

Reproducibility of the disordered vortex structure in twinned single crystals of YBCO

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Bitter decorations of the vortices in twinned single crystal YBCO have been obtained to study the disordered structure formed on successive cooldowns of the sample under the same conditions of field and temperature. Between successive decorations, the iron dots could be removed completely, giving a surface clean enough for further decoration. It was found that successive realizations of the disordered vortex state were very similar at long range, and differed mostly on short scales, compared to the average vortex separation. We have quantified the correlation between successive structures, and double sided decorations have been also performed to compare with the extent of spatial correlation in the applied field direction. The coincidence of the position of the vortices in successive realizations of the structure, is unexpected, and indicates an unusual behavior for a glassy system. Our technique makes it possible to image the position of the vortices in detail and repeatedly, providing us with a model amorphous system in which to study the reproducibility of the disordered structure.

Disorder introduced by pinning centers destroys the long range order of the vortex lattice in superconductors[1]. We have studied this disordered structure by the Bitter decoration technique[2], and have been able to obtain repeated images when the structure is formed upon cooling for the same conditions of field and temperature.

Experiments were performed on YBCO single crystals prepared by growth from the melt as described in Ref. [3]. Samples were fully oxygenated with typical values of T_c around 91.5 K. and approximate dimensions $(1 \times 1 \times 0.01) \text{ mm}^3$.

Bitter decoration was performed at 4 K, using a field cooling procedure. The samples were warmed to room temperature and vortex images were obtained in a scanning electron microscope. They were then cleaned in ultrasound with isopropyl alcohol, giving a surface which was clean enough to perform further decorations. A given region can be identified in successive decorations by using irregularities in the sample surface.

Fig. 1 shows the positions of the vortices for two successive decorations in a typical, heavily twinned, region of the sample. These positions were determined by looking for the maximum density in each image, by means of a computer program. It can

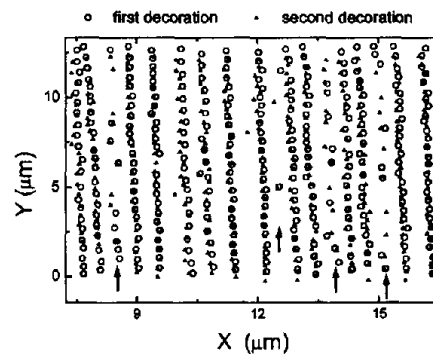


Figure 1. Vortex positions for two successive decorations, in the same region of a twinned sample, $H=36 \text{ Oe}$. Vortices not pinned to TB's are marked by arrows.

be seen that the ideal triangular lattice is lost, and the structures is disordered, although there is orientational order along the twin boundary (TB) direction (placed vertically in this image).

The first question we wish to address is whether the vortices will pin to the same TB for successive decorations. We have counted the number of vortices

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N (for a fixed length of $19 \mu\text{m}$ along the column) in each vortex column for approximately 40 TB's, and in Fig. 2 we plot N against the coordinate of the TB for two successive decorations. The vortex column positions coincide within experimental resolution and the number of vortices in some of the columns has small variations when comparing both realizations of the glassy state. The fact that the vortex columns occupy the same random positions (that is, they are pinned to the same twin boundary) and reproduce almost the same density along the TB is one of the main results of this experiment. Although we show in detail only a few images, the same result is obtained in all heavily twinned regions we have checked. It is also found in samples where three successive decorations were made.

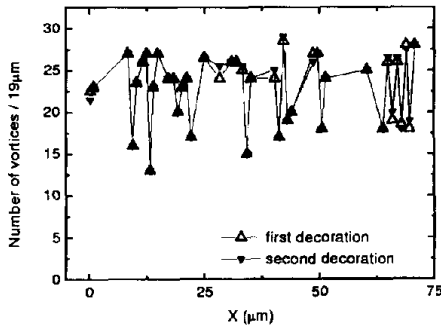


Figure 2. Number of vortices over a (vertical) distance of $19 \mu\text{m}$ along a column, vs. the (horizontal) column position for two successive images. $H = 36$ Oe.

In the successive decorations shown in Fig. 1 in general it is possible to find a vortex in the second decoration which is closer than the average vortex spacing to a corresponding one in the first. To quantify the decorrelation between the different realizations of the disordered structure we have defined an *rms* fluctuation as

$$\langle D_{1,2} \rangle_{//} = \frac{1}{N} \sum_{i=1}^N \sqrt{(y_{1i} - y_{2i})^2};$$

$$\langle D_{1,2} \rangle_{\perp} = \frac{1}{N} \sum_{i=1}^N \sqrt{(x_{1i} - x_{2i})^2}.$$

Where x_1, y_1, x_2, y_2 are the coordinates of the vortices in the first and second images and the subindices $//$ and \perp refer to distances measured parallel and perpendicular to the TB. The anisotropy introduced by the twin boundaries is seen by the fact that $\langle D_{1,2} \rangle_{\perp} = 0.065 \mu\text{m}$ and $\langle D_{1,2} \rangle_{//} = 0.18 \mu\text{m}$. The average lattice spacing is $a_{0||} \approx 0.9 \mu\text{m}$ along the TB and the average *rms* combined displacement $\langle D_{1,2} \rangle = 0.2 \mu\text{m}$.

We have also performed a two sided decoration on a $12 \mu\text{m}$ thick, twinned YBCO crystal from the same batch. Evaluating the *rms* deviation between the side A and the side B, we find $\langle D_{A,B} \rangle_{\perp} = 0.1 \mu\text{m}$ and $\langle D_{A,B} \rangle_{//} = 0.14 \mu\text{m}$.

Low *rms* displacement between images in the two sides is not unexpected, because of the correlated character of the vortex lines[3], and furthermore it indicates that vortex positions must be determined by pinning averaged over the bulk of the sample. The elastic constants of the vortex structure and the correlated TB pinning potentials also favor correlation, in competition with thermal fluctuations and possible differences in pinning over the vortex length. Thermal fluctuations should be comparable in the two sided decoration and successive decorations, but the effect of the elastic constants is absent in the latter where the *rms* displacement along the TB $\langle D_{1,2} \rangle_{//} > \langle D_{A,B} \rangle_{//}$. The differences in pinning potential along the vortex length are absent in the former, and the perpendicular displacement $\langle D_{1,2} \rangle_{\perp} < \langle D_{A,B} \rangle_{\perp}$. The fact that disordered structures related by different mechanisms show different types of correlation is to be expected, but it is remarkable that the correlation has similar absolute magnitude in both cases.

In conclusion, we have shown that successive vortex decorations provide unique insight into the reproducibility of the disordered vortex structure in twinned YBCO, and also offer a model glass where structural information can be obtained repeatedly and in detail.

REFERENCES

1. G. Blatter *et al.*, Rev. Mod. Phys. 66 (1994) 1125.
2. P. L. Gammel *et al.*, Phys. Rev. Lett. 59, 2592 (1987).
3. F. de la Cruz, D. López, and G. Nieva, Philos. Mag. B 70 (1994) 773.