Abstract:

Previous measurements of the specific heat of helium-4 ($^4$He) confined in all three spatial dimensions suggested a coupling between neighboring confinements through the tiny channels used to fill them [1]. Measurements of the superfluid fraction in the filling channels also suggested an enhancement attributed to their proximity to the larger regions of superfluid [1]. Recent measurements of confinement structures designed at the Cornell NanoScale Science and Technology Facility have confirmed these effects [2], and begun to address their nature.

Summary of Research:

Using the facilities at CNF, we are able to etch various geometries out of thermally grown silicon oxide. Then, through direct wafer bonding of two patterned wafers, we have been able to construct extremely uniform and well characterized confinement cells (see Figures 1 and 2). Measurements of the specific heat and superfluid fraction of liquid helium in these confinements has allowed, for the first time, observation of coupling between neighboring confinements as well as proximity effects on a thin film in equilibrium with larger regions of superfluid [2].

Specific heat data for an array of (1 µm)$^3$ confinements showed various anomalies [3]. It was suggested that these anomalies could be explained by a coupling between the confinements through the small channels used to fill them [1]. This coupling reveals itself as an enhancement in the specific heat. A measurement of (2 µm)$^3$ confinements has allowed us, via scaling, to quantify this enhancement (Figure 3) [2].

The (2 µm)$^3$ measurement also identified proximity effects on the 31.7 nm film used to fill the (2 µm)$^3$ boxes [2]. These proximity effects include an increase in both the superfluid fraction and the specific heat of the film, as well as an increase in the temperature of the specific heat maximum.

Figure 1: Confinement Cell. A diagram (not to scale) of a cell used to confine liquid helium. This consists of an array of (2 µm)$^3$ boxes etched in a thermally grown oxide on a 2 inch silicon wafer. A second wafer has an outer wall and several support posts etched into a 31.7 nm oxide. This wafer forms a uniform film used to fill the (2 µm)$^3$. After patterning of the silicon wafers they are bonded together and form a confinement cell to be filled with helium.

Figure 2: Confinements. An scanning electron microscope image of (2 µm)$^3$ boxes etched out of thermally grown silicon oxide. These boxes are filled with liquid helium creating an extremely well defined array of uniform confinements.
and the temperature of the superfluid onset (Figure 4) [2]. These proximity effects are analogous to similar effects seen in superconducting sandwiches with one apparent difference. The standard model for proximity effects in superconductors allows for the effects to occur over distances comparable to the correlation-length $\xi$ of the system, however in our case we observe these effects across distances over 100 times $\xi$. This has mirrored recent measurements of a “giant proximity effect” in high temperature superconductors [4]. Although these measurements cannot be explained using the standard theory for superconducting proximity effects, recently a group has proposed an explanation involving phase fluctuations [5]. It is believed that the analogous effect measured by our group may owe itself to a similar mechanism.

Our current work involves changing the periodicity of the (2 µm)$^3$ boxes in equilibrium with the 31.7 nm film in order to correlate the periodicity with the magnitude of the proximity effects. This will shed some light on the nature of these effects, as well as determine if the mechanism from Reference 5 can be applied to the liquid helium system.

References: