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Excess resistance in the superconducting transition of a mesoscopic Al disk

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Abstract

We report resistance measurements on a mesoscopic Al disk whose size is comparable to the superconducting coherence length. As the magnetic field increases, resistance peaks successively appear and some of the peak resistances are larger than the normal state value R_N. These peaks are ascribed to the transitions between different vortex states in the superconducting Al disk. The experimental results suggest that some anomalous energy dissipation is caused by the dynamics of the vortices in the confined geometry.

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Keywords: Superconducting nanostructures; Excess resistance; Vortex states

1. Introduction

Rapid development of the microfabrication technique enables us to produce nanostructures of any given geometries, and a number of experimental and theoretical works have been done in nanometer-scale samples. In aluminum (Al) nanostructures, the superconducting state is reported to strongly depend on the boundary conditions when their size becomes comparable to the coherence length ξ or the London penetration depth λ [1–5]. In the disk structures, the size effect plays a crucial role for the configuration of the vortices inside the disks because the boundary condition depending on the sample size and shape determines the confinement geometry for the superconducting condensate [1–5]. In such systems, there are two possible vortex configurations: giant vortex states (GVSs) with a single core in the center and multivortex states (MVSs) with a spatial arrangement of singly quantized vortices [4,5]. GVSs are expected to be more stabilized in

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smaller size. Both configurations are reported to show characteristic magnetic field dependence of T_c, which causes oscillatory behaviors in the resistive transitions with field. On the other hand, it is known that the resistance exceeds the normal state value (R_N) near T_c or H_c in mesoscopic wire samples [6–8]. Such anomalous behaviors have been explained by the models based on the charge imbalance which is created near phase slip centers (PSCs) [6,7] or S/N boundaries [8]. However, the origin is still controversial.

In this work, we have fabricated an Al disk with four narrow leads. We have performed the resistance measurements under magnetic fields and found new features in the resistive transitions, which are probably related to the vortex dynamics in the disk.

2. Experiment

Sample was patterned on SiO_2 substrates by electron beam lithography (Hitachi S4200 equipped with Tokyo Technology Beam Draw System). Al film (20 nm thick) was deposited by thermal evaporation of high-purity Al (99.999%) at room temperature followed by a lift-off process. The structure of the disk sample is depicted in the inset of Fig. 1. The diameter of the circular disk is 1.0 μm and the width of the leads is 0.1 μm. The resistance measurements were performed with Stanford Research SR830 lock-in amplifies at a frequency of about 20 Hz at temperatures down to 500 mK under magnetic fields up to 2000 G. All the electrical leads were shielded by low-pass filters (60 dB cutoff at 100 MHz) located near the samples. The resistance ratio $R(300\,K)/R(4.2\,K)$ is about 2.1 and the coherence length ξ_{GL} is estimated to be about 0.2 μm from the residual resistance of the sample.

3. Results

Fig. 1 shows the resistance variations as a function of the magnetic field at different temperatures. The magnetic field is applied perpendicular to the sample plane. As the field increases, a transition from a superconducting to a resistive state is observed below T_c (= 1.28 K), then the successive resistance peaks appear (dashed lines in Fig. 1). The positions of the resistance peaks are independent of the temperature and some of the peaks have resistances larger than R_N (the normal state value $R_N = 0.5\,\Omega$). Although the above results are obtained by AC measurements, the similar results have also been obtained by DC measurements. At a fixed temperature, the peaks become less evident with increasing field. Fig. 2 shows the field intervals of the resistance peaks ($\Delta H'$) versus peak number n. Such peaks in the resistance curves have been explained in terms of the transitions between the different vortex states. For

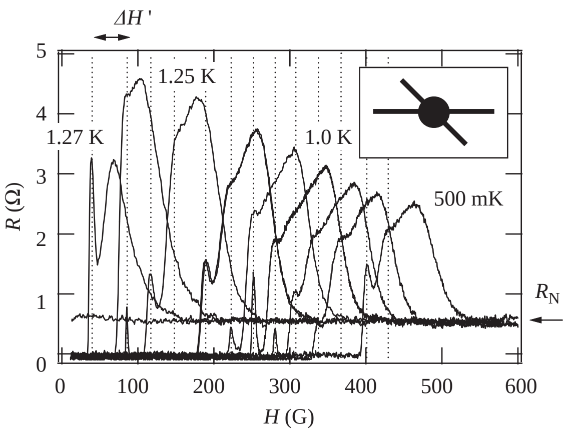

Fig. 1. Magnetic field dependence of the resistance at different temperatures. Inset: Schematic view of the Al sample.

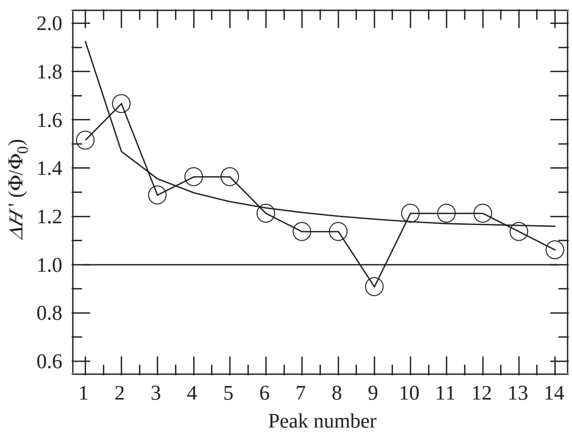

Fig. 2. The field intervals of the non-periodic resistance peaks ($\Delta H'$) versus peak number. Φ_0 is flux quanta. The thick solid curve shows the theoretical prediction [9].