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Research paper

Visualization of microbubble dynamic behaviors in open rectangular microgrooves heat sinks under saturated boiling condition

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HIGHLIGHTS

- Bubble dynamics and oscillation of triple-phase contact line were studied.
- Surface temperature of microgrooves by infrared thermal imager was conducted.
- There exists a time peak of oscillation time of the triple-phase contact line.
- Equivalent diameter of bubble-burst increases with the increasing heat flux.
- There is a temperature peak in 3D temperature distribution of the nucleate site.

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ABSTRACT

The development of the bubbles under saturated boiling condition was investigated by a high speed camera with shooting speed of 4301 frames per second and a macro lens with the combination of VERSION and MATLAB software. Oscillation of the triple-phase contact line caused by bubble-burst, geometrical characteristics of triple-phase contact line under different heat fluxes condition, effect of heat flux on the oscillation time of the triple-phase contact line, influence of heat flux on the bubble period, impact of the superheat on the bubble departure frequency, effect of heat flux on the equivalent diameter of bubble-burst and surface temperature distribution of the microgrooves heat sink were all discussed. Experimental results show that bubble-burst makes the triple-phase contact line oscillate periodically. Oscillation time of the triple-phase contact line first increases and then decreases with the increasing heat flux, and there exists a time peak; bubble period reduces as heat flux increases; equivalent diameter of bubble-burst increases with the increase of heat flux; under the condition of the same heat flux and depth of the microgroove, equivalent diameter increases as the width of the microgroove increases. The surface temperature distribution of the microgrooves heat sink under saturated boiling condition is fluctuant, and there exist wave crest and trough on the surface of the microgrooves heat sink, corresponding to the temperature of the liquid and top wall between adjacent microgrooves, respectively. With the increase of the heat flux, the mean surface temperature of the microgrooves heat sink increases. There exists a temperature peak in 3D temperature distribution of the nucleate site when bubble bursts.

1. Introduction

The open rectangular microgroove is a new type of cooling micro-configuration and heat sinks with such a configuration can efficiently dissipate the heat generated by the high-power electric equipment or highly integrated electronic chips [1–6]. There exists small temperature difference between the heating element and the heat sink and temperature uniformity could be achieved on the heated surface. The fluid in the open capillary microgrooves heat sink is driven by capillary force and disjoining pressure, and forms meniscus in cross sections, which is divided into three parts: non evaporating region, evaporating thin film region and instinct region as shown in Fig. 1.

Many scholars have experimentally investigated effect of bubble dynamic behaviors on the heat transfer and flow characteristics in micro-configuration heat sinks. For example, Li et al. [7] analyzed the bubble dynamic behaviors in two parallel

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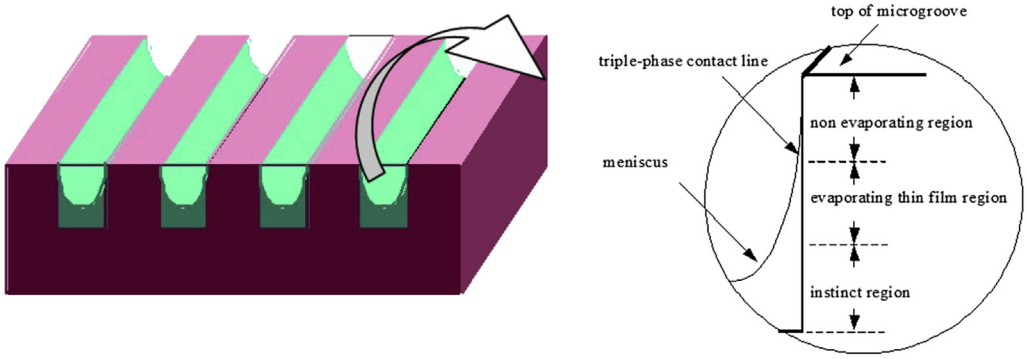
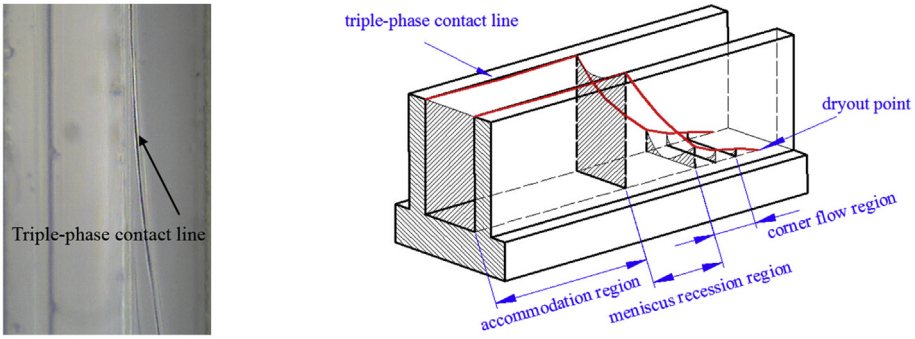


