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Parametric study on the performance of double-layered microchannels heat sink

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ABSTRACT

Microchannel is one of several high-heat-flux removal techniques being used in electronic cooling. Double-layered microchannel heat sink (DL-MCHS) with counter current flow arrangement is found not only to be able to lower the thermal resistance of the heat sink, but also decrease the maximum temperature and streamwise temperature rise on the base surface compared with single-layered microchannel heat sink (SL-MCHS). The present paper numerically investigated the thermal resistance, pumping power and temperature distribution on the base surface of substrate of DL-MCHS in different microchannel parameters and flow conditions, so as to find the complicated relationship between the overall performance of DL-MCHS and its geometric parameters and flow conditions. The numerical results show that the optimal width ratio of DL-MCHS should be increased when the microchannel aspect ratio is increased. The effectiveness of increasing aspect ratio of microchannels on improving the overall performance of DL-MCHS is dependent on the pumping power provided. DL-MCHS with higher aspect ratio and smaller width ratio is suited to the situation when higher pumping power is provided. Compared with the situation with identical inlet velocity being assigned to the bottom and upper microchannels, adjusting the inlet velocity of upper channels to be smaller than that of bottom channels may result in the improvement of the overall performance of DL-MCHS at a given pumping power, especially when the given pumping power is lower. These strategies could be tried in the real application of DL-MCHS.

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1. Introduction

Heat dissipation or generation in micro-electro-mechanical systems (MEMSs), integrated circuit (IC) boards, laser-diode arrays, high-energy mirrors, and other compact products' applications can easily exceed 200 W/cm^2. Microchannel heat sink (MCHS) is one of several high-heat-flux removal techniques being used in electronic cooling. The effectiveness, compactness and low cost are still the basic requirements to MCHS. These requirements can be detailed as lower thermal resistance, uniform temperature distribution and lower maximum temperature on the base surface, lower pressure drop or pumping power, higher compactness and lower fabrication cost. In recent years, the single-layered microchannel heat sink (SL-MCHS), as shown in Fig. 1, has been extensively used in various electronic devices for cooling purpose. Optimization of the geometric size of SL-MCHS is still a hot research topic to improve the overall performance in its real application.

For still growing miniaturization and integration of electronic devices, circuits and whole systems whose power density are continually increasing, SL-MCHS exhibits a large temperature variation in substrate along the streamwise direction, as well as on the base of the heat sinks. Large temperature variation results in thermal stresses in devices and then reduces the electrical performance via electrical–thermal instability, thermal breakdown, etc. Increasing depth or aspect ratio (ratio of depth to width) of microchannel in SL-MCHS can allow more coolant flowing through the microchannels to carry high heat load away. However, aspect ratio of microchannel is a very sensitive parameter to the overall performance and fabrication of heat sink. Firstly, the pressure drop due to flow friction in a microchannel increases dramatically when the channel size shrinks, leading to an increase of pumping power required. Secondly, the difficulties associated with the microfabrication and bulky package of electronic devices also increase when aspect ratio of microchannels is increased. Vafai and Zhu [1] first proposed a conceptual design for double-layered microchannel heat sink (DL-MCHS), as shown in Fig. 2, to allow more coolant flowing through the channels. In Fig. 2, two layers of microchannel heat sink structures are stacked, one atop the other, with coolant

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Nomenclature

c_p	specific heat capacity (J/kg K m)
h	heat sink total height (μm)
h_{ch}	microchannel depth (μm)
k	thermal conductivity (W/m K)
L	heat sink total length (μm)
N	microchannel number
P	pumping power (W)
q	heat flux of heat sink (W/m^2)
R_{th}	thermal resistance (K/W)
t_b	bottom thickness of substrate (μm)
t_u	middle thickness of substrate (μm)
T	temperature (K)
u	velocity (m/s)
$\dot{V}$	volume flow rate (m^3/s)
W	heat sink total width (μm)
W_{ch}	microchannel width (μm)
W_f	fin width between channels (μm)
x_i	direction coordinates, $i = 1,2,3$ (m)

