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Liquid-Cooled Microchannel Heat Sink Thermal Analysis Using a Porous-Medium Model

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Extended Abstract

The use of liquid-cooled microchannel heat sinks (MCHSs), both in single-layered and double-layered configurations, represents a well-established practice for the thermal control of electronic chips in integrated circuits [1]. For the optimization of these devices, CFD plays a crucial role, but in the past most numerical simulations were carried out under the scenario of heat sinks with all parallel microchannel (with co-current or counter flow configurations for double-layered MCHSs). In these cases, in fact, by taking advantage of geometrical symmetries, it is possible to refer to extremely basic computational domains made up of one half-channel or two stacked half-channels [2]. As a result, more intricate heat sink designs have hardly ever been investigated due to the prohibitive computing cost required for their domain discretization, which calls for a very high number of cells. This means that not only was the crossflow configuration seldom considered, but effects of flow maldistribution and parasitic heat transfer in headers were also disregarded. To allow an approximate thermal analysis of entire micro microchannel heat sinks, possibly including the manifolds, an alternative method is presented, which involves treating an entire layer of microchannels as a porous medium with properties empirically determined based on comparisons of results of 3D simulations for a single microchannel of the heat sink and those of calibration tests of a 2D porous-medium model.

The porous-medium approach has previously been shown to be valid, particularly when used in conjunction with the local thermal non-equilibrium (LTNE) method. Commercial software with the LTNE option can be used for this kind of analysis. Nevertheless, even though Ansys Fluent [3], one of the most widely used of these codes, features the LTNE model, it is unable to account for heat transfer between the solid porous matrix and the nearby solid portions of the domain. To get around the issue and enable the use of the porous-medium technique in conjunction with the LTNE model of Ansys Fluent, a novel approach is proposed in this study. Since in Ansys Fluent the porous solid zone only interacts with the fluid and not with the solid walls with regard to heat transfer, a thin fluid layer is defined, where the velocity is zero, the thermal conductivity of the fluid is equal to that of the solid, and the fluid-solid interfacial heat transfer coefficient is very large so that the adiabatic boundary of the porous solid matrix can be short-circuited.

The method is validated by the successful comparison of computed results with those from accurate analyses concerning double-layered microchannel heat sinks with non-uniform velocity distributions, that are carried out using an in-house FEM procedure [4]. It is thus proved that the suggested approach can be applied with confidence for the study of the thermal performance of micro heat sinks with complex geometries while saving a significant amount of computational work.

References

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