Vortex state in microfabricated superconducting disk probed by tunneling spectroscopy

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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 magnetic flux configuration was also obtained. The results are partially in accordance with the distribution predicted for the giant multi-quanta vortices. © 2000 Published by Elsevier Science B.V. All rights reserved.

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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 $\lambda$ and the coherence length $\xi$ [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\textsubscript{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 ($I'$) taken into account by the density of states definition:

$$N(E)_{\text{f}} = \text{Re} \left\{ \frac{E + iI'}{\sqrt{(E + iI')^2 - A^2}} \right\}.$$  

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 $\Delta$ at the center of the In island when magnetic field was applied perpendicular to the

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

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 ($\delta$ and $\sigma_0$ 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 $\delta_n$ 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