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Original Article

CFD Approach for Thermal Management to Enhance the Reliability of IC Chips

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Abstract *- The current study validates numerical studies on heat management of a single IC chip put on a circuit board. In the design that has been proposed, PCM is placed inside a narrow channel that is located on the outside of IC chips. The substrate board directly conducts latent heat to the PCM. This causes the material to change its phase, which enables the system to have high thermal cooling performance. The present study creates a comparative analysis between not having any PCM, having mini channels connected together, and having a single mini channel optimized near a heat source. According to the findings, the cooling capabilities of N-Eicosane are superior to those of paraffin wax, ATP 78 PCM, and N-Eicosane, respectively.*

Keywords *- CFD, IC chips, Minichannel, PCM, Thermal control.*

1. Introduction

The control of a device's temperature is absolutely necessary for maximizing both its performance and its lifespan. The heat dissipation area has decreased due to the downsizing of electronic components. Finally, incorporating PCM into the channels is a more effective tactic. The PCM absorbs and then dissipates the heat produced by the IC chips while they are not in use (not loaded). The two most crucial elements to consider when selecting a PCM are the melting point temperature and application compatibility.

Qarnia et al. [1] computationally used three projecting heat sources in 2D space with n-eicosane and natural convection. They reasoned that increasing the distance between the various sources of heat would result in an improvement in performance. Baby and Balaji [2] investigated heat sinks based on n-eicosane, showing that even though the PCM improvement ratio rose heat sink-facing, the heat exchange stayed the same. Ebrahim et al. [3] conducted circular cross-section research on mini-channel heatsinks that included both experiments and numerical simulations. They researched how the channel hydraulic diameter influenced the decrease in pressure caused by heat sinks and the augmentation of heat transmission. They discovered that doing so enhanced the coefficient by 5.7 %, which caused the components to lose heat at a speedier pace. Numerical simulations were used by Khademi et al. [4] to examine thermal energy storage inside a container that contained water and oleic acid. Three alternative scenarios of water inside the enclosure were used in the simulations, which were done at extremely low temperatures (about 10 °C). Mathew et al. [5] found that mixed convection cools protrude independent heat sources better than natural and forced convection. Mathew and Hotta [6] employed a numerical analysis to estimate the optimal IC location on an SMPS board under mixed convection. Zeng et al. [22] found that the topology-optimized sink maintains 44.5 °C while utilizing reduced power by 54.9%. Transient numerical studies of heatsinks made of PCM installed on quad flat package electrical devices were performed by Kandasamy et al. [8]. They noticed that paraffin wax did a superior job of cooling the QFP device. Faraji and Qarnia [9] simulated three projecting discrete heat sources in an enclosure using n-eicosane in two dimensions. The centre heat source had the highest conduction and convection temperature. Loganathan et al. [10] choose the optimal PCMusing fuzzy multi-criteria. They found that RT-80 is superior for electronic temperature control. Mahmoud et al. [11] discovered that honeycomb paraffin wax heat sink inlay outperformed six PCM heatsinks. Arshad et al. investigated PCM (paraffin wax) heat sink heat flow values [7] (Finned and finless).

They found that A 100% PCM volume 2 mm pin-fin improved heat sink thermal efficiency and performance.

Rehman et al. [13] tested a heat sink for PCM made of copper foam. PCM significantly lowered heat sink temperature. Song et al. [14] investigated conjugate battery cooling using liquid and PCM. The PCM decreases battery temperature substantially. Abdulrahman et al. [15] calculated a paraffin wax heat exchanger and found that it is melted at 295 S at 18 W. Kurhade et al. [16] evaluated the influence of substrate board thermal conductivity on electronic component temperature management using copper cladding board. Kurhade et al. [17] examined smartphone PCM cooling CFD. Kurhade et al. [18] investigated phase transition material for IC chip thermal management. S.E. Ghasemi [19] studied circular minichannel heat sinks. Lowering channel hydraulic diameter increases the heat transfer coefficient by 5.7%, speeding component heat dissipation. pation rate and boost their performance. Yavari et al. examined composite PCM thermal conductivity and nanostructured graphene [20]. (1-octadecanol). PCM with 4% graphene has 140% higher thermal conductivity, and 15.4% reduced heat capacity. Rabie et al. [21] used the RT35HC (Tm: 41–44 °C) heat sink for solar cell experiments. Adjusting the heat sink slope and cell height ratio to optimise solar cell temperature dispersion was their goal. Forming liquid PCM at the heat sink's top layer decreased heat sink cooling efficacy at 45° cell tilt. Huang et al. [22] investigated how composite PCM affects integrated circuit critical time.

