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TECHNICAL NOTES

Peculiar bubble generation on a film heater submerged in ethyl alcohol and imposed a high heating rate over 10^7 K s^{-1}

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1. INTRODUCTION

WHEN LIQUID is heated up to the limit of superheat, an explosive boiling due to the fluctuation nucleation may occur. Much attention has been given to such boiling phenomena because of academic interests and engineering requirements concerned with vapor explosions by way of example [1]. A number of researchers have investigated the boiling due to the fluctuation nucleation by heating rapidly a fine metallic heater immersed in various kinds of liquids [2–7]. The most marked works are those by Skripov *et al.* [2–4], who have demonstrated that the heater surface temperature at the inception of boiling agrees well with the theoretical value of the homogeneous nucleation temperature for several organic liquids when a very high heating pulse is supplied to a wire heater. The nucleation, however, may occur in the very thin layer of the superheated liquid, because an extremely steep temperature gradient near the heater surface develops for rapid heating. The behavior of the nucleation and the bubble growth, therefore, may differ from that for uniform heating. In spite of the difficulty of using the wire heater for observing bubble behavior, the experiments conducted for the organic liquids and using a flat film heater, which is optimum for observing and exploring the nucleation behavior, can be hardly found in the literature.

In the present study, the heater surface temperature at the inception of boiling, when an extremely high heating pulse is supplied to a thin film heater submerged in ethyl alcohol, has been measured and the bubble behavior near the inception of boiling has been observed. The rise rate of the surface temperature ranges over 10^7 K s^{-1}. The surface temperature at the inception of boiling has increased asymptotically to the homogeneous nucleation temperature of the liquid with the increase of the surface temperature rise rate. The peculiar bubble generation considered to be originated by the fluctuation nucleation on the heater surface and/or in the liquid layer with the extremely steep temperature gradient has been observed. The increasing rate of the bubble number has been compared with that calculated using the homogeneous nucleation theory.

2. EXPERIMENTAL APPARATUS AND PROCEDURES

Figure 1 shows the sketch of the film heater, which is a composite film of platinum of 0.2 μm and chromium of 0.05 μm in thickness deposited by sputtering on a quartz glass substrate. The width of the heater is 0.10 mm and the distance between potential voltage taps is 0.25 mm. The heater, whose platinum surface is cleaned by acetone prior to the set-up, is set facing upward in degassed ethyl alcohol maintained at atmospheric pressure and room temperature T_l.

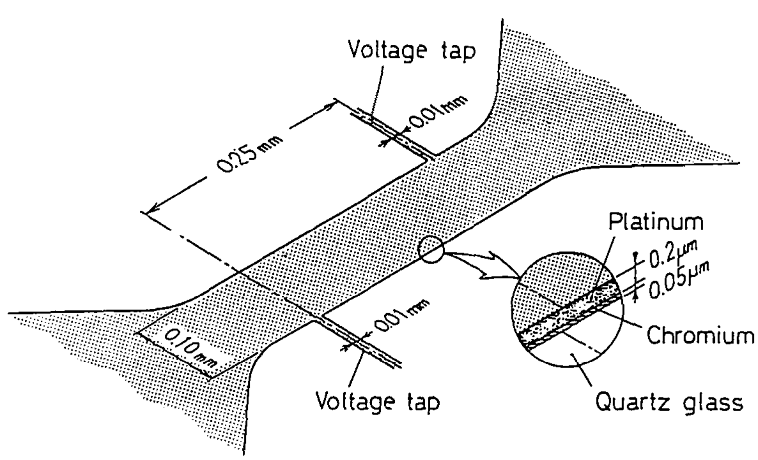

FIG. 1. Sketch of the film heater.

