Interdigital Capacitor as Solid ^{4}He Height Detector

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Abstract

A compact interdigital capacitor is developed as a level detector of solid ^{4}He. The capacitor consists of 38 interlaced 50 μm wide and 3.8 mm long gold films separated by 50 μm and deposited onto a flat 5×5 mm^2 sapphire substrate. The background capacitance is 6.5 pF. The capacitance change is 1.3×10^{-3} pF/mm of solid ^{4}He height change. A height change of 20 μm is detectable. Observations at 1.2 K in a 6.7×8.7×9.1 mm^3 cell show over pressures (measured with a low temperature strain gauge) up to 25 mbar prior to nucleation of solid. The solid height may be controlled by varying heat applied to a pressure bomb cooled to 77 K.

Key words: quantum solid;Grinfeld instability;interdigital capacitor

1. Introduction

A simple compact height detector is desirable for diagnostic and monitoring purposes in experiments with solid helium. Capacitor sensors with simple parallel plate configuration are commonly used in low temperature experiments to detect changes in the amount of material residing between the plates[1]. For our study, confining helium into small volume is not suitable in reducing the boundary effects. For this reason, we choose to work with an interdigital capacitor(IDC) which occupies a minimal volume and can be mounted onto the wall of a sample chamber. The goal of our research is to study the instability of solid surface morphology under applied stresses taking solid ^{4}He as a model material. For investigation of interface related phenomena, the solid/liquid interface of ^{4}He below 2 K has many advantages such as small latent heat, rapid melting and freezing and superfluid heat conduction.

2. Apparatus

The solid helium sample chamber is depicted in Fig. 1. The chamber is rectangular in shape and has dimensions 10×10 mm^2 at the base and 15 mm height. An IDC is mounted on one wall and a piezoelectric transducer(PZT) with plunger plate is mounted on the opposite wall. Solid helium is grown between the two walls by feeding in helium via fill tube(not shown). The pressure in the chamber is monitored by a Straty-Adams type capacitive strain gauge(not shown). By applying dc voltage across the PZT, stress can be applied on the solid.

The IDC consists of 38 interlaced 50 μm wide and 3.8 mm long gold finger films separated by 50 μm and deposited onto a flat 5×5 mm^2 sapphire substrate. The total capacitance C is given by $C = (C_1 + C_2 + C_3)NL$ where N is the total number of pairs, L the length of the fingers. The capacitance of helium adjacent to IDC is given by $C_1 = \frac{\epsilon_o \epsilon_1 K[(1-(a/b)^2)^{1/2}]}{2K[a/b]}$ where K[x] is a complete elliptic integral of the first kind[2]. Here, ϵ_1 is the dielectric constant of helium deposited on the IDC. The capacitance between fingers is given by $C_2 = \epsilon_o \epsilon_2 \frac{h}{a}$ where h is the thickness of the film and a is the distance between the edges of the adjacent fingers and b is the distance between the centers of the adjacent fingers. The term C_3 is similar to C_1 except ϵ_1 becomes the dielectric constant of the sapphire substrate. Since the thickness of the fingers is at most 5×10^3 $\mathring{A}$, C_2 does not contribute significantly to the total capacitance. If the average dielectric constant of sapphire is taken as

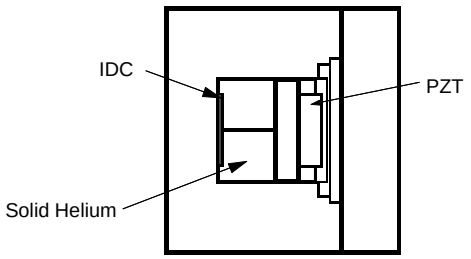

Fig. 1. schematic of solid helium sample chamber

10 ($\epsilon_{\|\mathbf{c}} = 9.4$ and ($\epsilon_{\perp\mathbf{c}} = 11.5$), $C_3 = 8.1$ pF. This is close to the measured background capacitance of 6.5 pF.

