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Synchronized Observations of Bubble Growth and Microlayer Evaporation in Horizontal Pool Boiling

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1. Introduction

The present study is aiming at the visualization of the boiling structures for various pool boiling and flow boiling conditions by applying multiple visualization techniques simultaneously. The bubble growth rate and microlayer behavior were simultaneously visualized for an isolated boiling regime of a water by using a shadow graph and a total reflection technique, respectively.

2. Experimental Setup and Results

The experimental apparatus consists of a boiling pool with a transparent heating surface, a power supply system, a data acquisition system, a lighting system and two high speed digital video cameras (Fig. 1). A rectangular sapphire glass, 80 × 120 mm^2 and 1 mm thick, was sit at the bottom central part of the boiling pool. A 350 nm thick transparent ITO (Indium Tin Oxide) layer was sputtered at the bottom surface of the sapphire glass and it was used as a heating source. Details of the test apparatus can be found in the reference [1].

A total reflection occurred at the top surface of the sapphire glass when the bubble was attached to the heating surface. The total reflection images and the lateral images of the bubble growth were recorded by two high speed digital video cameras with a time resolution of 0.05 msec (20,000 frames per second) and a spatial resolution of 30-40 μm.

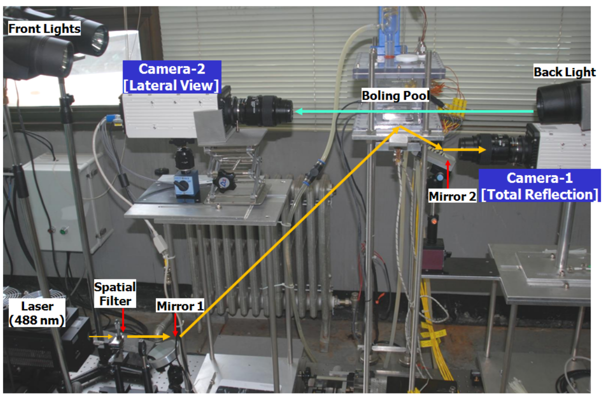

Fig. 1 Photo of the test apparatus

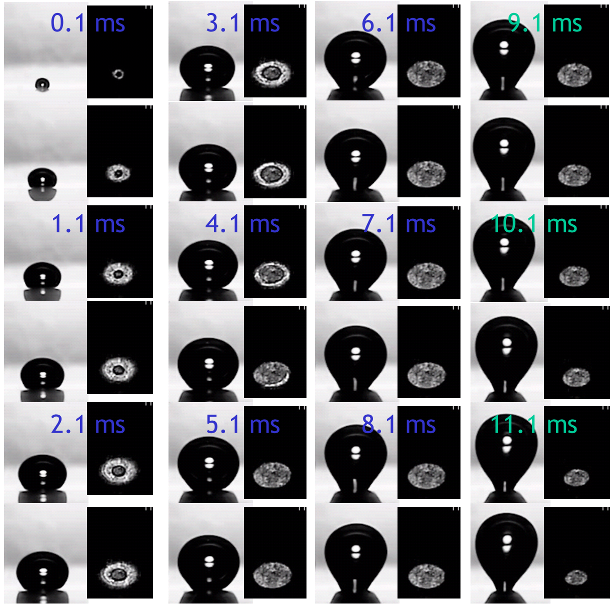

Fig. 2 Consecutive images of the lateral view (left) and the total reflection (right) for isolated bubble growing in the saturated horizontal water pool boiling at a heat flux of 45 kW/m^2.

The total reflection occurred at the bubble base consisting of the central dry area and the microlyer region. The total reflection from each region can be clearly discerned from the images of 0.1~4.1 msec in the Fig. 3. That is, the bright circle at the center and the bright outer ring correspond to the total reflections from the dry spot and the microlayer, respectively.

From the total reflection images of the growing bubble, it could be found that the dry spot area was much smaller than the microlayer area at the beginning period of the bubble growth. That is, the growth of the microlayer preceded the growth of the dry spot. Then the dry spot grew due to the evaporation of the microlayer. The whole bubble base became dry when the microlayer was totally depleted at the time of 5.1 msec.

Bubble grows by the following three mechanisms: (1) inertia of pressure potential, (2) evaporation of the microlayer beneath the bubble, and (3) evaporation of the superheated liquid layer (macrolayer) around the bubble periphery. The bubble growth rate by the macrolayer evaporation can be evaluated by calculating the volume increase rate of the bubble after the instance when the microlayer was totally depleted (time of 5.1 msec). The contribution of the inertia and the microlayer evaporation can be evaluated by subtracting the contribution of the macrolayer evaporation from the total increase rate of the bubble volume from the time of 0.1 to 5.1 msec.

