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Analysis of a platform for thermal management studies of microelectronics cooling methods

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HIGHLIGHTS

- A platform for evaluating microelectronics cooling methods was demonstrated.
- Phase change materials (PCM) performed better than cooling under ambient conditions.
- Nanostructure Enhanced Phase Change Materials (NEPCM) outperformed PCM.
- A lumped parameter model was applicable for the platform.
- Additional insulation and size reduction may improve the platform.

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ABSTRACT

This study describes the demonstration and analysis of a platform for thermal management studies of microelectronics cooling methods. The platform consists of an aluminum base with a heater cartridge inserted to simulate the microelectronics heat source. Over the last decade, several promising methods for next generation cooling of microelectronics have been proposed and studied using various testing platforms. However, it is difficult to compare results obtained for different platforms. The platform presented in this study is applicable for testing several different cooling methods thereby eliminating the difficulty in comparing results across methods. In this study, the platform is first demonstrated for testing of phase change materials as a cooling method for microelectronics. Then, results obtained from the demonstration guide further analysis of the platform using experimental, analytical and computational approaches. The results of the analysis indicate the applicability of a lumped parameter model for platforms of the type presented in this study. Furthermore, the results quantify the applicability of the zero flux boundary condition often assumed for thermal management studies and also show that, as the area of the insulated portion of the platform increases, the thermal response time increases due to the decrease in the surface area for heat transfer. Finally, overall, the study confirms the utility of the platform for thermal management studies and provides insight into its performance.

1. Introduction

As microelectronics become smaller and faster, waste heat generation increases and developing more robust thermal management strategies becomes more urgent. Traditional methods of cooling microelectronic devices, such as forced convection using fans, are reaching their limits, and, although device manufacturers would like to further develop traditional methods, it has been shown that these methods present diminishing returns [1]. Currently, among others, methods such as microchannel transport, solid–liquid phase change materials (PCM), jet impingement, heat pipes, thermal interface materials (TIMs) and thin film thermoelectric coolers are being considered for next generation cooling of microelectronic devices [1–6]. In order to evaluate these methods, a test platform needs to be developed or adopted from other researchers. Several researchers have chosen to develop platforms

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referred to as "mock-ups" that resemble microelectronic devices [7,8]. Although these studies are valuable because the results are more directly applicable to real devices, it is more typical to develop or adopt a platform that is highly idealized.

For example, Nguyen et al. [9] investigated the heat transfer of a nanofluid in a closed cooling system for electronics cooling. The experimental testing station consisted of a closed loop flow system with the following features: a 5 liter reservoir tank, a 12V/DC magnetically driven pump, which was used to ensure forced recirculation through the system, an aluminum heating block with overall dimensions of 60 mm by 60 mm by 75 mm, a 100 W cartridge heater to heat the block, a water block installed on top of the heating block with overall dimensions of 60 mm by 60 mm by 15 mm, a mini air cooled radiator, used for heat removal, and a collection and weighting station, used to measure the mass flow rates within the system. The heating block with the cartridge heater simulated the heat generated by the electronic device. The water block's external body was made of copper and, internally, there were thick pin-like fins as the base. Thermal grease between the water block and heating block reduced the thermal contact resistance, and the heating block and the water block were thermally insulated using 50 mm thick fiberglass insulation to cover all exposed areas. K-type thermocouples measured the temperatures throughout the system.

Weinstein et al. [10] investigated the use of graphite nanofibers embedded in PCMs for thermal management of electronics using a cube-shaped platform base. The cube was constructed of Kydex T Acrylic/PVC with a thermal conductivity of 0.15 W/m K. The bottom of the cube, constructed of copper 110 alloy, was subjected to a constant flux using a Kapton thin film resistance heater. The top of the cube was an isothermal cold plate, and T-type thermocouples located throughout the test platform measured the temperature of the PCM. Tests were conducted for different power settings ranging from 3 to 7 W with additional insulation applied beyond using low thermal conductivity materials of construction to approach a zero flux boundary condition.

