Kinetic growth properties of the interface in phase-separated ^{3}He$-^4$He liquid mixtures

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Abstract

The interfacial dynamics in a phase-separated ^{3}He$-^4$He liquid mixture plays an important role in the nucleation process of the c-phase from the supersaturated d-phase. We have determined the kinetic growth coefficient of interface ξ_ω by measuring the transmission of a sound wave through the interface within 12mK$-$200mK at frequencies 9, 14 and 32MHz. It is observed that the sound transmission coefficient demonstrates a remarkable reduction compared with the standard acoustic-mismatch theory below $\sim$70mK for 9MHz, $\sim$100mK for 14MHz, and $\sim$160mK for 32MHz. Correspondingly, the growth coefficient ξ_ω starts to increase drastically with the further decrease of the temperature. The whole data for the anomalous behavior of ξ_ω can be fitted very well as $\xi_\omega \propto \omega^{5/2}/T^3$.

Key words: Interface Growth ; ^{3}He$-^4$He Mixture ; Sound Transmission

The low temperature nucleation phenomena have been stimulating an interest in observing the quantum nucleation and the crossover from the quantum to the classical regime. The recent systematic investigation on the critical supersaturation of superfluid ^{3}He-^{4}He mixtures[1] has revelaled the existence of the temperature region where the the critical supersaturation increases with the growth of the temperature. It is suggested that this anomalous behavior corresponds to the quantum nucleation accompanied with the energy dissipation. This is based on the experimental fact that the time necessary to attain the equilibrium state after the start of nucleation becomes remarkably longer as the temperature increases. That is, the growth rate of the nucleated c-phase becomes notably smaller with the increase of the temperature. From the theoretical point of view, it is known that such situation results in suppressing the quantum nucleation rate, i.e., one naturally expects the increase of the critical supersaturation as the temperature increases.

In order to get further insight into the nucleation phenomenon, it is very desirable to study the dynamical properties of the interface and, in particular, the dependence of the growth coefficient ξ_ω on temperature and frequency. The physical meaning of ξ_ω, which vanishes in the case of two immiscible liquids, can be defined as

$$J = \xi_\omega \left[\rho_d \rho_c/(\rho_d - \rho_c)\right]^2 \Delta\mu \tag{1}$$

where $\Delta\mu$ is the difference in the chemical potentials per unit mass of the c- and d-phases in contact, $\rho_{c,d}$ is the density, and J is the mass flow across the interface per unit area. As is discussed in [2], ξ_ω is related to the transmission of sound wave through the interface. For the present case of ^{3}He-^{4}He mixtures, the theoretical discussion is given in [3] within the framework of the entirely hydrodynamic approximation and the assumption of the phase equilibrium at the interface.

In order to extract the information on the interface from the sound experiment, it is necessary to separate the bulk contribution from the transmitted sound signal. We take a way to move the position of the interface with a constant velocity between two transducers. The arrangement of the sound cells is schematically shown

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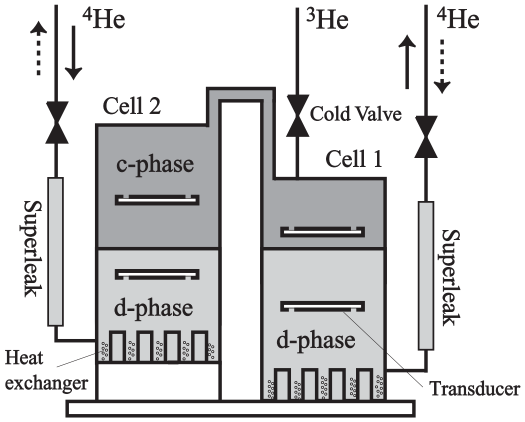

Fig. 1. Arrangement of the sound cells.

in Fig.1. This is essentially same as described previously [4]. The main modifications are that the interface velocity is controlled with the outside sysytem and the cells are fastened to a nuclear stage. The details will be given in a separate paper [5]. An example of the data is shown in Fig.2 in which the normalized amplitude of the transmitted sound from the c-phase to the d-phase is plotted as a function of the c-phase thickness l_c taken down from the upper transducer. The normalization is made to the amplitude of a signal A_d in the absence of the c-phase between the transducers. So, the transmission coefficient $\tau_{c\to d}$ can be obtained from the intercept of the straightline of the slope of $(\alpha_c - \alpha_d)$ with the ordinate at point $l_c = 0$.

