Quartz microbalance study of superfluid helium thin films adsorbed on a hydrogen pre-plated gold surface

Shalva Ben-Ezra [a,1], William I. Glaberson [a],

[a] *The Racah Institute of Physics, The Hebrew University 91904 Jerusalem, Israel*

Abstract

We have developed highly sensitive torsional oscillator technique for probing the effect of the substrate character on the Kosterlitz-Thouless[1] transition in thin helium films. We have measured the vortex diffusivity in thin superfluid helium films adsorbed on a hydrogen pre-plated gold substrate at temperatures from 1.4 K to 2.0K. Helium adsorbed on such surface exhibits the Kosertlitz-Thouless transition at pressure remarkably higher than that for Helium adsorbed on the gold substrate. We study the finite amplitude and frequency effects for substrate velocity up to 32cm/sec and in frequency range from 3.3MHz to 36MHz of single quartz crystal microbalance.

Key words: Helium films; hydrogen substrate; torsional oscillator; Kosertlitz-Thouless transition.

1. Introduction

Recent investigations of the interaction of ^{4}He with weak binding substrates (i.e., alkali metals, noble gases, solid H_2) have led to the discovery of nonwetting of cesium and the probable existence of prewetting phases. Naturally, this has spurred widespread interest in the nature of thin film superfluidity on inert surfaces. The third sound measurements by Chen, Roesler and Moshel[2] show two third sound modes in certain ^{4}He coverages on an H_2 surface. It has been proposed that the additional third sound mode is the result of ordering of pairs of oppositely oriented vortices in analogue to an ionic crystal lattice, or due to the helium atoms ordering into hexatic phase, and that may be sensitive to such a transition. The high - Q Torsional oscillator technique, provides an extremely sensitive and direct measure of superfluid density through the transition. A study of ^{4}He films on H_2 was carried out by Adams and Pant[3] using a low frequency torsional oscillator technique, but no unusual behavior was found. In 1998 Tulimieri, Mulders and Chan[4] presented an another torsional oscillator study of ^{4}He films on H_2 with oscillator sensitivity to a factor of 20 greater than in Adams' work. They studied different coverage of ^{4}He films on 2 and 5 layers of H_2 and no features in or the dissipation were found that could be identified with an additional transition. In 1987 Adams and Glaberson[5] investigated the effect of changing the substrate on the temperature dependence of vortex diffusivity. A 100Å argon film was deposited on a Mylar substrate. They could not observe any changes in either the magnitude or temperature dependence of D. In 1996 Yano et al[6]. reported double torsional oscillator studies of ^{4}He films adsorbed on solid hydrogen. They could not observe any anomaly associated with a new phase in the superfluid state. In same work they plotted the temperature differences of the dissipation peak between two oscillator frequencies as a function of dissipation peak temperature.

2. experiment and results

In order to probe the effect of the substrate character on the diffusivity, we have under token simultaneous

[1] glabersn@vms.huji.ac.il

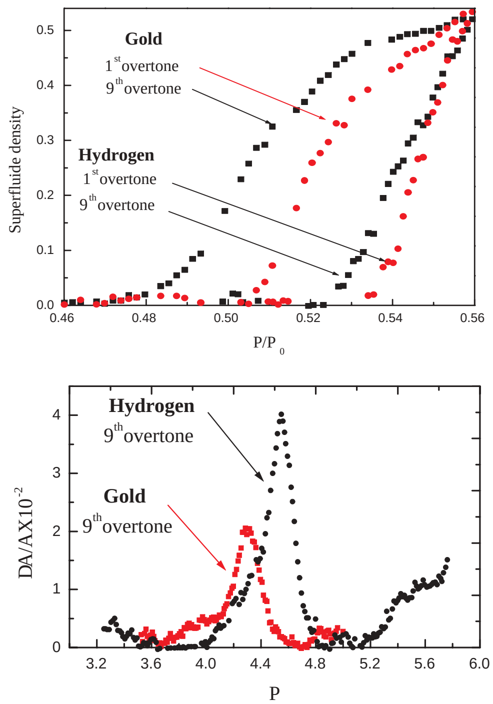

Fig. 1. The typical phase transitions for gold and hydrogen plated gold substrate.

measurements of the dissipation and the change of the oscillation period for different harmonics of a high frequency quartz crystal oscillator, pre-plated with about 3000Å of H_2. Using this technique, the diffusion coefficient has been measured with high precision, where the possible complication associated with affect surface character in the double-oscillator systems are avoided In the case of these hydrogen-coated substrates, we observe changes in the frequency shifts and in the inverse quality factor Q^{-1}, but we did not observe a second additional transition. Typical phase transition in ^{4}He on pure gold and the hydrogen pre-coated gold substrates, for the two harmonic modes at a temperature of 1.45K, after subtracting background behavior, is shown in Fig.1. The decreasing in the frequency and the shift of the KT transition at higher pressures indicate an increase in the values of diffusivity. The investigation of the frequency dependence of the magnitude of D, for gold and hydrogen pre-plated gold substrate is shown in Fig.2 at a temperature of 1.6 K. The graphs show that the hydrogen pre-plating has clearly affected the magnitude of D, whereas its frequency dependence is nearly unchanged. We investigated the changes in half width of the dissipation peak as a function of frequency and the data is shown in Fig.3. As we

