

In Fig. 1a it can be seen that J_c decreases rapidly as the flux penetrates between grains and as screening of the grains increases. However, J_c is nearly independent of H_a once the flux begins to penetrate into the grains. This could be a result of the magnitude of B between the grains and its effect on the weak link behavior.[2] The fields associated with screening of individual grains would increase B between the grains as H_a increases. As flux begins to penetrate, rather than only produce increases in screening, B would increase more slowly between grains. As H_a is reduced there is a significant increase in J_c corresponding to a reduction of the screening currents of individual grains and a decrease of B between grains.

REFERENCES

1. M. E. McHenry, M. P. Maley, and J. O. Willis, Phys. Rev. B 40 (1989) 2666.
2. J. E. Evetts and B. A. Glowacki, Cryogenics 28 (1988) 641.