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HEAT SINK INTEGRATING PHASE CHANGE MATERIALS FOR COOLING HIGH POWER ELECTRONIC DEVICES

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Abstract

This research explores the numerical analysis of phase change materials (PCMs) heat sinks, focusing on high heat flux dissipation applications, e.g. electronics cooling. Both 2D and 3D numerical models using gallium and paraffin RT31 as PCMs are considered within a heat sink design framework featuring a rectangular cavity and dual opposing vertical copper walls serving as fins to dissipate heat from the hot sink base that receives heat from the heat source. The inclusion of a Triply Periodic Minimal Surface (TPMS) 'Primitive' structure as an in-fill thermal conductivity enhancer (TCE) in the case of the gallium heat sink, and a 'Primitive' TPMS structure combined with high thermal conductivity metal foam in the case of the RT31 heat sink, aims to enhance the heat dissipation efficiency within the sink cavity. To further enhance the thermal performance, the study fosters a temperature differential across the sink cavity, initiating buoyancy-driven circulations within the melted PCM to augment cooling of the hot sink base by natural convection. This temperature differential is achieved by subjecting one of the two opposing sink walls to external forced convection cooling with the ambient surroundings and insulating the other wall. Investigations extend to varying sink-base placements on top of the heating source surface area, sink cavity aspect ratios while maintaining PCM volume, and the impact of using metal foam and TPMS structures for improved heat transfer. A range of cavity heights from 14mm to 20mm, corresponding to aspect ratios (height/width) from 0.65 to 1.3, respectively, are considered. Two heat flux levels are applied at the sink base, 15 W/cm², and 6 W/cm², across a 15mm span. However, for the paraffine sink cases, only 6 W/cm² heat flux was applied, as paraffin failed to withstand such a high heat flux value of 15 W/cm², even when the TPMS structure and the metal foam were utilized. Results indicate that the most effective thermal management occurs at an aspect ratio of 0.963, with the sink optimally positioned at the heat source's edge. This configuration ensures minimal peak temperatures and restricted spreading of the hottest spots on top of the sink base. For the gallium heat sink cases, gallium alone as PCM (without the inclusion of TPMS structure or metal foam) stands out for its superior heat dissipation performance. When gallium is integrated within the TPMS structures it shows markedly enhanced heat dissipation features in the sink, resulting in a peak temperature reduction of approximately 10°C compared to the baseline case without TPMS structures. Furthermore, for the paraffine sink cases, the integration of the metal foam within the TPMS configurations demonstrates efficient heat dissipation, achieving a steady-state peak temperature decrease by about 5°C, compared to the baseline case. This comparative analysis underscores the importance of PCM material selection, structural and design configurations, and the synergistic effects of paraffin, metal foam, and TPMS structures in achieving optimal thermal management for high heat flux generating devises such as electronics.

Keywords: Heat sink, Metal foam, Triply Periodic Minimal Surface (TPMS) structures, Gallium, Electronics cooling, Buoyancy-driven circulation, Heat transfer enhancement, Low thermal conductivity PCMs.