Scanning SQUID Microscopy for Sensing Vector Magnetic Field

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Contents

1. Aim of present study
2. Design of a vector SQUID sensor
3. Characteristics of vector SQUID sensors
4. FLL readout system of vector sensors
5. Concept of vector scanning SQUID microscopy
6. Successful observation of vortices using our own non-vector Z sensor and X coil of vector sensor
7. Summary
Aim of present study

- SQUID microscope: Various applications such as nanoscience, nano-engineering, nano-biology, spintronics, vortex physics, etc.


• How to improve sensitivity and spatial resolution

☐ Sensitivity is essentially governed by an inductance of a pick up coil
☐ Spatial resolution is limited by inner diameter of a pick up coil

➢ Novel vector pick-up system

Our action
- Multiply winding coil with small area
- Image processing

Our action
- 3D XYZ pick-up coils fabricated on one chip
Sensor design for vector scanning SQUID microscope

**Cross sectional view of a designed pick up coil of X and Y direction**

- **Chip 1**: X,Y&Z coils are orthogonal to each others.
- **Chip 2**: X,Y&Z coils are single turn in winding and their centers are located along a single line.
- **Chip 3**: X,Y&Z coils are two turns and their centers are located along a single line.
Lab-made system to measure the characteristics of SQUID sensors

Windows 10 Pro with LabVIEW

National Instruments CompactDAQ

24bit

NI9239 ADC

NI9263 DAC

DC current source

semi-rigid cables and SMA connectors

Preamplifier

T = 4.2 K
1.5K Gifford–McMahon cryocooler

@ Room Temperature

NI9263 DAC

NI9239 ADC

47nF 1 kΩ
47nF 1 kΩ
47nF 1 kΩ
47nF 1 kΩ
100Ω 1 kΩ
100Ω 47nF
47nF 1 kΩ
100Ω 1 kΩ
1µF 100Ω
1µF 100Ω
1µF 400Ω
1µF 400Ω
1µF 200Ω
1µF 200Ω
1µF 200Ω
1µF

IEEE-488

DC current source

T = 4.2 K
1.5K Gifford–McMahon cryocooler
Characteristics of vector SQUID sensors

Construction of the IV curve tracer by using a 1.5K GM cryocooler

Equivalent circuit of our SQUID sensor

$I_c$ of a SQUID sensor is 25 $\mu$A at 4.2 K, as designed in CAD

Each SQUID in a vector sensor has a similar characteristic in the IV curve

$I$-V curves of sensor are dependent on $T$.

$I_c = 25\mu$A

$I$-V curves of 3 axes sensor.

Influence of external field
How to apply an external magnetic field

- **Applied current**: (-50mA to 50mA)
- **20-turns coil**
- **Vector Pickup Coil**
- **Package**
- **Wire bonding**
- **Coil to apply an external magnetic field**

**Circuit Details**:
- $R_{sh} = 7.8\ \text{ohm}$
- $I_c = 12.5\ \text{uA}$
- $L_{wsh} = 50\ \text{pH}$

**Connections**:
- **Bias current (supply)**
- **Voltage terminal (plus)**
- **Bias current (return)**
- **Voltage terminal (minus)**
Installation of MAGICON electronics system

3CH FLL controller

Connector box

USB to RS485

IEEE-488

DC current source

National Instruments CompactDAQ

NI9239 ADC

NI9263 DAC

LPF

LPF

LPF

LPF

GND

V

\Phi

MAGICON Readout Electronics

M

T = 4.2 K

1.5 K Gifford–McMahon cryocooler

NI9263 DAC

NI9239 ADC

LPF

LPF

LPF

LPF
characteristics and the voltage of readout circuit

We confirmed a good linearity.
Our Scanning SQUID System

- MAGNICON 3 CH FLL SQUID controller
- Temperature controller
- XYZ piezo-driven controller
- @ 4.2 K

A vector SQUID microscope on the refrigerator platform & anti-vibration system
Non-vector sensor with double windings

SSM vortex Images obtained by using our own sensor

New sensor was set up in SII system

We observed clear vortices on Mo$_{80}$Ge$_{20}$ film

Step size 0.5µm

Step size 2µm

Step size 0.5µm
X coil gives a polarized field image by sensing the broadened magnetic flux.

X coil and Y coil of sensor has no essential difference from X coil.

T = 3.04K, H = -35mG, Nb thin film

Step size 2 μm

Step size 0.5 μm
1. Characteristics of 3D SQUID sensors have been investigated systematically by using a lab-made I-V curve tracer.

2. Fundamental characteristics of our SQUID sensors showed a good performance, which is suitable for our SQUID microscope.

3. Voltage outputs from a commercial readout circuit were in good agreement with the profiles of the V-Φ characteristics.

4. We succeeded in observing vortices by using a doubly winding pickup Z coil as well as an X coil on the conventional platform.

5. We are going to construct a vector SQUID microscope on the refrigerator-based platform in near future.
Thank you for your attention