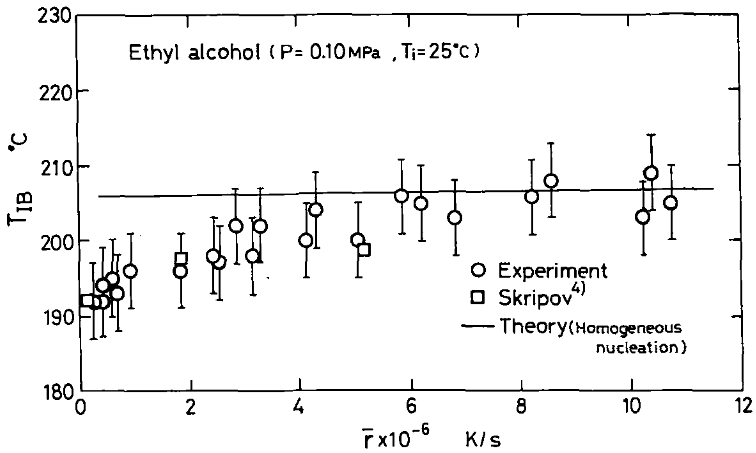

FIG. 2. Relation between the time-averaged rise rate of surface temperature and the surface temperature at the inception of boiling.

The film is heated by d.c. current supplied from a pulse generator via a power amplifier. The voltage drop across the taps and the heating current measured by a current probe are recorded in a storage oscilloscope. The temperature of the film is obtained by referring the measured resistance to the calibration result of the resistance vs temperature. The calibration is carefully conducted over the temperature range of interest using a thermostatic bath and the platinum wire resistance thermometer. According to the simulation of one-dimensional heat conduction to the media, the temperature distribution across the film thickness is less than 1 K even at the maximum heating pulse. The heater temperature, therefore, can be regarded as the surface temperature of it with a difference of less than 1 K. The maximum uncertainty of the temperature measurement of the heater, which is primarily dependent on the accuracy of measured voltage, is estimated to be less than ± 5 K.

The bubble behavior is observed through a microscope and photographed by a 35 mm single-lens reflex camera. A stroboscopic lamp whose lighting period is 10 ns and discharging energy 2 mJ during the period is used. This lamp enables taking a still photograph during only one exposure. The lighting time after the onset of the pulse heating is controlled by the delaying circuit of the pulse generator.

3. EXPERIMENTAL RESULTS

Figure 2 shows the relation between the time-averaged rise rate $\bar{r}$ of the surface temperature until the inception of boiling

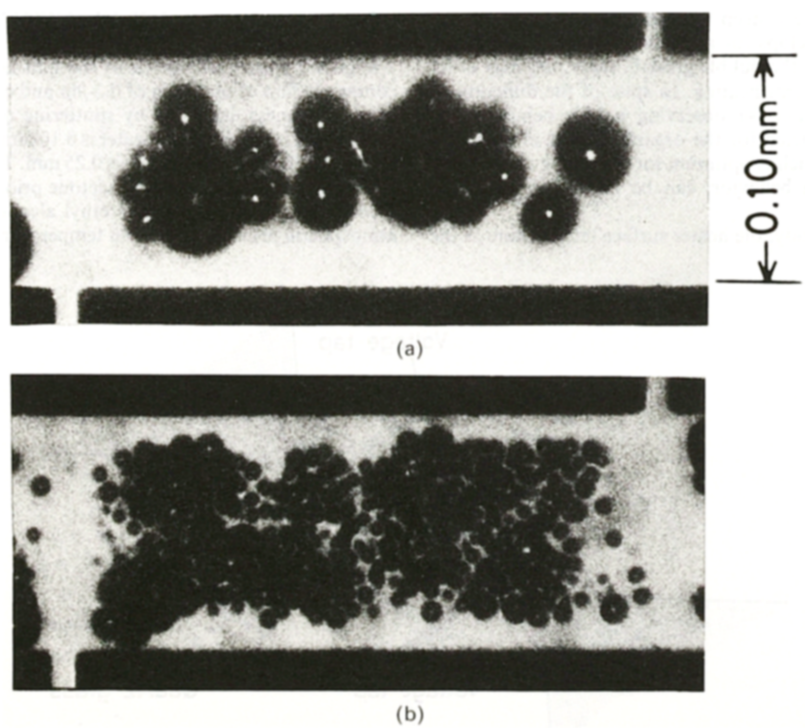

FIG. 3. Photographs of bubble behavior just after the inception of boiling for two cases of the surface temperature rise rate (ethyl alcohol): (a) 2.6×10^6 K s^{-1}, $t = 78.0$ μs; (b) 10.7×10^6 K s^{-1}, $t = 19.9$ μs.

