Vortex Dynamics in Nanofabricated Superconducting Devices

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Abstract:
We are fabricating superconducting devices for controlling the dynamics of vortices with experiments ranging from dc measurements up to microwave frequencies. Vortices are quantized bundles of magnetic flux that thread many different superconductors over a particular range of applied magnetic field. These measurements are useful for probing fundamental physical properties of vortices and for developing devices based on the controlled motion of magnetic flux in superconductors, including vortex ratchets. In addition, trapped vortices are an important loss mechanism that can limit the performance of superconducting microwave detectors and quantum coherent circuits.

Summary of Research:
For technological applications of superconductors in large magnetic fields, controlling the dynamics of magnetic flux vortices that penetrate the superconductors is important, as the motion of many vortices can cause unwanted dissipation. The addition of defects to the superconductor can pin the vortices in place and hinder their motion. In this case, each vortex can be treated as a classical particle interacting with a potential energy landscape generated by the pinning defects and the other vortices. By nanofabricating pinning structures, it is possible to control the vortex dynamics to probe such phenomena as commensurability and ratchet effects [1]. Nanofabricated devices are also useful for probing the microwave response of vortices in superconductors. Vortices trapped in superconducting traces can result in substantial reductions in the quality factor of microwave resonators. Thus, understanding and controlling this dissipation mechanism can be important in the design of superconducting systems that use microwave resonators, including sensitive photon detectors and quantum computing applications.

We are fabricating a system of superconducting, thin-film microwave resonators for studying the loss contributed by trapped flux over the frequency range from 2-11 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. For some resonators, we have also been exploring the addition of nanostructured vortex pinning with a corresponding reduction in the loss due to trapped flux by over an order of magnitude compared to resonators without such patterned pinning [3].

Following a technique developed at Leiden University for controlling vortex confinement [4], we fabricate devices with narrow thin-film channels with weak vortex pinning...
surrounded by banks of different superconductor with much stronger pinning. Such a structure allows easy motion of vortices in the weak-pinning channels, while the vortices in the strong-pinning banks remain immobilized. In our research program, we are fabricating similar weak-pinning channels but with various contrictions of the channel walls for controlling the potential energy landscape experienced by vortices in the channels. We have recently been studying commensurability and hysteresis in periodic sub-micron channel constriction structures [5].

We fabricate our microwave resonators from various superconducting films, including aluminum deposited onto sapphire or silicon wafers in our electron-beam evaporator at Syracuse University. We define the patterns on the Autostep 200 and transfer them into the films with reactive ion etching. We measure these circuits at temperatures down to 300 mK in our lab at Syracuse University. We fabricate our weak-pinning channels from bilayer films deposited at Leiden University. The lower weak-pinning film consists of an amorphous layer of NbGe, while the upper film is a 50nm-thick layer of reactively sputtered NbN, which has strong pinning. We produce channels as narrow as 150 nm with electron-beam lithography and reactive ion etching using CF4. We measure these channel devices in cryogenic systems that we have constructed in our lab at Syracuse University.

References: