The heat transfer crisis in shear driven water film

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In this work the authors demonstrate efficiency of thin water film, shear driven by gas flow in the mini-channel with local heater. The effect of microgrooves on heating surface is demonstrated. It is shown that microgrooves on the heating surface can provide an increase in the critical heat flux due to the capillary effect of microgrooves.

1. Introduction

In semiconductor technology, the size of transistors is decreasing, so density of transistors for each processor is increasing. Unfortunately, this causes higher heat fluxes and power dissipation from a microprocessor. For a microprocessor, the local heat flux could be around 1 kW/cm² [1]. A microprocessor can be cooled by different methods: by single-phase flow, as well as by the flow with phase transitions during boiling. In [2] it is demonstrated that in a gas shear-driven liquid film the critical heat flux is five times larger than that in the falling liquid film for the same liquid flow rate. So, authors, in the papers [2, 3] proposed to use thin shear driven liquid film flow in a minichannel. In [4, 5] a stable shear-driven liquid film flow can be realized in micro- and minichannels, at different inclination angles of the setup to the vertical axis. The critical heat flux up to 1200 W/cm² from the heating zone of 10x10 mm² can be reached by means of stratified flow [6].

A heat transfer coefficient could be increased by various kinds of structures on the heating surface [7]. Stabilization of the falling liquid film flow on a horizontal heated tube by using microstructures along the flow was studied in [8]. A critical heat flux for shear-driven liquid film of FC-72 flowing inside a minichannel along the surface with micro-structures was studied in [9]. It is shown that the critical heat flux on the surface with microgrooves is higher in comparison with the smooth surface. This effect is due to additional liquid flow in microstructures of the heated surface due to the capillary effect.

2. Experimental setup and techniques

The experiments to study critical heat flux in shear-driven water film with structured heater were carried out using the experimental setup (Fig. 1). For experiment, water and gas were supplied from the water and gas tanks. By means of gas flow controller (Bronkhorst) gas was supplied to the test cell. Using the syringe pump, degassed water was pumped to the test cell. A two-phase mixture was evacuated from the test cell through the two-phase outlet. Constant temperatures of the liquid and gas were controlled by temperature stabilization system. The program developed in the LabView system was used to measure temperature inside the test cell using K-type thermocouples.

The experimental test cell is demonstrated in Fig. 2. It consists of stainless steel and textolite plates. The minichannel is mounted by fixing textolite frame to the textolite plate, and it is covered from the...
top side by the transparent optical window, so a minichannel with a height of 1.5 mm and a width of 30 mm was created. Water was supplied to the minichannel through liquid nozzle (with a height of 150 microns, and width of 30 mm). The gas flow was supplied to the minichannel and forced the water film to move along the minichannel. A rod made of copper (sized 10 x 10 mm²) was pressed to the stainless steel plate. A ceramic heater was attached to the copper rod. The surface of the copper rod in the minichannel could be smooth or with microgrooves (period of the structures was equal to 0.5 mm).

Before experiments with liquid film flow inside a minichannel a wetting contact angle was measured by Kruss DSA-100 system (Fig.3). The contact angle was about 90±3°.

Fig. 1. Experimental setup.

Fig. 2. Cross view of the experimental test cell with the position of thermocouples.
3. Experimental results

The critical heat flux during the flow of a water liquid film in a minichannel with smooth heater or that with microgrooves (the width and height of grooves were 0.5 mm), shear-driven by the nitrogen flow was studied experimentally. The critical heat flux for the heaters with a smooth and microgrooves surface was measured for various gas and liquid Reynolds numbers. The experiments have shown that the critical heat flux on a heater with microgrooves was larger than that for the smooth surface (Fig. 4).

Fig. 3. Experimental setup Kruss DSA-100 to measure wetting contact angle.

Fig. 4. The critical heat flux for the gas-driven water film flowing in a horizontal minichannel with smooth surface and microgrooves (0.5 mm).

1 — microgrooves, Rel = 14.5; 2 — smooth heater, Rel = 11.7; 3 — microgrooves, Rel = 20.5; 4 — smooth heater, Rel = 18.0; 5 — microgrooves, Rel = 29.0; 6 — smooth heater, Rel = 29.0.
For some flow rates, critical heat flux for surface with microgrooves can be up to two times higher than that for a smooth surface at the same flow rates. It can be seen that the critical heat flux increases with increase in gas and liquid flow rates.

4. Conclusion

The critical heat fluxes for shear-driven water liquid film in a minichannel with smooth heating surface and the surface with microgrooves have been measured. Due to capillary effect a critical heat flux for the surface with microgrooves is higher than that for smooth surface.

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