Fig. 1. A rectangular microgrooves heat sink and its meniscus.

trapezoidal microchannels and found that the bubble grows in the axial direction both forward and backward and its length increases exponentially due to evaporation of the thin liquid film between the bubble and heated surface. Wang et al. [8] conducted an experimental study on boiling in a high aspect ratio channel and analyzed the bubble growth dynamic. Results show that bubble aspect ratio increases with applied heat flux and decreases with the mass flux. Houshmand et al. [9] investigated bubble characteristics downstream in microchannel. Results show that three distinct bubble flow patterns were observed depending on slit angle and flow rates. Zuber et al. [10] investigated the bubble growth and collapse processes in subcooled boiling and gave a complete picture of the life cycle of bubbles formed in subcooled boiling. Thorncroft et al. [11] studied the vapor bubble growth and departure in vertical upflow and downflow forced convection by a visualization experiment. The results show that the process of vapor bubble sliding is responsible for the energy transfer enhancement on the heated surface. Cao et al. [12,13] investigated the influence of the bubble dynamic behaviors on triple-phase contact line in microgrooves heat sinks under subcooled boiling condition. The results demonstrate that bubble dynamic behaviors can affect the shape of the triple-phase contact line and change the thickness, area and the curvature of the meniscus in cross sections, which directly affect the heat transfer characteristics of the microgrooves heat sinks. The triple-phase contact line is a continuous curve of the intersection of the meniscus and the side wall along the axial direction of the microgroove as shown in Fig. 2 [14].

A distinguishing feature of the work of space station and spacecraft electronic components is presence of vibrations, and micro-configuration heat sinks such as heat pipes are widely used for cooling in space technology [15]. Many scholars have verified that vibration has great effect on the heat transfer enhancement in micro-configuration heat sinks [16–20], and it could be either mechanical vibration or vibration caused by growth and burst of bubbles. For example, under high heat flux condition, when spacecraft electronic components is stable, there exist triple-phase contact line oscillation caused by growth and burst of bubbles; however, when the spacecraft electronic components is under vibration condition, there exist not only mechanical vibration but also vibration caused by growth and burst of bubbles, and the two vibrations are coupled. Hu [21] has verified that combined phase-change heat transfer occurs in microgrooves heat sink under high heat flux condition, and they are evaporation thin film heat transfer in thin film region and nucleate boiling heat transfer in thick film region. Characteristics of triple-phase contact line, such as shape of the contact line, have influence on the characteristics of the evaporation thin film. Consequently, it would affect the heat transfer characteristics of microgrooves heat sinks. Thus oscillation of triple-phase contact line has effect on heat transfer of micro-configuration heat sinks. In cooling device, working fluid is always under saturated boiling condition, and thus investigation of heat transfer characteristics under saturated boiling condition would make more sense. However, few research of effect of bubble dynamic behaviors on triple-phase contact line could be found. This paper, based on previous research, is aim to investigate characteristics of the triple-



(a)Triple-phase contact line[14] (b)Distribution of triple-phase contact line in a rectangular microgroove

Fig. 2. Schematic of triple-phase contact line in the rectangular microgrooves heat sink.