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# Thermal Characterization of a Copper Microchannel Heat Sink for Power Electronics Cooling

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**An investigative prototype of a single-phase cooling system based on the microchannel heat sink with water as the heat transfer medium was developed to study the fluid flow and forced-convection heat transfer characteristics for the cooling of electronics microprocessors with extremely high heat fluxes. The microchannel heat sink was made from copper with a high fin aspect ratio of 17.5. In the experiment, pressure losses through the heat sink and thermal characteristics of the cooling section under different heat fluxes (25 to 200 W from $7 \times 7\ \mathrm{mm}^2$ and $11 \times 13\ \mathrm{mm}^2$ heat sources) and coolant flow rates (1.7 to $15\ \mathrm{cm}^3/\mathrm{s}$) were studied. Under similar test conditions, minimum cold-plate thermal resistances $R_{cp}$ of 0.11 and $0.33°\mathrm{C/W}$ were achieved with $11 \times 13\ \mathrm{mm}^2$ and $7 \times 7\ \mathrm{mm}^2$ sources, respectively. Heat fluxes of up to $4.1\ \mathrm{MW/m}^2$ were effectively dissipated while maintaining a junction temperature below 100°C. With a $15\ \mathrm{cm}^3/\mathrm{s}$ ($Re = 150$) coolant flow rate, maximum values of $5334\ \mathrm{W/m}^2 \cdot \mathrm{K}$ for the convection heat transfer coefficient and 3.4 for the Nusselt number were achieved with a 3.3 kPa coolant pressure drop through the system. As an outcome of the present investigation, the copper water-based microchannel heat sink has proved to be a reliable cooling solution for high-end microprocessors.**

## Nomenclature

| | | |
|---|---|---|
| $A$ | = | area, $\mathrm{m}^2$ |
| $D$ | = | diameter, m |
| $d$ | = | depth, m |
| $f$ | = | Darcy friction factor |
| $h$ | = | heat transfer coefficient, $\mathrm{W/m}^2 \cdot \mathrm{K}$ |
| $\bar{h}$ | = | average heat transfer coefficient, $\mathrm{W/m}^2 \cdot \mathrm{K}$ |
| $I$ | = | current, A |
| $k$ | = | thermal conductivity, $\mathrm{W/m} \cdot \mathrm{K}$ |
| $l$ | = | length, m |
| $m$ | = | parameter defined by Eq. (8) |
| $N$ | = | number of fins |
| $Nu$ | = | Nusselt number |
| $P$ | = | perimeter, m |
| $Q^{\bullet}$ | = | heat load, W |
| $R$ | = | thermal resistance, °C/W, K/W |
| $Re$ | = | Reynolds number |
| $T$ | = | temperature, °C, K |
| $t$ | = | thickness, m |
| $U$ | = | flow velocity, m/s |
| $V$ | = | voltage, V |
| $\alpha$ | = | aspect ratio |
| $\Delta P$ | = | pressure drop, Pa |
| $\eta$ | = | efficiency, % |
| $\rho$ | = | density, $\mathrm{kg/m}^3$ |

*Subscripts*

| | | |
|---|---|---|
| $a$ | = | applied |
| az | = | active zone |
| $b$ | = | base |
| $c$ | = | convection |
| ch | = | channel |
| cp | = | cold plate |
| ct | = | contact |
| es | = | external spreading |
| ew | = | external wall |
| $f$ | = | fin |
| fc | = | fin cross section |
| fi | = | fluid inlet |
| fo | = | fluid outlet |
| $h$ | = | hydraulic |
| hsb | = | heat-sink base |
| ht | = | heater |
| iw | = | internal wall |
| $j$ | = | junction |
| mf | = | mean fluid |
| $o$ | = | overall |
| sp | = | spreading |
| $t$ | = | total |
| TIM | = | thermal-interface material |
| $w$ | = | wall |

## I. Introduction

WITH the rapid advancement in semiconductor technology, Moore's law [1] prediction that the number of transistors on a microprocessor chip will double about every two years has become a reality. These developments have boosted the processing capabilities and functionalities of the microprocessors, but at the same time, new challenges have been presented in the cooling of these chip sets. Thermal management of the high-density processors in power electronics (including standalone desktops, application servers, and data centers [2,3]) requires continuous research efforts to develop thermal control architectures with cost-effective design and reliable performance. Typically, the waste-heat output by the processing unit in servers can range from 150 to 250 W [4,5] and is expected to rise further in the future with the increase in the number of integrated circuits on a chip set. Such power outputs can result in heat flux as high as $2.5\ \mathrm{MW/m}^2$ from a die footprint of $1\ \mathrm{cm}^2$. Also, as a necessary thermal requirement for the reliable operation and

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