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EXPERIMENTAL INVESTIGATION OF TOPOLOGICALLY OPTIMIZED MINI-CHANNEL HEAT SINKS FOR REDUCED TEMPERATURE NON-UNIFORMITY

Joshua Palumbo[1*], Omri Tayyara[1], Cristina H. Amon[1,2], Sanjeev Chandra[1]
[1]Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, Canada
[1]Department of Chemical Engineering and Applied Chemistry, University of Toronto, Toronto, Canada
*josh.palumbo@mail.utoronto.ca

ABSTRACT

The number of high-performance power electronics has exponentially increased over the last decade, evidenced by (i) the need for increased computing power within the consumer electronics market, (ii) electrification of the transportation sector to mitigate climate change. Traditionally, these high-power density electrical architectures consist of numerous heat-producing transistor devices. The efficiency of these devices is dependent on maintaining uniform device temperatures. Therefore, developing a thermal management solution to ensure a uniform device temperature is paramount to ensure the safe and reliable operation of these systems.

In this work, we developed and fabricated liquid-cooled heat sinks with channel dimensions on the millimetre scale to cool an 86 mm x 63 mm uniformly distributed heat load. A pseudo-three-dimensional density-based topology optimization model was developed in COMSOL to generate a non-traditional internal geometry that minimizes the temperature non-uniformity for a prescribed pressure drop while conserving computational resources. This was achieved by thermally coupling a two-dimensional conductive heat sink layer which applies a uniform heat load, with a thermo-fluid design layer, in which the optimal fluid channels are generated. The density in the designated thermo-fluid design layer is morphed from fluid to solid via impermeable porous media and the solver is run until a Pareto optimum is achieved. Finally, the resulting two-dimensional design is propagated in three dimensions to conduct conjugate convection-conduction simulations to accurately assess heat sink performance.

Complex geometry at the millimetre scale is challenging to fabricate using traditional methods, due to long processing times or high cost. To overcome this, a novel additive manufacturing method using metal spray was developed. Metal spray refers to techniques in which molten or softened metal is accelerated toward a workpiece. By controlling the location of metal deposition, complex metal structures were fabricated onto a metal plate. A water-tight channel seal was created by filling the surface channels with a water-soluble polyvinyl alcohol (PVA) paste that was allowed to harden, depositing a metal coating over it, then dissolving the PVA.

The optimized geometry heat sink was compared experimentally to a heat sink with parallel channels, a common geometry for traditional liquid-cooled heat sinks. The heat sinks were placed on a uniformly heated copper block and temperatures along the heated heat sink face were measured to determine temperature non-uniformity.

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