Greek symbols

α	aspect ratio
β	width ratio
γ	velocity ratio
Δp	pressure drop (Pa)
ΔT	temperature difference (K)
Φ	viscous dissipation function (1/s^2)
η	dynamic viscosity (N/m^2 s)
ρ	density (kg/m^3)

Subscripts

b	bottom channel
in	inlet
i,j,k	index
max	maximum
s	solid
u	upper channel
w	wall

flows in the opposite direction (counterflow arrangement) in each of the microchannel layers. The following review will show that parallel flow arrangement (coolant flows in the same direction in stacked microchannels) was also suggested in other research. Vafai and Zhu [1]'s results indicated that the upper and bottom layers of the fluid had apparent different temperature difference. At the two ends of the microchannels, there were regions where the outlet coolant temperature for one layer was higher than the temperature of the surrounding substrate cooled by the other coolant layer at its inlet. This implies that heat transfer also occurs from the heated coolant to the substrate around in somewhere, compensating the streamwise temperature rises for the coolant and the substrate through conduction between the two layers. The maximum temperature on the heated surface for DL-MCHS occurs at some position in-between the two ends. This is different from that in a SL-MCHS structure where the maximum temperature occurs at the coolant outlet end. The maximum temperature difference in the streamwise direction in the double-layered structure was greatly decreased compared with that of single-layered one when the pressure drops and other parameters were kept the same for the two structures. Wei and Joshi [2] numerically investigated a heat sink based on a multilayer stack of liquid cooled microchannels with parallel flow arrangement. For a given heat removal capability for the heat sink, the required pumping power for a stack of microchannels was found significantly lower compared to a SL-MCHS, while the required flow rate for a double-layered microchannel heat sink was slightly lower compared to a SL-MCHS. Wei et al. [3] experimentally measured and numerically simulated the effects of coolant flow direction (counter flow or parallel flow), flow rate allocation among layers, and non-uniform heating on the thermal performance of DL-MCHS. Excellent overall cooling performance (thermal resistance was low to 0.09 K/W cm^2) had been shown for the stacked microchannel heat sink in their experiments. It had also been identified that over the tested flow rate range, counterflow arrangement provided better temperature uniformity, while parallel flow had the best performance in reducing the peak temperature when flow rate was low. It was indicated that the flow ratio between the top and bottom layers can be customized to achieve both low pumping power and superior thermal performance. Levac et al. [4] conducted a three-dimensional

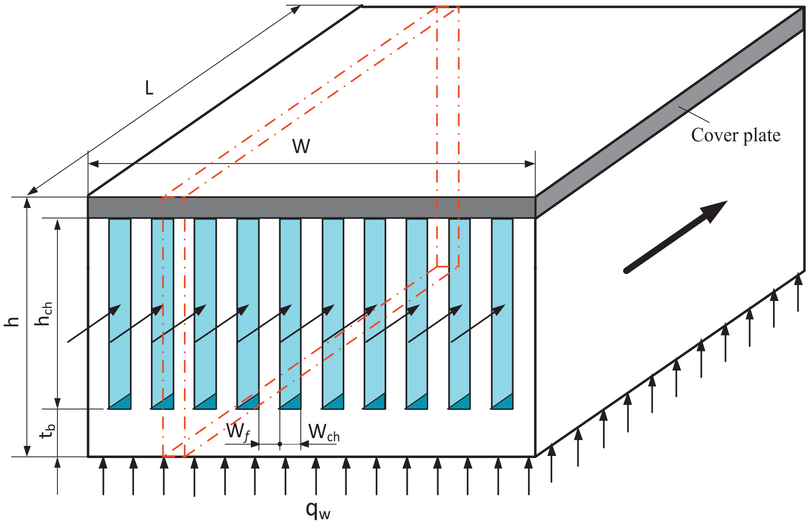

Fig. 1. Schematic of SL-MCHS.

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