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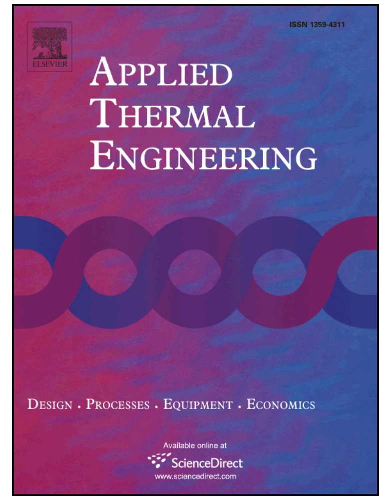

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An experimental and numerical investigation of the use of liquid flow in serpentine microchannels for microelectronics cooling

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Abstract:

This paper presents a combined experimental and numerical investigation of single-phase water flow and heat transfer in serpentine rectangular microchannels embedded in a heated copper block. The performance of four different microchannel heat sink (MCHS) configurations are investigated experimentally, the first having an array of straight rectangular microchannels (SRMs), while the other have single (SPSMs), double (DPSMs) and triple path multi-serpentine rectangular microchannels (TPSMs). Three-dimensional conjugate heat transfer models are developed for both laminar and turbulent single-phase water flows in each of these MCHSs and the governing flow and energy equations solved numerically using finite elements. The numerical predictions of pressure drop (ΔP) and average Nusselt number (Nu_{avg}) are in good agreement with experimental data, and indicated that the single path serpentine microchannel (SPSM) leads to a 35% enhancement of the Nu_{avg} at a volumetric flow rate of 0.5 l/min and a 19% reduction in total thermal resistance (R_{th}) compared to the conventional SRM heat sink. However, this enhancement is at the expense of a large (up to ten-fold) increase in ΔP compared to the SRM heat sink, so that a suitable compromise must be struck between heat transfer and pressure drop in practical MCHS designs.

Keywords: Experiments, Conjugate Heat Transfer, CFD, Serpentine MCHS.

1. Introduction

The increasing density of transistors in electronic components and products is leading to an inexorable rise in the heat dissipation that must be achieved in order to preserve reliability and performance. The International Technology Roadmap for Semiconductors (ITRS) in 2010, for example, predicted a continuous increase in transistor density to reach 10 billion transistors/cm^2, by 2018 [1]. For this reason, improving the thermal management of electronic devices is a crucial goal for future generation of electronic systems. Single-phase microchannel heat sinks (MCHSs) with water as a coolant are an increasingly common means of cooling electronic devices because of their ability to provide very high convective heat transfer fluxes. Single-phase MCHSs rely on sensible heating achieve the cooling, where high heat transfer coefficients (h) can be achieved simply by using small microchannel dimension [2]. Flow boiling (Two-phase flow) MCHSs, on the other hand, have also received much attention from researchers due to their ability to dissipate high heat fluxes with lower pumping powers compared with single-phase liquid MCHSs, by utilising the coolant's latent heat [3]. However, pressure fluctuations and flow reversal associated with flow boiling instabilities can reduce the heat transfer characteristics in MCHS [4].

The use of single-phase MCHS was proposed by Tuckerman and Pease [5] in 1981, who used a water-cooled heat sink, fabricated with an array of SRMs etched in a 1cm^2 silicon wafer. Their pioneering work stimulated many researchers to investigate the fluid flow and thermal performance of the MCHS using different substrate materials with various cooling liquids, see e.g. the recent review of Salman et al. [6] Another major milestone was the experimental study of Phillips [7] on rectangular MCHS test section with an Indium Phosphide heat sink substrate and water as a coolant. Subsequently, a computer model was developed to predict the thermal and flow characteristics of this MCHS,