Interfacial tension of ^{3}He–^{4}He mixture in the low temperature region

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Abstract

We measured the interfacial tension of ^{3}He-^{4}He mixture by means of the capillary-rise method. Change in the capillary-rise was obtained from the capacitance change of two capacitors with different gap widths. It was found that the present data are in good agreement with those obtained from the resonance of the interfacial wave, and that the temperature dependence of this tension varies as T^2 down to 100 mK.

Key words: Interfacial tension; ^{3}He-^{4}He mixture; capillary-rise

Interfacial tension is one of the fundamental quantities with respect to the interface. In the system of ^{3}He-^{4}He mixture, the bulk properties have been studied extensively. So that the relation between the interface and the bulk can be studied systematically. Recently, we measured the interfacial tension of ^{3}He-^{4}He mixture down to 0.15 K by means of the resonance of the interfacial wave, and revealed that this tension decreases as T^2 from 0.4 K down to 0.15 K.[1] This T^2-dependence is attributable to the effect of the change in density difference between the ^{4}He-rich and ^{3}He-rich phases.

On the other hand, the surface tension of liquid ^{3}He has been measured down to 15 mK.[2,3] Although this tension exhibits the T^2-dependence from 1 K down to 0.2 K, it deviates downwards below 150 mK and has a small maximum around 100 mK. The T^2-dependence of this tension in the high temperature region is explained by the combination of two parts, ripplon and bulk contributions.

Although both of ^{3}He-^{4}He mixture and liquid ^{3}He show the T^2-dependence in the high temperature region, the origin is different. It is therefore of great interest to measure the interfacial tension of ^{3}He-^{4}He mixture in the low temperature region.

At low temperatures, it is difficult to measure the interfacial tension by means of the resonance of the interfacial wave because of a lager viscosity of the ^{3}He-rich phase. In the present experiment we applied the capillary-rise method, and measured this tension at saturated vapor pressure.

The equilibrium condition of the capillary-rise hight h between two parallel plates is expressed as

$$h = \frac{2\sigma}{(\rho_D - \rho_C)gd}\cos\theta \qquad (1)$$

where σ is the interfacial tension, $\rho_D - \rho_C$ is the density difference between the ^{4}He-rich and ^{3}He-rich phases, g is the acceleration due to gravity, and d is the gap width of the parallel plates. Here, the angle of contact θ is thought to be zero in the low temperature region.[4]

In the present experiment, change in the capillary-rise hight was detected by capacitance change. Two sets of capacitors with different gap widths were immersed in the sample liquid, as shown in Fig. 1 (a). The interface was kept in the lower capacitors while the upper ones were used as a reference. By using the capacitors with different gap widths we could avoid measuring the depth of the ^{4}He-rich phase precisely. In addition, the capacitance change caused by the density change of the ^{4}He-rich phase was canceled by the

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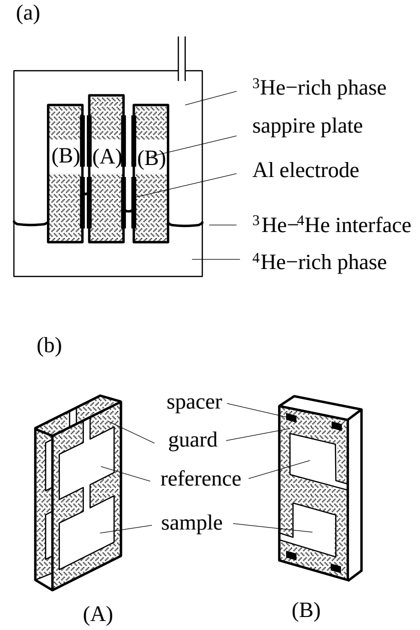

Fig. 1. Experimental setup

change in dielectric constant which is proportional to density. These capacitors consisted of three sapphire plates with Al electrodes. To avoid picking up the change of the capillary-rise near the edges, the electrodes were divided into an active area and a guard area, as shown in Fig. 1 (b). These plates were spaced with fused quartz of 50 μm and 103 μm thick.

