Vortex diode effect in pinning enhanced thin films

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***Abstract*– The critical current anisotropy in the cuprate superconductor YBCO arises due to a number of different sources. We have found that the contribution of geometric effects, essentially due to surface pinning, cannot be neglected in YBCO films with pinning enhanced through the introduction of a second phase. We show a significant variation in critical current when the direction of the Lorentz force is reversed. We associate this effect with the substrate/film interface consisting of a region of graded superconductivity. Finally we point out the importance of measuring the full angular range of field when characterizing the critical current anisotropy of YBCO.**

I. Introduction

The critical current anisotropy in YBCO arises from a number of different sources. Leaving aside those effects that relate purely to angles between field and current other than 90 degrees and the effects of introduced anisotropic pinning centres the contributions fall into three categories. Firstly there is the variation in the G-L superconducting parameters due to the intrinsic anisotropy of the material [1,2], there is a well described scaling law which predicts the variation of the superconducting parameters with field angle that can fit angular data over a certain range of angles [1,2]. Secondly the layered structure introduces more complexity both from "intrinsic" pinning due to the layers but also from the cross over from rectilinear Abrikosov vortices to kinked vortices at temperatures below 80K and for fields applied near parallel to the *a-b* planes [2]. Finally surface pinning effects exist which are normally less significant due to the large demagnetizing effect found in thin films, however for fields near parallel to the surface of the film surface barriers can be significant. This has been shown most clearly in experiments on vicinal films where the angular position of the field parallel to the surface and field parallel to the *a-b* plane geometries are different [3]. In experiments on thin films of the isotropic superconductor NbTa Kumar et al. [4] found significant peaks in the angular critical current behavior arising when the film surfaces were sharply defined. Films grown with superconducting parameters varying slowly at the interfaces exhibited no such peaks. They attributed this to the removal of the surface barrier to flux entry associated with a sharp discontinuity in superconducting parameters.

II. Results and Discussion

In YBCO films containing pinning additions we regularly observe a suppressed "intrinsic" pinning peak or even a small minimum superimposed on the in-plane (or "intrinsic") peak. However, we have observed that if a full scan of critical current versus field is performed which takes in both in-plane peaks it is noticeable that, at low fields, the two peaks are often of dissimilar form.

A typical characteristic is shown in figure 1 for a measurement at 77 K and +/- 0.25 T on a rare earth tantalate [5] doped YBCO film. The film's critical current was measured in a lithographically defined track using a conventional four point measurement geometry. Each critical current value was derived from an IV curve using a ~1μV/cm criterion, the nanovoltmeter used was nulled before each IV curve and the current swept in one direction.

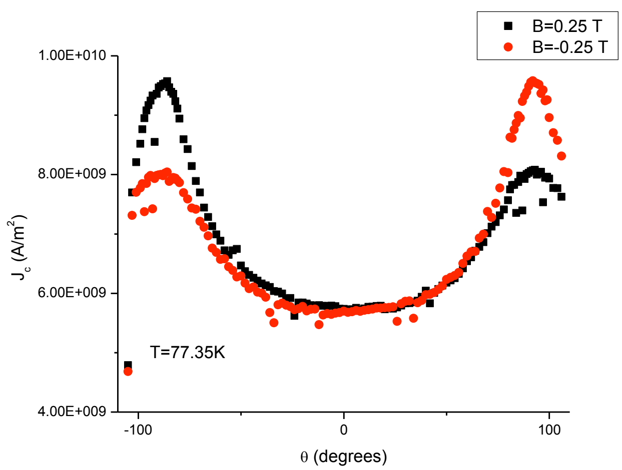

Figure 1. Variation of critical current with applied field tilt with respect to the a-b plane in a 500nm thick thin film of tantalate doped YBCO. Note the difference between the two "in-plane" peaks and the symmetry obtained with reversing the applied field

The data set shown in figure 1 indicates that the difference between the two peaks is not due to measurement artefacts but is in fact due to the change in the direction of the applied field.

Figure 2 shows how the difference in critical current value for the two peaks varies with applied field. It is instructive to note that the effect disappears at high field, as would be expected if the effect is indeed associated with a surface barrier. Similar effects have been seen in a number of different samples. The common factor is that such samples appear to have a disordered layer at the film substrate interface.

