水平矩形流道中單矽晶片表面微針狀鰭片之流動沸騰熱傳及氣泡特性研究

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摘要

本論文利用雙相流冷媒循環系統針對介電冷卻液 FC-72 在截面為寬 20 毫米、高 5 毫米之水平矩形流道（水力直徑為 8 毫米）中進行流動沸騰熱傳實驗研究，矽晶片埋至於測試段之底板中央且其尺寸為寬 10 毫米和長 10 毫米。另外，矽晶片表面包含三種不同微結構，分別是平滑、微鰭片 200 及微鰭片 100 三種形式，微鰭片 200 之鰭片尺寸為寬 200 微米、長 200 微米和高 70 微米，微鰭片 100 之鰭片尺寸為寬 100 微米、長 200 微米和高 70 微米，微鰭片 200 及 100 兩種表面之鰭片間距皆等於其鰭片寬度，而實驗的目的著重於探討在不同的介電冷卻液 FC-72 質通量、入口之次冷度、矽晶片之加熱通量及矽晶片表面微鰭片之幾何尺寸下對其熱傳性能及產生沸騰氣泡特徵之影響，在實驗參數範圍上，介電冷卻液 FC-72 質量通率從 280 到 502 kg/m^2s、FC-72 於測試段入口處次冷度從 0 到 4.3 ^oC、矽晶片之加熱通量從 0.1 到 10 W/cm^2 而系統壓力為常壓。

由實驗結果發現隨著 FC-72 之質通量及次冷度的提升使得沸騰

起始受到延遲，而雙相對流熱傳遞係數隨著次冷度的增加而減少但是受到質通量增加的影響則不顯著，另外，具有微鰭片結構之表面可以有效減少在單相及雙相區域之晶片表面溫度並且增加單相及雙相對流熱傳遞係數，在氣泡特徵方面氣泡脫離半徑及活躍成核孔穴密度隨著 FC-72 質通量及次冷度的增加而減少，而較高的 FC-72 質通量及較低的次冷度則導致較高的氣泡脫離頻率，再者，氣泡脫離半徑、氣泡脫離頻率及活躍成核孔穴密度則皆隨著加熱通量的上升而增加，另外，我們也發現到表面微鰭片之結構造成較小的氣泡脫離半徑、較高的氣泡脫離頻率及較高的活躍成核孔穴密度，然而，由於微鰭片 100 表面之鰭片間距太小因而導致其氣泡脫離半徑大於在微鰭片 200 之表面且具有較小的氣泡脫離頻率。

最後，將發展飽和態及次冷態之流動沸騰熱傳係數及沸騰熱通量之經驗公式。此外，氣泡特徵包含氣泡脫離半徑、氣泡脫離頻率以及活躍成核孔穴密度之量測數據的經驗公式也將被完成。

Heat transfer and associated bubble characteristics for flow boiling of FC-72 on a heated micro-pin-finned silicon chip

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ABSTRACT

An experiment is carried out in the present study to investigate the FC-72 flow boiling heat transfer performance and associated bubble characteristics on a heated micro-pin-finned silicon chip flush mounted in the bottom of a rectangular channel. The test section is a horizontal rectangular-channel with the cross section 20 mm in width and 5 mm in height (hydraulic diameter D_h = 8 mm). The silicon chip of surface area 10 mm ╳ 10 mm is flush mounted around the geometric center of the bottom plate of the test section. Besides, three different micro-structures of the chip surface are examined, namely, the smooth, pin-finned 200 and pin-finned 100 surfaces. The pin-finned 200 and 100 surfaces are respectively equipped with micro-pin-fins of size 200 μm × 200 μm × 70 μm ($W_f \times L_f \times B_f$) and 100 μm × 100 μm × 70 μm ($W_f \times L_f \times B_f$). The space between the two adjacent fins is equal to its width for both pin-finned 200 and pin-finned 100 surfaces. The micro-structures are fabricated on silicon chips through MEMS procedures. The experiment intends to explore the effects of the FC-72 mass flux, inlet liquid subcooling, imposed heat flux, and surface micro-structure of the silicon chip on the FC-72 flow boiling characteristics. In the experiment the coolant mass flux G ranges from 280 to 502 kg/m^2s, inlet liquid subcooling ΔT_{sub} ranges from 0 to 4.3 ^{o}C, imposed heat flux of the silicon chip q” ranges from 0.1 to 10 W/cm^2, and the system pressure is at atmospheric pressure, covering the saturated and subcooled flow boiling.

The experimental results show that increases in the FC-72 coolant mass flux and / or inlet liquid subcooling causes a delay in the boiling incipience. The subcooled flow boiling heat transfer coefficient is reduced at increasing inlet liquid subcooling but is slightly affected by the coolant mass flux. Besides, adding the micro-pin-fin structures to the chip surface can effectively lower the surface temperature in both single- and two-phase regions and raise the single-phase convection and flow boiling heat transfer coefficients. Moreover, the mean bubble departure diameter and active nucleation site density are reduced for rises in the FC-72 mass flux and inlet liquid subcooling. Higher coolant mass flux or lower inlet liquid subcooling results in a higher mean bubble departure frequency. Furthermore, larger bubble departure diameter, higher bubble departure frequency, and higher active nucleation site density are observed as the imposed heat flux is increased. We also note that adding the micro-pin-fins to the chip decrease the bubble departure diameter and increase the bubble departure frequency. However, due to the relatively small space between the fins on the pin-finned 100 surface, the departing bubbles are larger for the pin-finned 100 surface than the pin-finned 200 surface but the bubble departure frequency is lower on the pin- finned 100 surface than the pin-finned 200 surface.

Finally, empirical correlations for the FC-72 single-phase liquid convection, saturated flow boiling, and subcooled flow boiling heat transfer coefficients for the boiling flow over the silicon chips are proposed. Besides, the experimental data for the mean bubble departure diameter, mean bubble departure frequency, and active nucleation site density are also correlated.