Detection of microlayer geometry in nucleate boiling using interferometry of infrared light

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1. Introduction

Nucleate boiling is very efficient heat transfer mode using latent heat of evaporation from liquid to vapor. Although a number of studies have been carried out over half a decade, understanding the exact physical mechanism of nucleate boiling is still not enough due to the complexity of the phenomena and the multi time and length scale, respectively, ranging from μsec to msec and from nm to mm.

When a bubble rapidly grows on a heated surface, it is supposed that a thin liquid layer, the so-called microlayer, is generated underneath the growing bubble, which plays an important role in the single bubble growth behavior. Cooper and Lloyd [1] measured the wall temperature of the local points underneath the growing bubble using a micro-sized thermocouple. They argued the presence of microlayer under the growing bubble based on changing temperature of surface and analysis of heat flux of surface. Koffman and Plesset [2] successfully measured the geometry of microlayer using interferometry of monochromic visible light on microlayer.

In this work the geometry of microlayer in nucleate boiling is measured using DEtection of Phase via Infrared (IR) Thermometry (DEFIcT) [3], which is a new measurement technique to study the distribution of liquid-vapor phase on a boiling surface. By observing the geometric evolution of microlayer during the nucleation, growth, and departure periods of bubbles, the role of microlayer in nucleate boiling heat transfer will be studied for various heat flux values under atmospheric and saturation condition.

2. Equipment

2.1 Microlayer interferometry

Basically the DEPIcT technique measures the temperature to detect the liquid-vapor-solid triple contact line on the infrared-transparent boiling substrate. Let us consider that a microlayer on a boiling surface as described in Fig. 1. The boiling surface is made of the IR-transparent optical-grade silicon wafer, which allows the IR lights from the microlayer to reach the IR camera. However, some IR light from the microlayer is reflected on the boiling surface and the top surface of the microlayer in serial, and then comes to the IR camera. Due to the difference in optical path length of the two cases, the interference patterns are generated. By analyzing the spacing of the interference pattern, the shape of the liquid layer can reconstruct.

The fringe spacing (Δ) is related to the wavelength (λ) of the infrared light and local slop of the film (θ) [3],

$$\Delta = \frac{\lambda}{2n}\theta \qquad (1)$$

where n is the index of refraction of the microlayer liquid. The geometry of the microlayer can be reconstructed by analyzing the interference patterns with Eq. (1).

2.2 Experiment

Fig. 2 shows the schematic of the experimental setup, which is consisted of a silicon wafer heater, boiling chamber, IR camera, data acquisition system, and DC power supplier. The boiling chamber was made of aluminum and Teflon. It has the two transparent windows on the side made of polycarbonate to visualize boiling phenomena. The top and bottom of the boiling chamber were made of Teflon plastic. A sheath type thermocouple was imbedded on the top plate to measure the bulk temperature of the working fluid. A rectangular silicon plate heater (area: 4×5 cm^2, thickness: 300 μm) is placed at the center of the bottom plate and connected to the power supplier. To diagnose the boiling phenomena with the infrared camera, a 2×2 cm^2 square hole was machined at the center of the bottom plate underneath the heater plate. Two Kapton heaters were installed to preheat the bulk temperature on the aluminum walls of the boiling chamber.

