ELSEVIER

Physica B 284–288 (2000) 817–818

PHYSICA B

www.elsevier.com/locate/physb

Vortex state in microfabricated superconducting disk probed by tunneling spectroscopy

Maxim Zalalutdinov[a,]*, Hiroyuki Fujioka[a], Yoshiaki Hashimoto[b], Shingo Katsumoto[a,b], Yasuhiro Iye[a,b]

[a]CREST, Japan Science and Technology Corporation, Mejiro 1-4-25, Toshima-ku, Tokyo 171-0031, Japan
[b]Institute for Solid State Physics, University of Tokyo, Roppongi 7-22-1, Minato-ku, Tokyo 106, Japan

Abstract

Low-temperature STM and STS were applied to the study of superconducting gap variations induced by perpendicular magnetic field within a microfabricated In disk. Abrupt changes of the gap observed at the disk center during magnetic field sweep are attributed to the switch between different vortex states. Spatial distribution of the superconducting gap defined by a magnetic flux configuration was also obtained. The results are partially in accordance with the distribution predicted for the giant multi-quanta vortices.

Keywords: STM/STS; Tunneling

Anomalous vortex structures: giant multi-quanta vortex and peculiar multivortex configurations are anticipated in perpendicular magnetic field in mesoscopic superconducting disks, whose radii and thickness are comparable or less than the penetration depth λ and the coherence length ξ [1–5]. Order parameter, confined by the boundary conditions has to be adjusted to the magnetic flux, which penetrates freely inside the thin disk. Numerical simulations based on non-linear Ginzburg–Landau equations reveal the vortex phase diagram, which predicts reentrant transitions between multivortex configurations (vortices arranged in ideal polygon along the disk periphery) and the giant vortex states as a function of magnetic field [6].

In the present work STM–STS technique was used to obtain local gap spectra in order to identify configuration of the order parameter in microfabricated superconducting In disks.

Pt film (15 nm thick) sputtered on SiO_2–Si wafer was used as a substrate. A 2D array of low-temperature (77 K) deposited indium disks with 500 nm radius, 32 nm height and 3000 nm separation was fabricated by the electron-beam lithography. A low-temperature STM system operated at 2 K allowed us to identify In disks and to place the tip at any desired location. Typical dI/dV spectrum obtained on the In disk in zero magnetic field is shown in the insert of Fig. 1. Conventional fitting was done assuming an S–N tunneling contact, with the finite lifetime effect (Γ) taken into account by the density of states definition:

$$N(E)_{\mathrm{T}} = \mathrm{Re}\left[\frac{E + \mathrm{i}\Gamma}{\sqrt{(E + \mathrm{i}\Gamma)^2 - \Delta^2}}\right].$$

Gap parameter $\Delta \approx 0.7$ meV obtained from such fitting is not far from the bulk indium value. Because of the lack of in situ cleaning of the surface under UHV, a point-contact would be formed between the tip and the sample. The above result, however, manifests that such a "point contact" could be used to detect the superconducting gap.

The gap at the disk center should be most suggestive for the vortex state reconstruction. Fig. 1 shows evolution of the gap parameter Δ at the center of the In island when magnetic field was applied perpendicular to the

* Corresponding author.
E-mail address: maxim@kodama.issp.u-tokyo.ac.jp (M. Zalalutdinov)

0921-4526/00/$ - see front matter
PII: S0921-4526(99)02116-X

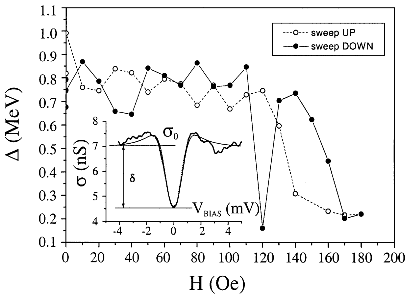

Fig. 1. Magnetic field dependence of the superconducting gap Δ acquired at the center of the indium disk at 2 K. The insert illustrates the extraction procedure of Δ value by the fitting of the BCS form (thin solid lone) to a differential spectrum acquired at zero magnetic field (shown by dots). Arrow bar shows the definition of δ.

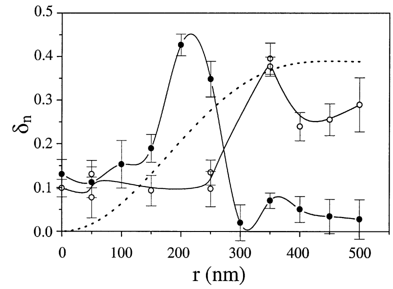

Fig. 2. Spatial distribution of the normalized gap depth δ_n observed along the diameter of the In disk at 115 G. Solid circles: results of scan along the X-axis; opened circles: those for the Y-axis. The dotted line illustrates order parameter distribution calculated for a giant vortex state.

disk plane. When the field was decreased, $\Delta(H)$ vanished abruptly around 115 G then recovered to the zero-field value. Note that this behavior was highly reproducible.

The abrupt suppression of the superconducting gap at the disk center can be attributed to the transition from a polygon multivortex state to giant vortex state upon expelling one fluxoid [6]. Further decrease of the magnetic field should cause transition into another multivortex state and hence restoration of the gap at the disk center.

Next, the magnetic field was fixed at 115 G, where the giant vortex is expected. The spatial distribution of the normalized depth $\delta_n \equiv \delta/\sigma_0$ of the gap was measured along the radius in X and Y directions (δ and σ_0 are defined in the inset of Fig. 1). The conductance, related to the contact area was kept constant within 15% for different tip locations in Fig. 2.

Increase of the δ_n in Y direction toward the disk boundary is in accordance with the behavior expected for a giant vortex state (dotted line in Fig. 2). However, in X direction the periphery of the disk was gapless, while full superconducting gap was observed in narrow region about the middle of the radius. Though this suggests that the giant vortex is distorted by some sort of disorder present inside the indium disk, it would also be possible that some unexpected vortex state was observed. Further research aimed at the full mapping of the vortex state is in progress.

References

[1] A.K. Geim et al., Nature 390 (1997) 259.
[2] V.V. Moshchalkov et al., Nature 373 (1995) 319.
[3] H.J. Fink, A.G. Presson, Phys. Rev. 151 (1966) 219.
[4] V.A. Schweigert, F.M. Peeters, Phys. Rev. B 57 (1998) 13 817.
[5] A.I. Buzdin, J.P. Brison, Phys. Lett. A 196 (1994) 267.
[6] V.A. Schweigert, F.M. Peeters, P. Singha Deo, Phys. Rev. Lett. 81 (1998) 2783.