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PHYSICA B

POSSIBLE OBSERVATION OF THE SUBSTRATE STATE IN ^{3}He-^{4}He MIXTURE FILMS

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We report on measurements of third sound in ^{3}He-^{4}He mixture films. The third sound velocity is measured as a function of temperature for ^{4}He thicknesses between 3.6 and 5.8 atomic layers (a.l.) and ^{3}He coverages up to 1.25 a.l. An anomaly in the third sound velociy is found around 200 mK for films with a ^{4}He thickness of less than 5 a.l. and ^{3}He coverages around 0.5 a.l. Comparison of the results is made with the model of Guyer and Miller and the calculations of Pavloff and Treiner [1, 2].

1. INTRODUCTION

The exact location of ^{3}He atoms added to a pure ^{4}He film remains a problem. Experiments to date give contradictory results, indicating that the ^{3}He atoms are mixed throughout the film [3] or located in the surface [4]. Recent theoretical calculations yield several ^{3}He bound states, the sequence in the energy spectrum depending on a delicate balance between the substrate potential and finite-size effects [2]. We have performed third sound measurements to try to answer some of the questions emerging from this rich system.

2. EXPERIMENTAL SETUP

We use a time-of-flight technique similar to the one described by Ellis *et al.* [5]. Two heaters and two detectors are evaporated on two glass plates, that are 5 μm apart. The capacitances formed by the detectors are part of tunnel-diode driven oscillator circuits with a sensitivity of about 10 Hz/Å. Frequency noise limits the minimum detectable thickness change to about 0.01 Å. We use an array of 2 μm i.d. glass capillaries as a surface area buffer (A = 3.24 m^2). No signs of capillary condensation were seen in the measured range of film thicknesses: d_4 = 3.62 a.l., 4.21 a.l. and 5.85 a.l. with ^{3}He coverages up to d_3 = 1.25 a.l.

3. RESULTS

One of the most interesting measurements is the third sound velocity as a function of temperature for different ^{3}He coverages, shown in fig. 1.

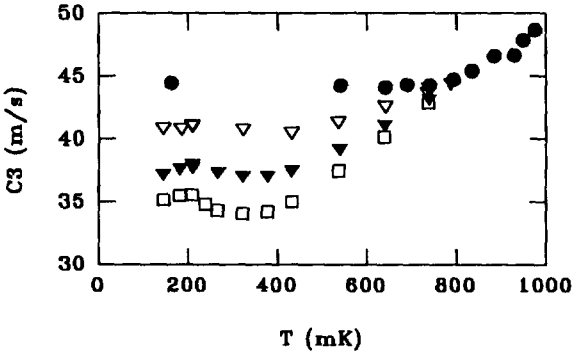

Figure 1. Third sound velocity versus temperature for (●) d_3 = 0.00 a.l., (▽) d_3 = 0.16 a.l., (▼) d_3 = 0.31 a.l. and (□) d_3 = 0.47 a.l. with d_4 = 3.62 a.l. in all cases.

An anomalous temperature dependence can be seen at about T = 200 mK. This anomaly is reproducible and is present in all the films studied but it shifts to higher ^{3}He coverages with increasing ^{4}He thicknesses. For d_4 = 4.21 a.l. the anomaly develops for $d_3 > 0.6$ a.l., while it is hardly seen for coverages up to d_3 = 1.25 a.l. in the d_4 = 5.85 a.l. film. A similar anomaly has been reported before, but only for thicker films and larger coverages [6].

The anomaly in the third sound velocity becomes more pronounced as the excitation energy is increased (fig. 2). This may explain why it has not been reported before in films of similar thicknesses in studies using resonant techniques.

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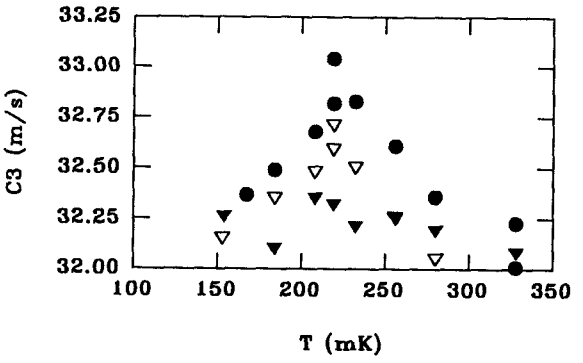

Figure 2. The anomaly in the third sound velocity for a film with d_4 = 4.21 a.l. and d_3 = 0.23 a.l. for different excitation energies: (▼) 13 nJ, (▽) 32 nJ, and (●) 54 nJ.

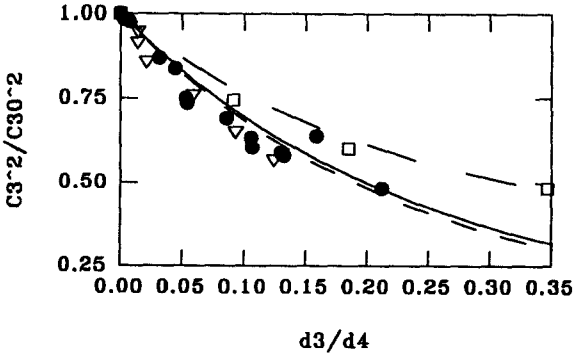

Figure 3. Comparison of the model predictions for (— —) isotopic layering, (——) complete mixing, and (- - -) substrate state with experimental results: (●) our results, (□) the results of Ellis *et al.*, and (▽) the results of Noiray *et al.*

4. DISCUSSION

The third sound data for the different films studied have been analyzed using the bilayer film model of Guyer and Miller [1]. Expressions can be derived for the third sound velocity as a function of d_3/d_4 for the limiting cases of complete mixing (film state) and isotopic layering (surface state). A third possibility, a bound ^{3}He state near the substrate, has recently been suggested by Pavloff and Treiner [2]. The third sound velocity change, as a function of d_3/d_4, for these three states is shown in fig. 3. As can be seen, the film and substrate state yield almost identical predictions.

Ellis *et al.* conclude from their measurements that the ^{3}He atoms in the film are located in the surface while the measurements of Noiray *et al.* show that this is not the case for thin films. Our results support the results of Noiray *et al.* However, reanalysis of Ellis' measurements, shows that in the range of d_3/d_4 studied by us, these results do not contradict ours. Ellis' results even seem to indicate a transition to isotopic layering when d_3/d_4 is increased. This transition seems to occur at lower d_3/d_4 with increasing temperature.

The anomaly can be explained qualitatively by assuming the presence of three bound states in the order: substrate state, surface state and film state. When the substrate state is filled, ^{3}He atoms will start to occupy the surface state by thermal excitation. This lowers the film thickness and increases the third sound velocity. This is consistent with the transition in Ellis' measurements. The decrease in third sound velocity is a result of the transition of ^{3}He atoms into the film state, which increases the film thickness again.

The dependence of the anomaly on the excitation energy suggests that the occupation of these different states is a dynamical process induced by the disturbance of the film shortly after the excitation pulse.

5. ACKNOWLEDGEMENT

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