The evaluation of PCM-based mini-channels seems to be fairly uncommon in the scholarly literature. Consequently, the work being done right now focuses on computational analyses of mini-channels of paraffin wax to speed up the pace at which IC chips dissipate heat and improve their overall performance. Thus, this work optimizes integrated circuit chip heat dissipation and performance using the Paraffin wax-based minichannel. The manufacturer's catalogue gives the best setup for placing nine integrated circuit substrate board chips and shapes and sizes of ICs and the substrate board.

2. Interpretation of the Model

Fig. 1, focuses on the numerical analysis of IC chips encircled by mini channels. The 9 different IC chips are mounted, and around their edges are little channels filled with PCM that let the IC chips transmit heat away from the substrate board directly. The commercially available ansys fluent application, version 2021 R2, is used to create the computational domain for analysis. The substrate board for the numerical model's original dimensions are 269 x 189 x 5 (Fig.1). The heat flux for the different IC chips ranges between 0.5 and 8 W.

Transient numerical simulations in ANSYS Fluent V2021 with a mushy zone area value of C = 10^5 are used to simulate all of the circumstances in Fig. 2. The mushy zone constant C describes PCM's capacity to transmit heat. The melting point classifications of the phase transition materials employed in this work are shown in Table 1.

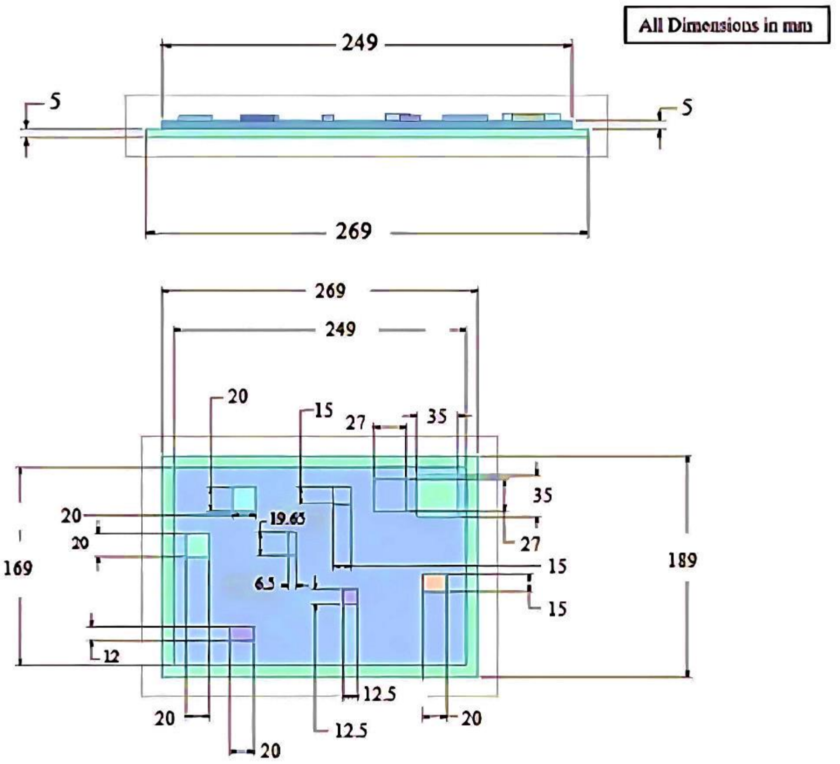


Fig. 1 Configuration

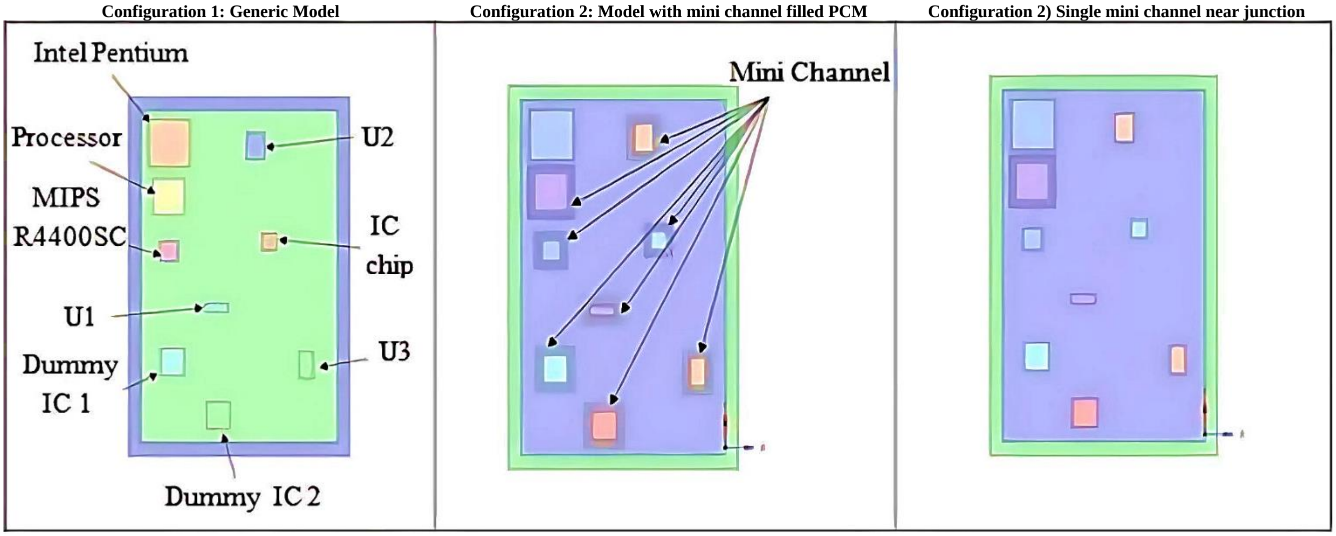


Fig. 2 Different configurations under study

Table 1. Properties of PCM

Sr. No.	Property	n-Eicosane	Paraffin wax	ATP 78
1	Density	785	758	770
2	Thermal conductivity	0.23	0.24	0.24
3	Dynamic viscosity	0.01	1.9	0.01
4	Specific heat	2460	2950	2250
5	Melting point	36.5	42 - 48.55 (Melting range)	78

Table 2. Grid study

Sr. No.	Type of Mesh	Skewness	Cells	Convergence Time (Sec)	Temperature (3600 Sec)
1	Polyhedral (Selected)	0.899	096558	546	53.234

3. Mathematical Structure

Within the Ansys software, the approach that is being used is referred to as enthalpy porosity modeling. The solidification and melting models offered by the Fluent solver are used in this strategy, and the constant value for the mushy zone is established to be 10^5. This mushy zone has a fraction of PCM liquid which ranges between 0 and 1. The liquid fraction is zero (0) for solid PCM and one for liquid PCM. If the PCM is in its liquid state, the solid fraction is equal to zero. After it turns solid or at its initial state when it is solid, it is referred to as 1—the 3-D continuity equation, Momentum equation & Energy Equation [18] used for numerical modelling.