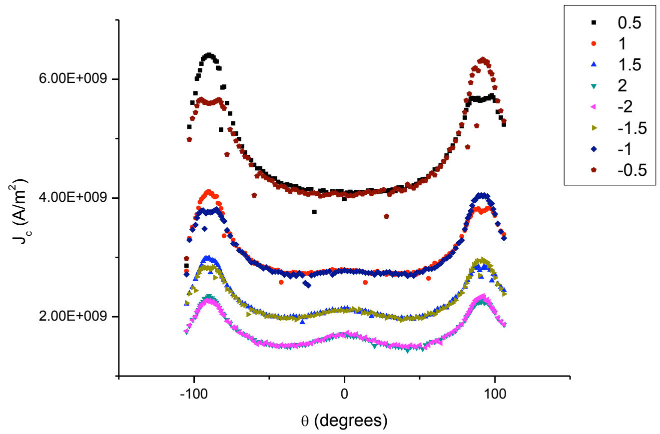

Figure 2 Critical current versus field angle data for varying positive and negative fields showing how the "intrinsic" pinning peak varies with Lorentz force direction

Figure 3 depicts a STEM through thickness image of a films exhibiting this large surface pinning anisotropy. The geometry of the measurement is such that the reduced critical current corresponds with flux lines entering at the the substrate/film interface.

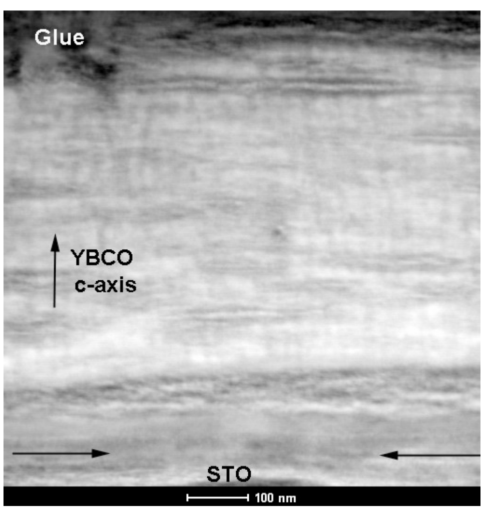

Figure 3 A through-thickness STEM image of a pinning enhanced film showing the difference between the two interfaces.

As a final check that the observed results are purely due to the reversal of the Lorentz force a bipolar *IV* characteristic was recorded at 0.5 T and 77 K and with the field orientated in the plane of the film. It can be seen in figure 4 that the two side of the *IV* curve are indeed different and correspond to the variation in critical current associated with a Lorentz force reversal arising from reversing the field direction as shown in figure 2. Although in a semiconductor diode the difference in magnitude between the two sides of the characteristic is much larger it is apparent that this thin film is a superconducting diode with the opposite properties to those seen in a semiconductor diode. Essentially the voltage generated is zero until a particular current is reached, which depends on the current direction. In a semiconductor diode the current passed is zero until a certain voltage is reached which depends on the direction of voltage bias, typically for a semiconductor diode these values would be 0.7 V and 500 V

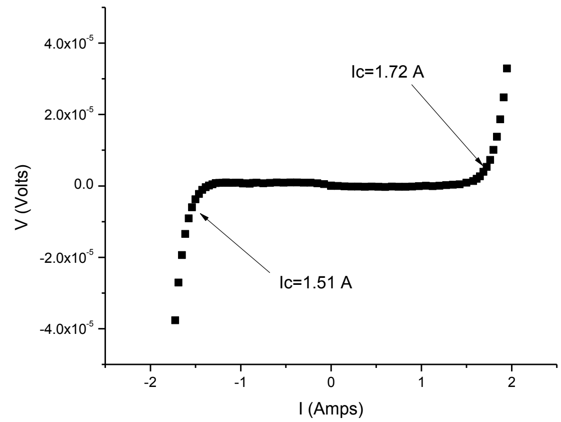

Figure 4 A bipolar IV curve recorded at 0.5T and 77K with field applied in plane showing the vortex diode effect

III. Conclusion

We have shown that it is possible to observe a striking variation in the critical current for an in-plane applied field in a pinning enhanced YBCO film. That this variation depends on the direction of the Lorentz force has been verified by reversing the orientation of the film, the field direction and the transport current direction. We conclude therefore that this effect arises from the differing barriers to surface entry at the two interfaces. We postulate that the large mismatch between the YBCO lattice and the pinning addition leads to a thicker layer where the superconducting parameters gradually increase at the film substrate interface.

The resultant vortex diode effect may be of practical application, especially if the variation of critical current reversed Lorentz force can be optimized.

Importantly we also note that when characterizing the angular dependence of critical current both "intrinsic" peaks must be measured and methods which average over both current directions to take *IV* curves can give misleading results.

References

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