Acoustic Properties of Liquid ^{4}He Measured by Rayleigh-SAW

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Abstract

Damping and velocity of Rayleigh surface acoustic wave (SAW) were measured in liquid ^{4}He. Rayleigh-SAW propagates along the substrate surface by emitting compressional waves into the liquid and thus the damping of the Rayleigh-SAW is determined by the acoustic impedance of the surrounding liquid ^{4}He. Temperature dependence agreed well with the reported values of the impedance and the superfluid transition in ^{4}He was clearly seen. We also set up a reflection plate 1.5 mm above the SAW device which reflected the emission waves. They were converted back into the SAW and used to measure the velocity and damping of ultrasound in liquid ^{4}He separately.

Key words: liquid ^{4}He, acoustic impedance, surface acoustic wave

1. Introduction

Ultrasound measurements play very important roles in a ^{3}He investigation [1]. The time scale of ultrasound corresponds to quasiparticle life times at low temperatures and first to zero sound crossover was observed. Energy scales of ultrasound match the binding energies of Cooper pairs in superfluid ^{3}He and thus resonant absorptions by order parameter collective modes were observed coupling through density oscillations. Sound transmission method or transducer impedance measurements have usually been used for these studies. Many types of surface acoustic wave (SAW) sensors have now been developed [2,3] for acoustic and electrical property measurements of adjacent liquid or gas, but have not been applied to superfluid ^{3}He. We made a Rayleigh-SAW sensor and checked how it worked for liquid ^{4}He at low temperatures.

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2. Results and Discussion

We used a 36° rotated Y-cut $LiNbO_3$ for the substrate of Rayleigh-SAW which propagated along X-axis. SAWs were excited and detected by two sets of interdigital transducers separated by 20 mm. SAW frequency was about 69MHz and the pulse mode was used. Substrate motion in Rayleigh-SAW is in ellipses. Parallel motion to the propagation direction couples with viscosity and transverse motion excites a compressional wave into liquid, both of which result in the damping of SAW. In liquid ^{4}He damping by the former process is negligibly smaller than that of the latter[4]. Damping by emitting wave is given by [4],

$$\alpha = k\frac{\rho_l v_l}{\rho v \lambda}, \qquad (1)$$

where ρ_l and v_l are density and sound velocity of adjacent liquid, ρ, v and λ are density, velocity and wavelength of SAW in the substrate. We can determine the acoustic impedance of liquid from the damping of SAW. A reflection plate was set up 1.5 mm above the SAW device which reflected emitted waves and converted them back to SAW. Signals detected after the excitation pulse at t=0 are shown in Fig. 1; three can be seen: single transit signal, emission wave signal and

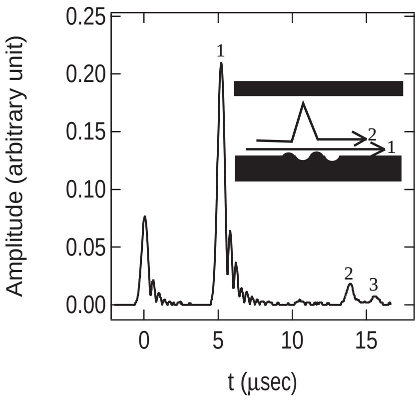

Fig. 1. Detected signals after the excitation pulse at t=0. 1: single transit signal, 2: emission wave signal, 3: triple transit signal. Inset shows propagation path of these waves.

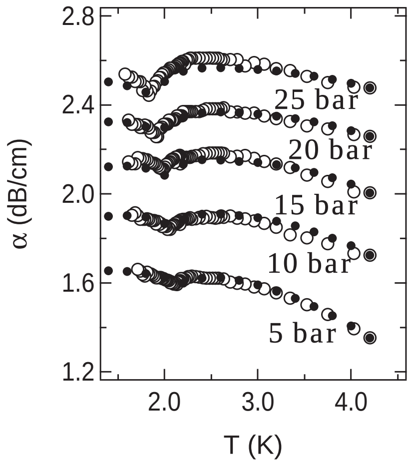

Fig. 2. Temperature dependence of damping of single transit signal at various pressures (open circles). Solid circles are calculated from eq. (1).

triple transit signal. Propagation paths of these waves are shown in the inset of Fig. 1.

Temperature dependences of damping in single transit signal at various pressures are shown in Fig. 2 (open circles). Solid circles are calculated from eq. (1) using the reported values of acoustic impedance of liquid ^{4}He [5]. We determined the parameter $k \approx 0.5$ at T= 4.2 K and used it for all other temperatures. Agreement of these data with eq. (1) is good and superfluid transitions are clearly seen. Using the emission wave signals it is possible to measure damping and velocity of ultrasound in liquid directly. Under our experimental conditions the damping of the emission wave signals was determined by the damping in liquid, which is shown in Fig. 3. The time interval between a single transit signal and an emission wave signal can be used to measure sound velocity of liquid and is shown in the inset of Fig. 3.

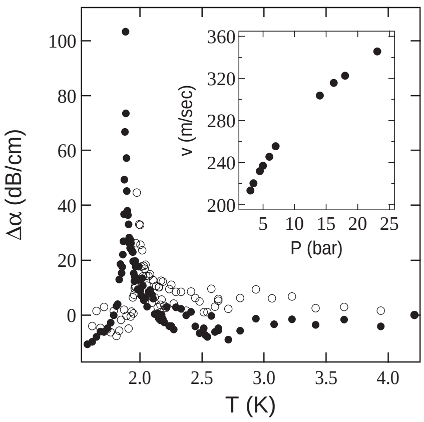

Fig. 3. Temperature dependence of damping in liquid ^{4}He at 16.3 bar (open circles) and 23.1 bar (solid circles) obtained from emission waves. Inset is the pressure dependence of sound velocity of liquid ^{4}He measured by emission wave at T= 4.2 K

These measurements demonstrated that Rayleigh-SAW can be used to study the acoustic properties of liquid ^{4}He at low temperatures. It will be interesting to apply this sensor to superfluid ^{3}He in a narrow gap or superfluid ^{3}He film which are very difficult to study with ordinary acoustical setup. A SAW sensor is essentially a surface probe and expected to pick up information near the surface, such as the surface bound state, by avoiding the huge bulk background.

Acknowledgements

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