Vortex Dynamics in Nanofabricated Superconducting Devices

CNF Project Number: 1314-05
Principal Investigator: Britton L.T. Plourde
Users: Kenneth Dodge, JJ Nelson

Affiliation: Department of Physics, Syracuse University

Primary Source of Research Funding: Army Research Office

Contact: bplourde@syr.edu, krdodgej@syr.edu, jjnelson@syr.edu

Website: http://plourdelab.syr.edu

Primary CNF Tools Used: ASML 300C DUV stepper, JEOL 9500, Plasma-Therm PT740

Abstract:

We fabricate superconducting microwave devices for studying the dynamics of vortices and quasiparticles at low temperatures. Vortices are quantized bundles of magnetic flux that thread many different superconductors over a particular range of applied magnetic field. Our experiments are aimed at investigating loss mechanisms that can limit the performance of superconducting circuits for quantum information processing. In addition, we are probing the microwave properties of various superconducting materials for future implementations of qubits.

Summary of Research:

Superconducting microwave circuits play an important role in quantum information processing. Circuits composed of Josephson junctions and capacitors with superconducting electrodes can serve as qubits, the fundamental element of a quantum computing architecture. Various loss mechanisms limit the ultimate performance of these devices, including trapped magnetic flux vortices. Vortices can be trapped in the superconducting electrodes when background magnetic fields are present and contribute dissipation when driven with microwave currents [1]. Thus, techniques for controlling the trapping of vortices are critical to the development of large-scale quantum information processors with superconducting circuits. In addition, investigations of microwave vortex dynamics can be a useful tool for probing new superconducting materials for use in future implementations of qubits.

We are fabricating a system of microwave resonators using a variety of superconducting thin films, including Nb, TiN, NbTiN, and disordered Al, for studying the loss contributed by trapped flux in these materials over the frequency range from 1.5-11 GHz [2]. By cooling the resonators in different magnetic fields, we are able to probe the loss from vortices as a function of field at the resonance frequencies contained in our design. We study the microwave properties of the vortex response as a function of various parameters, including temperature, frequency, device geometry, and film disorder.

We fabricate our microwave resonators from various superconducting films, including aluminum, deposited onto silicon wafers in vacuum systems at Syracuse University or by collaborators at other institutions. We define the patterns on the ASML stepper and transfer them into the films with a combination of reactive ion etching and wet-etch processing. We measure these circuits at temperatures of 100 mK and below in our lab at Syracuse University.

References:

[1] Song, C., Heitmann, T.W., DeFeo, M.P., Yu, K., McDermott, R., Neeley, M., Martinis, John M., Plourde, B.L.T.; "Microwave response of vortices in superconducting thin films of Re and Al"; Physical Review B 79, 174512 (2009).

[2] Dodge, K., Nelson, J., Senatore, M., Xu, P., Osborn, K., Pappas, D., Plourde, B.; "Microwave Response of Vortices in Superconducting Resonators with High Kinetic Inductance"; Bull. Am. Phys. Soc. 2018, http://meetings.aps.org/Meeting/MAR18/Session/Y39.11.

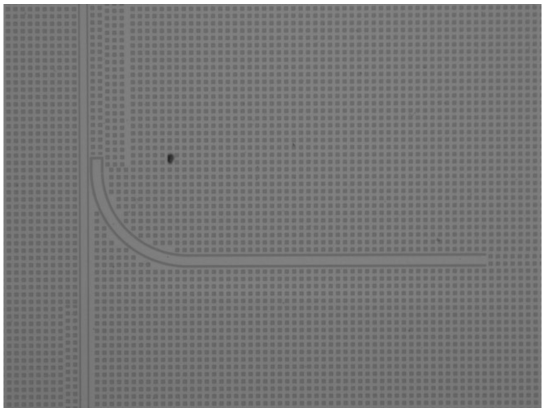

Figure 1: Coplanar waveguide resonator for probing microwave losses and magnetic field dependence in disordered superconducting aluminum thin films.

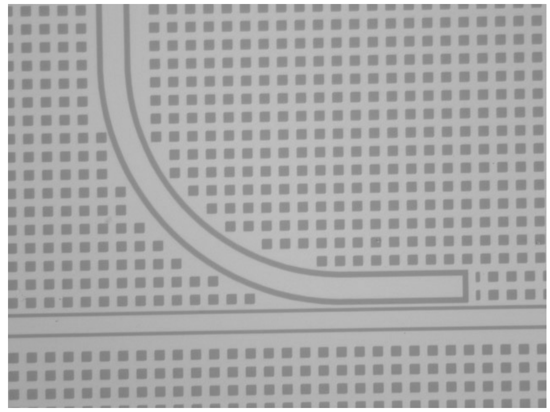

Figure 2: Capacitive coupling elbow structure for measurement of superconducting microwave resonator.

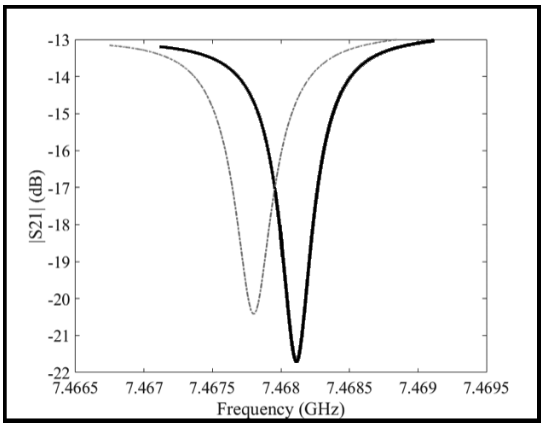

Figure 3: Measurement of microwave transmission dips corresponding to resonator patterned from disordered superconducting aluminum thin film; black (grey) curve corresponds to measurement in zero magnetic field (194 μT).

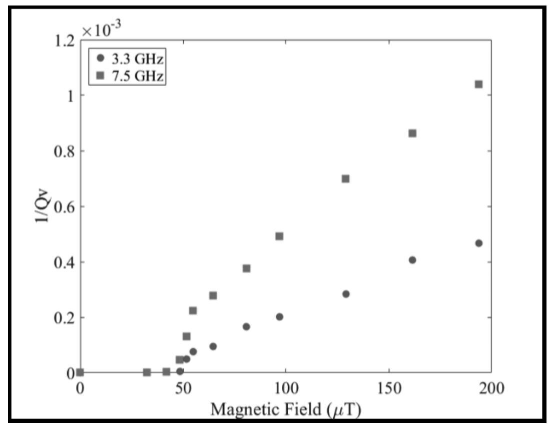

Figure 4: Microwave loss contribution from trapped vortices as a function of magnetic field in resonators patterned from disordered superconducting aluminum thin film for two different resonance frequencies.