Amplitude and frequency effects on the Kosterlitz-Thouless transition in thin helium films.

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Abstract

We have developed a technique for probing the Kosterlitz-Thouless transition in thin helium films in which a single quartz crystal microbalance is excited at six different harmonic frequencies. We operate a single quartz crystal microbalance at two different harmonic frequencies simultaneously in frequency range from 3.3 MHz to 36 MHz. We observe previously unreported non-linear behavior in superfluid dissipation associated with finite amplitudes, at the various frequencies. In addition we measure the shifts and broadenings of the transition associated with the predicted finite frequency effects. manuscript.

Key words: Helium4 superfluid fims, non-linear effects.

1. Introduction

Torsional oscillator techniques have proven invaluable in investigation of Kosterlitz-Thouless[1] behavior in thin superfluid helium films. A characteristic dissipation peak is observed of the transition. Reppy et al[2] observed dissipation peak broadening, shifting to lower temperatures, and decreasing height of the peaks, with increasing the substrate velocity.

2. Experiment and results

To investigate this behavior at different frequencies and higher drive values, we have made a series of experiments using a quartz crystal oscillator operating at different drive levels and at six different overtone modes. The procedure for taking data was somewhat different from the one generally used. We simultaneously excited the quartz crystal at two different overtones and slowly added helium gas to the cell thought the Kosterlitz-Thouless transition. We simultaneously monitored two quartz crystal resonant frequencies, for example see 1^{st} overtone as a reference and another frequency as the investigated overtone (for example 3^{rd} or, $5^{th} \ldots 11^{th}$). The drive level of the reference used as low as possible. The gas entrance rate was sufficiently slow to avoid systematic errors due to the relaxation time of the oscillator. With increasing drive amplitude we observed dissipation peak broadening, changing peak height, and shifting of the peak to higher-pressures. A typical sequence of data is show in Fig.1.

The data can be divided into tree distinct velocity regions. Beginning from $v = 0.005$cm/sec we observed linear dependence of dissipation peak height on substrate velocity. In this regime the location of the peak is unchanged. Above $v = 0.03$cm/sec the dissipation maxima shift to higher pressures (lower temperature). The peak begins to broaden with increasing drive and the height of the peaks increases more slowly than in linear region reaching a maximum at $v = 0.15$cm/sec. The peaks continue to broaden with increasing drive, the height of the peaks decreasing reaching minimum at $v = 2.9$cm/sec. Surprisingly peak high begin his second grouting at $v = 8.8$cm/sec, and continue broadening with increasing drive. Our results we compared with those of Reppy et al[3] in Fig.2. In the low sub-

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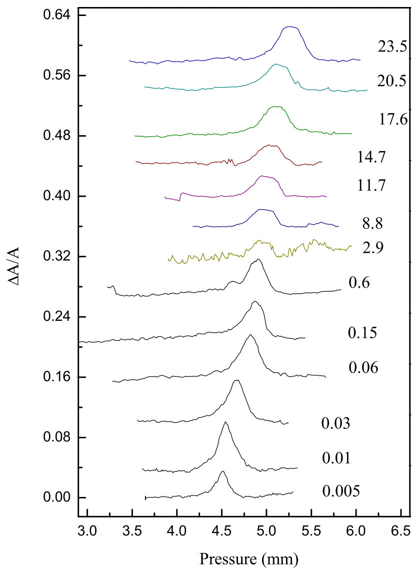

Fig. 1. Velocity dependence of the dissipation peak, measured for 5^{th} overtone of quartz crystal microbalance. The nominal substrate velocities in units of (cm/sec) are indicated for each trace.

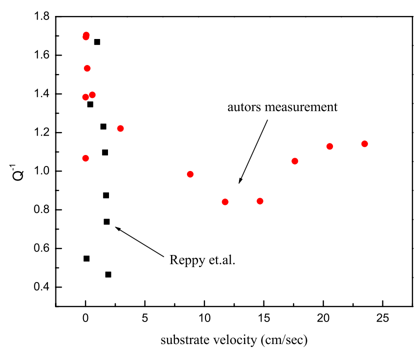

Fig. 2. Velocity dependence of the dissipation peak: squares, data by Reppy and et.al., circles, our measurements at 5^{th} overtone of quartz microbalance.

strate velocity region our measurements agree qualitatively with those carried out by Reppy et al. The decrease in the peak height above the maximum is much slower than observed by Reppy at el. For substrate velocities up to velocity corresponding the minimum on the graph, the oscillator period appear to be independent on drive amplitude (see fig.3). At substrate velocities above the minimum, the oscillator period does change as seen in figure 4. Not that the reference mode (in this case 9^{th} overtone) is not shifted so that heating effects are dealing not present. The surprise comes from the end of the graph driven on Fig.2, where, we at

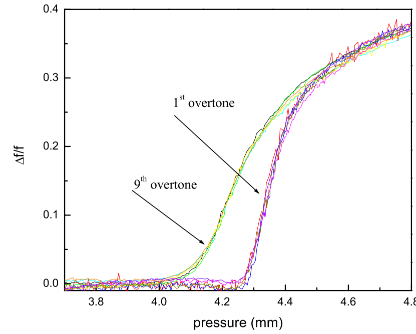

Fig. 3. The period changes for 1^{st} and 9^{th} overtone at different drive levels of quartz crystal.

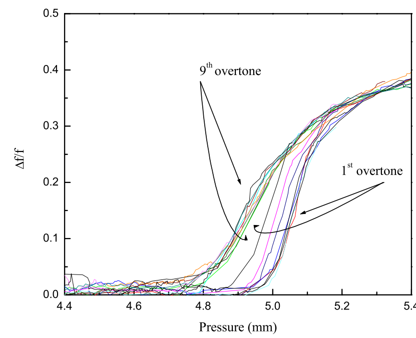

Fig. 4. The period changes for 1^{st} and 9^{th} overtone, in the case when we keep 9^{th} overtone without changes and 1^{st} overtone drive covers interval between 0.0025 and 5.4cm/sec.

first time observed the increasing of dissipation peak. At this point we strongly underline, the changes in the drive of quartz microbalance don't heat the substrate. We argued that, by measuring the KT transition at another overtone of same quartz crystal, drive it simultaneously with observant at his minimum velocity. To visualize this fact, we present in the Fig.4 the period change dependence on drive velocity at both, as example, first and ninth overtones of same quartz crystal in the case when only first overtone drive changes from his $v_{\min} = 0.0025$ up to $v_{\max} = 5.4$cm/sec value and at same time we keep ninth overtone drive at those level, which correspond minima in velocity $v = 0.006$cm/sec.

References

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

[2] D.J Bishop, J.D. Reppy Phys. Rev. B**22** (1980) 5171.

[3] G. Agnolet, D.F. McQueeney, J.D. Reppy Phys. Rev. B**39** (1989) 8935.