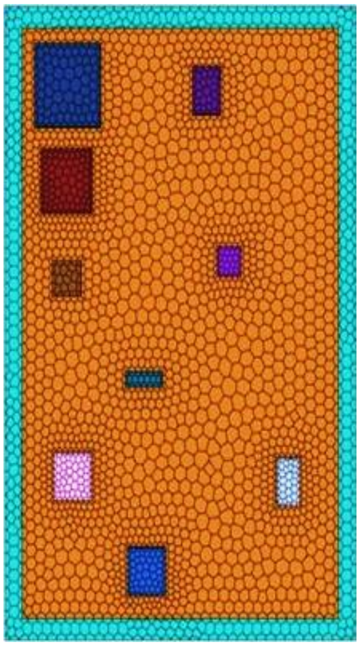
3.1. Grid Index Discussion

In this, the ANSYS fluent mesher is put to use in order to discretize geometry into a number of different components, including finite volumes. As can be seen in Fig. 3, the first step is to conduct a grid-independent analysis. The grid investigations produce a generic design for nine different IC chips placed on a substrate board. The convergence time determines the appropriate grid type, the Skewness quality check, and the variance in the results. The default value for the global size factor in mesh creation is 2 millimeters.

This investigation preserved quality control standards using skewness correlation and aspect ratio. Skewness should be 0.89 and aspect ratio 0.15 for the polyhedral grid type to function properly, as stated by ANSYS fluent. In addition, selecting a grid decreases the total number of cells, which cuts down significantly on the amount of time required for calculations, as can be shown in Table 2.

Table 3. Mesh selection study

Mesh Size (mm)	Temperature in Degree	Skewness	Convergence time (Sec)
7	48.524	0.98	160
4	50.103	0.97	435
3	53.017	0.93	510
2	53.234	0.89	546
1	53.237	0.84	1034



(a) Polyhedral

Fig. 3 Type of grids Selected

The chosen polyhedral grid type was without considering the mesh size to discover how sensitive it is to changes in the mesh size. When doing research that is not reliant on a mesh, the element size is changed to investigate how this alteration affects output accuracy, the amount of computing time required and quality. An independent mesh study can be seen in table 3.

According to the data, the mesh size of 2 millimeters is optimal since it satisfies the ANSYS fluency criterion by having a skewness of 0.89 and an aspect ratio of 0.15.

4. Experimental Work

Fig. 4a demonstrates the natural convection arrangement. A substrate board that contains nine asymmetric IC chips that generate much heat is held inside an enclosure. These components are enclosed. Bakelite, with 1.4 W/mK heat conductivity, makes the circuit board. The board's nine IC chip volumes may be used to locate the device's heat source.

Aluminium mini-channels are inserted on the IC chip's periphery. Crushed paraffin wax must be pumped into channels. Paraffin wax melts between 48.28 and 54.21 degrees Celsius and is solid at room temperature. Two thermocouples can measure channel and paraffin wax temperatures. This study considers various-sized little aluminium tubes. Since aluminium is isothermal, 2 thermocouples are used to measure channel temperature. This correctly measures channel temperature. The 0.8-millimetre thermocouple bead is placed in the centre in mini-channels filled with PCM. Thus, monitoring paraffin wax melting and channel temperature is adequate. More thermocouples may have made the experiment harder to set up. The contact surface that exists between IC chips and the electrical device channels is protected by thermal paste.

A differential scanning calorimeter and a thermocouple were used to determine the PCM's melting point temperature. A heater with an 80/20 Nichrome wire coil might boost IC chip power input—a possible solution. IC chips store heater wires in a depression on the bottom. Chips have this depression in the middle. The chip's surface allows full access to these hollows. Each IC chip has a bottom slot for heater wires and thermocouples, which may be connected to a DC power source. IC chips' bottoms have these slots. The manufacturer's brochure states that these thermocouples detect the temperature in 0.39 seconds into a UniPro Log Plus data logger every second. Recently discovered thermocouples have a relative accuracy of 0.24% to 0.26%. Thermocouple is placed under each IC and 2 on the substrate board. Two minichannels are transiently tested on a substrate board. Paraffin wax fills these minichannels. The substrate board also has nine asymmetric IC chips. This research used natural convection to transport heat. Four volumetric heat generation instances give erratic heat inputs to IC chips. Volumetric heat production generates this heat. Since most electronic applications need horizontal substrate boards, all PCM-based mini-channel research is done on them. The data logger saves one-second temperatures from IC chips, mini-channels, and paraffin wax in the computer. Heat is lost when integrated circuit chips radiate heat or transfer heat to the substrate board.

