Development of high-T_c SQUID microscope

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Abstract

We have developed a SQUID microscope using a high-T_c SQUID sensor. The SQUID sensor has a sensitivity of 1 pT and the effective sensor area is 0.08 mm^2. An X-Y stage moves over 30× 30 mm area and its resolution is 0.05 μm at most. The SQUID sensor is cooled by liquid nitrogen, and can be held at 77 K for 1 h. The distance between the sensor and a sapphire window is less than 100 μm. The sample temperature is limited to room temperature. The device is controlled by a LabVIEW-6i software and a motion controller. The performance of the SQUID microscope is examined by a tiny Ni rod.

Key words: SQUID ; microscope ; X-Y stage ; High-T_c

1. Introduction

A SQUID microscope has been developed rapidly in recent years. The SQUID microscope using a conventional superconductor requires a lot of liquid helium [1]. The recent progress of high-T_c SQUID extends to the application in the field of magnetic field measurements. Since the SQUID resolution reaches 10^{-12} tesla, the apparatus becomes extremely sensitive compared to other means.

Black *et al.* [2] pioneered a high T_c SQUID microscope having a spatial resolution of 60 μm. Several groups have utilized the SQUID microscopes with higher spatial resolution to investigate superconductors [3–5]. This apparatus may find a wide variety of the applications in the material sciences.

In this paper, we report the construction of our high-T_c SQUID microscope, and describe the results of the test experiments by using a tiny nickel rod.

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2. SQUID microscope

In Fig. 1, we show the schematic diagram of our SQUID microscope. The SQUID sensor was fabricated by the Sumitomo Hightechs Inc. (Osaka, Japan), and we assembled it as the SQUID microscope. Most of the motional control parts were systemized by us.

The SQUID microscope consists of (1) a high-T_c SQUID sensor, (2) a liquid nitrogen Dewar, (3) double permalloy shields of the SQUID microscope, (4) a sapphire window (100 μm in thickness), (5) an XY stage with stepper motors (0.05 μm at the minimum), (6) a Z stage in manual operation, (7) a CCD camera with a scope, (8) a CRT monitor to examine a distance between the sapphire window and a sample, (9) an electronic SQUID controller, (10) a control computer, (11) a LabVIEW software developed by us, (12) a motion interface and a control box for the XY stage, (13) an vacuum pump for the liquid nitrogen Dewar, (13) a digital multimeter to measure the SQUID output and (14) an active band pass filter for the SQUID output.

A SQUID sensor is fabricated on the STO substrate of which the thickness is 1.0 mm [6]. A sample can be scanned in the two dimensions while the SQUID sensor is fixed to the nitrogen Dewar.The SQUID sensor having the sensitivity of 1pT, and the effective sensor area is smaller than $0.08mm^2$. The SQUID sensor can be cooled down to 77 K for one hour by using the evacuated Dewar ($\sim 5 \times 10^{-4}$ Pa). A distance between the SQUID sensor and the sapphire window can be minimized as short as 100 μm. The sample space can be subjected to light to monitor the distance between the Dewar window and the sample.

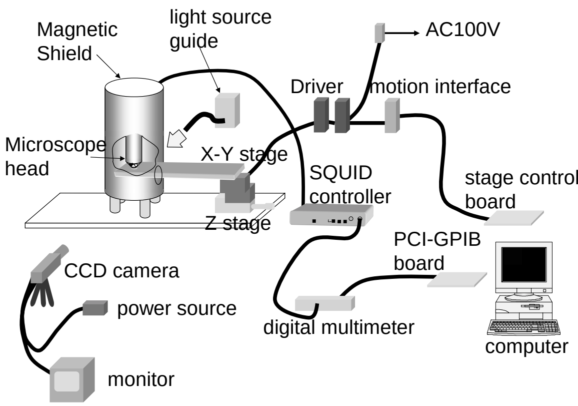

Fig. 1. Schematic diagram of our SQUID microscope.

3. Experimental

We used a magnetized Ni rod ($0.1^{\phi} \times 4$ mm). We fixed the Ni rod on a cover glass by using a vacuum grease. We scanned the sample over 4000×4000 μm along the X and Y axes. The scan step is typically 1μm. The distance between the sapphire window and the sample was changed from 1 mm to 10 mm in a 1-mm step. A band pass filter between 10 Hz and 20 Hz was used to minimize the electronic noise. The whole measurements was controlled from a computer by the LabVIEW-6i software.

4. Results and Discussion

In Fig. 2, we show the three-dimensional field profile from the Ni sample where the distance between the sample and the window is 1 mm.

Since the magnetization direction is not determined when the sample was fixed, the detailed analyses were not carried out. However, we can clearly see the shape of the Ni rod from the magnetic field profile. When the distance increases more than 6 mmm, the SQUID signal is on the order of the noise level.

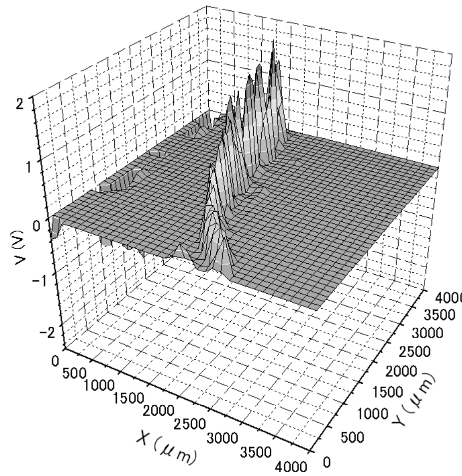

Fig. 2. The three-dimensional representation of the local magnetic field over a Ni rod. The sample is located by 1 mm apart from the sapphire window.

5. Conclusions

We have constructed the SQUID microscope using the high-T_c SQUID sensor. The field profile reproduces the shape of the Ni sample. The apparatus can be used for the nondestructive inspection.

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