A simple sample-inverting cryostat for Hall resistance measurements

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Abstract

A simple sample-inverting cryostat with no mechanical gears and motors has been introduced to a superconducting magnet up to 17 T combined with a variable temperature insert from 1.5 to 300 K for the Hall resistance measurements. An elliptical sample stage surrounded by a coil in 100 turns is turned upwards or downwards by switching the current to the coil under a magnetic field. The direction of the stage is controlled by the minimum current from 100 mA at 0.2 T to 1 mA at 15 T.

Key words: sample-inverting cryostat; Hall resistance; high magnetic field

1. Introduction

In the Hall effect measurements using the *dc* five-probe technique, a drift of the balance circuit to offset a part of electric resistance often gives a systematic error. In particular, for a sample with a large magnetoresistance, it is necessary to distinguish a part of the Hall effect from the mixing effect with the magnetoresistance carefully. In order to extract the data for the Hall effect, we usually measured the signals with opposite field directions each other by the way of changing the current polarity for the electromagnet, rotating the split magnet, or changing the sample direction itself. In the superconducting magnet, the change of current polarity leads a large consumption of liquid helium and a time loss. Rotating magnet is generally troublesome. In this report, we introduce a sample-inverting cryostat on the basis of a simple idea to use a magnetic torque on the sample stage under the high field, although many techniques for the precise sample rotation have been reported so far [1–5]. The merits of the cryostat are no mechanical gears, no motors, and the easy operation under the high magnetic field.

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2. System construction

The essential features of the apparatus are shown in Fig. 1. Under a magnetic field, the turning motion is derived from applying the current to the 100-turn coil built in the sample stage. It was machined from bakelite, cut into the coil bobbin, wound 100 times copper wire, which was covered with a stycast. The insulating materials are beneficial to avoid eddy current effects in the high field region. The sample stage contains a cernox thermometer (Lake-Shore) for measuring temperature from 1.5 K to 300 K, a heater made from manganin for regulating the temperature, and a Hall probe (THS118, TOSHIBA) for monitoring the stage orientation. The thermometer, the Hall probe and samples were set on a sheet of sapphire which is thermally anchored to the sample stage. The sample stage is loosely fixed to the stainless tube by two screw pins so as to allow a free motion around a horizontal axis.

Electric leads to the sample stage are fed after winding around the rotation axis. This acts as a torsion spring as well. The sample holder is elliptical to avoid entangling the twisted wires in the screw pins. A stainless tube has a window for convenience of sample replacements. It enables us to change a sample directly without disassembling the stage from the cryostat. Since the assembly is placed in a variable temperature

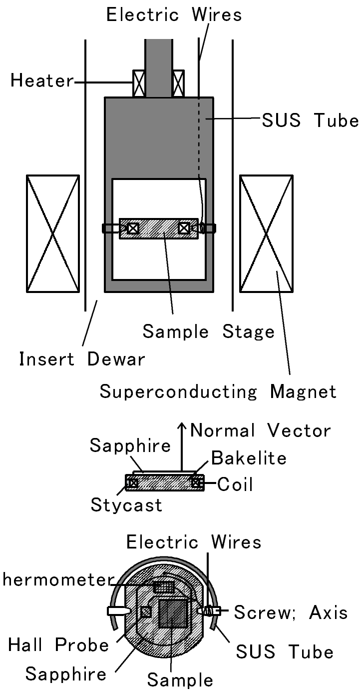

Fig. 1. Illustration of the lower section of the cryostat and the sample stage. The lower section, having a diameter of 29 mm, fits inside the tail of a variable tempreture insert dewar which is situated within a superconducting solenoid.

insert (31 mm in diameter), it is designed as 29 mm in outer diameter.

3. Performance

First, we tested the inverting capabilities of the sample stage at room temperature under the low magnetic field $B = 0.22$ T. Appling the driving current of 100 mA to reverse the current polarity 100 times, we monitored the Hall probe resistance. The resistance variation is estimated to be ± 10 mΩ to the average resistance 40.76 Ω, namely $\delta B/B \approx \pm 2.5 \times 10^{-4}$, which corresponds to the angle variation of $\pm 1.2^{\circ}$.

Next, the driving current dependence of the sample stage orientation was measured as shown in Fig. 2. The angle θ between the normal vector of the stage and the field direction is obtained from the resistance of the Hall probe. $I_{\pm}(\bullet)$, $I_{\rm dec}(\bigtriangledown)$, and $I_{\rm inc}(\bigtriangleup)$ represent the data for changing the current polarity alternately, for decreasing current from100 mA to -100mA, and for increasing current from -100 mA to 100 mA, respectively. The inverting motion is described as the balance of the turning torque.

$$\tau = -k(\theta - \theta_0) + \tau_{\rm m} \pm \mu \quad (1)$$

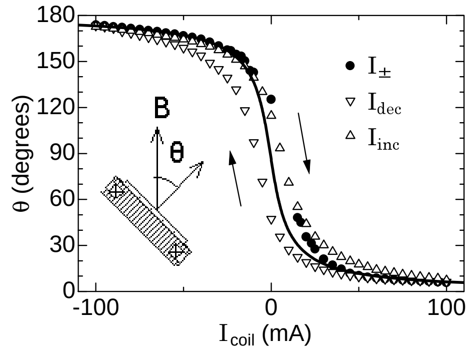

Fig. 2. Driving current dependence of the sample stage orientation. For three conditions: Changing current polarity alternately, $I_{\pm}(\bullet)$; Decreasing current from100 mA to -100mA, $I_{\rm dec}(\bigtriangledown)$; Increasing current from -100 mA to 100 mA, $I_{\rm inc}(\bigtriangleup)$.

$$\tau_{\rm m} = -NISB\sin\theta \quad (2)$$

where k is a torsional spring constant of the wires, θ_0 is the initial angle before applying current, μ is a static frictional torque, N=100 turns, I is the driving current, and S=406.5 mm^2 is the area of the sample stage. The data for $I_{\pm}$ was fitted by Eq. (1) with the balance condition $\tau = 0$ as shown in Fig. 2 by a solid curve. In sweeping the current for the data of $I_{\rm dec}$ and $I_{\rm inc}$, a clear hysteresis due to the static frictional torque was observed. The maximum magnetic torque in $I =$ 100 mA is $\tau_{\rm m} = 8.943 \times 10^{-4}$ N·m, is large enough to invert the sample stage. We found that a coil current 1 mA enables to invert the sample stage at 15 T.

4. Conclusion

A simple sample-inverting cryostat for Hall resistance measurements has enabled us to measure the Hall resistance easily and precisely at temperatures from 1.5 to 300 K in magnetic fields up to 17 T. Elliptical sample stage is confirmed to turn upwards or downwards by switching the current from 100 mA at 0.2 T to 1 mA at 15 T.

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