



An investigation of microlayer beneath nucleation bubble by laser interferometric method

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ABSTRACT

The laser interferometric method and high-speed camera techniques are used to study dynamic characteristics of the microlayer beneath an ethanol vapor bubble during nucleation process. Clear fringe patterns of the microlayer are captured showing the movement of the gas–liquid–solid triple contact line, the dynamic changes of the micro-contact angle, bubble root radius, and volume of the microlayer during the bubble nucleation process before and after dried out have occurred.

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1. Introduction

It is well-known that a thin liquid film exists at the bottom of boiling bubbles [1], which has been called a microlayer (see Fig. 1). Although the thickness of the microlayer is only several micrometers, it plays an important role in the boiling heat transfer process. During bubble nucleation, heat generated from the heating surface was taken away by the evaporation of the microlayer. In 1961, Moore and Mesler [2] first measured surface temperatures during nucleate boiling by a special thermocouple. Using the interferometric method, Sharp [3] used a mercury arc lamp as the light source to measure the thickness of a microlayer from the top of bubble for the first time in 1964. In 1969, Cooper and Lloyd [4] measured the temperature of the heating surface below bubble, and with the aid of a boundary layer analysis, suggested that the microlayer was “wedgelike” in shape. In the same year, Jawurek [5] studied the microlayer geometry and the macroscopic bubble dynamics in nucleate boiling. In 1975 Voutsinos and Judd [6] studied the growth and evaporation of a microlayer using laser interferometry and high speed photography. In 1983, Koffman and Plesset [7] investigated the microlayer formation and its thickness during nucleation of water and ethanol. They found that the thickness of the microlayer of ethanol was approximately 1.6 times of water. In 1992 MacGregor and Jawurek [8] recorded fringe patterns of a microlayer and analyzed experimental errors in previous non-laser studies. Koffman and Plesset [7] as well as MacGregor and Jawurek

[8] have performed calibration tests to check the accuracy of the interferometric technique. The results of these calibrations showed that errors of this technique were lower than 0.5%.

In most of previous experimental studies, researchers focused their attention on the investigation of thickness change and evaporation of a microlayer. As far as the authors are aware, no previous research work was carried out on the investigation of the movement of gas–liquid–solid triple contact line, and the changes of the microlayer's thickness and its micro-contact angle during the entire period of bubble growth. In this paper, we adopted Koffman and Plesset's [7] method to investigate changes of microlayer's thickness, using a He–Ne laser to provide highly coherent, collimated light, and a high speed CCD to record fringe patterns.

2. Experimental investigation

2.1. Heating surface

In this experiment, we used ITO glass consisting of Pyrex glass and ITO-coatings as the heating surface. Chemical corrosion method was first used to fabricate a heating surface (10 mm × 10 mm in size) as shown in Fig. 2(a). Two copper sheets were bonded to the edges of the ITO film surface by conducting resin. The total electric resistance was about 15Ω. Since the middle of the heating surface was narrower than that of two sides, so the resistance was higher at the middle. When DC voltages were applied at edges of the heater with electric current passing through the heater, a bubble was generated at the middle part of the heater.

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Nomenclature

A	empirical constant	λ	wavelength of He–Ne laser, μm
a	empirical constant	δ_m	thickness of microlayer at m fringe order, μm
B	empirical constant	ρ_v	density of saturated vapor, kg/m^3
b	empirical constant	ρ_l	density of saturated liquid, kg/m^3
C	empirical constant	$\delta(R_b, t)$	the maximum thickness of microlayer at the time of t and $r = R_b$, μm
D	empirical constant	θ_d	micro-contact angle at the time of t_d
E	empirical constant	θ_2	micro-contact angle
F	empirical constant		
m	empirical constant	Subscripts	
n	empirical constant	d	dry spot
n_l	refractive index of ethanol	l	liquid
p	empirical constant	m	fringe order
r_d	radius of dry spot, μm	v	vapor
R_b	bubble root radius, μm		
t	bubble growth time, ms	Superscript	
t_d	dry spot appear time, ms	0	initial
V	volume of microlayer		
Greek symbols			
ν	kinematic viscosity of liquid		