The total increase rate of the bubble volume increased rapidly from the instance of the bubble nucleation and reached maximum at the time of 2.1~3.1 msec (Fig. 3), and the area of the microlayer also reached the maximum at the time of 2.1~2.6 msec (Fig. 4). The total increase rate of the bubble volume dropped sharply at the time of 5.1 msec (Fig. 3), which corresponded to the time when the microlayer was totally depleted. After then, the increase rate of the bubble volume decreased continuously, corresponding to the continuous decrease of the perimeter of the bubble base, i.e., the heat transfer area of the macrolayer (Fig. 3).

The contribution of the macrolayer evaporation to the bubble volume increase was comparable to or even higher than that of the microlayer evaporation during the time of 0.6~4.6 msec when the microlayer evaporation was active (Fig. 3). The total contribution the macrolayer evaporation to the whole process of the bubble growth was about 70%, and the rest of the bubble growth was due to the inertia of the pressure potential and the microlayer evaporation.

The bubble growth due to the microlayer evaporation was closely related to the area of the microlyaer underneath the bubble and showed the same tendency with the area of the microlyaer (Fig. 4). However, at time of 0.1 msec, the bubble growth rate was about 75% of the maximum bubble growth rate even though the area of the microlayer was about 10% of the maximum area. This discrepancy was due to the bubble growth driven by the inertia of the pressure potential.

3. Conclusions

The bubble growing mechanisms were analyzed by the synchronized observations of the lateral view and the total reflection for an isolated bubble in a saturated horizontal water pool boiling. The volume change rate of the bubble and the area of the microlayer were quantified from the synchronized observations. The total contribution of the macrolayer evaporation to the whole bubble growth process dominated over the contributions of the intertia and the microlayer evaporation. The bubble growth due to the microlayer evaporation was closely related to the area of the microlyaer underneath the bubble.

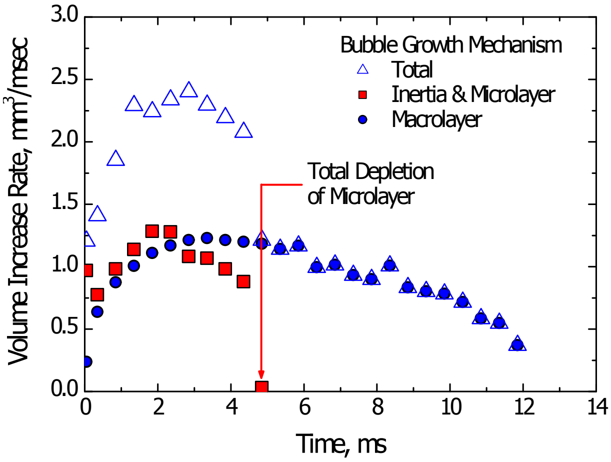

Fig. 3 Bubble growth rate by the inertia, microlayer and macrolayer evaporations.

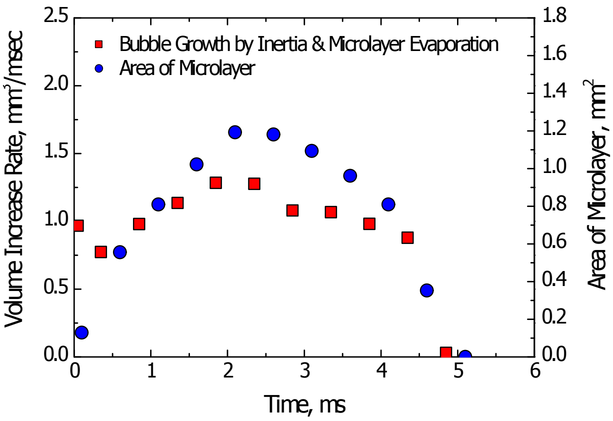

Fig. 4 Comparison of the bubble growth by the inertial and microlayer evaporation with the area of the microlayer.

REFERENCES

[1] I.-C. Chu, C.-H. Song, H. C. NO, Observation of boiling structures on a horizontal heating surface using a total reflection technique, Transactions of the Korean Nuclear Society Spring Meeting, Pyeongchang, Korea, May 27-28, 2010.