Study of Evaporation Phenomena in Micro Channels

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Abstract - Two-phase convective flow in micro channels has numerous promising applications such as electronic cooling. This study investigates evaporation phenomena and capillary-driven heat in a rectangular micro channels structure with hydraulic diameters of 100 ~ 250μm and length of 75 mm. The micro channels made of (110)-orientated silicon is fabricated by bulk micromachining. The temperature distributions in micro channels chip structure, as well as the induced evaporation mass flow rate of water, were measured under different heat flux and inclination angle. Thermal resistances were calculated to evaluate the chip cooling performance. The experimental results show that with an increase of the imposed heat flux, the evaporation mass flow rate increases and thermal resistance decreases. The effect of channel sizes and inclination angle on the heat transfer characteristics are also examined.

BACKGROUND

Capillary force and capillary press difference are main motive force to transfer working fluid in micro channels. Therefore, capillary transfer in micro-channels is an important factor for electronic cooling systems designing. Studies of micro-channels on heat transfer since Tuckerman and Pease [1] analyzed compact water-cooled integral rectangular micro channels heat sink for silicon integrated with Pyrex glass, the heat sink may greatly enhance the feasibility of ultrahigh-speed VLSI circuits. Stores et al. [2] studied for triangular micro channels experiment in depth. Peng and Peterson [3] found in rectangular micro channels’ diameters of 0.133 ~ 0.367mm, the turbulent heat transfer was to be a further function of a new dimensionless variable, Z, such that Z=0.5 will be the optimum configuration for turbulent heat transfer regardless of the groove aspect ratio.

Liao and Zhao [4] showed experimental results of capillary-driven heat and mass transfer in vertical rectangular capillary porous structure, heated from grooved block placed on the top. With an increase of the imposed heat flux, the heat transfer coefficient increases to a maximum value and then decreases afterward, it also found that the liquid-vapor interface moved toward the downward-facing heated surface as the imposed heat flux was increased. L. J. Yang et al. [5] describe an experimental method and an analytical model for characterizing the surface energy inside a micro channel of micrometer size by measuring the marching velocity or position of a capillary meniscus. Nilson et al. [6] derived from evaporating flow in open rectangular micro channels having a uniform depth and a width that decreases along the channel axis, results demonstrate that tapered channels provide substantially better cooling capacity than straight channels of rectangular or triangular cross section.

Current Results

In this experiment, the micro channels made of (110)-orientated silicon is fabricated by bulk micromachining and measurements of structure are length of 84mm and width of 12mm, channels inside are length of 75mm in Fig.1 and Fig.2. There are total 16 kinds of cross-section size for micro-channels, by four widths (W) of 100μm, 150μm, 200μm, 250μm, four depths (D) of 100μm, 150μm, 200μm, 250μm, and the interval between channels (Wc) equal to width setting in Fig.2. This study investigates evaporation phenomena and capillary-driven heat in a rectangular micro channels structure in two parts of capillary test and thermo test shown in Fig.3 and Fig.4.

Capillary test with inclination angle: Before starting the thermo test, by the observation of capillary transfer experiment, without heating source and used pure water for working fluid, there were several sizes of micro-channel structure couldn’t bring fluid through full channel length when inclination angle increased. The phenomena also stand for in these circumstances, working fluid can’t be transfer to the evaporating section and capability decreasing.

Thermo test: Compare to differential inclination angle and channel size, we find the curves of thermo resistance (R) and evaporation mass flow rate (M ) with heat flux (Watt) be showed in Fig.5 & Fig.6 , with same channel depth of 100μm and 4 widths of 100μm, 150μm, 200μm, 250μm at 3 inclination angles of (a) 0°, (b) 45°, (c) 90°. Experimental results show that with a decrease of the channel size, the thermal resistance decreases and evaporation mass flow rate increases. The effect of the imposed heat flux increase, trend are the same.

The experimental processes also show several priorities like parameter control of etching surface by bulk micro-machining to cause the differential fluid transfer is very important (like clearing process, temperature, relative humidity (RH) control, etc.) After micro-channel structure coupled to the test device, level of three-dimensional directions must be indeed control to reduce the error. Pre-wetting to keep off dry-out situation, make sure that working fluid transfer continuously. Finally, we can try to find out the better surface characteristic for contact angle of channel- surface inside with working fluid and channel size with location arranged by simulation.

References


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Fig. 1. Micro channels structure.

Fig. 2. Channel size design.

Fig. 3. Capillary test device.

Fig. 4. Thermo test.

Fig. 5. Thermo Resistance with heat flux (channel depth of 100µm) for different inclination angles (a) 0° (b) 45° (c) 90°.

Fig. 6. Evaporative mass flow rate with heat flux (channel depth of 100µm) for different inclination angles (a) 0° (b) 45° (c) 90°.