The nucleate boiling heat transfer by the hydrophobic milli-dot on the silicon surface

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1. Introduction

Over the past years, the enhancement of nucleate boiling heat transfer is an interesting topic in two-phase area. Because of this point, many researchers attempt to derive a better nucleate boiling heat transfer condition. Among those many tries, the change of wettability is regarded as a powerful method. Recent studies have shown that the nucleation site density, which is a dominant factor on nucleate heat transfer, is related with the surface wettability. In this respect, the pool boiling experiment result on interesting surface, which has the hydrophobic milli-dots on the silicon surface, is introduced in this paper.

2. Methods and Results

2.1 Sample preparation

Three kinds of the heating surface, i.e. silicon, 1-milli-dot, and 9-milli-dots surfaces, are examined in the pool boiling experiments under 1 atm. Each heating surface has a different surface condition but it is based on the same basic silicon oxide surface which has the Ti heater under the silicon surface for Joule heating. The effective heating silicon area is 10mm x 15mm.

The basic surface material is the silicon oxide whose contact angle to water is 60^o at room temperature. By the hydrophobic dot stamping method, all the bare silicon oxide surfaces are changed to unique individual surfaces from a silicon surface condition.

The hydrophobic dots on the silicon surface are made of the peculiar Teflon (AF1600). A characteristic of the AF 1600 enables it to be dissolved in an appropriate solvent and its contact angle to water is 120^o in the room temperature when all of the appropriate solvent get evaporated

2.2 Surface Characterization

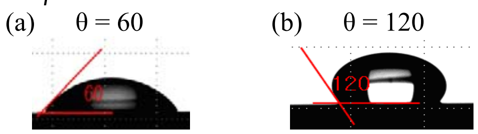

Fig. 1. Static Contact angle on (a) Silicon surface and (b) Teflon coated surface

We measure the static contact angle to know the exact difference on the surface wettability. 3 micro-liters of water are needed to generate a droplet on the surface of the heating sample. The results of repeated measurements indicate that the measuring uncertainty of the contact angle is about 3^o. The contact angle of the silicon surface, which contains the native oxide layer, is 60^o. The exact contact angle made by the AF1600 coated surface, which is the particular Teflon, is 120^o in the present condition.

It is confirmed by the 3D-profiler that the Teflon dot does not possess a micro structure which can affect the boiling phenomena. Table I shows detailed data about the Teflon dot. The Ra, which is one of the roughness parameter most commonly used so far, of Teflon dots is 12.04nm. It is a small order enough to observe that boiling phenomena is not governed by the dot micro structure effect.

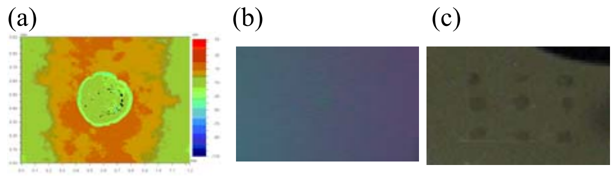

Fig. 2. (a) Dot by 3d-profiler, (b) 1-mlli-dot,(c)9-milli dots

Table I: Information about Teflon dots

Type	1-Milli-dot	9-Milli-dots
Ra	12.04nm	
Average Diameter	1.07mm 1.25mm	1.25mm 1.07mm
Area Ratio =Total Teflon Area/ Heating Area	0.8% =[1.23/150]	5.4% =[8.09/150]
Pitch	none	>1mm

2.3 Result and Discussion

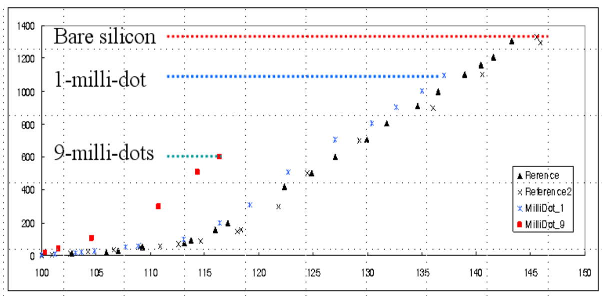

Fig. 3. Boiling curves: Silicon, 1-milli-dot, and 9-milli-dots

All experiments are conducted through the same procedure and condition in 1 atm at saturated with distilled water by electronic joule heating method. Fig.3. shows the boiling curve in experiment with the bare silicon surface, 1-milli-dot, and 9-milli-dots on silicon surface. In terms of the nucleate boiling heat transfer, hydrophobic dots have a good effect. Of the 2 hydrophobic type samples, the 9-milli-dots shows a great better enhancement of nucleate boiling heat transfer than reference silicon surface, and the 1-mlli-dot shows a slightly better than silicon surface. But the hydrophobic dot cases show the bad effect for CHF. The 9-milli-dots experiment record the worst CHF among all experiment and 1-milli-dot is next.

To analyze the difference of heat transfer between samples, the bubble growth at the onset of nucleate boiling (ONB) is shot by the high speed camera. According to analysis of bubble growth by photograph, there are the big three differences between the hydrophobic dots and bare surface.

One is the timing of ONB. Bare silicon surface's ONB is near 115C, but the ONB of hydrophobic dots is 101~102C. The early ONB can induce the boiling phenomena to good heat transfer situation, and is well shown at the 9-milli-dots boiling curve. The other is bubble departure frequency which shows very slower on the hydrophobic dots than on the silicon surface. From the photograph analysis, the bubble on silicon surface takes 16.31ms, and that on the hydrophobic dots takes 0.61s from the initiate to the departure. It is conjectured that the ONB of the hydrophobic dots is too early to make many bubbles for certain period of time. The last point is initiation bubble size. The bubble size is affected by many factors, like as the surface condition, so their size and initiated place is not exactly same through all experiments on the silicon surface. But the experiment with the Teflon dots has the exactly same initiated place, the hydrophobic dots, and the initiated bubble size on the hydrophobic dots is depended on the size of the hydrophobic dots. It means that the 1-mlli-dot and the 9-milli-dots have almost same bubble diameter on a dot at the ONB.

With these observations, the nucleate boiling heat transfer characteristic of each case can be explained. All hydrophobic dots make the early ONB but the bubble departure frequency at the ONB is very slow. So 1-milli-dot case shows a slightly better than the reference; only one milli dot doesn't make total bubble volume which can majorly affect the nucleate boiling heat transfer. But 9-milli-dots case shows a great better than the reference; the frequency on 9-mlli-dots is same as 1-milli-dot. But the total bubble volume on 9-milli-dots is larger than that on 1-milli-dot: Because bubble is initiated at the hydrophobic dots not at a dot and the each size of that contains same as 1-mlli-dot.

In the point of CHF, the bad result on the hydrophobic dot is conjectured that the characteristic of hydrophobic material which likes the vapor more than the liquid. It means that the liquid inflow could not approach the hydrophobic dot surface at the high heat flux situation. So the larger area of the hydrophobic dot can have the more chances to meet CHF at low heat flux. These tendencies are well shown in fig.3; the 9-milli-dots have the largest Teflon, and worst CHF.

3. Conclusions

1. The hydrophobic milli-scale dots have a good effect for nucleate boiling heat transfer.
2. The difference between the 1-milli-dot and 9-milli-dots about nucleate boiling heat transfer is explained by the particular bubble dynamics on the hydrophobic dot.
3. The hydrophobic milli-scale dot have a bad effect for CHF

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