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FLUX CREEP IN HIGH-T_C SUPERCONDUCTORS

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Abstract

The time decay of the zero field cooled magnetization was investigated for a $Bi_2Sr_2CaCu_2O_{8+x}$ single crystal (T_C=85K) at different temperatures. From the low temperature data, interpreted with a thermally activated flux creep model, an average pinning energy is derived for different magnetic fields applied parallel to the c axis (e.g. U_o=2.4 10^{-3} eV for H=1 kOe).

Introduction

Hard type II superconductors are characterized by magnetic irreversibility and relaxation effects in the mixed state. The observation of these effects in high - T_C superconductors was originally attributed to the existence of a glassy state [1], arising from a network of random weakly linked superconducting clusters, because of the qualitative similarities with the spin-glass properties (splitting between zero field cooled and field cooled susceptibility, non exponential decay of zero field cooled and remanent magnetization, field/temperature irreversibility line de Almeida Thouless like ...).

Although this description seems to be reasonable for sintered materials, constituted by weakly linked superconducting grains, it is presently believed that these properties can be interpreted, at least at low temperature, in terms of the thermally activated flux creep model [2].

The above mentioned properties are common to the conventional superconductors, but a very important difference does exist: in high-T_C superconductors there is a much more important degree of thermal activation for the flux motion, which manifests itself in a faster magnetic relaxation and then in a more rapid decrease of J_c with increasing temperature.

The thermally activated flux motion is enhanced by two combined factors:

a) the average pinning energy U_o is one or two orders of magnitude lower, because of the much smaller coherence length (U_o scales as $H_c^2\xi^3$) [2];

b) the critical temperatures are almost one order of magnitude higher.

In this paper the results of critical current and relaxation measurements in a $Bi_2Sr_2CaCu_2O_{8+x}$ single crystal are reported.

Results and discussion

A single crystal (2.2 x 1.7 x 0.3 mm^3) grown by the flux technique [3] was selected for the measurements. The magnetic properties were investigated by AC susceptibility measurements, carried out by means of a mutual inductance bridge ($H_{AC}\approx 1$ Oe at ν=200 Hz) and by DC susceptibility and magnetization measurements, carried out by means of a commercial SQUID magnetometer.

The AC susceptibility curve, measured applying the field both parallel and perpendicular to the c axis, shows only one transition at 85 K, ascribed to the 2212 phase. No trace of a drop at 110 K could be detected, thus indicating the absence of any contribution from the higher T_c phase.

Magnetization cycles were performed at different temperatures applying the magnetic field parallel to the c axis. (Fig. 1). The lower critical field, estimated as the field at which deviation from the linearity occurs in the M vs H plot, is $H_{c1}\approx 350$ Oe at 4.2 K.

With increasing temperature the irreversible regime of the magnetization cycles is rapidly restricted to low fields. J_c becomes strongly field dependent at temperatures so low as 20 K and vanishes at 30 K in presence of moderate fields.

The critical current in zero field was determined from the remanent magnetization at the end of the magnetization cycle by using the Bean formula for the critical state (a shape of a cylinder with a radius R=0.1 cm was assumed).

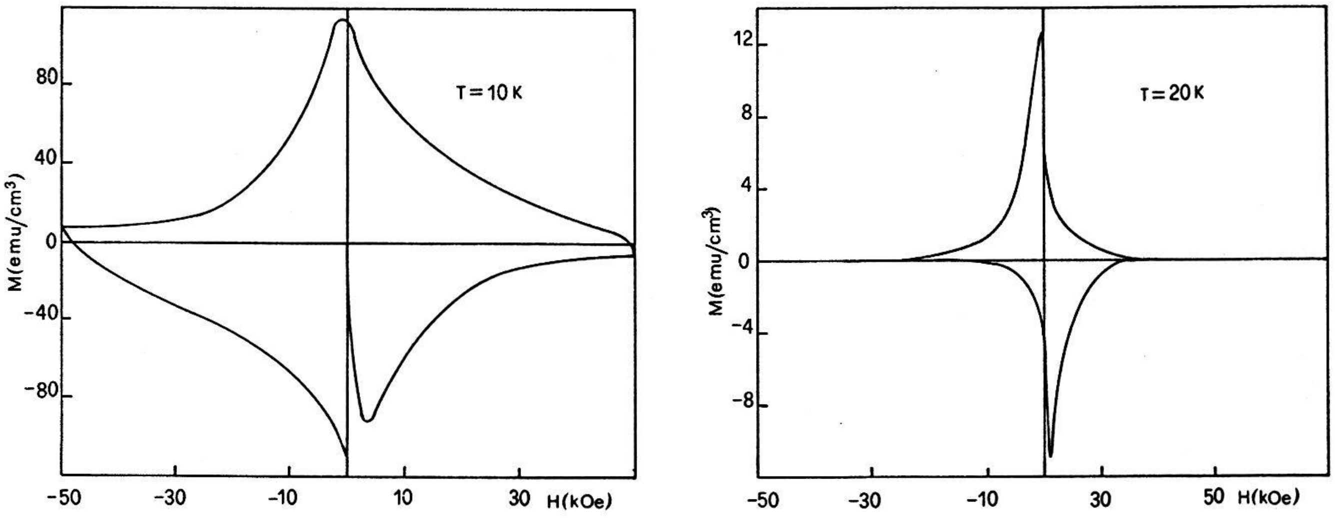

Fig. 1 Magnetization cycles

At 4.2 K the critical current $J_{c//}$ is 2.1 10^6A/cm^2. The temperature dependence of J_c was satisfactorily described by the phenomenological law

$$J_c=J_c(0)(1-T/T_c)^n$$

with n=8,as reported for YBaCuO [4].The decrease of J_c with temperature is much more rapid than in conventional superconductors, where n ranges from 1 to 2.5 . Such behavior, indicating an important thermal activation for the flux motion, implies pinning energies lower than those reported for conventional superconductors ($U_o \approx 1$eV).