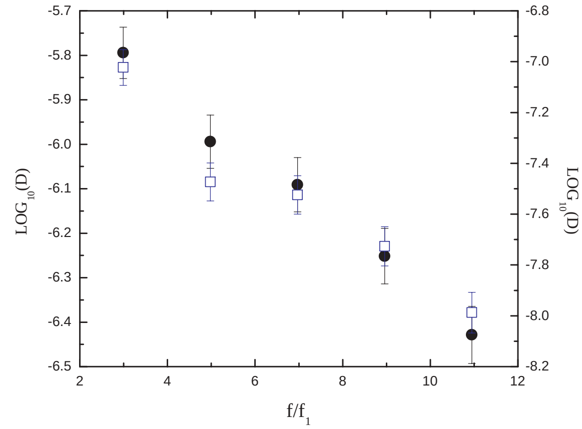

Fig. 2. The frequency dependent of diffusivity on the hydrogen pre-plated gold substrate (closed circles, left said scale) and gold substrate (open squares, right said scale) at a temperature of 1.6K (f_1 = 3.3 MHz, the frequency of 1^{st} overtone).

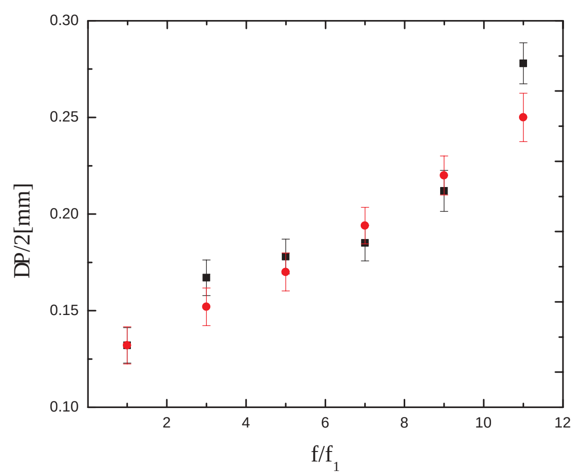

Fig. 3. Half width of dissipation as a function of frequency for gold and hydrogen coated substrates(The squares are for hydrogen coated and circles for pure gold surfaces).

see from the figure, we did not observe any changes in neither the magnitude nor the frequency dependence of ΔP. Finally, we measured the dependence of dissipation peak half width on the substrate drive amplitude for the 9^{th} harmonic on a hydrogen pre-plated gold substrate. In the cases of both gold and hydrogen surfaces, the quartz crystal fundamental overtone driven at low drive amplitudes (to keep it in linear regime) was used to monitor any heating effect if present. No change in the 1^{st} overtone period of the on the onset helium pressure was observed. Fig.4 represents a com-

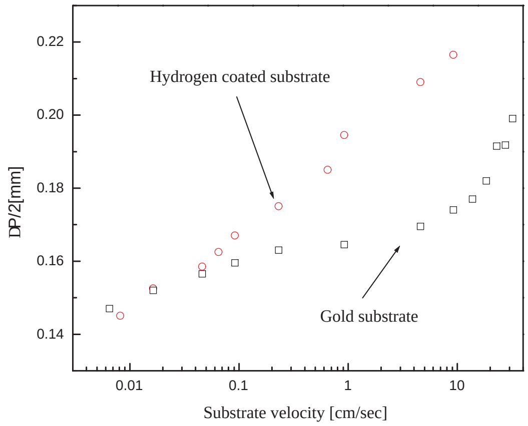

Fig. 4. Dissipation curve half width at half height for hydrogen pre-plated and gold substrates at quartz microbalance 9^{th} harmonics.

parison of our observations on a hydrogen pre-plated gold surface with those on a gold substrate.

References

[1] J.M. Kosterlitz, D.J. Thouless, J. Phys. C 6 (1973) 1181.

[2] M.-T. Chan, J.M. Roesler, J.M. Mochel, J. Low Temp. Phys. 89 (1992) 125.

[3] P.W. Adams, V. Pant Phys. Rev. Lett. 68 (1992)2350.

[4] D. Tulimieri, N Mulders, M.H.W. Chan J. Low Temp. Phys. 110 (1998) 609.

[5] P.W. Adams, W.I. Glaberson, Phys. Rev. B 16 (1987) 1966.

[6] H. Yano, T. Jocha, N Wada, Czechoslovak J. of Phys. 46 (1996) 417.