Mechanism of Flux-flow Activation in C-axis oriented $Bi_2Sr_2CaCu_2O_{8+\delta}$ Thin Films

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INTRODUCTION

The study of vortex line dynamics and its relationship with different kinds of defects is one of the major concepts tackled in the search for understanding the vortex matter of high critical temperature superconductors (HTSC). The pinning centers may be point defects, columnar or planar disorders and grain boundary or intra/intergranular non-superconducting regions (Poole et al., 1995). In this paper, transport measurements were done which gave insights into the macroscopic motion of the vortices. This, in turn, gives us an idea of the pinning sites predominating in a certain external magnetic field and temperature regime. This work is motivated by the fact that knowing the mechanism of flux–flow activation allows for the possibility of controlling the dissipative and noise properties of devices based on HTSC films.

Flux motion is the mechanism leading to power dissipation and flux-flow resistance in the superconducting mixed state. This motion is due to the Lorentz force induced by the applied transport current. Above a certain value, the critical current, the vortices are 'de-pinned' and start to move with a velocity proportional to the electric field strength that develops along the sample. In addition to the Lorentz force, motion of the vortices may be due to thermal activation/fluctuations. Furthermore, effects on the film electrical characteristics are expected even in the absence of an externally applied field. The pinning sites, inherent in the film, influence the motion of the vortices produced by the self-magnetic field of the bias current (Huebener et al., 2000). The dissipative properties of these sites may also be affected by thermal fluctuations.

In this study, the mechanism of flux flow activation in *c*-axis oriented $Bi_2Sr_2CaCu_2O_{8+\delta}$ was determined in different temperature regimes with no external field and at different applied magnetic fields below 1.0 T when the film is in its transition region. From the theoretical fitting of our I-V data, we find that flux flow and flux creep contribute largely to the activation of vortex motion in these films. In addition, our measurements with and without an external magnetic field show that pinning due to point defects is not a factor for these films at currents below 20mA and temperatures below the transition temperature.

METHODOLOGY

The films used in this study were $Bi_2Sr_2CaCu_2O_{8+\delta}$ thin films grown via liquid phase epitaxy, with preferential growth along the *c*-axis (Santos, 2000). Electrical contacts consisted of e gold wires attached to the film surface by silver paste. The transport measurements were done using the in-line contact configuration to minimize errors from leads and contact resistances (Ison, 1999).

The samples were cooled down to ~10K, in a closed-cycle helium cryostat, where magnetoresistivity measurements were done using a current of 10mA in different magnetic fields below 1.0 T to determine the transition region.

Then, the current-voltage (I-V) characteristics of the film were investigated at several temperatures between 10K and 85K with no applied field. I-V profiles were also obtained at different external fields below 1.0 T during transport at 65K.

RESULTS AND DISCUSSION

From the resistivity measurements performed at varying fields below 1.0T, the T_c onset was determined to be 81K. A broadening of the transition region was observed as the external magnetic field was increased-especially at the foot of the transition. This broadening is attributed to thermally activated flux flow brought about by the decrease in activation energy of the vortices (de la Cruz et al., 1999).

When measuring the transport behavior in the dissipative regime ($I>I_c$), one can distinguish between different behaviors. These appear more clearly by obtaining the differential resistance ($R_{ff} = \delta V/\delta I$) profile as a function of the DC current (Fig. 1) (Lefloch et al., 2000). Just above the critical current, R_{ff} increases exponentially (Regime 1) before plateauing at some high current value (Regime 2). These different regimes are attributed to flux creep and flux flow respectively. It was also observed that even if there is no transport current, R_{ff} has a finite value during transport at 50K and 60K. This is attributed to thermal activation of vortices in the transition region.

Fig. 2 is a log-log plot of critical current as a function of external magnetic field. From this plot, we find that the critical current decreases as a power law of the field, $Ic=B^{-n}$. Two regimes were observed, for n=0.7 and n=1.5. The origin of these two regimes is unclear at the moment. However, the power-law dependence indicates that these regimes are predominated by collective pinning of the vortices. Even if no magnetic field was applied during the I-V measurements at temperatures below Tc, the self–magnetic field induced by the currents was large enough to allow for nucleation of magnetic vortices. The observed I-V dependencies were accounted for by the functional relation:

$$V = RI \exp\left(-\frac{E_k(I,T)}{k_B T}\right) = RI \exp\left(-\left[\frac{I_T}{I}\right]^{\mu}\right)$$

where $E_k(I,T)$ is the current dependent activation energy, k_B is the Boltzmann constant, R and I_T are constant and do not depend on I, μ is a parameter depending on the specific activation mechanism involved (Camerlingo et al., 2000).