The growth coefficient ξ_ω is calculated from

$$\tau_{c\to d} = 2Z_d/(Z_c + Z_d + Z_c Z_d \xi_\omega) \qquad (2)$$

where $Z_{c,d}$ is the acoustic impedance. In Fig.3, thus obtained ξ_ω is plotted as a function of temperature for the frequencies 9, 14 and 32MHz. It is seen that ξ_ω becomes relatively large at ∼70mK for 9MHz, ∼100mK for 14MHz and ∼160mK for 32MHz and increases by more than 2 orders of the magnitude to the lowest temperature investigated for each frequency. This may evidence that the superfluid-normal interface between the d- and c-phases can behave itself as a highly mobile one at sufficiently low temperatures. As is shown in Fig.3 with the solid lines, the whole data in the anomalous region can nicely be fitted as

$$\xi_\omega = A\omega^{5/2}/T^3 \qquad (3)$$

with $A = (7 \pm 2) * 10^{-28}[\mathrm{cm}^2 \cdot \mathrm{s}^{7/2} \cdot \mathrm{K}^3/\mathrm{g}]$.

The frequency-dependent behavior suggests that we are in the hydrodynamic regime. We recognize, however, that the observed behavior of ξ_ω cannot be explained within the theory [3].

It may be necessary to involve a possible appearance of the shear mode which decays into the bulk and results in an additional dissipation of the sound energy. Such mode may exist even for the normal incidence, since the sound beam is limited in the transverse dimensions.

At present, we have no convincing model to explain the result of (3). The extension of the experiment below 10mK seems most informative.

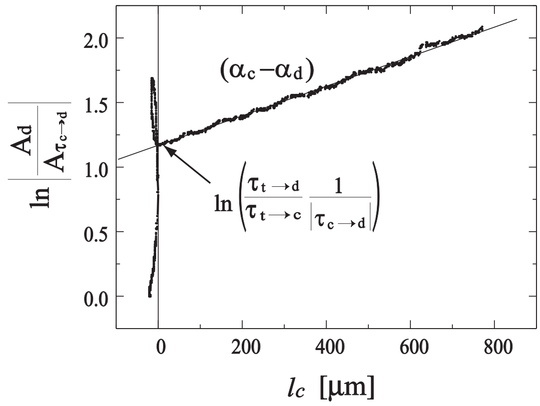

Fig. 2. Example of the data. The normalized amplitude of the transmitted signal is plotted as a function of the thickness of the c-phase under the upper transducer. $\alpha_{c,d}$ are the sound attenuation coefficients. $\tau_{t\to c,d}$ are the transmission coefficients from the transducer to the c- or d-phase.

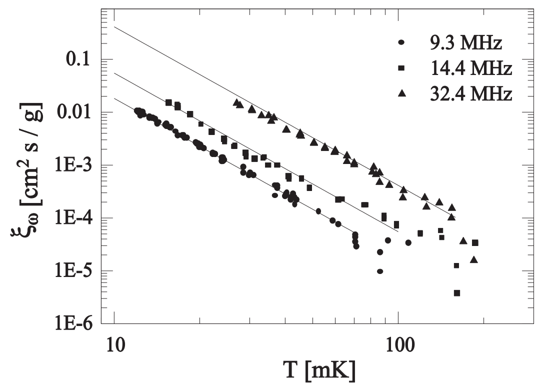

Fig. 3. The kinetic growth coefficient ξ_ω vs. temperature for various frequencies. The solid lines represent eq.(3)

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