Ultrasound Velocity and Attenuation of Liquid ^{4}He in Aerogel

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Abstract

The ultrasound velocity and attenuation of liquid ^{4}He in various porosity aerogels were measured for a frequency of 10 MHz. The superfluid transition temperature was suppressed by aerogel which was determined as a dip of sound velocity and a attenuation peak. Sound velocity in this composite system depended seriously on the aerogel porosity. An aerogel-^{4}He composite model, in which normal fluid was clamped to aerogel strand gave almost satisfactory temperature and aerogel porosity dependence of the sound velocity. The sound attenuation in aerogel was considerably larger than that in bulk liquid. That in the normal phase had small porosity dependence. However, that in the superfluid phase decreased with decreasing temperature and became constant at low temperatures. The attenuation peak ascribed to roton-phonon interaction was not observed in aerogel-^{4}He system.

Key words: liquid ^{4}He; ultrasound; aerogel

1. Introduction

Recent studies have shown that the nature of the superfluid transition of liquid ^{4}He in aerogel substantially differs from that of bulk liquid[1,2].

There has been an interest in the sound mode in aerogel-^{4}He system. In this system, two sound modes which are different from that in other porous media have been observed [3]; one is the intermediate mode between first and fourth sound and the other is the second sound like mode. Though the normal fluid is clamped to aerogel matrix like in the other porous media, the highly porous aerogel are compliant and so mechanical and thermal gradients are able to move the normal fluid together with aerogel matrix.

We have reported the observation of the complex sound mode using the 10 MHz ultrasound in aerogel-^{4}He system [4]. At this frequency, the viscous penetration depth is comparable to the typical aerogel strand separation. The fast mode (intermediate between first and fourth sound) in the superfluid phase continuously connected to the modified first sound in the normal phase. The sound velocity has been shown to have a large aerogel porosity dependence in both normal and superfluid phase. In this paper, we report the sound velocity and the attenuation to study the phonon scattering with the silica strand and roton in aerogel.

2. Results and discussion

Aerogels of 92.6% and 94.0% porosity were immersed in liquid ^{4}He at SVP. The cylindrical aerogel samples enclosed in brass shells were 8.5 mm in diameter and 3.0 mm in length. The sample cylinder was sandwiched between two $LiNbO_3$ transducers with springs. The transmitted sound pulse was observed with a phase sensitive detection.

We could observe the sound signal throughout the temperature from 4.2 K to 0.5 K so that the observed sound mode should be the fast mode in the superfluid phase and modified first sound in the normal phase. Figure 1 and 2 respectively shows the sound velocity

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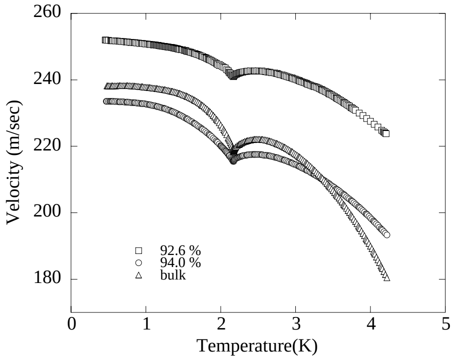

Fig. 1. Sound velocity of 10 MHz ultrasound in the aerogel-^{4}He system at SVP (square in 92.6% open aerogel; circle in 94.0% open aerogel). For comparison, that of bulk ^{4}He obtained in a different run was plotted as triangle.

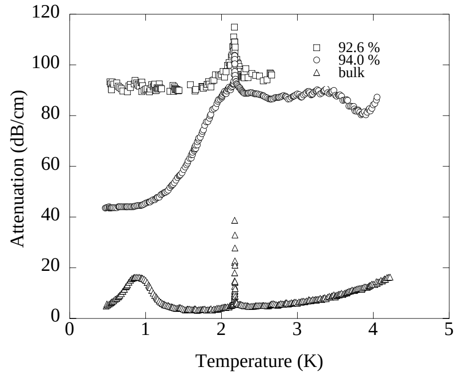

Fig. 2. Attenuation of 10 MHz ultrasound in the aerogel-^{4}He system at SVP (square in 92.6% open aerogel; circle in 94.0% open aerogel). That of bulk ^{4}He was plotted as triangle.

and attenuation for two aerogels as a function of temperature. For comparison, the those of bulk helium obtained in a different run was plotted as well. The sound velocity in aerogel had a dip at the superfluid transition. A sharp attenuation peak due to the superfluid transition has been observed in every aerogel as is observed in bulk liquid. The attenuation peak in every aerogel which was so sharp as that in bulk represented the homogeneous transition in aerogel. The transition temperatures in aerogels determined from the dip in velocity and the absorption peak were suppressed about 5 mK for 92.6% porosity. Increasing porosity diminished the suppression, which agreed with specific heat measurement[1,2].

It is evident from Fig. 1 that the sound mode has similar temperature variation to the first sound in bulk. However, there is a notable difference between those in aerogel and bulk. This velocity modulation has been accounted to the motion of the aerogel clamped to the normal fluid. The aerogel-^{4}He system can be regarded as a composite material. Aerogel is so compliant that would contribute to the total elasticity and density. We could fit the obtained sound velocity by this model using the aerogel sound velocity 257 m/s and 213 m/s for 92.6 % and 94.0% respectively. In this experiment, the sound velocity of aerogel itself could not be obtained because of the large attenuation. However, the sound velocity of aerogel obtained as the fitting parameters were reasonably agreed with those of other experiments[3,5,6]. Considering that the mechanical properties of aerogel crucially depend on sample preparation, result of this aerogel-^{4}He composite model is satisfactory.

Figure 2 shows that the attenuation in aerogel was much larger than that in bulk and the temperature variation was different from that in bulk. In the normal phase, the attenuation was about 90 dB/cm, which was almost independent of temperature and aerogel porosity. However, the attenuation decreased with decreasing temperature in the superfluid phase and became constant at low temperatures. The limiting attenuation at low temperatures decreased with aerogel porosity. The broad attenuation peak around 1K in bulk due to roton-phonon interaction was invisible because of the large attenuation resulted from aerogel.

The attenuation at low temperatures could be related with aerogel phonon interaction. In bulk liquid, the mean free path of phonon becomes larger with decreasing temperature, which gives rise to small attenuation at low temperatures. The constant attenuation in aerogel suggests that the mean free path is limited by scattering with the aerogel strand. The porosity dependence of the low temperature attenuation supports this idea.

It is remarkable that the sound velocity in liquid ^{4}He is tunable with aerogel porosity. Acoustic properties for various porosity aerogel would reveal the interaction between phonon, roton and aerogel in this system.

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