Flux Quantization in Superconducting Micro-Disks

Yoshiaki Hata [a,1], Jun-ichi Suzuki [a], Itsuhiro Kakeya [a], Kazuo Kadowaki [b], Akikazu Odawara [c], Atsushi Nagata [c], Satoshi Nakayama [c], Kazuo Chinone [c]

[a] *Advanced Science Research Center, Japan Atomic Energy Research Institute, Tokai, Naka-Gun, Ibaraki 319-1195, Japan*
[b] *Institute of Materials Science, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan*
[c] *Seiko Instruments Inc., Matsudo, Chiba 270-2222, Japan*

Abstract

Magnetic flux images of a YBCO microdisk with 50 μm in diameter were observed using the scanning SQUID microscope. Single quantanized vortices are observed in the disk and the number of vortices increases with increasing applied magnetic field by step by step. These results suggest that the multi-vortex state appears in the disk and the giant vortex state was not observed.

Key words: scanning SQUID microscopy ; vortex imaging ; $YBa_2Cu_3O_{7-\delta}$

1. Introduction

Recent progress in microfabrication technology has stimulated interest in a mesoscopic superconductor as components for quantum computing and cryoelectronics. The distribution of vortices in such superconductor is interested since the character of the mesoscopic superconductor is determined by it.

To study such superconductors, we observed magnetic flux images of a YBCO micro-disk with 50 μm in diameter by a scanning SQUID microscope (SSM). Although the spatial resolution of our SSM is not sufficient to image enough small micro-disk, it has enough flux sensitivity and resolution to image quantanized vortices quantitatively.

2. Preparation of YBCO micro-disk

A $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin film on the $SrTiO_3$ substrate was prepared by pulse laser deposition. The thickness of the film is 480 nm and the superconducting transition temperature is 90.21 K. A micro-disk was patterned on the YBCO film by Ga ion sputtering (forcused ion beam microscope, SMI2200, Seiko Instruments). The diameter of the disk is 50 μm.

3. Magnetic imaging of YBCO micro-disk

Magnetic flux distribution of the YBCO micro-disk is imaged by the scanning SQUID microscope (SQM2000, Seiko Instruments). The effective sensing diameter of the pickup coil is 10 μm and the spatial resolution of this sensing coil is several μm. Magnetic field, up to 10 μT, was applied perpendicularly to the sample surface. The effect of the background magnetic field, e.g. geomagnetism is minimized by μ-metal shield and finally it was corrected by measuring residual magnetic field at sample stage. The sample is measured after cooling above T_c to 4.2 K under the magnetic field. Fig.1(a)-(f) shows SSM image of YBCO micro-disk under the magnetic field of 4.2, 4.5, 5.5, 8.5, 8.7 and 9.4 μT respectively. A dark region with 50 μm in diameter corresponds to the YBCO micro-disk of Meissner state. White spots in the disk correspond to the vortices and they are quantanized as ϕ_0. The shape and size of vortex images are determined by the

[1] E-mail:hata@neutrons.tokai.jaeri.go.jp

shape of the pick-up coil. Asymmetry of vortex image is caused by the design of the pick-up coil.

Increasing magnetic field, the number of vortices N increases and the each vortex is quantanized as ϕ_0. The relation between the magnetic field and the number of vortices is shown in Fig. 2. The average width of each step is $\Delta B = 1.17\mu$T. In the case of the disk with the radius of R the width of the step is given by

$$\Delta B = \frac{\phi_0}{\pi R^2} \tag{1}$$

where ϕ_0 is flux quantum and B is the magnetic flux density of the sample space. Effective disk radius deduced from this experiment is about 23 μm. According to the result, it seems that the magnetic flux of disk edge of 2 μm is expeled out from the disk.

A. K. Geim *et al.* studied the magentization of mesoscopic superconducting disks by ballistic hall micromagnetometry[2]. They found first or second order transition that depend on the radius and thickness for the superconducting state to normal state and for the sufficiently large radius of the disk, several transitions in the superconducting phase are appeared that correspond to the different angular momentum giant vortex state. Furthermore they found kinks in magnetization curves and this indicate second-order transitions, in which several Abrikosov vortices coalesce into a single giant vortex [3]. In this study, the multi-vortex state appeared in the micro-disk and no giant vortex state was observed . The arrangement of multi-vortex is irregular and it seems to be caused by the flux pinning effect.

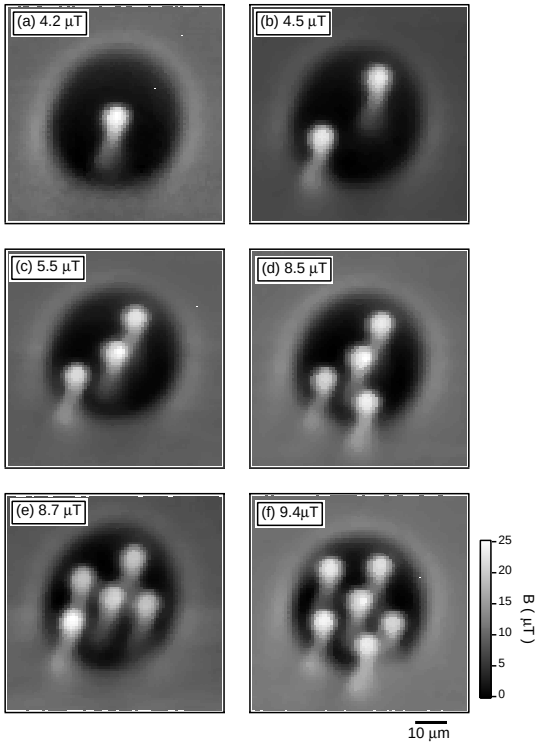

Fig. 1. SSM images of a YBCO micro-disk with 50 μm in diameter under various magnetic fields.

Acknowledgements

The authors thank M. Mainer and H. Adrian of University of Mainz for the preparation of YBCO thin films.

References

[1] D. Saint-James, Phys. Lett. **15** (1965) 13.

[2] A. K. Geim, S. V. Dubonos, J. G. Lok, I. V. Grigorieva, J. C. Maan, L. Theil Hansen, P. E. Lindelof, Appl. Phys. Lett. **71** (1997) 2379.

[3] A. K. Geim, S. V. Dubonos, J. J. Palacios, I. V. Grigorieva, M. Henini, J. J. Schermer, Phys. Rev. Lett. **85** (2000) 1528.

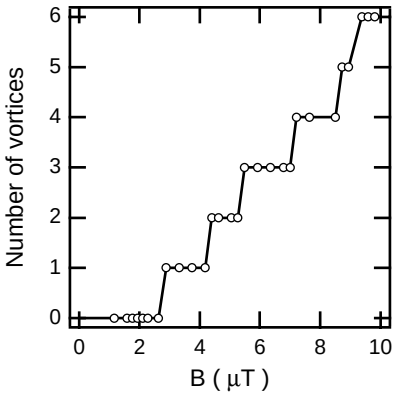

Fig. 2. The relation between the number of vortices in YBCO micro-disk with 50 μm in diameter and applied magnetic field.