2.2. Experimental setup

Fig. 2(b) is the schematic of the laser interferometric and high speed CCD record system used in this experiment. An He–Ne laser provided the highly coherent and monochromatic light source

suitable for interferometry. The laser power was 50 mW with wavelength at 632.8 nm. As seen from Fig. 2(b), He–Ne laser emitted a beam of laser. The laser beam was directed to a beam splitter which positioned between microscope lens and boiling vessel. Then the laser beam was reflected to the bottom of boiling bubble with normal incidence. When the laser beam passed through the bubble, parts of the laser beam were reflected by two surfaces of liquid microlayer (Fig. 1(b)). Then the two reflected beams interfered at the lower surface of microlayer. The beams, passing through the beam splitter and microscope lens, were reflected into the high-speed CCD which were used to record interference fringes. The high speed CCD used in this experiment was X-stream™ XS-4 with 5145 fps at full resolution, and it could be as high as 400,000 fps at low resolutions. The recording frequency in this experiment was 28,000 fps with the exposure time of 30 μs .

3. Interpretation of fringe patterns

3.1. Fringe patterns record

In this experiment, ethanol was used as the test fluid. The experiment was conducted at atmospheric pressure of 102,573 Pa at a subcooling temperature of 6.1 °C. The total input heat flux was at 32.4 kW/m^2 and the framing rate was at 28,400 frames/s. After simple image processing, such as contrast changing and background correction, fringe patterns were obtained and are presented in Fig. 3(a). As seen from this figure, the shape of the fringe patterns was similar to those obtained by previous researchers [6–8]. It can be seen that the microlayer grew very fast at the initial period of bubble growth. Subsequently, a dry spot began to appear at the center of fringe patterns, and the size of the dry spot expanded slowly.

3.2. Calculation of fringe pattern

The laser beam was first reflected by the two surfaces of liquid microlayer. Then, the two reflected beams interfere at the lower surface of microlayer. The thickness of microlayer can be calculated from the fringe patterns as follows:

The optical thickness of the two adjacent light rings is:

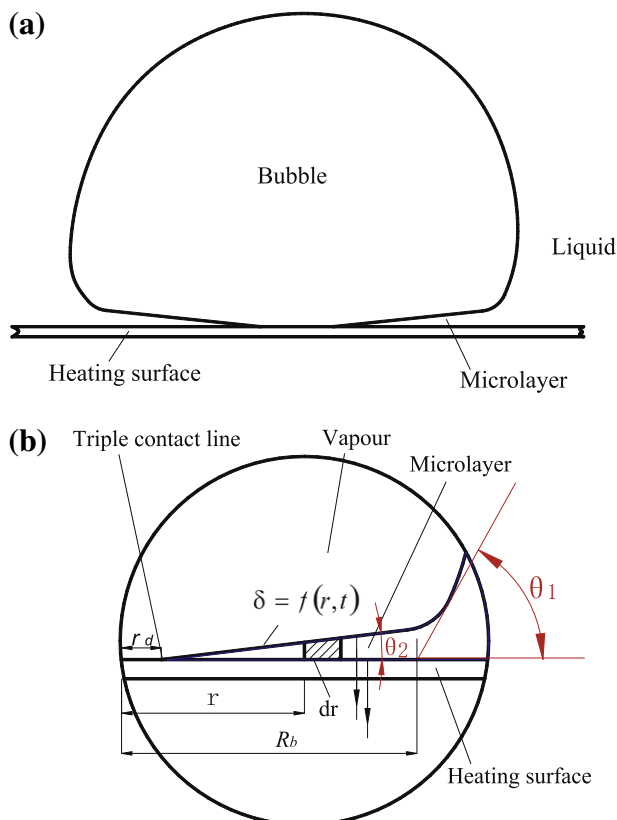


Fig. 1. Schematic of microlayer beneath a nucleation bubble at certain instant of time: (a) microlayer beneath a nucleation bubble, (b) enlargement of the microlayer.

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