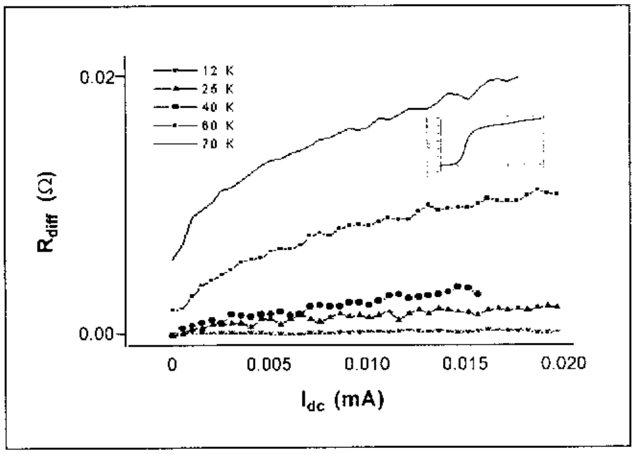

Fig. 1. Differential reisistance vs. applied DC current in a $Bi_2Sr_2CaCu_2O_{8+\delta}$ thin film at 0.0T. Inset shows a typical resistivity plot of the sample with T_c=81K.

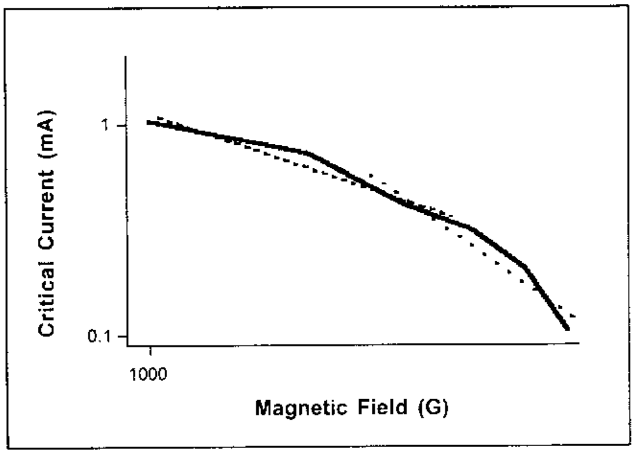

Fig. 2. Log-log plot of the critical current versus

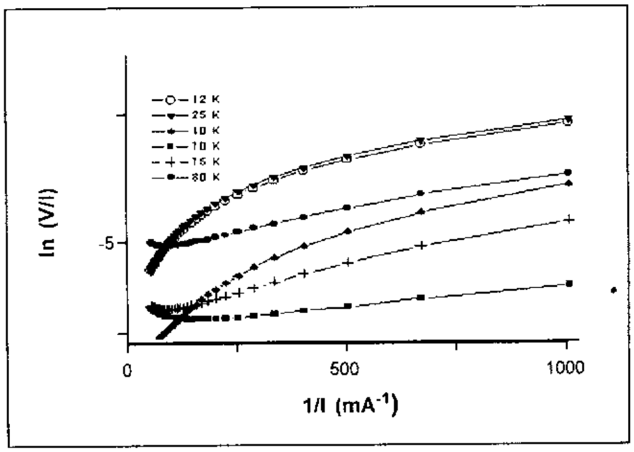

Fig. 3. Dependence of ln (V/I) on the inverse of the bias current I for Bi-2212 thin film. For T>60K, the plots were shifted down for comparison with plots for T<60K

The I-V characteristics measured at different temperatures were considered, analyzing ln(V/I) vs. 1/I (Fig. 3). In all the measurements, $\mu < 1$ so that point defects, for which $\mu = 1.0$, is not predominant. Planar defects can actually occur at the grain boundaries, where the superconductor order parameter is reduced. Also, the relatively high Jc in the samples implies a strong proximity coupling between grains. In addition, the magnetic field dependence of the Jc (Fig.2) indicates an influence of the intergrain regions on the observed behaviors.

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