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Investigation of Some Fundamental Aspects of Pool and Flow Boiling Heat Transfer

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Extended Abstract

The rapid growth in microelectronic devices, mini refrigeration systems and other high power dissipating devices, is driving a broad interest in multiphase boiling that provides heat transfer enhancement compared to single-phase cooling. Boiling plays a crucial role in thermal management systems such as high-power systems and electrical devices including electric vehicles, photovoltaics, and supercomputers. Unlike single-phase heat transfer, boiling two-phase-change can attain higher heat-transfer coefficients with smaller interface temperature increase and effective area for heat transfer due to the high-energy transfer resulting from the phase-change process. Extensive research has focused on bubble growth and departure during pool boiling as a convenient and effective method to investigate the performance of the boiling mechanisms. Flow-boiling on the other hand is an effective cooling mechanism for high heat flux applications. Depending on requirements, different flow passage orientations may be necessitated, which can significantly alter the heat transfer performance, specifically due to the nature of two-phase flow. Rapid vapour expansions may result in dynamic instabilities, reverse flow, and flow oscillations. Flow instability can also cause component damage and variable heat transfer performance including un-intended localised dry-out, and possible critical thermal failure. This is of particular significance to mini/microchannels because of the resulting large bubble-to-channel volume ratio. In the first part of this lecture, bubble behaviour during the boiling process, incorporating nucleation, growth, coalescence and departure, is studied. This latter being an important phenomenon affecting heat transfer and heat removal. Observing the bubble behaviour is a crucial method to understand the boiling heat transfer mechanism. This work studies the dynamics of single bubbles nucleating and departing from isolated artificial cavities with different diameters on different wettability coated surfaces. The experiments were conducted with FC-72 under saturation pressures. The bubble behaviour during nucleation was obtained by analysing high-speed videos. During the whole bubble growth period, Bubbles growth shape is spherical and its only contact with the boiling surface is by what we have termed the narrow 'Vapour Bridge' after an initial growth period. The contact area size is affected by the cavity diameter, with a larger bubble departure diameter for a larger cavity mouth. In addition, the higher saturation pressure will result in smaller bubble departure diameter. The bubble departure diameter is found to be nearly constant with different degrees of superheat for similar cavity diameter and saturation pressure. The bubble departure frequency increases linearly with increasing degree of superheat. The nucleation pool boiling from an isolated artificial cavity with 70 µm diameter on a horizontal silicon substrate. The bubble dynamic with SiO2, FDTS and Glaco coated surface materials were compared to investigate the effect of surface characteristics on bubble vertical coalescence. The single- and multi- vertical coalescence were observed at the boundary between the departure bubble and the initial bubble. In addition, vertical coalescence appears earlier on FDTS surface than it appears on SiO2 and Glaco coated surfaces. It is due to the faster growth of the bubble at the initial period on FDTS coated surface. It is also pointed out that the vertical coalescence of the bubble has a limited effect on bubble departure diameter. The second part of the talk will be dedicated to flow boiling in high aspect ratio micro-channels. Flow instabilities as well as effect of orientation of the channel are explored. Although there has been a great effort to cover various parameters influencing the flow boiling, there are only a few studies that investigate the high aspect ratio microchannel which considers the effect of channel orientation. Furthermore, few studies have investigated the influence of inclination on flow instability in high aspect ratio mini/microchannels with one-sided heating. In this part, flow boiling characteristics in a high aspect ratio microchannel at different channel orientations are investigated. Results show that the wall temperature distribution is affected by both heat flux and flow orientation. In terms of thermal performance, the heat transfer coefficient increases with the vapour quality, later it experiences a gradual decrease. The influence of heat flux in

heat transfer can be strongly observed in the case of low heat flux and become less important in high heat flux cases. It is also found that the vertical upward flow, due to the bubble movement and liquid film behaviour, performs better compared to the horizontal flow. Pressure instability during flow boiling in this high-aspect micro-channel was analysed during flow-boiling at different inclinations under non-uniform one-sided heating conditions to simulate the single-sided heating of microelectronics. Several different inclination angles were investigated and ranged from -20° (downward flow) to 0° (horizontal flow), and up to +90° (vertical upward flow). Flow instability decreased the surface temperature on the heated wall. Flow instability was determined to be beneficial to flow boiling heat transfer by increasing the heat transfer on the surface through instability-driven cooling. Major reverse flow, minor reverse flow and two-phase mixing were the only flow instability observed. Reverse flow instability maps were created which show that an increase in mass flux decreased the intensity of the reverse flow and the strength of the expected instability. An analysis of the pressure between the inlet and outlet found that the mass flux effect on the frequency of reverse flow and two-phase mixing events was variable. Channels inclinations of 0°, +30°, +45° and +60° experienced the most cooling from instability. The heat transfer improvements increased as heat flux increased.