Pool boiling experimental study for enhancing boiling heat transfer on modified surfaces.

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1. Introduction

The problem of cooling has become increasingly critical in the nuclear industry. The most effective way of cooling a nuclear power plant running at high temperatures is boiling heat transfer, which exploits the latent heat of vaporization during the phase change from liquid to gas. Among the many factors, the nucleate boiling heat transfer is regarded as most important factor because it is directly related with the efficiency of power plants.

Based on this motivation, many pool boiling experiments have been conducted for the enhancement of the boiling condition over the past several years. It has produced brilliant and challengeable results that the boiling condition is governed by the condition of the heating surface.[1-6] Consequently in this letter, we conduct the pool boiling experimental study to increase the boiling heat transfer by using the modified surfaces which consist of hydrophobic and hydrophilic materials.

2. Methods and Results

2.1. Experimental apparatus

The test apparatus is designed for a pool boiling experiment under atmospheric pressure by electronic joule heating method. It consists of a test sample jig, a main test pool, and a lid with an immersion heater and a condenser to sustain the 1atm saturated condition.

2.2. Sample preparation

To facilitate both the heating and surface modification, a thin film heater was embedded on one side of a silicon wafer and artificial surfaces were created on the other side of the wafer using the MEMs technique. The test heater is a rectangular silicon wafer plate. The substrate silicon plate is 25mm x 20mm, and has SiO_2 layer to eliminate the native oxidation effect on both the top and bottom. The heating part was a platinum thin film of about 1500 Å thickness layered on the bottom of the substrate using an E-beam evaporator. The complete platinum film heater has an H shape because they consist of electrode part and main heating part. The center region of the H shape is 15mm x 10mm which is main heating area.

Three kinds of the heating surfacec, i.e. silicon dioxide surface, Teflon coating surface, the 500μm hydrophobic dots surface, are examined in the pool boiling experiments under 1atm. We develop the surface modification method to precisely fabricate the

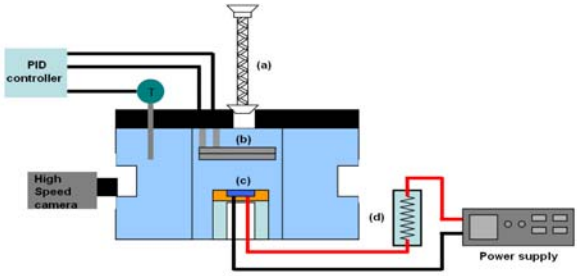

Figure 1 Schematic diagram of pool boiling facility (a)reflux condenser (b)immersion heater (c)Heating sample part and (d)Constant temperature vessel and reference resistance.

hydrophobic pattern surface which consists of two different wettability characteristics; the hydrophobic coating part and hydrophilic substrate part. The Teflon and silicon dioxide are used as the hydrophobic and hydrophilic surface.

2.3. Surface characterization

Because the wettability and surface roughness are a dominant factor in enhancing the nucleate boiling heat transfer, we investigate the static contact angle and surface roughness. The contact angle of the silicon dioxide surface, which contains the 5000Å oxidation layer, is 54^{o}.The exact angle made by the Teflon coated surface is 123^{o} in the present condition. And we confirm that the patterning procedure didn't change the contact angle of each surface.

By using 3D profiler, the roughness of bare surface (silicon dioxide surface), Teflon coated surface, and pattern surface is measured. As a result, the roughness of each surface is less than sub-micron level. It is also confirmed by the 3D profiler that the Teflon dot does not possess a micro structure which can affect the boiling phenomena. Table 1 contains the surface information.

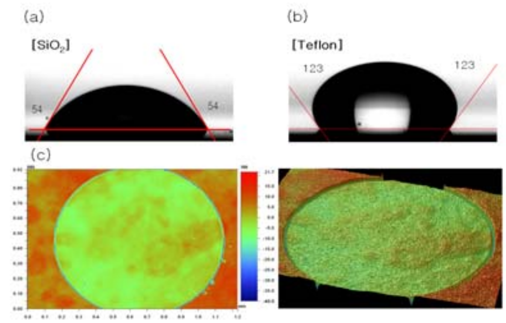

Figure 2 The picture of (a) contact angle on SiO_2, (b) on Teflon, (c) 3D profiler image about Teflon pattern

Property		Bare	Teflon	Pattern
Contact Angle (°)		54	123	Each value is preserved
Roughness (nm)	Ra	1.75	1.55	4.38
	Rt	17	27.04	52.76

