Porous Thin Films for Supersolid Hydrodynamic Devices

CNF Project # 1458-06

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Abstract

After many years of unsuccessful searches for the self-organized supersolid phase, Kim and Chan [1] reported in 2004 evidence for a new quantum phase of matter in solid helium-4, which is consistent with supersolidity. Recent experiments indicate that disorder in the solid crystal strongly affects the flow: Reppy’s group at Cornell demonstrated the ability to quench the signal by annealing the helium [2], while the Balibar group found that grain boundaries appear to be necessary for flow [3]. Despite these findings, the fundamental nature of the flowing solid, as well as the hydrodynamic details, remain largely unknown.

Summary of Research

We are developing patterned thin porous oxide film devices to study superflow through solid helium microcavities and address these issues. Our design relies on a curious property of superfluid helium in a porous material: it takes extra pressure to solidify. This allows superfluid reservoirs to coexist with solid helium crystals—a situation not found otherwise in stable equilibrium. We will probe helium supercurrents directly, as they interact hydrodynamically with micron-scale solid crystals. This allows us the freedom to investigate directly whether a macroscopic quantum order parameter penetrates solid helium, and its dependence on crystal size and/or boundary defects.

A simple circuit schematic of our device is shown in Figure 1. There are two porous superfluid reservoirs connected via a bulk solid (non-porous) helium crystal. Each porous reservoir also acts as the dielectric region of a parallel-plate capacitor. Due to the polarizability of He-4, the density of fluid on each side of the solid crystal can be driven (or detected) by means of an applied (or measured) electric field. If there exists a hydrodynamic path through the solid helium crystal, then a helium supercurrent can be forced from one reservoir to the other and detected as a density change.

To fabricate the thin porous films, we have integrated a known recipe [4] for creating thin porous dielectrics with electrode metallization and cavity photolithography to develop functional superfluid devices. SEM images of a prototype porous film are shown in Figure 2, indicating roughly 15 nm pores.

Figure 1: Simple circuit schematic of device.

Figure 2: SEM images of a prototype porous film.
Though early devices will employ simple rectangular cavities in which the solid crystal is formed, one of the advantages of thin-film fabrication is that we can control the size and shape of the crystal through photolithography. Future devices can be designed to investigate boundary-induced defects or finite-size hydrodynamics. Figure 3 shows the edge of a prototype (unsealed) solid cavity boundary, where it meets the superfluid detector reservoir.

We are currently testing a calibration device on board our dilution refrigerator, which includes a porous dielectric superfluid reservoir but no patterned solid crystal. We have detected the bulk helium flow into the device and are currently searching for superfluid sound modes, with the goal of probing their interaction with the bulk solid bath to find the suppressed solidification curve.

References