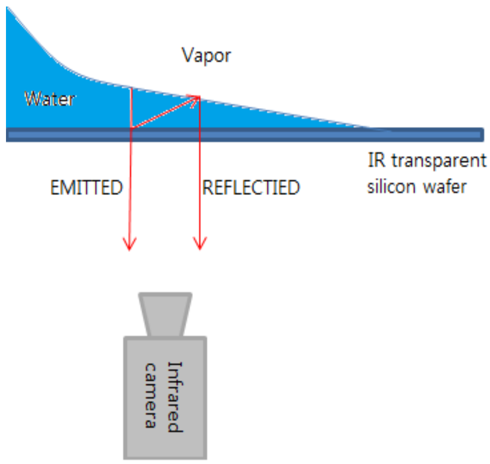

Fig. 1 Microlayer interferometry for IR light

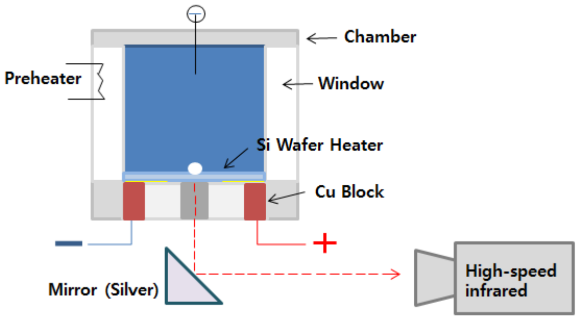

Fig. 2 Schematic diagram of the experimental setup for nucleate boiling test.

The Agilent N8760A DC power supplier (150V/5kW) was used to supply power to the heater. The applied voltage and current values to the heater were measured using the Agilent 34972A data acquisition system. The surface heat flux was calculated using the measured voltage and current values. All experiments were carried out with deionized water at atmospheric and saturation condition

3. Results

Fig. 3 shows the IR pictures of a boiling bubble at heat flux of 8 W/cm^2. The bright area indicates the liquid region, and the dark area at the center is vapor region. The interference patterns, similar to Newton's ring, between the dark (vapor) and bright (liquid) areas are observed from 1 ms through 4 ms. The interference pattern indicates the existence of microlayer in the region. The macrolayer area extends in the initial period of the bubble growth (1-3 ms). Thereafter, the area of the microlayer starts to disappear from the center and the region completely is gone until 5 ms.

The visualization results in Fig. 3 are in good agreement with the typical illustration of microlayer formation. In the initial growth period when a bubble rapidly grows due to the difference of pressure inside and outside the bubble, the very fast expending bubble front on the surface remains a thin liquid layer behind the interface, which is microlayer. The rapid initial expansion is followed by the thermal growth period in which evaporation of the microlayer takes place contributing to the continuous slow growth of the bubble.

In the present preliminary test, although the obtained results provide some noteworthy insights about microlayer, the quality of the pictures was not enough to qualitatively analyze the interference patterns and determine the geometry of microlayer. Therefore the additional works are underway to improve the image quality by optimizing the experimental setup.

REFERENCES

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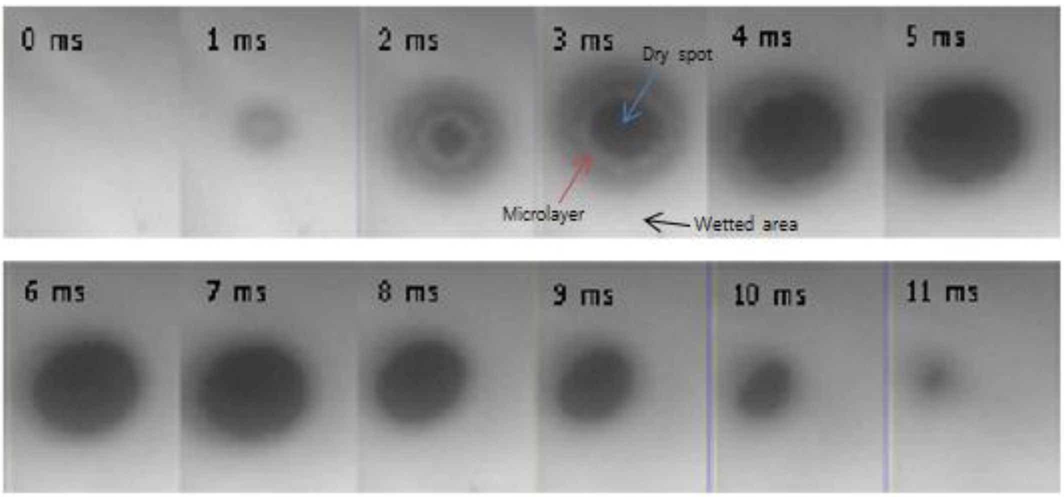

Fig. 3 IR picture during bubble nucleation, growth and departure in saturated water on an electrically-heated silicon