Search for Spontaneous Magnetization in Sr_2RuO_4

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Abstract

A micro-Hall probe is used to search for spontaneous magnetic field at the edge of chiral domains in the time-reversal-symmetry-breaking state in Sr_2RuO_4. We did not detect any additional magnetic signal larger than 20 mG at low fields, which is much smaller than the theoretical estimate for an isolated chiral domain. This fact suggests that either the spontaneous magnetization is absent or the chiral domains are smaller than the size of Hall probe, 5 μm. In the latter case, magnetic history dependent measurements of the vortex pinning force strongly suggest that the chiral domains can be easily flipped by magnetic fields.

Key words: Sr_2RuO_4; spantaneous magnetization; chiral domain

1. Introduction

Soon after the discovery of superconductivity in Sr_2RuO_4 by Maeno *et al*. [1], an exotic mechanism for superconductivity with spin-triplet pairing was proposed [2]. The spin-triplet superconductivity is confirmed by NMR [3] and neutron measurements [4]. Furthermore, μSR measurements in Sr_2RuO_4 indicate that an internal magnetic field is established below T_c, suggesting that the superconducting state breaks time-reversal symmetry [5]. Although there are several superconductors with triplet pairing, existence of time-reversal-symmetry-breaking superconducting state, chiral state, is still an open question. Here we report on a search for spontaneous magnetic field (SMF) at the edge of chiral domains using a micro-Hall probe. No additional magnetic signals larger than 20 mG are observed at low fields. We also characterize how the chiral domains flip in response to the magnetic field.

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2. Experiments

Sr_2RuO_4 crystals used in the present experiments are grown by the floating-zone method using infrared furnace. Local magnetic induction is measured by a micro-Hall probe with an active area of $5 \times 5\ \mu m^2$ fabricated from GaAs/AlGaAs hetero structure. Typical noise level of the Hall probe at low fields is about 20 mG. The crystal is mounted directly on the Hall probe so that the active area is located at the edge and the center of the crystal for edge field and local magnetization measurements, respectively. In the edge field measurement, the edge of the sample is carefully polished so that its roughness is less than 1 μm.

3. Results and Discussion

Figure 1 shows temperature dependence of the local magnetization, B-H, for various applied field at the edge of Sr_2RuO_4. The global feature of measured response is that for ordinary superconductors. It should be noted that even at zero field we see some magnetic

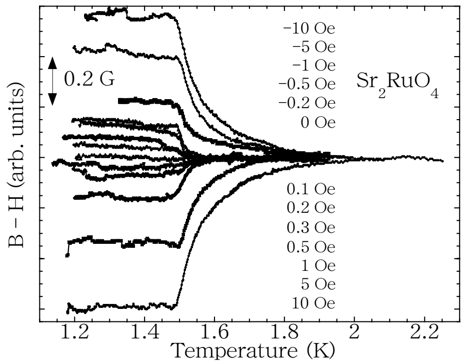

Fig. 1. Temperature dependence of the local magnetization at the edge of Sr_2RuO_4 between H=+10 Oe and -10 Oe. Diamagnetic signal above T = 1.5 K is due to the 3 K phase.

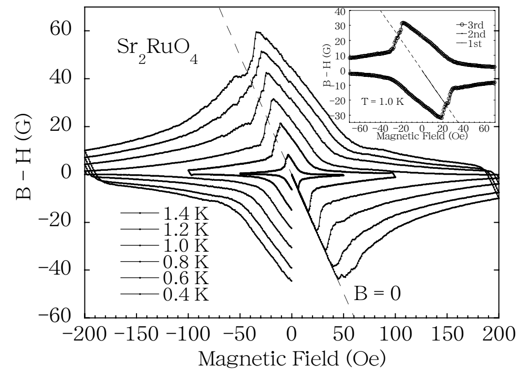

Fig. 2. Local magnetization hysteresis loops for Sr_2RuO_4. Note the presence of anomalies near B = 0. Inset shows magnetic history dependence of local magnetization hysteresis.

signal. However, we now believe that this is not due to SMF but from offset of the actual applied field at the sample position despite our careful calibration of the applied field. Actually, by shifting all curves -0.2 G they display fairly symmetric response for positive and negative fields. Hence our conclusion is that near zero field, we do not observe any signal larger than the noise level of 20 mG, which is much smaller than the theoretical estimate [9] taking into account of the Hall probe size. This fact suggests that either the SMF from the chiral domain is absent or the SMF is averaged out because the domain size is much smaller than the size of the Hall probe, 5 μm. At larger fields, clear diamagnetism starts above 1.5 K, which is confirmed to be originated from tiny amount of the 3 K phase [6].

Figure 2 shows the local magnetization hysteresis loop for Sr_2RuO_4. Among several noticeable characteristics, a sudden decrease of local magnetization close to B=0 is worth mentioning. Although the magnitude of the structure near B=0 is sample dependent, it is always observed [7,8]. In another triplet superconductor UPt_3, noise generation near zero field is explained by assuming that the chiral domain boundaries act as fence for incoming vortices. When the force exerted by the accumulated vortices overcomes the pinning force, avalanche-like penetration through the boundary generates noisy response [10]. Hence we believe that anomalies near B=0 is a strong indication of the presence of chiral domains. The absence of anomalies close to zero field is confirmed in conventional superconductors, $Cd_2Re_2O_7$ and In-Sn alloy.

In chiral superconductors, two superconducting states with opposite chiralities are degenerate and two domains can coexist. Under magnetic field, the domain having angular momentum opposite to the field (vorticity antiparallel to chirality) is stabilized [11]. The stability of chiral domains in response to the applied field is characterized by making a series of M-H loop measurements at T = 1 K with different initial conditions. In the first process, the sample is zero field cooled and M-H loop is measured with maximum excursion less than H_{c2}. In the second process, the same measurement is repeated to confirm the reproducibility. In the third process, M-H loop is measured with maximum excursion larger than H_{c2}. All three measurements give essentially the same result as shown in the inset of Fig. 2. In the first process, chiral domains with opposite chiralities coexist just like ferromagnetic domains in ferromagnets. By contrast, single chiral domain is expected at least in the field-decreasing branch of the third process, since they nucleate in the presence of positive vortices. If the chirality does not flip in response to the applied field, irreversible magnetization in the field-decreasing branch of the first (second) and the third process should be different. Indistinguishable local magnetization in the two processes strongly indicates that the chiral domains in Sr_2RuO_4 can be flipped easily.

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