5. Validation

A validated numerical model with the configuration of having a mini channel for 3600 s. The validation is calculated for temperature in the transient time scale. The achieved results show that the percentage error difference is less than 5%, as shown in below figure 4b. between Mathew V K [5] and the present work.

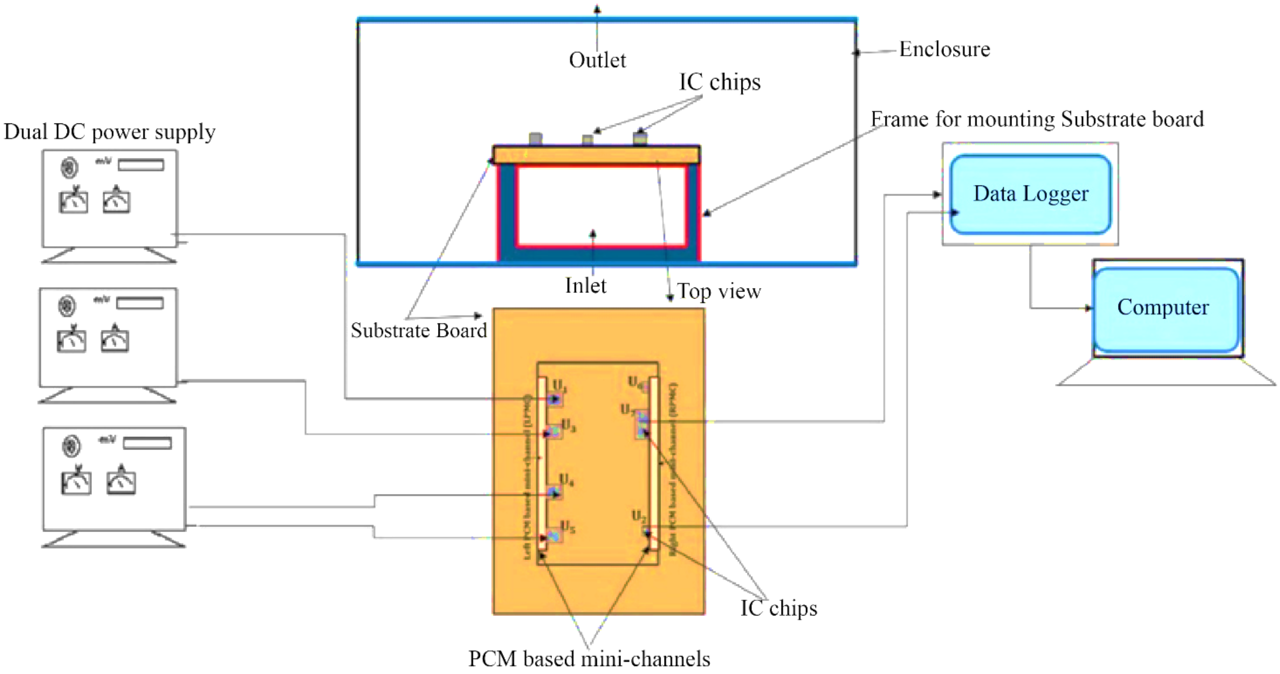


Fig. 4 a. Experimental Work

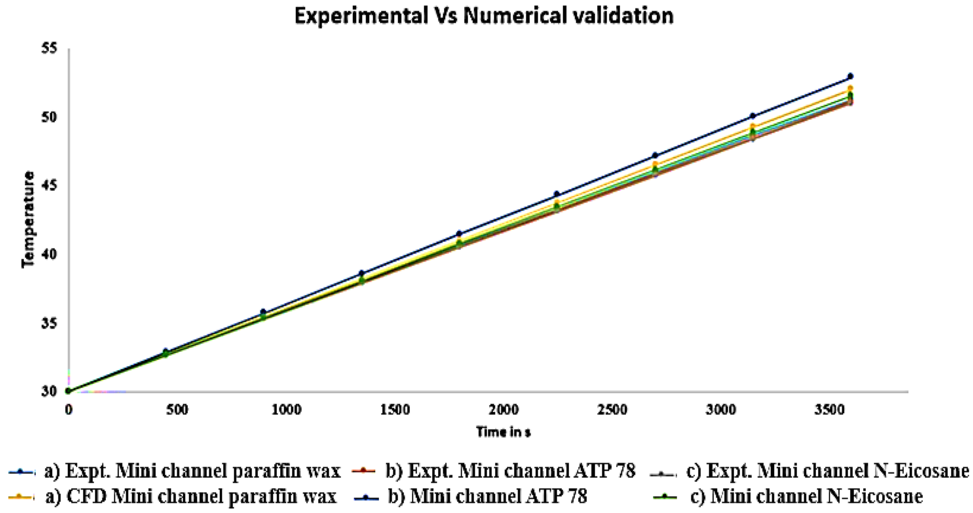


Fig. 4 b. Validation plot

6. Result and Discussion

This investigation's key focus is the development of numerical transient simulations of a novel model for a phase change material connected minichannel. In each and every one of the situations detailed in Table 1, the PCM that is embedded inside the minichannels is the component that is responsible for cooling the IC chips.

6.1. Configuration 1) Generic model

The first configuration, referred to as the generic model, consists of placing nine identical IC chips. In this design, micro channel and PCM passive cooling are not considered. The temperature curve for this arrangement may be seen in the Fig. 5.

The findings indicate that IC chip 1, whose distribution is most likely to be highest at 53.234 degrees Celsius, is the source of heat that propagates to neighboring localized IC chips, as shown in Fig. 5. A mini channel coupled cooling method has been developed with the intention of absorbing the greatest possible quantity of latent heat to lower system temperature. This reduction in propagation and improvement in performance has been made possible thanks to the introduction of this method. As a result, the current scenario is changed to conform to configuration 2.

