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Development of High Tc SQUID Microscope with Flux guide

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Abstract—A new type of Superconducting Interference Device (SQUID) microscope was designed and fabricated. A direct-coupled SQUID magnetometer with a high μ-metal needle was used. The needle was attached to the vacuum window. One end of the needle penetrated through the superconducting pick-up loop so that it couples well with the loop. Magnetic field images from laser printed patterns were successfully demonstrated.

I. INTRODUCTION

In recent years SQUIDs have been used in a wide variety of applications due to their superior magnetic field sensitivity. In particular, SQUID microscopes have become a powerful tool for the investigation of flux dynamics and other studies in physics [1] – [6]. For a low Tc SQUID, a small transfer coil was developed and connected to the SQUID [3], [4]. However, for a high Tc SQUID, there is no technology to transfer a small magnetic field from a small area to the SQUID. Therefore, the high Tc SQUID must be sufficiently small and the separation of the SQUID and the sample must be as small as possible. Some groups have proposed a high Tc SQUID microscope using a high μ-metal tip or needle to solve the above-mentioned problems [7] – [10]. The advantage of this system is that magnetization of the sample by the modulation coil of the SQUID can be avoided, because the coil is far enough from the sample. We have designed and fabricated a new type of high Tc microscope using a fine flux guide. One end of the flux guide penetrates through the pick-up loop of the 77K SQUID; the needle was held by the window with the other end sharpened and at room temperature. A system in which a room temperature flux guide penetrates the SQUID pick-up loop has not been reported on to date. We present a design based on a computer simulation of the magnetic field distribution and the results of the microscope.

II. STRUCTURE

A direct coupled dc SQUID made of a 200 nm-thick $YBa_2Cu_3O_{7-y}$ (YBCO) thin film on a 500 μm-thick $SrTiO_3$ substrate by sputtering was used. The junctions utilized in the SQUID are a 30-degree bi-crystal type. The inductance of the SQUID and the pick-up loop are 40 pH and 3nH from calculations, respectively. The outer and inner diagonal dimensions of the pick-up loop are ϕ6.4mm and ϕ2.2 mm, respectively. The substrate at the center of the pick-up loop was machined so that a 100-200 μm deep-dimple was created for the needle space. It was not a through-hole but a dimple because the substrate was fragile.

A schematic cross-sectional view of the microscope is shown in Fig. 1. Most of the parts of the cryostat are made of G-10 fiberglass and Delrin [5]. The cryostat contains a liquid N_2 copper reservoir, having a volume of 0.8 liters.

A needle made of a high μ-metal was set at the center of the pick-up loop. The length of the needle was 7mm; its cross-section at the bottom was a 300μm x 300μm square shape. The top of the needle was filed so that it had a sharp edge. The diameter of the top edge was 50 μm from microscope observation. The needle penetrated a vacuum window through a hole. About 100 μm from the top of the needle was outside of the window. The hole was sealed with a silicone rubber glue after penetration. The distance between the needle and the pick-up loop was adjustable by turning three micrometers.

A home-made XYZ translation stage was placed on the top plate of the cryostat. The stage was made of an aluminum alloy and steel and driven by an ultrasonic linear motor. The minimum step size is 0.5 μm. The translation stage is controlled by a personal computer using signals from positioning sensors. The maximum scan range is 6 x 6 mm^2.

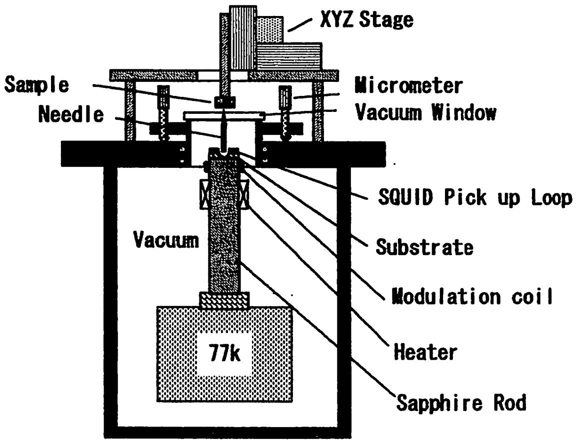

Fig. 1. Schematic cross-sectional view of the SQUID microscope. The SQUID chip was on the top of a sapphire rod. A needle made of a high μ-metal was set at the center of the pick-up loop. The needle penetrated the vacuum window through a hole. The hole was sealed with silicone rubber glue after penetration.

