

## High $T_c$ SQUID Probe Microscope

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A SQUID probe microscope has been developed. A super sharp needle which was polished to be submicron chip-top by electrochemically and micron-size toner particles of laser printed letters were observed clearly by this SQUID probe microscope. Sample vibration technique improved S/N ratio. Data defects in two dimensional observation occurred by noise, flux trapping and line drift. These were removed by the image processing to get clear images.

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### I. INTRODUCTION

SQUID microscope has been developed recently [1–10] and it can observe magnetic flux in superconductor so on. A SQUID microscope using a low  $T_c$  SQUID has high resolution, because its SQUID is micron size and it almost touches to the sample. But the sample should be cooled down to ultra low temperature and should be kept in vacuum. While, the SQUID microscope using a high  $T_c$  SQUID has relatively low spatial resolution, but the sample can be located at room temperature in the air, because the SQUID and the sample was separated by a thin sapphire window. In this case the SQUID can be approached to the sample up to about 0.3 mm and its limits its spatial resolution to more than 0.1 mm. Recently a SQUID probe microscope which uses a needle as a magnetic flux guide to improve spatial resolution [10–13]. Here, a SQUID probe microscope with a fine needle has been developed shown in Figs. 1 and 2. Some techniques have been investigated to improve magnetic images. A superfine needle has been used to improve spatial resolution. Sample vibration technique has used to reduce noise. Image processing has been also applied to make clear two dimensional magnetic images by removing noise, defects and line drifts.

### II. SUPER SHARP NEEDLE

The super sharp needle was used to get high spatial resolution. The needle was made of permalloy wire with diameter of 0.6 mm. Its end was polished electrochemically under a microscope to have its top radius of less than one micron shown in Fig. 3. In order to demonstrate its ability of the spatial resolution, laser printed letters were observed. Fig. 4 shows an optical image and a magnetic one by an optical microscope and by the SQUID probe microscope respectively. As this pattern was printed by magnetic toners, magnetic image was clearly observed. Fine toners with diameter of about one micron were observed

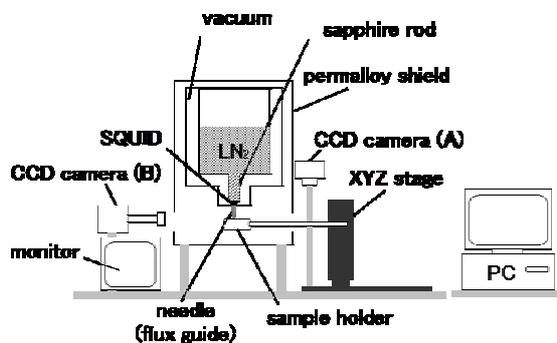


FIG. 1: Schematic figure of SQUID probe microscope.

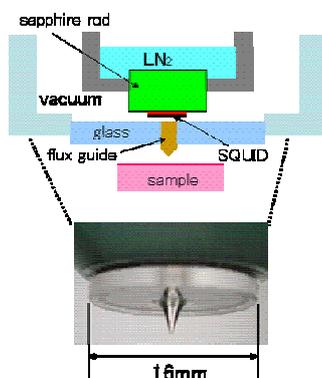


FIG. 2: SQUID and needle for probe.

clearly around the letter pattern. Therefore this technique has spatial resolution of less than a few microns. Actually, as it is limited by the scanning stage, it would be improved to be less than a micron using more precise scanning stage such as a piezo tube so on.

### III. SAMPLE VIBRATION TECHNIQUE

In order to eliminate noise, sample vibration technique has been investigated. Fig. 5 shows this experimental set up. The sample was vibrated by a piezo element. Its amplitude was 40 microns with frequency of 380 Hz. SQUID signals were detected by a lock-in amplifier with time constant of 30, 100 and 300 ms. The S/N ratio was well improved from the results without vibration shown in Fig. 6. As increase time constant, noise could be reduced and S/N ratio become higher. However longer time constant made signal peak broad and results in a poor spatial resolution.

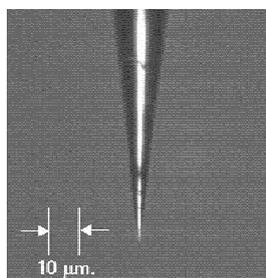


FIG. 3: Super sharp needle.

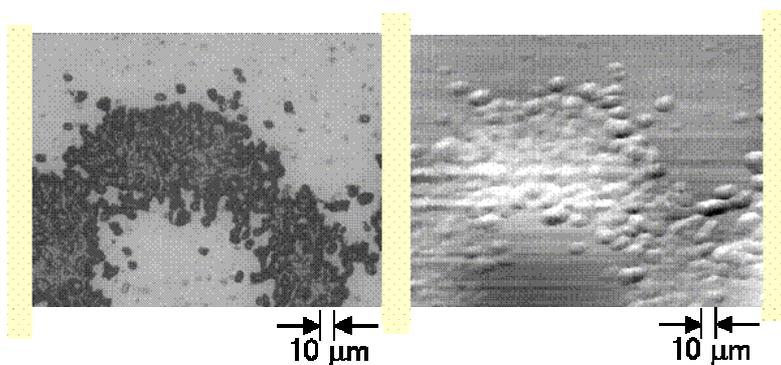


FIG. 4: Optical (left) and Magnetic (right) images.

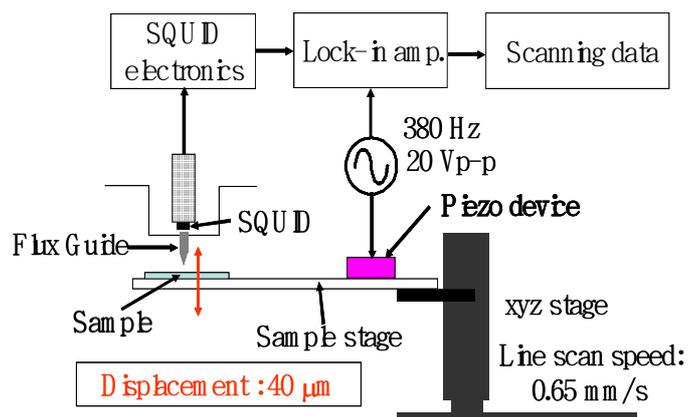


FIG. 5: Sample vibration technique to improve S/N. Frequency of vibration is 380 Hz. Its displacement is 40 micro meter. Signal is detected by a lock-in amplifier.

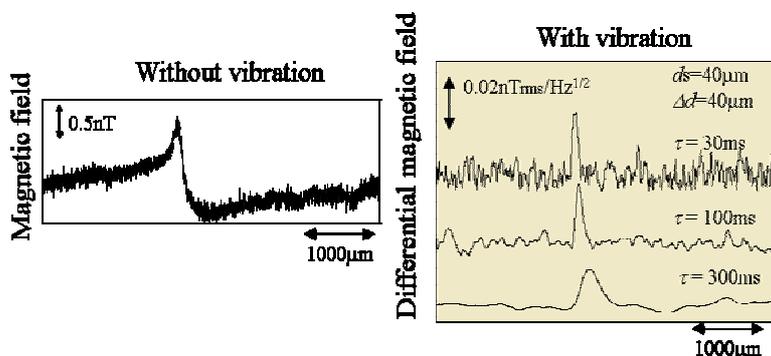


FIG. 6: Line scan with and without vibration (time constant of lock-in amplifier was selected 30, 100, and 300 ms).

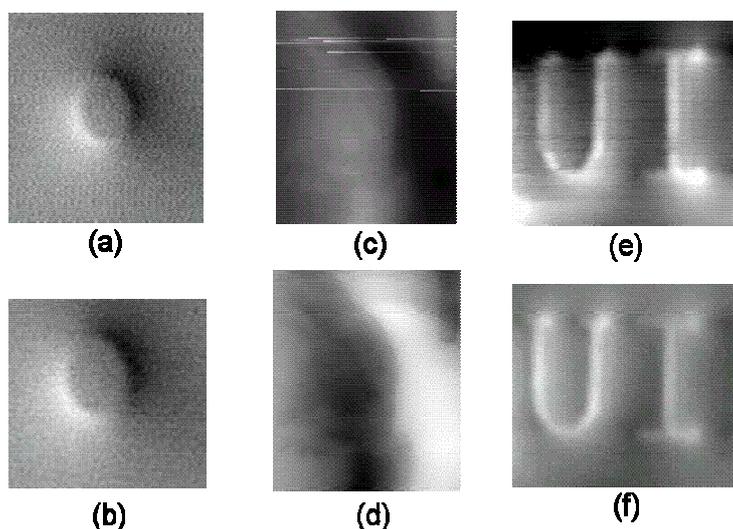


FIG. 7: Improvement of magnetic image by the data treatment.

#### IV. IMAGE PROCESSING OF TWO DIMENSION IMAGE

There are some problems of a two-dimensional magnetic image, such as wavy background by noise (Fig. 7(a)), jumping signal by drift in a line scan (Fig. 7(c)) or drift between lines (Fig. 7(e)). As these make the image of the sample unclear, they should be removed. We developed a computer process to eliminate these. The wavy background noises from commercial electric line were detected by the spatial FFT and their noise peaks were removed, then a sample image without background noise was reconstructed by a reverse FFT (Fig. 7(b)). The lines with a drift were removed and were interpolated by the next lines (Fig. 7(d)). The drifts between lines happened when the scanning stage returned

with some noise. Averaged level of each signal line was fixed, so the drift between lines was modified (Fig. 7(f)). These treatments make magnetic field image clear without noise, defects and drifts.

## V. CONCLUSION

A SQUID probe microscope using a high  $T_c$  SQUID was developed. A super sharp needle made spatial resolution a micron level. Sample vibration technique reduced noise a lot. Image processing removed noise and drift in a line and between lines and it makes a image clear. Micron-size magnetic toners of laser printing were observed clearly by this SQUID probe microscope with a superfine needle. This technique will be applied to observe magnetic micro structure without any perturbations of atomic force.

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