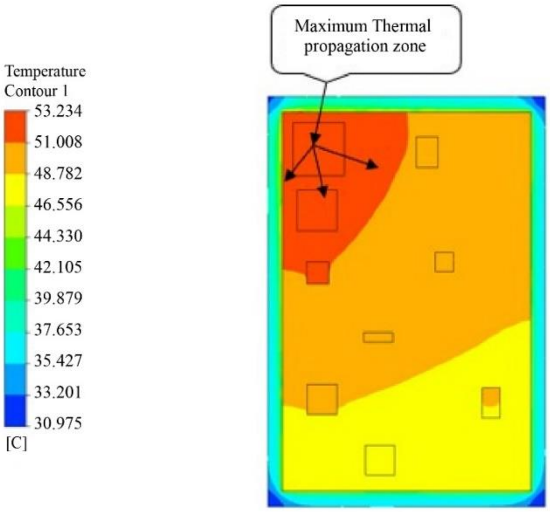


Fig. 5 Temperature distribution

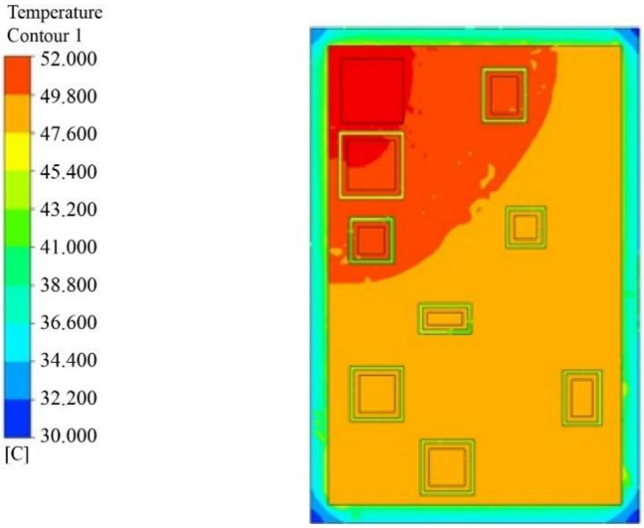


Fig. 6 Temperature distribution

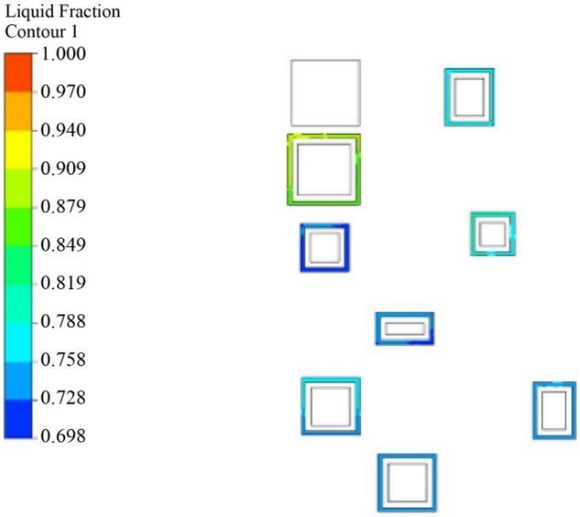


Fig. 7 Liquid fraction contour

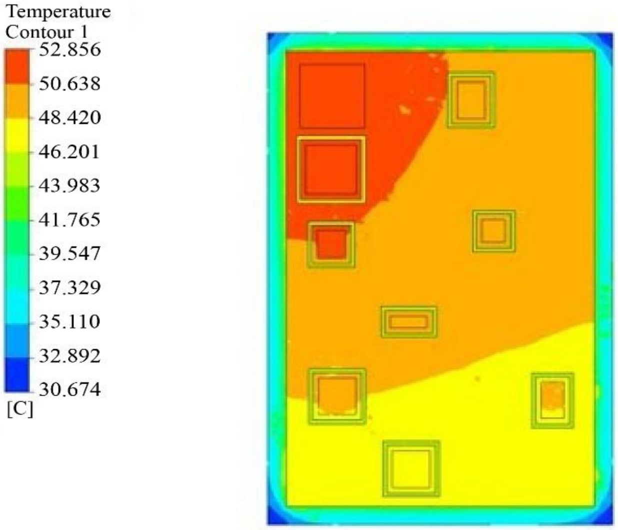


Fig. 8 Temperature contour

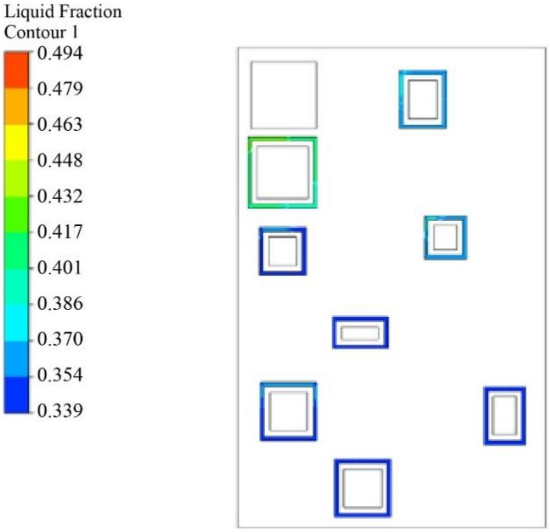


Fig. 9 Liquid fraction rate

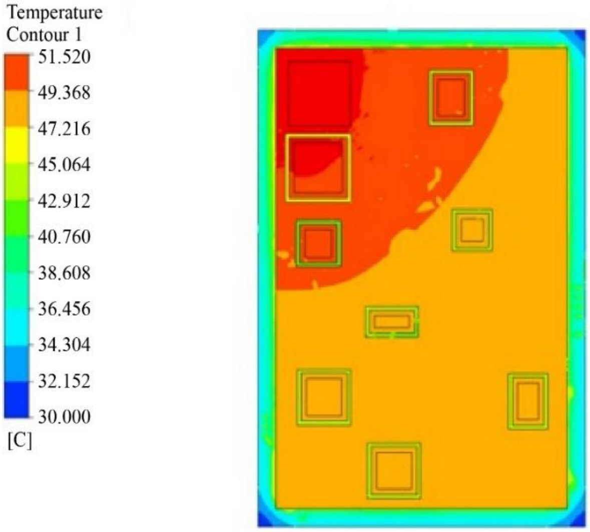


Fig. 10 Temperature contour

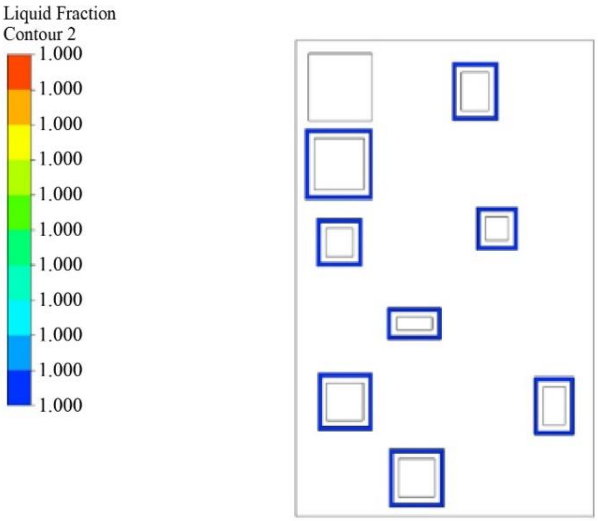


Fig. 11 Liquid fraction rate

6.2. Configuration 2) Minichannel coupled PCM cooling

The minichannels are laid out in this configuration so that they encircle the perimeter of the IC chip they are located on. The goal of the design that has been suggested is to reduce the system's temperature as a whole while absorbing the maximum heat that the heat source can generate. This will bring the system's temperature down to an acceptable level.

6.2.1. Case a) Mini channel with Paraffin Wax