and the heater surface temperature at the inception of boiling T_{IB}. The T_{IB} is defined as the temperature at which one initial bubble appears on the heater surface. The temperature, whose data are shown with the band of the error in the figure, increases with the increase of $\bar{r}$ and agrees asymptotically with the theoretical temperature of the homogeneous nucleation of ethyl alcohol at atmospheric pressure.

Figures 3(a) and (b), respectively, show the photographs of the bubble behavior just after the inception of boiling for the two cases of the surface temperature rise rate. In Fig. 3(a), the rather flat bubbles appear on the heater. These bubbles grow and soon coalesce with one another on the heater surface. In Fig. 3(b), however, a large number of tiny bubbles, which look spherical or hemispherical, nucleate on the heater as if they are 'caviar spread on bread'. Thus, the authors call the behavior 'caviarwise bubble generation'. The surface temperature at the inception of boiling in the latter case almost reaches the theoretical value of the homogeneous nucleation temperature. The bubble nucleation behavior is considered to bear some resemblance to that observed on a platinum wire in liquid nitrogen by the present authors [6] and is obviously different from that at the lower heating rate of the former case and those in steady state nucleate boiling. The boiling, whose rise rate of the surface temperature is 10.7×10^7 K s^{-1}, therefore, can be regarded to be originated by the fluctuation nucleation. No appearance of the bubbles near the edge of the heater and near the taps may be due to the temperature distribution caused by the thermal conduction in the direction along the surface. The difference between the temperature in the center of the heater and the averaged temperature over the width is estimated to be about 4 K for the case of 10.7×10^7 K s^{-1} from the numerical analysis of the two-dimensional and transient heat conduction.

Figure 4 shows the time variations of the number density of the bubbles to appear on the heater surface for three cases of the surface temperature rise rate, where $t' = 0$ is defined as the inception time of boiling for the respective case. At the lower temperature rise rate, the number of bubbles shows the tendency to saturate with time. The number of bubbles at the higher temperature rise rate, however, continues to increase remarkably before the growth and the coalescence of the bubbles on the heater surface. The solid lines in Fig. 4 show the number of bubbles, calculated by integrating numerically the theoretical homogeneous nucleation rate by the Döring–Volmer equation [2] with time and over the superheated layer. Even at the higher temperature rise rate, the increasing rate of the measured bubbles is found to be less than that by the homogeneous nucleation theory. This fact may be due to the reason why the following nucleation is affected by the preceding one.

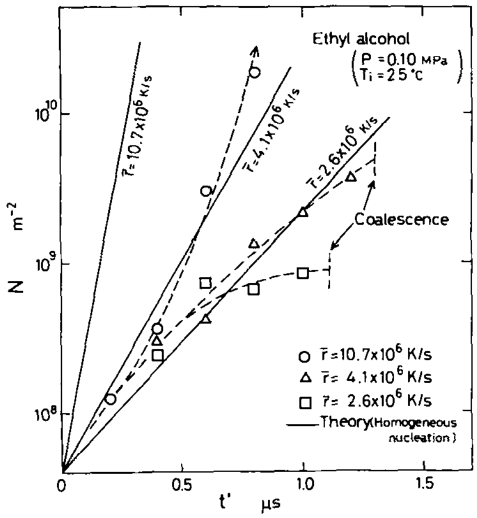

FIG. 4. Time variation of the number density of bubbles for three cases of the surface temperature rise rate.

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