Low temperature measurement system based on a closed-cycle refrigerator

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Abstract

We have built a new torque magnetometer with a closed-cycle helium refrigerator. The temperature can be lowered down to 1.5 K by pumping liquefied helium in sample space. The temperature can be stabilized within ±0.01 K by using the two-independent PID loops. A piezoresistor bridge configured with a silicon cantilever surface is used to detect a torque. A transeverse magnetic field, which is fabricated by the several pieces of the permanent magnets, can produce a field up to 10 kG in any direction. The system has complete control from a computer by coding a LabVIEW. We have demonstrated the torque curves of a single crystal $YBa_2Cu_4O_8$ successfully even at 1.6 K.

Key words: Torque magnetometer; refrigerator; piezoresister; LabVIEW;

1. Introduction

The low temperature measurement requires cryogen such as liquid helium in the past. Liquid helium has a lot of trouble such as high cost, high consumption by evaporation, and elaborated labor. A computerised measurement on the purpose of a long term experiment is also a difficulty without supplying helium. We plan to save liquid helium consumption in our laboratory.

With a progress of a 4-K refrigerator, it is possible to perform a low-temperature experiment without liquid helium. In our study, we have developed a torque magnetometer system using a 4-K closed cycle refrigerator.

In this report, we describe the details of our system.

2. Experimental

In Fig. 1, we show a schematic diagram of our cryostat system. This system consists of a 4-K refrigerator (Sumitomo Heavy Industries, Ltd.) of cooling power 1 W at 4 K and an exchange gas cooling system (Janis). The cryostat has a top-loading sample space, and

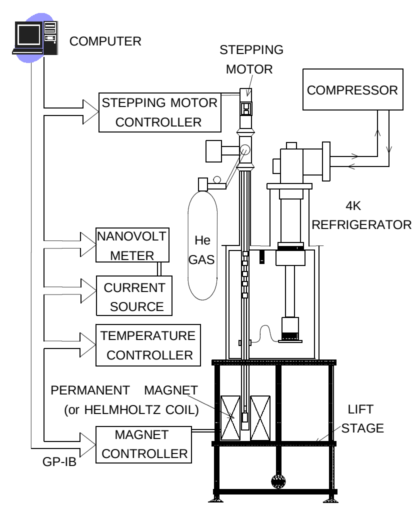

Fig. 1. Schematic diagram of the torque magnetometer system

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a sample rod can be rotated by a stepper motor (Oriental Motor) with a resolution of 0.0036°. A bottom of the sample rod equips with a sample holder, and the location of the sample holder can be applied by a valiable magnetic field of an assembled permanent magnet (Magnetic Solutions MM-1000-48) up to 10 kG. A couple of the two coaxial permanent magnets can move independently by a stepper motor. Vector sum of the two fields varies both in amplitude and direction.

A torque sensor equipped with a sample holder consists of the silicon cantilever which has a sample stage is 2×2 mm, 25 μm in thickness and an arm is 1 mm in length. Two piezoresistors attached on the cantilever arms configure the bridge with other two ones. Torsion of the cantilever generates a change in piezoresistors. The off-balance signal can be immediately measured by a direct trigger link between a nanovoltmeter (Keithley 2182) and a current source (Keithley 2400).

A temperature controller (LakeShore 340) has two-independent PID loops. The inner sample space and the outer sample tube are controlled with a typical stability of ± 0.01 K. We describe a software for the temerature control, the field control, and the motion control by LabVIEW6*i*.

3. Results and Discussion

Our new system of torque magnetometer is shown in Fig. 1. We made it 1.5 K without transfering liquid helium. A sample space is sealed with 1-atm helium at room temperature. After cooling down to 6.5 K, it is liquefied by pressurizing helium in a sample space. A 1.5 K state can be achieved by pumping the helium bath, and it can be kept at 1.5 K for 90 min.

We measured a $YBa_2Cu_4O_8$ single crystal to demonstrate the usefulness of our system (Fig. 2). We confirm the fact that a sample rod rotates smoothly by monitoring a Hall sensor attached on a sample holder. We found that the fixing of leads by GE7031 varnish diminishes the electronic noise remarkably. The typical standard deviation of the signal is on the order of nanovolt. We analyze the reversible torque curve of this sample using a Kogan model[2], we estimate an anisotropy parameter $\gamma = 10.02 \pm 0.48$ at 70 K ($T_c = 80$ K). We consider that this system is very useful for the studies of other high T_c superconductors.

4. Conclusion

We have built a low temperature measurement system without consuming liquid helium. We performed a torque measurement of $YBa_2Cu_4O_8$ down to 1.6 K.

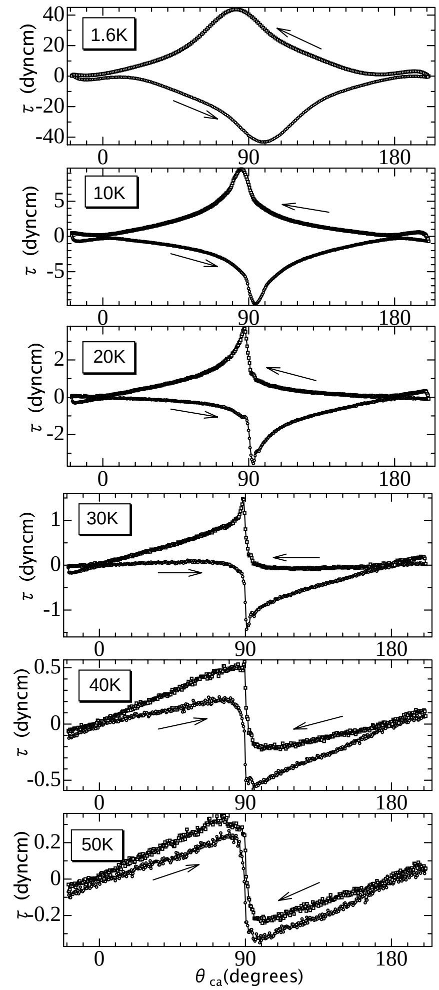

Fig. 2. The torque curves of $YBa_2Cu_4O_8$ ($\sim$30 μg) in 10 kG at the several different temperatures.

The present system can be used for the versatile purposes in the economical low-temperature experiments.

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