It shows that the small channel lowers the temperature to 52 °C, employing paraffin wax purified small channels Fig. 6. The system's total gross temperature falls by 1.23 degrees Celsius. Referring to the Liquid fraction contour, the region around IC chip 1 absorbs the most latent heat. Liquid fraction near 1 is observed near tiny channel 1. As shown in Fig. 7.

6.2.2. Case b) Mini channel with ATP 78

ATP 78 lowered the temperature to 52.85 °C in the current situation Fig. 8. In comparison to the standard model. It decreases the system temperature by 0.42°C. The ATP 78 does not feature temperature regulation. At 3600 seconds, ATP 78 at the junction of the first microchannel has a liquid fraction rate of 0.49%. The high melting point of ATP 78 PCM prevents it from delivering a system-cooling temperature delay, as in Fig. 9.

6.2.3. Case c) Mini channel with N-Eicosane PCM

N-eicosane controls the system's temperature, and its values vary from 53.234 degrees Celsius in the general model to 51.520 degrees Celsius, as shown in Figure 10. When compared to the general model, there is a significant drop in temperature of 1.74 degrees Celsius. Additionally, there is a drop in temperature of 0.5 degrees Celsius when compared to the paraffin wax and 1.35 degrees Celsius compared to the ATP 78. N-eicosane has the potential to reduce junction temperature by increasing PCM's latent storage capacity. N-eicosane turns into a liquid after three minutes and sixty seconds because it cannot sustain its latent heat.

7. Conclusion

The study yields the following results.

(1) Microchannel cooling is one way to manage temperature and thermal propagation from a heat source properly. Direct conduction may reduce junction temperature in narrow channel-linked PCM cooling; however, it raises the structure's overall weight and reduces the package's energy density.
(2) Comparing configurations 6.2 and 6.1 reveals that the N-Eicosane connected mini channel can more effectively reduce junction temperature than other PCMs.
(3) N-Eicosnae controls the system temperature by 3.21 %.
(4) A strong agreement with experimental results also validates the accuracy of the present numerical scheme.
(5) The validation results are less than 5 % which shows good accuracy

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