Weak Link Superconducting Quantum Interference Devices for High-Resolution Scanning Magnetometry

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Primary CNF Tools Used: AJA Sputter Deposition Tool (I), JEOL JBX-6300FS 100 kV Electron Beam Lithography System, CVC SC4500 Combination Thermal/E-gun Evaporation System (Odd-hour), Angstrom Load Lock E-beam Evaporator, DWL2000 Laser Pattern Generator and Direct Write System, Oxford PlasmaLab 80+ RIE System (Oxford 81), Zeiss Ultra 55 Scanning Electron Microscope

Abstract:

Magnetic imaging is a powerful tool for studying quantum materials. To make a sensitive magnetometer for use in a scanning probe microscope, a small super-conducting loop is interrupted by two Josephson junctions to create a super-conducting quantum interference device, or SQUID, which converts the magnetic flux coupled into the loop into a measurable signal. This research explores one way to increase the spatial resolution and maximum operating field of a SQUID, which is to replace the often-used superconductor-insulator-superconductor (SIS) Josephson junctions with narrow constrictions (weak links) in the super-conducting loop, which allow the size of the loop to be less than 1 μm [1]. Initial measurements have demonstrated the sensitivity of test SQUIDs to magnetic flux, with improvements in progress.

Summary of Research:

Figure 1 depicts a weak link SQUID, made of a 50 nm niobium film with a 20 nm aluminum shunting layer on a silicon substrate. For the weak links to behave like Josephson junctions, they must have dimensions comparable to the super-conductor's coherence length [2], which necessitates the use of electron beam lithography to pattern a mask for the SQUID loop. A bilayer lift-off process patterns the SQUID loop in 20 nm of aluminum. Since the electron beam write time for bond pads would be excessive, instead a separate 20 nm layer of aluminum that overlaps with the SQUID loop is patterned by direct-write photolithography and lifted off. The two aluminum layers mask the niobium during a dry etch step, leaving a bilayer SQUID pattern with the layer stack depicted in Figure 2.

A SQUID with slightly different dimensions to those depicted in Figure 1 was measured in a liquid helium dipping probe setup at 4.6 K. As is the case for conventional SIS junction SQUIDs, a series SQUID array amplifier was used to voltage bias and read out the weak link SQUID, which avoids issues encountered when using noisy, high-impedance room temperature amplifier electronics [3]. Figure 3 depicts the voltage output from the array as a function of the magnet current applying a magnetic flux to the SQUID. The array output voltage modulates with flux, demonstrating that the niobium constrictions are behaving like weak links, as intended.

Conclusions and Future Steps:

While these weak link SQUIDs operate as magnetic flux sensors, some aspects of their behavior and use in a readout circuit are not fully understood. Future work will continue to explore the design parameter space for these devices. We will also develop an etching process to place the SQUID loop at the corner of a chip so that it may scan across a sample surface [4].

References:

[1] Vasyukov, D., et al. Nature Nanotech 8, 639-644 (2013).

[2] Likharev, K. K. Rev. Mod. Phys. 51, 101-159 (1979).

[3] Huber, M. E., et al. Review of Scientific Instruments 79, 053704 (2008).

[4] Pan, Y. P., et al. Supercond. Sci. Technol. 34, 115011 (2021).

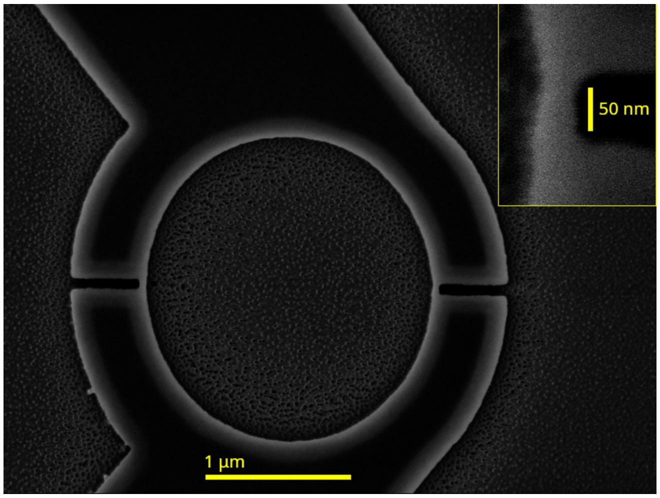

Figure 1: Scanning electron microscope image of the SQUID loop. Inset: Right constriction at higher magnification.

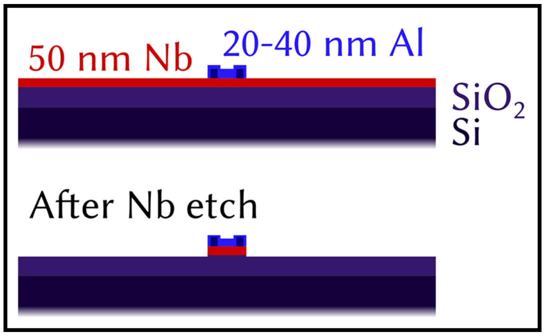

Figure 2: The SQUID fabrication process patterns a niobium film on a silicon substrate by using an aluminum hard mask (made of two overlapping aluminum layers to reduce the write time for electron beam lithography). A dry etch process transfers the aluminum pattern into the niobium.

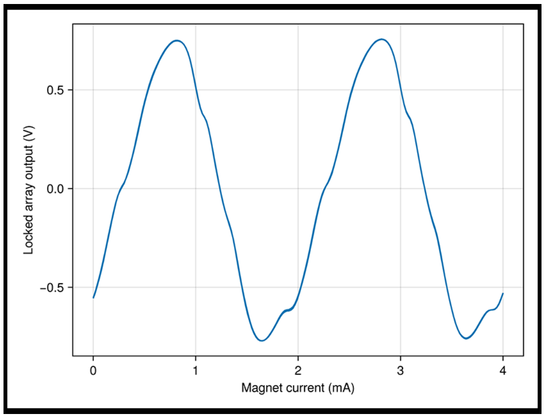

Figure 3: The voltage output of a series SQUID array amplifier (operated in a flux feedback locked loop) oscillates in response to a magnet coupling magnetic flux into a SQUID loop similar to the loop in Figure 1. Refinements to this readout scheme are in progress.

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