Cui et al. [11] investigated the effect of carbon nanoadditives on phase change materials. Similar to Weinstein et al. [10], the test station included a platform base constructed of Kydex T Acrylic/PVC. However, instead of a cube shape, a cylindrical shape was selected. The bottom surface of the cylinder was made of copper 110 alloy in order to apply a constant flux through a Kapton heater attached with high temperature metallic tape. The top surface of the cylinder was an isothermal cold plate, and the entire system was insulated using fiberglass insulation. K-type thermocouples aligned on one sidewall of the cylinder measured the temperatures throughout the system.

Selvakumar and Suresh [12] investigated the convective performance of a copper oxide-in-water nanofluid in an electronic heat sink. The test station consisted of an aluminum base with dimensions 55 by 55 by 75 mm and a cartridge heater inserted in the base to heat the water block. The system was insulated with glass wool and K-type thermocouples were placed in four different locations on the aluminum base to measure the interface temperature.

Lastly, Koyuncuoğlu et al. [13] investigated the heat transfer and pressure drop on complementary metal–oxide–semiconductor (CMOS) compatible microchannel heat sinks for monolithic chip cooling using water as the coolant. The group implemented a monolithic approach to the fabrication of the microchannel heat sinks. The monolithic approach consisted of silicon etching and electroplating techniques which are CMOS compatible. The cross sectional areas of all the microchannels were rectangular with a width of 100–200 μm and height of 20–50 μm. In this study, the group used microfabricated resistance heaters to simulate the heat from a microelectronic device, and T-type thermocouples recorded the experimental temperatures.

The aforementioned studies illustrate the types of platforms used for microelectronics thermal management studies. From these examples, several themes emerge. For example, the heat from the microelectronic device is simulated using either a Kapton thin film heater, a cartridge heater inserted in a metal base or microfabricated resistance heaters. Either K or T type thermocouples measure the temperature, and insulation is a critical issue that is addressed by, if possible, constructing the platform of low thermal conductivity materials and also using additional, traditional insulation. Lastly, reduction of thermal contact resistances is addressed using high thermal conductivity tapes and pastes.

For this study, the goal was to develop a platform that could be used to study a range of cooling methods including, but not limited to, traditional methods such as fans and high surface area heat sinks as well as emerging methods such as solid–liquid PCMs and microchannel cooling using both pure solvents and nanofluids [14]. The rationale for developing a single station was to make a fair comparison of the cooling methods investigated. In this work, the platform utility is initially demonstrated by testing a PCM cooling method. Subsequently, insight, gained from initial demonstrations and both analytical and computational modeling, underscores the platform utility and also guides researchers toward potential improvements.

2. Experimental methods

The platform used in this investigation is shown in Fig. 1 and includes an aluminum bar as the base (a), a cylindrical cartridge heater (b), and a power transformer to simulate the microelectronics heat source. Surface mounting K-type thermocouples (c) attached to the aluminum base measured the surface temperatures and an automated data acquisition system (d) collected the data. The cylindrical cartridge heater was inserted into the aluminum base and heated by a power transformer, which applies a voltage to the cartridge heater. The resulting energy heats the aluminum base until its surface reaches the desired temperature. The overall dimensions of the aluminum base grade 6061 (All Metals Inc.) are given in Fig. 2 with the placement of the heater cartridge inside the base also illustrated. The cartridge heater (Omega Engineering Inc.) has a diameter of 3″/16 (4.76 mm) and a power rating of 100 W for 120 V. The power transformer (ISE Inc.) has a voltage range from 1–140 V. Data can be automatically acquired and recorded from eight surface mounting K-type thermocouples simultaneously at desired sampling rates (typically 1 Hz) using the data acquisition

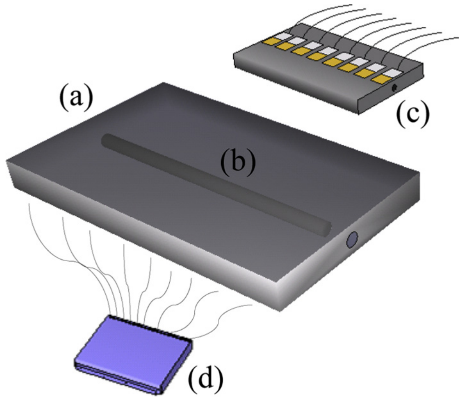

Fig. 1. Schematic of testing platform (a) aluminum base (b) cylindrical cartridge heater (c) surface mounting thermocouples (d) automated data acquisition system.