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Effect of ^{4}He pre-plating on third sound in superfluid ^{3}He

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Abstract

We recently reported observation of third sound resonances in superfluid films of pure ^{3}He on a disk-shaped polished copper substrate. From the observed spectra of resonant modes, the third sound speed, the average superfluid density, and information on dissipation were obtained. The film thicknesses studied were larger than or comparable to the superfluid coherence length, which is near 100 nm. We describe preliminary results from efforts aimed at using third sound in thinner films on a substrate which has been coated with a few atomic layers of ^{4}He. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: ^{3}He superfluid; ^{3}He superfluid film; ^{4}He film; Third sound

1. Introduction

The wave speed of third sound is given by

$$c_3 = \sqrt{\frac{\langle \rho_s \rangle}{\rho} a_{vdW} d}, \tag{1}$$

where $\langle \rho_s \rangle$ is the average superfluid density of the film, ρ is the density, and d is the film thickness [1]. a_{vdW} is the acceleration at the film surface due to the van der Waals restoring force of the substrate, which depends strongly on the film thickness. We recently reported the existence of third sound standing waves in superfluid films of pure ^{3}He [2]. This technique may lead to the use of third sound to probe 2-d films of superfluid ^{3}He.

So far, however, third sound in ^{3}He has been observed only in films with thickness d equal to or larger than the superfluid coherence length given by $\xi(T) = \xi_0(1 - T/T_c)^{-1/2}$ [3]. The films are formed on a circular horizontal substrate which is a height $h < 1$ mm above the surface of the ^{3}He bath. The film thickness d can be varied by varying h [4].

Electrodes suspended ~ 30 μm above the substrate are used to excite the standing waves electrostatically and detect their motion capacitively. $c_3(T, d)$ is determined from the observed resonant frequencies, and $\langle \rho_s \rangle$ can also be calculated by inverting Eq. (1). These results have been obtained for saturated superfluid ^{3}He films from 95 to 300 nm thick on a copper substrate [2].

2. Effect on c_3 of coating the substrate with a few atomic layers of ^{4}He

Superfluidity in ^{3}He films is strongly suppressed when the film thickness is near the coherence length. This is the case for the saturated films we have studied [2]. This effect hinders our ability to probe very thin ($d < \xi(T)$) films of superfluid ^{3}He. However, coating the substrate with about 3 atomic layers of superfluid ^{4}He has been shown to inhibit this suppression [5,6].

Here we report a preliminary study of the effect of such a ^{4}He substrate coating on the speed of third sound in superfluid ^{3}He. We compare previously obtained third sound resonant spectra, and hence $c_3(T)$, for a film of pure ^{3}He about 150 nm thick with spectra and speeds for a similar film where the substrate has been coated with about 2.5 atomic layers of ^{4}He. To produce a suitable substrate coating of ^{4}He, we first used the BET method to measure the effective surface area of the cell, obtaining 140 ± 3 m^2. We then added the amount of ^{4}He required to form 2.5 atomic layers to our pure ^{3}He sample at

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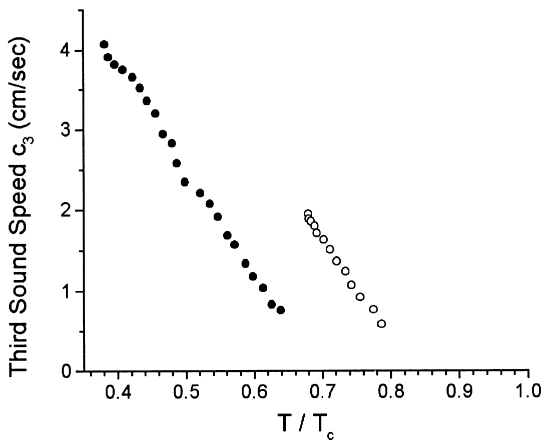

Fig. 1. Pure ^{3}He film – solid circles; ^{3}He film with ^{4}He substrate coating – open circles.

room temperature and filled the cell with the mixture, again forming a film about 150 nm thick. Precise film thickness measurements are somewhat unreliable; the films are better characterized by the heights from the liquid bath's free surface to the substrate, which were 1.05 and 0.95 mm, respectively.

Fig. 1 shows $c_3(T)$ obtained from the third sound spectra of each film. For the pure ^{3}He film, third sound resonances became detectable at about $T/T_c = 0.65$, with the addition of ^{4}He to the cell, this temperature rose to 0.80. Otherwise the resonant spectra were qualitatively similar, although the speeds are significantly different.

As can be seen in Fig. 1, the minimum temperature to which we were able to cool the film was also affected by the presence of ^{4}He, rising from $T/T_c = 0.38$–0.68. We attribute this deleterious effect to a reduction in the efficiency of the sintered heat exchangers in the cell when they are plated with ^{4}He. For future work using a ^{4}He pre-plating, we will address this problem by enlarging the cell's heat exchangers as much as possible, and by optimizing the thickness of the ^{4}He layer.

This observation of enhancement of ^{3}He third sound speed, superfluid density, and film critical temperature, due to a ^{4}He pre-plating is significant since third sound might be used to examine the properties of thinner ^{3}He films than has previously been possible. Among the research prospects are studying quantized vortices in 2-d films and the Volovik–Hall effect [7].

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