Velocity and Damping of the SH-SAW in Normal Liquid ^{3}He

Y.Aoki [a,1], Y.Sekimoto [a], Y.Wada [a], W.Yamaguchi [a], R.Nomura [a] and Y.Okuda [a]

[a] *Department of Condensed Matter Physics, Tokyo Institute of Technology, 2-12-1, O-okayama, Meguro-ku, Tokyo 152-8551, Japan*

Abstract

We developed a shear horizontal surface acoustic wave (SH-SAW) sensor to investigate the viscoelastic properties and the transverse sound in normal and superfluid ^{3}He. SAW was generated and detected by two sets of interdigital transducers on $LiTaO_3$ substrate. Distance between generator and detector was 21 mm. SAW frequency was 69.4 MHz and operated in the pulse mode. In a SH-SAW substrate displacement is transverse to the propagation direction on the substrate surface. It is coupled with the viscosity of the surrounding liquid ^{3}He. Velocity and damping of SH-SAW were measured in normal liquid ^{3}He down to 14 mK. Temperature dependences of the velocity and the damping were explained well by assuming the viscoelasitc properties of normal liquid ^{3}He.

Key words: liquid ^{3}He, viscosity, surface acoustic wave

1. Introduction

Landau predicted the existence of a transverse zero sound mode in his theory of Fermi liquid[1]. The zero sound regime is characterized by the condition $\omega\tau \gg 1$, where ω is the angular frequency and τ is the relaxation time. Early attempts to observe transverse sound in normal ^{3}He were not conclusive because of the incoherent single particle excitation[2-4]. Recently it was confirmed in the superfluid phase by observing the acoustic Faraday effect[5].

A shear horizontal surface acoustic wave (SH-SAW) couples with the viscosity of adjacent liquid because its displacement is transverse to the propagation direction and parallel to the substrate surface. One remarkable feature of SAW is that most of the energy is localized near the surface, within a depth of about one wavelength. Instead of propagating throughout the whole three-dimensional medium, the energy remains localized at the surface and spreads out primarily in the two-dimensional interface region. SAW devices provide a powerful method of sensing the properties of liquid but have not been applied for liquid helium. They are essentially surface probes and pick up information near the surface. We speculate that the SH-SAW couples with not only the viscosity but also transverse sound in the surrounding liquid ^{3}He. We measured temperature dependences of the velocity and damping of SAW immersed in normal liquid ^{3}He down to 14 mK.

2. Results and Discussion

A schematic drawing of the SAW sensor is given in Fig.1. We used a SAW pulse of 69.4 MHz and 1 μs duration. SAW wavelength was 60 μm. The SAW traveled across the surface about 21 mm and was detected using another set of transducers. Signals were received by a phase sensitive detector. Amplitude and phase of SAW were analyzed separately. The SAW mode is determined by the orientation of the substrate crystal. We used 36rotated Y-cut X-propagating $LiTaO_3$. In order to detect only the SH-mode, the substrate surface was electrically shorted to the ground.

[1] Corresponding author. E-mail: aoki@ltp.ap.titech.ac.jp, Fax: +81-3-5734-2751

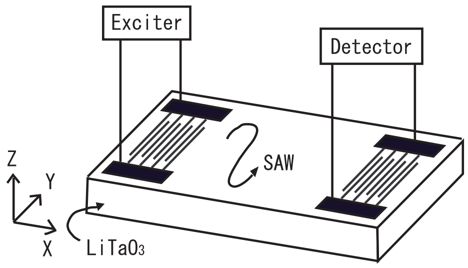

Fig. 1. Size of the substrate is 26×27mm. The transducers, each comprised of 20 finger pairs having 60 μm periodicity, are patterned from Al. Sound velocity on the substrate is 4134 m/sec. To detect only SH-mode, the substrate surface is shorted to the ground.

Temperature dependence of SAW in normal liquid ^{3}He was measured at 3 bar. Figures 2 and 3 show changes of the attenuation and the phase shift in liquid ^{3}He. In this system we cannot determine absolute values of the attenuation and the phase shift, so changes from 100 mK are plotted. Each data point was averaged 1024 times.

Let us consider the case that viscoelastic liquid is on the substrate and damping of SH-SAW is determined by the viscous force of the liquid. The attenuation and the phase shift obtained by McHale *et al.* [6] are

$$\alpha = \left(\frac{20\log_{10}e}{\sqrt{8}\pi}\right)\frac{\sqrt{\rho\eta}d\omega^{3/2}}{\rho_s v^2}F_+(\omega\tau), \qquad (1)$$

$$\Delta\,\omega = \frac{\sqrt{\rho\eta}\omega^{3/2}}{\sqrt{8}\pi v\rho_s}F_-(\omega\tau), \qquad (2)$$

where

$$F_\pm(\omega\tau) = \left(\frac{\sqrt{1+(\omega\tau)^2}\pm\omega\tau}{1+(\omega\tau)^2}\right)^{1/2}, \qquad (3)$$

where ρ, η and τ are density, viscosity and relaxation time of the liquid, d, ρ_s and v are propagation length of the SAW, density and sound velocity (4134 m/sec) on the substrate. The solid lines in Figs. 2 and 3 are calculated from Eq.(1) and (2). We used $\tau T^2 = 1.27\times 10^{-6}$(s·mK ^{2})[4]. The data is a little scattered, but we can say that the temperature dependence of the attenuation and the phase shift agreed with the calculation from Eq. (1) and Eq. (2). SH-SAW in normal liquid ^{3}He was found to be well described by its viscoelastic property. Saturation of damping and decrease of velocity at low temperatures indicate that we entered the collision less regime.

We plan to perform an experiment below superfluid transition, and hope to observe a new property of a very thin superfluid ^{3}He film using this SAW sensor. It will also be very interesting to observe the resonance of transverse sound in normal and superfluid ^{3}He with this method.

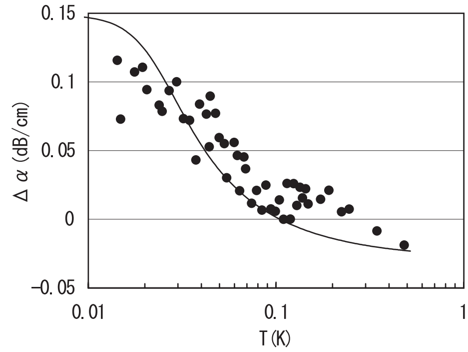

Fig. 2. Temperature dependence of the attenuation of SH-SAW at 3 bar. The solid line is calculated from (1).

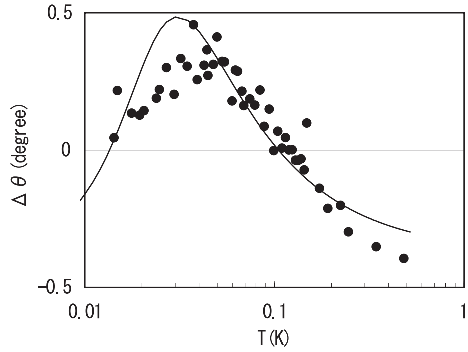

Fig. 3. Temperature dependence of the phase shift of SH-SAW at 3 bar. The solid line is calculated from (2).

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