Two pairs of capacitors were separately measured with two sets of standard capacitive bridges with a ratio transformer. These bridges were excited at the frequency of $\sim$ 600 Hz with the excitation voltage of $\sim$ 0.1 V. In the present experiment, the resolution of the bridge balance was better than 1×10^{-7} and the stability was $\sim 10^{-7}$.

Figure 2 shows the variation of the interfacial tension. Here, the absolute value at 0 K was chosen as 23.9 μN/m, which was obtained from the resonance of the interfacial wave.[1] It was found that the present data are in good agreement with those obtained from the resonance of the interfacial wave, and that the temperature dependence of this tension varies as T^2 down to 100 mK. In calculation, the angle of contact θ was assumed to be zero, i.e., this angle had no strong temperature dependence in the present temperature range.

Here, it is of interest to compare this behavior with that of the surface tension of liquid ^{3}He. In liquid ^{3}He, the surface tension deviates clearly around 150 mK and the difference at 0 K from the extrapolated T^2-dependence is about 0.5 μN/m. This behavior is explained by the effect of the decrease in density near the surface on the basis of a local approximation for the entropy of ^{3}He.[5,6] Regarding the interfacial tension, although a similar behavior would be expected near the interface, this tension did not deviate from the extrapolated T^2-dependence in the present temperature range. However, it is thought that the change in density difference between the ^{4}He-rich and ^{3}He-rich phases contributes the temperature dependence. Then, this effect may smear the deviation.

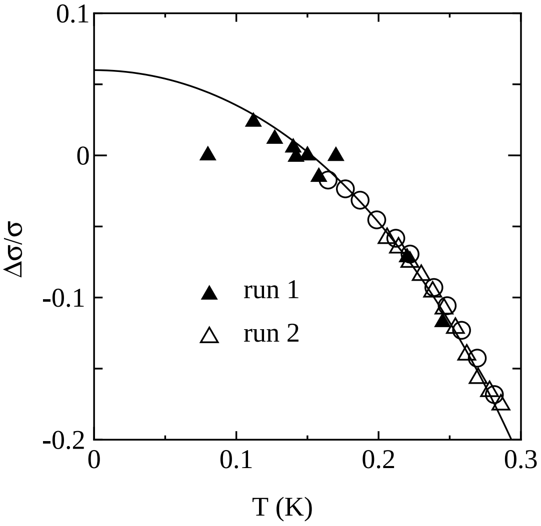

Fig. 2. Variation of the interfacial tension. Triangles correspond to the present data, and circles to the data obtained from the resonance of the interfacial wave.[1] Solid curve is the T^2-dependence which is calculated in the range from 0.4 K to 0.15 K. The absolute value at 0 K is 23.9 μN/m.

In summary, we measured the interfacial tension of ^{3}He-^{4}He mixture by means of the capillary-rise method. It was found that the temperature dependence of this tension varies as T^2 down to 100 mK. Up to the present, experimental conditions are rather limited. For further understanding, more experiments, especially those at lower temperature and under pressure, are needed.

References

[1] A. Sato et al., J. Low Temp. Phys. **107** (1997) 165; K. Ohishi et al., J. Low Temp. Phys. **112** (1998) 199.

[2] M. Iino et al., J. Low Temp. Phys. **59** (1985) 291.

[3] M. Suzuki et al., Europhys. Lett. **5** (1988) 333; K. Matsumoto et al., J. Low Temp. Phys. **125**, (2001) 59.

[4] Y. Sasaki et al., J. of Low Temp. Phys. **113** (1998) 921.

[5] S. Misawa, J. Low Temp. Phys. **125**, (2001) 49.

[6] F. Dalfovo et al., J. of Low Temp. Phys. **77** (1989) 307.