Characterization of ZYX Graphite for Studies of Two-Dimensional ^{3}He at Ultra-Low Temperatures

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Abstract

So far, theoretically predicted two dimensional (2D) superfluidity in monolayer ^{3}He has not been observed yet. This may be due to the smaller single crystalline size ($\simeq$10 nm) of Grafoil substrate than the expected superfluid coherence length ($\geq$ 100 nm), or pair breaking caused by trapped atoms on substrate heterogeneity. To eliminate these problems, we have made an NMR sample cell using ZYX grade exfoliated graphite substrate. This substrate has at least ten times larger crystalline size than Grafoil. NMR measurements are now under way to search for possible 2D and quasi 2D superfluidity in ^{3}He thin films.

Key words: superfluid helium three ; two dimension ; films

1. Introduction

One of the challenging topics in low dimensional ^{3}He physics is the search for possible 2D superfluidity. Theories predict exotic superfluidity or phase transition [1]. However, neither heat capacity [2] nor nuclear susceptibility measurements [3] succeeded in discovering superfluidity in this system. One reason for this might be the small crystalline-size of Grafoil ($\simeq$10 nm), which could be shorter than the expected superfluid coherence length ($\geq$ 100 nm). Another possibility is pair breaking due to the presence of trapped ^{3}He atoms on substrate heterogeneity. In addition, the background signal due to these trapped atoms can easily mask the small fluid signal below 1 mK [2,3].

To avoid these problems, we have to use substrates with much larger crystalline size. One of such substrates is ZYX grade exfoliated graphite. This material is made by exfoliation of highly oriented pyrolytic graphite, while Grafoil is made from natural graphite. The single crystalline size of ZYX is at least ten times larger and the mosaic spread (9 degrees) is three times smaller than that of Grafoil [4]. ZYX substrate has been used for heat capacity measurements of helium films at a few Kelvin [5] and for neutron scattering experiments of hydrogen films above 4K [6]. More recently, the Stanford group attempted to use this substrate in ultra-low temperature experiments [7].

In this paper, we report on the fabrication and characterization of ZYX graphite in order to use this substrate for ultra-low temperature experiments.

2. Substrate fabrication and characterization

The substrate was fabricated in the following way: ZYH-grade exfoliated graphite [8] with a density of 0.15 g/cm^3 was sliced into 1 mm thick slabs. The slab was then compressed to increase the density and improve the out of plane conductivity. Figure 1 shows the density dependence of the specific surface area of compressed ZYH, usually called ZYX. The surface area was determined by measuring N_2 adsorption isotherms at 77 K. ZYX has a specific surface area of 1.2$\pm$0.5 m^2/g at a density of 1.1 g/cm^3, while that of Grafoil is

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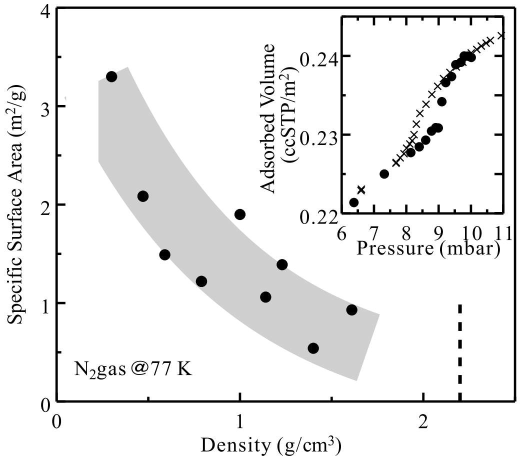

Fig. 1. Density dependence of the specific surface area of ZYX. The vertical dashed line corresponds to the density of bulk graphite. Inset: Sub-steps in N_2 adsorption isotherms at 77 K. (•) ZYX,(×) Grafoil.

about 20 m^2/g. The inset shows the sub-steps near the $\sqrt{3} \times \sqrt{3}$ registered solid formation measured by the adsorption isotherms. The sub-step is much clearer for ZYX than for Grafoil, indicating that the crystalline size of ZYX is much larger than that of Grafoil.

We have measured the electrical resistivity along the c-axis of ZYX by standard four-probe technique at 4 K for densities ranging from 1.1 to 1.6 g/cm^3. The electrical resistivity does not depend strongly on density and is of the order of $10^{-3}\Omega$m, similar to that of Grafoil. We therefore expect that this substrate can be cooled to similar low temperatures as Grafoil. Good mechanical contact between ZYX and silver foil is achieved by diffusion bonding at 750°C in vacuum for 3 hrs. The electrical contact resistance is similar to that between Grafoil and silver, which is negligible compared to the out of plane resistance of ZYX itself. The ZYX substrate should thus be very suitable for ultra-low temperature experiments on ^{3}He films.

3. NMR Cell

A schematic drawing of the sample cell for NMR measurements of 2D ^{3}He films is shown in Figure 2. Two ZYX sheets (0.2 mm thick) were diffusion bonded to both sides of a silver foil (0.05 mm thick), and 35 such silver foils were diffusion bonded to a silver rod (6 mm in diameter). An NMR pick-up coil embedded in the epoxy (Stycast 1266) cell wall produces an rf-field parallel to the ZYX sheets. A static field is applied parallel to the sheets by a home made superconducting magnet with a superconducting shield which is thermally anchored to the mixing chamber of the dilution refrigerator.

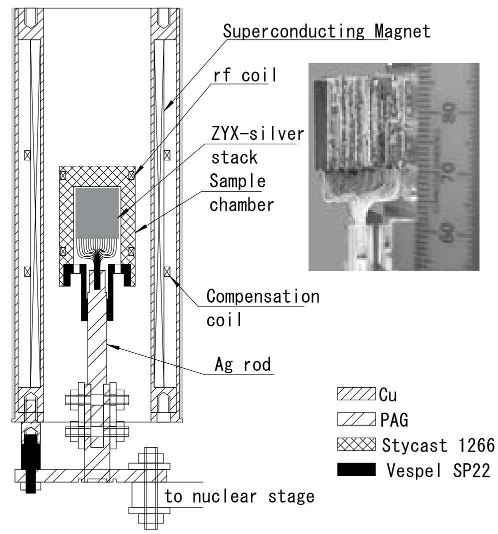

Fig. 2. A schematic drawing of the sample cell. The photograph on the right shows the ZYX-silver stack.

The superfluid transition should be detected by a possible NMR frequency shift or a decrease of the nuclear spin susceptibility.

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