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ANISOTROPIC FLUX TRAPPING IN HIGH TEMPERATURE SUPERCONDUCTOR CRYSTALS

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We measure the angular dependence of the thermoremanent magnetization of YBaCuO and of BiSrCaCuO single crystals. We find that the amount of trapped flux is determined by the component of the field $\vec{H}$ along the crystalline $\hat{c}$ axis.

In recent articles[1,2] we have demonstrated the existence of anisotropic flux trapping in a ceramic YBaCuO sample and in single crystals of YBaCuO and BiSrCaCuO by a direct measurement of the angular dependence of the remanent magnetization. In these measurements the sample is cooled in a field, the field is then turned off, and the remanent magnetization is measured while the sample is rotated relative to the original direction of the field around a principal crystalline axis. For single crystals, the nature of the anisotropy depends on the axis of rotation. Trapped flux in the a-b plane exhibits **unidirectional** features[1] when the sample is rotated around the $\vec{c}$ axis. These results are very similar to those observed[2] for ceramic HTSC. However, for transverse rotations, i.e. for the axis of rotation perpendicular to $\vec{c}$ (hereafter arbitrarily referred to as the $\vec{a}$ axis), we detect a clear **uniaxial** anisotropy; the anisotropy axis coincides with the crystallographic $\vec{c}$ axis. In the present article we first describe briefly the data of Ref. 1 for YBaCuO and BiSrCaCuO crystals at 4.2 K and then add data at higher temperatures.

Magnetic measurements were performed on a Vibrating Sample Magnetometer (VSM). The sample is cooled in a field H to a low temperature T. The "cooling angle" ϕ is the angle between $\vec{H}$ and the $\vec{c}$ axis. The field is turned off and the "initial remanent magnetization" M^{i}_{rem} is measured. The sample is then rotated relative to $\vec{H}$; the axis of rotation is parallel to $\vec{a}$. During the rotation, the remanent magnetization M_{rem} is measured as a function of the angle θ between $\vec{H}$ and $\vec{c}$.

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Figures 1a and 1b exhibit the angular dependence of the remanent magnetization as a function of the rotation angle θ, for various cooling angles ϕ, for YBaCuO (1a) and BiSrCaCuO (1b). In these figures the sample is cooled to 4.2 K in 1 kOe. The remanent magnetization obtained when the field is turned off is indicated by an arrow. The angular dependence data, obtained during the rotation of the sample in zero field, fit perfectly to a cos θ expression with an amplitude which decreases with ϕ. The dominant features in these figures are the pronounced minima at a fixed angle $\theta = 180°$, **independent** of the initial cooling angle ϕ (except for ϕ close to 90°, see Figure 1a). The fixed location of the minima is in very sharp contrast to the results of a similar experiment on ceramic materials where the minima always occur at 180° relative to the direction of the cooling field. We also note that the amount of trapped flux decreases gradually with ϕ ; for $\phi = 90°$ the trapping is quite low, being practically zero when compared to the trapping for $\phi = 0°$.

To understand the physics beyond these observations, we recall that in a VSM the measured magnetization is only the component of $\vec{M}$ along the magnetic field. Each of the curves in Figures 1a and 1b (except for those close to 90°) is dominated by a cos θ term. This suggest that $\vec{M}$ is fixed in the crystal frame of reference and rotates with the sample. This is very plausible; $\vec{M}_{rem}$ results from trapped flux and the pinning forces are strong enough, at least at low temperatures, to overcome the small torque which is applied by the small remanent field ($\simeq$20 Oe) during the rotation. The fact that the location of the minima always occurs at $\theta = 180°$ indicates that $\vec{M}$ is parallel to $\vec{c}$ independent of the cooling angle. Thus, the crystallographic $\vec{c}$ axis defines the anisotropy direction. In contrast to this behavior, in ceramic samples M_{rem} is created in the direction of the cooling field; rotation would yield a minimum at an angle 180° relative to the initial orientation.

The data described in Figures 1a and 1b may be summarized by[1]

$$M_{rem} = M^0_{rem} \cos\phi \times \cos\theta + \text{constant}\,, \qquad (1)$$

where M^0_{rem} is the remanent for $\phi = 0$ at $\theta = 0$ and the constants terms (100 emu/cc and 17 emu/cc for the "Y" and "Bi" samples respectively) are associated with the flux trapped in the a-b plane.

Figure 2 demonstrates that the qualitative features of the angular dependence of M_{rem} are independent of temperature (up to a temperture where rotation data show irreversible effects). In this figure, we present $M_{rem}(\theta)$ data for BiSrCaCuO for $\phi = 0$ at 4.2 K and at 14 K and compare these data to results $\phi = -60°$ at 14 K. We note the similarity among the curves and, in particular, the pronounced minima at $\theta = 180°$. Similar features are obtained for other ϕ values not shown here. Note that temperature in this experiment is limited to a narrow range (T < 25K) where M_{rem} is reversible, at least in the time window of the experiment. At higher temperatures we observe irreversible effects which apparently blur the information; these data are not discussed here.

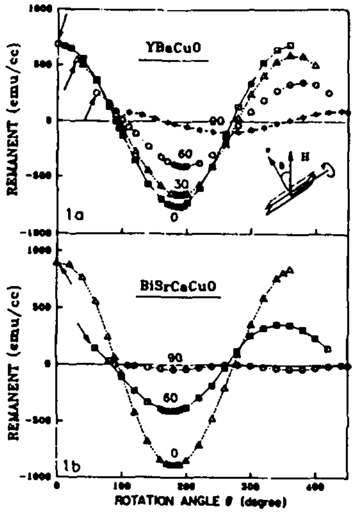

FIGURE 1

Angular dependence of the remanent magnetization for the indicated cooling angles at 4.2 K and a cooling field of 1 kOe for YBaCuO (a) and for BiSrCaCuO (b) crystals. Arrows denote the initial remanent values. Diagram in (a) sketches the orientation of the samples relative to the applied field during the rotation experiment.

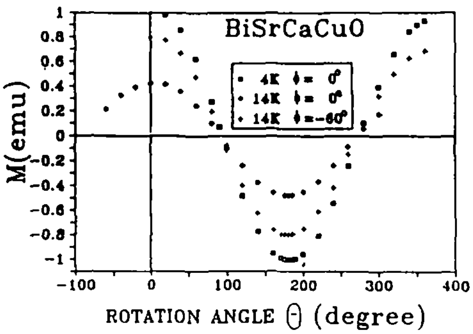

FIGURE 2

Angular dependence of the remanent magnetization for the indicated cooling angles and cooling field of 1 kOe for BiSrCaCuO crystal at 4 K and 14 K.

The simple result, Eq. 1, suggests the following scenario for the organization of the vortex lines: during the cooling process the vortex lines are aligned parallel to the magnetic field. However, trapping is extremely anisotropic; thus, when the field is turned off only the components cos ϕ of the total flux (i.e. current loops in the a-b plane) are trapped. Qualitatively, the anisotropy we find for flux trapping is consistent with the reported anisotropy of the critical currents J_c in HTSC. Preferred flux trapping for magnetic fields along the $\vec{c}$ axis is equivalent to larger J_c in the a-b plane.

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