We have determined the average pinning energy measuring the time decay of the zero field cooled magnetization at 4.2 K for different values of the external magnetic field (1 kOe; 3 kOe; 10 kOe) applied parallel to the c axis. The decay was found to be logarithmic (Fig. 2), in agreement with the classical flux creep model [2]. The fields we have used are lower than H^*, the field such that flux first penetrates through the sample. In such conditions and for $KT/U_o<1$, the relaxation rate of the magnetization for a cylinder is given, in first approximation, by the relation [4]:

$$\frac{d(4\pi M)}{d\ln t} = \frac{H^2}{H^*}\left[1-\frac{2H}{3H^*}\right]\frac{KT}{U_o}$$

which is derived by substituting the expression for the temperature decrease of J_c ($J_c=J_{co}[1-(KT/U_o)\ln(t/t_o)]$) [5] in the Bean equation for the critical state ($H^*=(4\pi J_{co}R)/10$) [6]. The deduced average pinning energy decreases increasing the applied field: $U_o=2.4\ 10^{-3}$ eV for H=1 kOe; $U_o=1.0\ 10^{-3}$ eV for H=3 kOe; $U_o=8\ 10^{-4}$ eV for H=10 kOe).

The relevant effect of the temperature is shown in Fig. 2, where the time decay of the magnetization M/M_o is reported at 4.2 K, 10 K and 15 K for a field H=10 kOe applied parallel to the c axis. At T=15 K after one hour the magnetization is reduced to ≈48% of the initial value. These data are consistent with the vanishing of J_c at low temperature in moderate fields, as shown by the reversible magnetization above ≈30 K.

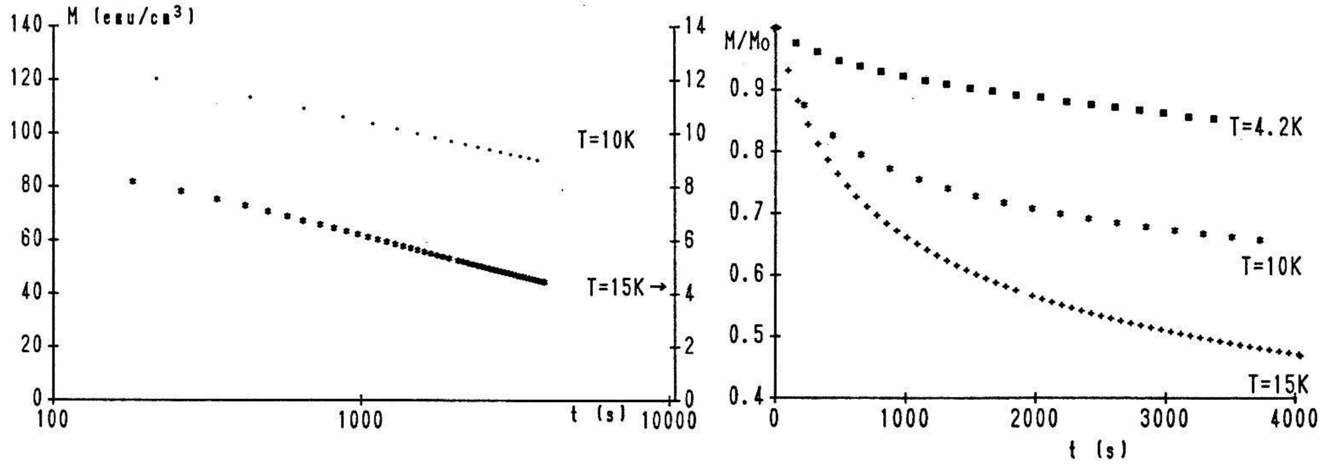

Fig. 2 Time decay of the magnetization for H=10 kOe

Conclusions

The results indicate strong magnetic relaxation for the zero field cooled magnetization of a BiSrCaCuO single crystal. With respect to YBCO, higher relaxation rates and smaller pinning energies (almost an order of magnitude) [7,8] are found. Furthermore, a stronger field dependence of J_c is observed above ≈20 K, giving rise to a wider reversible regime. These data are consistent with observations of strong dissipative effects (flux flow resistivity) [9] and with evidences of vortex lattice melting in moderate fields at temperatures much lower than T_c [10].

These differences, which involve the nature of the pinning centers, could be due to the absence of twin planes in BiSrCaCuO. They act as anisotropic pinning centers in YBaCuO and then they could be responsible for the higher J_c and U_o anisotropy [8,9] with respect to BiSrCaCuO.

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