Fabrication of Nanofluidic Cavities for Superfluid ^{3}He Studies

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Primary CNF Tools Used: Oxide furnace, Oxford PECVD, Oxford and Plasma-Therm RIE, dicing saw

Abstract:

We demonstrate nanoscale cavities that withstand 30 bar cooled to ultralow temperatures [1]. These structures have been utilized to observe an unexpected spatially modulated order parameter in superfluid ^{3}He [2].

Summary of Research:

Superfluid ^{3}He is a unique system for study. ^{3}He is a Fermion (like electrons), but its pairing into the superfluid state is more complex than its electronic counterparts producing a multiplicity of superfluid phases. In the bulk the anisotropic A phase and the isotropically gapped B phase emerge. Confinement favors the A phase over the B phase [2,3,4].

The superfluid state is attained between 0 and 35 bar and between 0.9 and 2.5 mK (respectively). Below the superfluid transition, pairs condense into the coherent superfluid state. The pairing length-scale (pair diameter) varies from ~ 80 nm at 0 bar to 14 nm at high pressure. Confinement alters the phase diagram and as the ^{3}He is progressively restricted to smaller sizes, the B phase should yield to the A phase and new phases should emerge.

A recent experiment [2], carried out by colleagues at Royal Holloway in London, explored the magnetic signatures of ^{3}He confined in a 1.1 µm tall chamber. Extracting signals from the ~ 70 nL sample at temperatures well below 1 mK required using their highly sensitive SQUID NMR techniques.

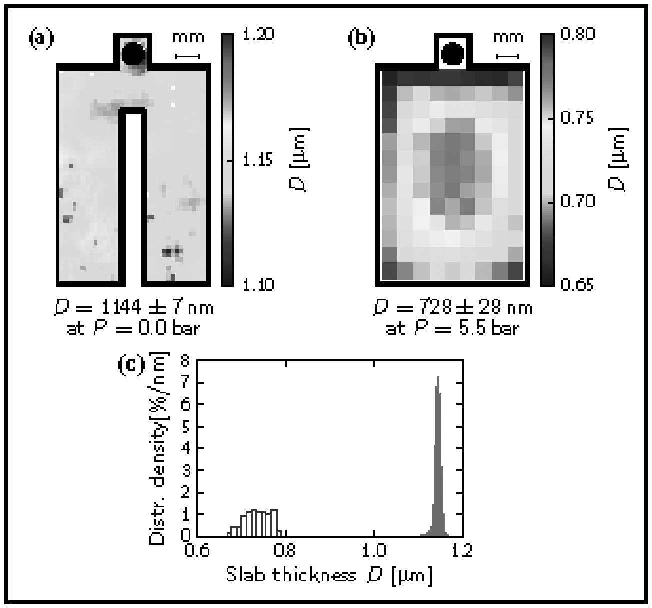

Figure 1: (a) Comparison of the heights within the new cell used in experiment [2] compared to (b) previous generation cell (at 5.5 bar pressure) using 3 mm thick silicon and glass. The addition of a "septum" to reduce the unsupported span results in a much more uniform spacing. The cavity dimensions are approximately 7 mm × 11 mm. (c) shows a comparison in height distributions of the two cells, the right one being the data from the newer cell, and the broader distribution at left, showing the height distribution measurement for the older cell.

To fabricate this device, a 1 mm thick silicon wafer was oxidized using the oxide furnace in CNF to grow thick oxide (> 2 µm), then further oxide was deposited using the Oxford PECVD. The device was patterned using contact photolithography and the oxide removed using both dry plasma etch (Oxford and Plasma-Therm RIE) and wet etch (6:1 BOE). The wafer was further oxidized to create a step in the Si-SiO_2 interface (modified LOCOS process) and oxide removed using HF. The chips were then diced using CNF's dicing saw. Matching polished glass pieces were also diced.

The final step to make the cells was to remove oxide off Si pieces, clean in SC-1 solution and bond using custom made anodic bonding jig. The resulting bonded cell had a very uniform height distribution (Figure 1 a, c) in comparison to previous cells (Figure 1 b).

The experiments represent the melding of theory (experiments were initiated following a seminal theory result [5] that predicted stripes), the development of fabrication and sealing technology over several years [1], and a whole suite of experimental measurement techniques [2,3,4]. The final results that point to a "polka dot configuration" rather than the simpler proposed striped configuration have received wide publicity [6].

Former Physics Ph.D. students Nikolay Zhelev (now Corning Research), Roberto DeAlba (now INTEL), and post-doctoral scientist Abhilash Sebastian (now VTT Research Labs, Finland) fabricated these structures before they left Cornell. Results from these structures are now emerging or have been recently published.

References:

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