Non-contact Current Measurement System Using SQUID

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Abstract

We have developed a non-contact current measurement system, which converts magnetic flux distribution measured with high sensitivity using DC-SQUID into current distribution. The DC-SQUID is composed of $Nb/AlO_x/Nb$ junctions with high thermal reliability, and a pickup coil. The diameter of the pickup coil and the standoff distance between the DC-SQUID and samples, which are important parameters for the spatial resolution, are respectively 200 μm and 500 μm. The spatial resolution is 200 μm and the current noise density calculated from the magnetic noise is 6.8 nA/$\sqrt{\text{Hz}}$. We applied the system to a solar cell, and then we could visualize the area, which does not generate electrical power.

Key words: DC-SQUID ; magnetic flux-current conversion ; solar cell

1. Introduction

Recently, a DC-SQUID system is expected to apply to the defect inspection of the delicate electronic devices and the molded semiconductor devices, because the system can make a non-contact measurement of the magnetic field generated by flowing currents in those devices. It is necessary for the defect inspection to measure the magnetic flux distribution with high spatial resolution on room temperature samples in the air. Therefore, we have developed the non-contact current measurement system for samples in such an environment. In order to investigate the system availability for defect inspection, we first applied the system to the measurement of current distribution of the solar cell.

2. Results and Discussion

Fig.1 shows the photograph of the non-contact current measurement system. The system consists of a compact cryostat whose height is 287 mm, a DC-SQUID, a scanning stage, a computer and software. The DC-SQUID is based on $Nb/AlO_x/Nb$ junctions

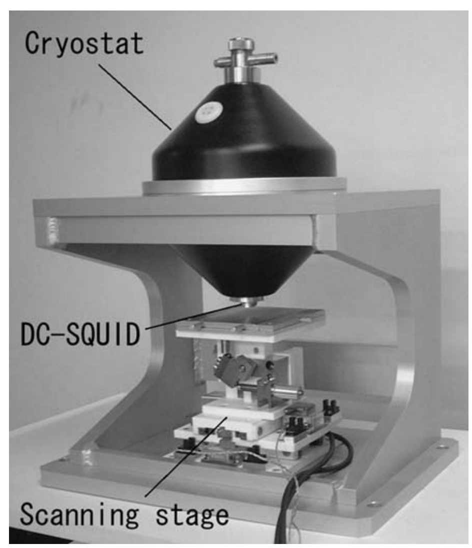

Fig. 1. Photograph of the system.

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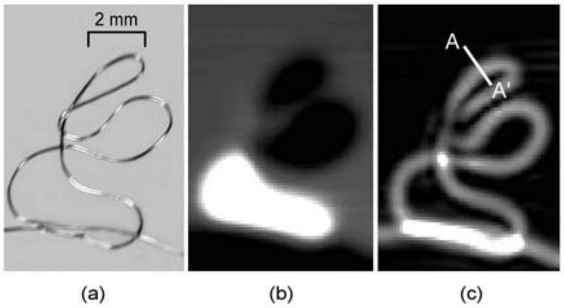

Fig. 2. (a) Photograph of the copper wire pattern. Diameter of the wire is 100 μm. Applied current is 500 μA. (b) The magnetic flux distribution generated from flowing current through the copper wire pattern. (c) The current distribution converted from the magnetic flux distribution.

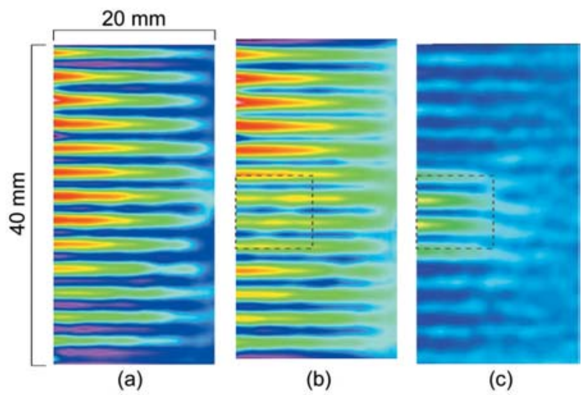

Fig. 3. Current distribution of the solar cell (a) without masking, (b) with masking. (c) Subtract (b) from (a). The dotted line indicates a location of the masking.

with high thermal reliability. The standoff distance between the pickup coil of the DC-SQUID and the samples, as well as the diameter of the pickup coil determines spatial resolution of the system, which is important for performance. We assumed the smallest standoff distance available to be several hundred micrometers. In order to balance spatial resolution and sensitivity, we fabricated a direct-coupled DC-SQUID magnetometer with a 200 μm diameter pickup coil [1]. To reduce the SQUID washer inductance, the SQUID washer was divided into 4 fun shaped coils, and the coils were connected in a parallel configuration. The cryostat has a 900 cc liquid Helium tank and a 100 μm thickness sapphire window. The DC-SQUID is held on a copper rod, which is thermally connected to the Helium tank, so the DC-SQUID is set closely inside the window. Therefore, a standoff distance of about 500 μm is currently obtained. A flux modulation type FLL circuit drives the DC-SQUID. System noise is 2.7 pT/$\sqrt{\text{Hz}}$ at 1 kHz. 2.7 pT/$\sqrt{\text{Hz}}$ corresponds to a current noise of 6.8 nA/$\sqrt{\text{Hz}}$ which flows through an infinitely long line at a distance of 500 μm. To convert magnetic flux distribution into the current distribution, we used a conversion technique by inverting the Biot-Savart Law [2]. The system can be operated continuously for 8 hours with full volume liquid Helium.

To evaluate the spatial resolution, we measured the flowing current through the meander line. The meander line consisted of a 100 μm-line width and 200 μm spacing between each line. We obtained the converted current distribution, which was discriminated at each line of the meander line. Therefore the spatial resolution was estimated at 200 μm. Additionally, to evaluate the accuracy of current measurement, we measured the flowing current through the copper wire pattern. Fig.2 (a) shows the form of the copper wire pattern. The wire was applied direct current 500 μA. Measured magnetic flux distribution is shown in Fig.2 (b). The current distribution converted from the magnetic flux distribution is shown in Fig.2 (c). By integrating the current distribution along A-A' line, flowing current value was estimated at 490 μA. The estimated value agreed well with the real flowing current value.

We first applied the system to the current measurement of a solar cell. The solar cell was a 100 mm $\times$ 100 mm polycrystalline silicon solar cell. A part of the solar cell was covered with a 10 mm $\times$10 mm masking to make the area, which does not generate electrical power. Fig.3 shows the current distribution converted from the magnetic flux distribution that was measured from the backside of the solar cell. The dotted line indicates a location of the masking. Fig.3 (a) and (b) are respectively current distributions without and with masking. The crossbars in the imaging correspond to the flowing current through the surface electrodes fabricated with 3 mm intervals on the solar cell. Furthermore, Fig.3 (c) shows the difference between with and without masking. Fig.3 (c) clearly visualizes a location of the masking that does not generate electrical power.

We therefore believe the system to be available for a non-contact current measurement of samples.

References

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