Studies Of Submicron ^{3}He Slabs Using A High Precision Torsional Oscillator

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Abstract. A high precision torsional oscillator has been used to study ^{3}He films of thickness in the range 100 to 350 nm. In previous work we found that the films decoupled from the oscillator motion below 60 mK, in the Knudsen limit. This precluded observation of the superfluid transition. Here we report measurements using a torsional oscillator whose highly polished inner surfaces have been decorated with a low density of silver particles to act as random elastic scattering centres. This modification locks the normal film to the surface. A superfluid transition of the film is observed.

Keywords: Superfluid ^{3}He films, torsional oscillator, interfacial friction, Knudsen limit
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INTRODUCTION

The study of flow in submicron ^{3}He films over a flat surface is expected to provide interesting insights into the problem of boundary scattering, since temperature provides a convenient method of tuning the inelastic mean free path relative to film thickness and surface roughness. Furthermore the superfluid transition of a film of thickness comparable to the superfluid coherence length is also of interest. We have developed a high precision torsional oscillator, with high frequency resolution and a very weak temperature dependent background, to study these phenomena [1].

DECOUPLING OF NORMAL ^{3}HE FILMS AND LOCKING THE FILM

In our first oscillator the ^{3}He film resided on two coin silver surfaces, mechanically polished to a measured surface roughness of approximately ± 10 nm. The films were observed to de-couple from the oscillator below around 60 mK, contrary to the naive expectation that a microscopically rough surface should lock the film [2]. Measurements of both the frequency shift and dissipation of the film could be described by a phenomenological model in which the film surface coupling is described by an interfacial friction. We found the surprising result that the momentum relaxation time between film and surface varied approximately as $1/T$.

Further analysis suggests that this result can be understood in terms of boundary scattering from a rough surface [3, 4]. For a model with surface of roughness amplitude l, with Gaussian correlations over length R, the film momentum relaxation time is given by

$$\frac{1}{\tau} = 3\left(\frac{1}{\tau_\eta \tau_F}\right)^{1/2}\left(\frac{l}{R}\right)^2 \frac{1}{k_F d} \qquad (1)$$

where τ_η is the appropriate quasiparticle relaxation time, $\tau_F = \hbar / 2E_F$, where k_F and E_F are the Fermi wavevector and Fermi energy, and d is the film thickness. This accounts for the temperature dependence of τ, since $\tau_\eta \propto 1/T^2$. We infer $R/l \sim 30$. Thus the slippage of the film is directly related to the surface profile, which can be independently characterised by modern surface probe techniques.

In order to lock the film we fabricated a new oscillator, in which the inner surfaces of the coin silver head on which the film resides were first polished, using the same procedures as previously, and

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subsequently decorated by silver particles, with a target spacing of order 10 μm. Assuming these particles act as elastic scattering centres, with temperture independent scattering time τ_{el}, we estimate that $\omega\tau_{el} \sim 3.10^{-3}$, sufficient to couple the film. The silver particles of nominal size 700 nm were deposited from an appropriately dilute suspension in ethanol. The surface was vacuum annealed at 750°C in order to bond the particles to the surface. This was followed by an ultrasonic cleaning step to dislodge weakly attached particles. Figure 1 shows a similarly treated surface.

Experiments on two ^{3}He films show that this surface treatment had the desired effect of locking the film to the surface (Fig. 2). No change in frequency shift is observed, as well as a much smaller film contribution to the dissipation.

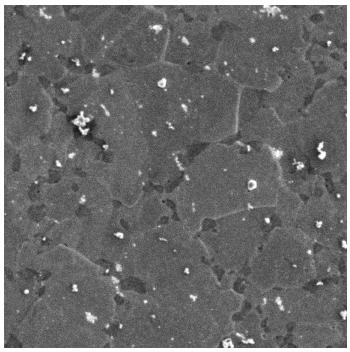

FIGURE 1. Polished silver surface, decorated by silver particle. Electron microscope picture (approx. 100 × 100 μm).

SUPERFLUID TRANSITION IN FILM

With surfaces similar to that shown in Fig.1, we are able to observe a superfluid transition in the film, with superfluid transition temperature suppressed below bulk T_c, as expected for diffuse quasiparticle boundary scattering. Preliminary indications are that the superfluid density is similar to that measured in comparable films by third sound [5], but significantly greater than that found in earlier torsional oscillator measurements [6]. Further studies of the temperature dependence of the superfluid fraction, its suppression relative to bulk values and the suppression of T_c as a function of film thickness are underway.

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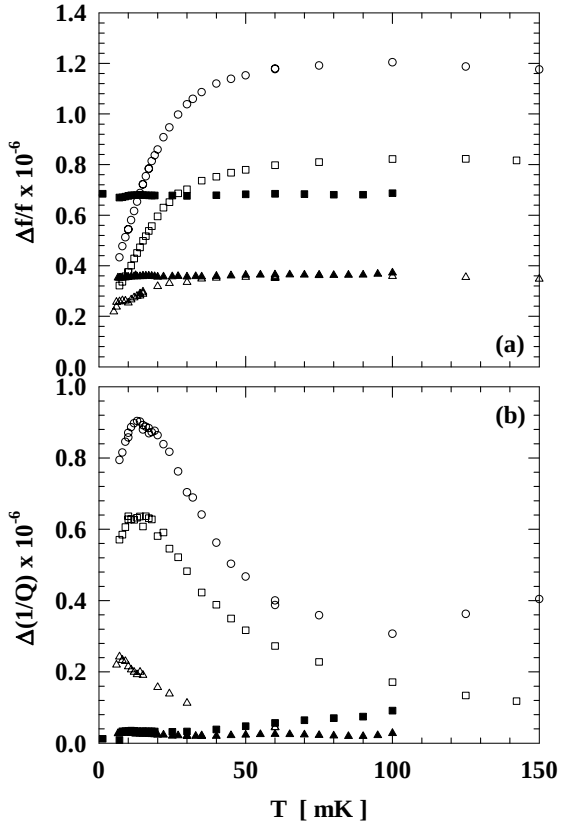

FIGURE 2. (a) Frequency shift due to film, and (b) film contribution to dissipation for two film thicknesses on the silver particle decorated surface (solid symbols), corresponding to frequency shifts of 0.9 and 1.8 mHz. In comparison, open symbols show previous data [2], obtained with a plain polished surface, for frequency shifts 0.9, 2.4, 3.5 mHz. Nominal film thickness is 100 nm/mHz for both oscillators.

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