Visualization of ^{3}He Nucleate Boiling

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Abstract

Boiling behavior of liquid ^{3}He was visualized as shadowgraph image between 0.7 and 1.8 K. A light source and a high-speed camera were arranged at room temperature. The light was guided to the ^{3}He cell by an optical fiber, and the shadowgraph image was transferred to the camera by an image fiber. The ^{3}He bubble shape on the heated copper surface was hemispherical reflecting the excellent wetting property. The size at departure from the surface and the bubble growth rate were measured as functions of heat flux and temperature.

Key words: Helium 3 bubble; Nucleate boiling; Visualization; Shadowgraph

Heat transfer characteristics from a flat copper surface to liquid ^{3}He had been studied previously from the nonboiling state to the film boiling one between 0.5 and 1 K under saturated vapor pressure [1]. The temperature difference ΔT caused by thin thermal boundary layer existing between a copper surface and bulk liquid ^{3}He was measured as a function of heat flux $\dot{q}$ under steady state. In the nucleate boiling state, the data were not explained with the Kutateladze's correlation [2]. Liquid ^{3}He has the lowest boiling point and the smallest surface tension among elemental substances. Those features mean that there is no pre-existing bubble nucleus, which would stimulate the bubble formation. Then, liquid ^{3}He is thought to show unique bubble formation process. In order to clarify the nucleate boiling state, we have observed the bubble by visualization method [3]. In the present study, we have observed the bubble formation process using a high-speed camera to see the bubble growth rate at wide temperature region.

A light source and a high-speed camera are arranged at room temperature. The light is introduced through an optical fiber, and is collimated to a parallel beam by a convex lens. When the beam passes through boiling liquid ^{3}He stored in a cell of Pyrex glass wall, the beam is refracted due to the difference of density. Therefore, the transmitted beam shows a shadowgraph image, and is imaged on the low temperature side of an image fiber by a convex lens. The image fiber is a coherent bundle of 30000 optical fibers whose each diameter is 3 μm.

Liquid ^{3}He stored in the optical cell (Fig. 1) was evaporated by pumps to maintain the steady state. The upper surface of a copper block whose diameter is 7 mm is the heat transfer surface polished with 1500 - grit sandpaper. After the steady state was established under a certain amount of heat flux $\dot{q}$, the temperatures of copper block and liquid ^{3}He were measured by Ge thermometer and carbon thermometers, and then, pictures were taken for 4 seconds by a high-speed camera capable of taking 500 frames per second. The obtained $\dot{q}$ - ΔT relations are shown in Fig. 2.

Fig. 3 shows 9 successive pictures of ^{3}He bubbles formed on heated copper surface at $\dot{q} = 8.04 \times 10^{-5}$ (W/cm^2) and 0.7 K of bulk liquid ^{3}He temperature. The time interval of each photo is 1/500 second. Fig.4 shows 6 successive pictures at $\dot{q} = 1.0 \times 10^{-4}$ (W/cm^2) and 1.8 K. The photographs were obscure at high temperature because the bubble growth time was short. The times for a bubble growth and departure from surface were 14 ms and 6 ms at 0.7 K and 1.8 K respectively. The shape of bubble on the surface is spheroid-like, which is explained by the low surface tension of

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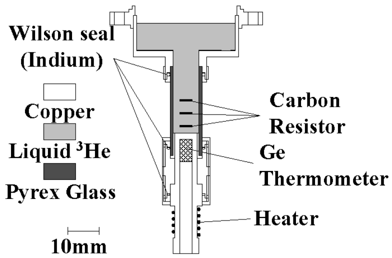

Fig. 1. Optical cell

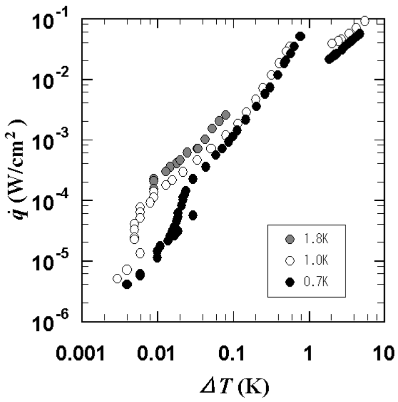

Fig. 2. $\dot{q}$ - ΔT curve at 0.7, 1.0 and 1.8 K under saturated vapor pressure.

liquid ^{3}He. On the other hand, a nitrogen bubble observed by Bland *et al.* was spherical with a short neck on the surface [4].

Fig. 5 shows the average bubble size D measured in the vertical direction as a function of heat flux at 0.7, 1.0 and 1.8 K. The departure size D is considered to depend on the contact angle, the surface tension and the density difference of liquid and vapor [5]. However, in order to explain the small D at 1.8 K, the effect of inertial force has to be considered because the bubble formation rate is high. The experiments at various conditions (temperature, heat flux, surface roughness) are in progress.

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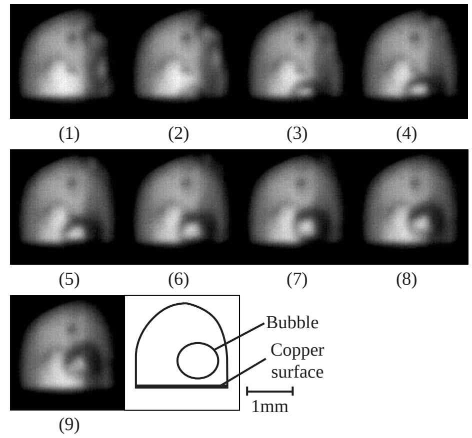

Fig. 3. ^{3}He bubbles formed on heated copper surface. Successive pictures for 1/500 second at $\dot{q} = 8.04 \times 10^{-5}$ (W/cm^2). Liquid ^{3}He is 0.7 K.

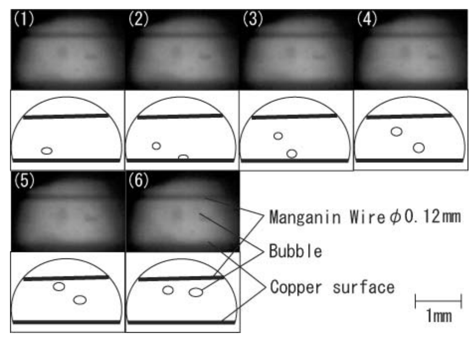

Fig. 4. Successive pictures for 1/500 second at $\dot{q} = 1.0 \times 10^{-4}$ (W/cm^2). Liquid ^{3}He is 1.8 K.

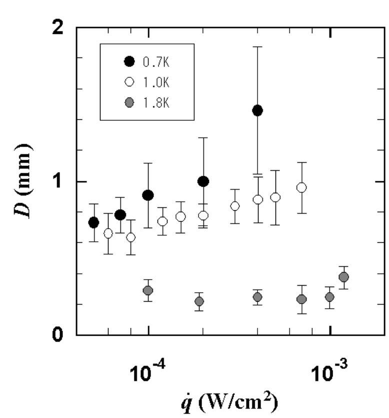

Fig. 5. Bubble size versus heat flux at 0.7, 1.0 and 1.8 K.