Table 1 Information of surface characteristic

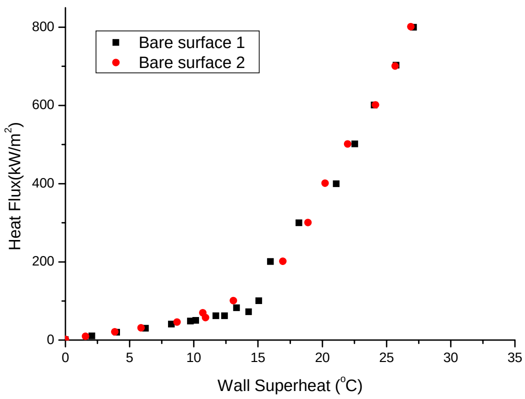

Figure 3 Experimental reproducibility

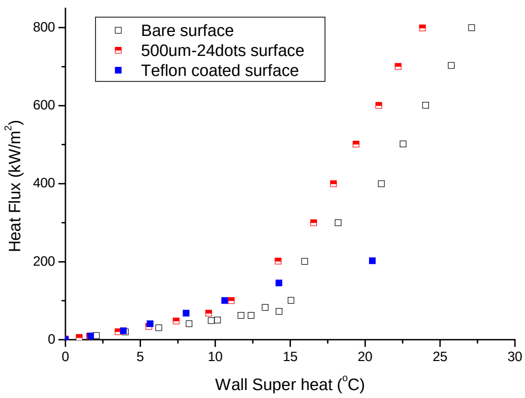

Figure 4 Boiling curve on several surfaces

2.4. Result and discussion

Figure 3 shows the reproducibility of some experimental cases for clear distinction. It is sure that the reproducibility of each result is enough to analyze the certain trend.

Now attention is focused on the boiling curve on hydrophilic, hydrophobic, and pattern conditions. According to boiling curves, the Teflon pattern and Teflon coated surface induce the better heat transfer performance than bare surfaces. The cause of enhancement results from the characteristic of hydrophobic surface. By several physicists, the existence of nanobubbles, which can play a role as a bubble nucleus of bubble initiation, and a height above the substrate of several tens nm, is reported. [7, 8] So it is conjectured that the nanobubbles on hydrophobic surface enhance the nucleate boiling heat transfer ability by activating at lower superheat than on bare surface which couldn't have the nanobubbles as a nucleus of bubble formation. But in the case of the Teflon whole coated surface, the CHF is too low to be compared with other boiling performance. The phenomenon of reduced CHF is caused by early bubble coalescence. It implies that the pattern surface is better to apply real thermal devices than whole unity surface.

Based on this pool boiling experiments on several wettability conditions, we conclude that

- The hydrophobic pattern can enhance the nucleate boiling heat transfer performance.
- The Teflon whole coated surface also showed increase of boiling heat transfer but the CHF of that is too low to apply real conditions.
- We can suggest the possibility of that the binary material heating surface has better than unity heating surface for good heat transfer ability.

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REFERENCES

[1]S.G. Liter, and M. Kaviany, Pool-boiling CHF enhancement by modulated porous-layer coating: theory and experiment, Int. J. Heat Mass Transfer, vol. 44, pp. 4287-4311
[2]T.M. Anderson, and I. Mudawar, Microelectronic cooling by enhanced pool boiling of a dielectric fluorocarbon liquid, J. Heat Transfer, vol. 111, pp. 752-759
[3] A.D. Messina, and E.L.Jr. Park, Effects of precise arrays of pits on nucleate boiling, Int. J. Heat Mass Transfer, vol. 24. pp. 141-145
[4] K.Ferjancic, and I. Golobic, Surface effects on pool boiling CHF, Experimental Thermal and Fluid Science, Vol. 25, pp. 565-571.
[5] R.W.L. Fong, G.A. McRae and C.E. Coleman, Correlation between the critical heat flux and the fractal surface roughness of zirconium alloy tubes, Enhaced Heat Transfer, vol. 8, pp. 137-146
[6]C.H. Wang and V.K. Dhir, Effect of surface wettability on active nucleation site density during pool boiling of water on a vertical surface, J.Heat Transfer, Vol. 115, pp. 659-669
[7]N. Ishida., T. Inoue., M. Miyahara. and K. Higashitani., Nano bubbles on a hydrophobic surface in water observed by tapping-mode atomic force microscopy, Langmuir, Vol. 16, pp. 6377-6380
[8]J.W.G. Tyrrell and P. Attard., Image of nanobubbles on hydrophobic surfaces and their interactions, Phys. Rev. Lett, Vol. 87, 176104