III. EXPERIMENTAL AND DISCUSSION

Using an FEED electro-dynamic simulation, it was found that when the needle penetrated the superconducting loop, the magnetic field density at the loop was one order of magnitude larger than that of the case of no penetration. Therefore, the needle was penetrated into the superconducting film in the experiment.

The performance of the direct-coupled SQUID magnetometer was investigated. A needle was positioned at the center of the pick-up loop. Then the needle was brought into contact once with the bottom of the dimple of the substrate by adjusting the micrometer and it was then lifted up a little bit above the bottom for thermal isolation.

The SQUID was driven by a flux-locked loop with a flux modulation frequency of 256kHz. All of the measurements were performed in a magnetically shielded room, which had a shielding factor of –50dB. A small one-turn coil with a radius of 1mm was prepared and put on the top end of the needle to measure the local effective area at the edge of the needle. A small coil rather than a large coil was used to avoid having the field from the coil couple directly to the pick-up loop of the SQUID. A sinusoidal current of 1 mA$_{p-p}$ with a frequency of 100 Hz was used. Then we found that the effective area $A_{\text{eff-needle}}$ of the magnetometer was 540 μm^2. This value corresponds to a small· SQUID with a washer size of about 15 μm x 15 μm [2]. Excess *1/f* flux noise, which may be generated by the thermal activated hopping of vortices trapped during cooldown was observed in the case with needle. However, since the optimal bias current was not changed in the measurements with and without the needle, the trapping was not significant.

Laser printed outputs were used as a sample to test the microscope. Laser printer ink contains ferromagnetic particles and therefore it is easy to generate a bar line. The finest pattern we prepared was a line width of 100μm and a spacing between lines of 200 μm. This pattern was restricted by the resolution of the laser printer. The samples. were moved in the direction that the needle crosses the bar lines. The velocity of the scanning was 620 μm/s. The surface of the sample was brought into contact with the end of the needle during the scan. Fig.2 shows the output signal of the SQUID. The signal was measured thorough a low pass filter of 5 kHz. All of the patterns were clearly observed. The peak- peak value of the signal that corresponds to the line was about 0.15 μT. Therefore this system has at least a resolution of line / space = 100 μm / 200 μm.

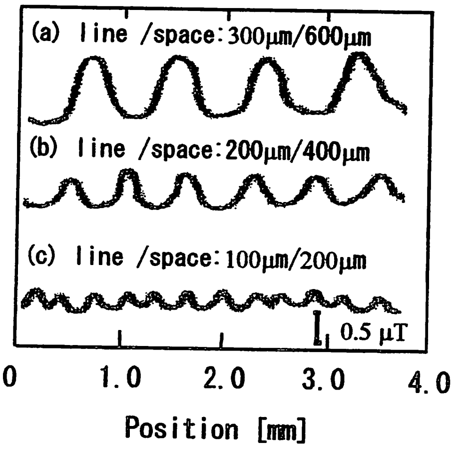

Fig. 2 The output signal of the SQUID when laser-printed bar patterns are scanned. The finest pattern we prepared was a line width of 100μm and a spacing between lines of 200 μm.

IV. Conclusion

W have designed and constructed a new type of magnetic microscope using a high-Tc SQUID with a high-μ metal room temperature needle. One end of the needle penetrated a superconducting pick-up loop in a vacuum; the needle was fixed in the vacuum window with the other end at room temperature in the outside atmosphere. Laser printed output was scanned by the microscope. Line bars with a line width of 100 μm and a spacing between lines of 200 μm were clearly imaged. We think that the space resolution can be improved by using a sharper needle edge.

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