3. Preliminary Results

After the cell is cooled down to and maintained at 1.2 K, it is slowly filled with helium from a room temperature source. The expected change in capacitance between empty cell and IDC covered with liquid helium ($\delta\epsilon_1 = 1.057 - 1 = 0.057$) at 1.2 K is $\Delta C = \frac{\epsilon_o \delta\epsilon_1 2.441 NL}{2\times 1.854} = 0.0458$ pF. The measured value is 0.040 pF in fair agreement.

Once the cell is filled with liquid helium, the cell is pressurized up to the melting pressure. The expected change from the increase in density of helium in the pressurization is 7.4 fF. The observed change is $\Delta C = +4.5$ fF in disagreement with the expectation. A small movement in the connecting leads not close to the IDC

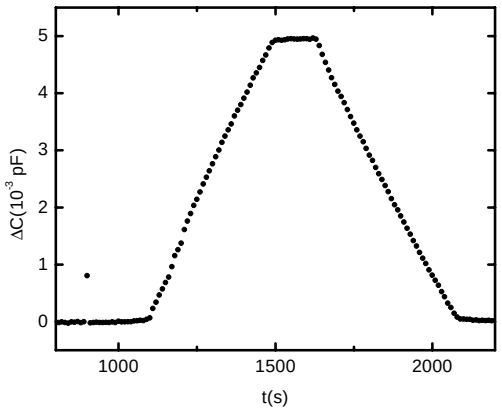

Fig. 2. nucleation, growth and melting of solid ^{4}He

When the cell pressure approaches the melting pressure, the rate of filling is controlled by applying heat to a small separate helium "bomb" cooled to near 77 K and open to the cell. An example of observed temporal evolution in growth and melting of solid is illustrated in Fig. 2. The cell pressure must often exceed

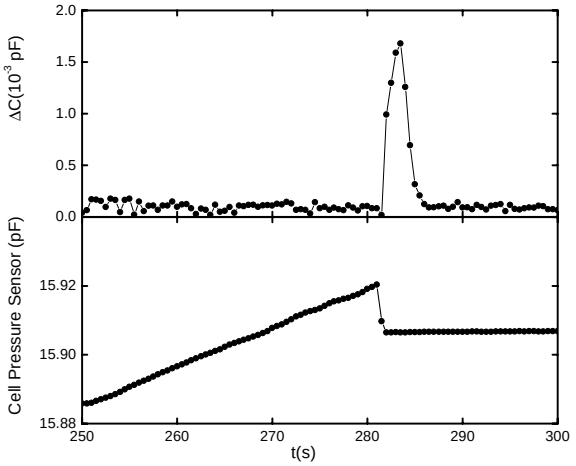

Fig. 3. nucleation of solid ^{4}He

the equilibrium melting pressure before nucleation of solid occurs as signaled by the spike in ΔC at t = 900 s. Once a nucleation occurs, the cell pressure remains constant as more helium is fed into the cell. The solid level reaches the lower end of IDC at about 1100 s. A relatively smooth increase in height of the solid is observed till the capacitance saturates when the solid level becomes higher than the top of the IDC. The observed change in capacitance is 5.0 fF. The expected change normalized by the change in density to the measured ΔC at vapor-liquid transition is 4.9 fF in good agreement. The melting is induced by removing helium from the cell. The rate of melting can again be controlled by varying the heater power applied to the bomb.

A nucleation event is captured in Fig. 3 which displays both the IDC signal and the cell pressure sensor capacitance as a function of time. The overpressure in the cell before the nucleation begins is 25 mbar. Subsequent to the nucleation event, the passage of the seed is sensed as it apparently slides along the IDC. In this run, the nucleation process could be repeated many times. However, the overpressure required for nucleation varies from cool down to cool down and at times it can barely be detected by our cell pressure sensor.

Acknowledgements

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References

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