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Thermal Analysis of Particulate Thermal Interface Materials (TIMS) Using Finite Element Analysis

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ABSTRACT: Particulate thermal interface materials (TIMs) are commonly used to transport heat from chip to heat sink. While high thermal conductance is achieved by large volume loadings of highly conducting particles in a compliant matrix, small volume loadings of stiff particles will ensure reduced thermal stresses in the brittle silicon device. Developing numerical models to estimate effective thermal and mechanical properties of TIM systems would help optimize TIM performance with respect to these conflicting requirements. Classical models, often based on single particle solutions or regular arrangement of particles, are insufficient as real-life TIM systems contain a distribution of particles at high volume fractions, where classical models are invalid. In our earlier work, a computationally efficient random network model was developed to estimate the effective thermal conductivity of TIM systems. This model is extended in this paper to estimate the effective elastic modulus of TIMs. Realistic microstructures are simulated and analyzed using the proposed method. Factors affecting the modulus (volume fraction and particle size distribution) are also studied. Thermal interface materials (TIMs) play a crucial role in removing waste heat from the chip. The heat flow depends on three factors namely (i) area of the surface (ii) Temperature difference and (iii) the convective heat transfer coefficient.

KEYWORDS: Thermal Interface Materials, Matrix, Convective Heat Transfer, Heat Flux.

I. INTRODUCTION

The past few decades have seen a revolutionary increase in computing performance and computers have become increasingly pervasive in all aspects of modern life. Evolution of the microprocessor is one of the most visible and representative facets of the computing revolution. Following Moore's law [1], the semiconductor industry has successfully doubled transistor density every two years and the microprocessor has been the flagship product, successfully exploiting the increased performance with each new technology generation along Moore's law. One of the historical consequences of increasing microprocessor performance is an associated increase in power dissipation. The microprocessor typically requires thermal management in three distinct environments

- 1) Cooling is required during functional test to prevent transient temperature rises from causing false performance readouts or failures.
- 2) During burn-in where infant mortality fails are identified as a function of the temperature, requiring accurate temperature control.
- 3) During functioning in a user environment. Managing the thermal environment is essential to ensure reliable, long-term performance.

Thermal interface materials (TIMs) play a crucial role in removing waste heat from the chip. Particulate TIMs consisting of thermally conducting particles in a polymer matrix are a common choice. In general, in particle filled TIM systems, the effective conductivity of the material is improved by increased volume fraction of the fillers, but this also has the effect of increasing the effective modulus. Increase in the effective modulus of the particulate material in turn induces greater thermal stress in the die increasing the risk of die fracture. Thus, the conflicting objectives in

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formulating the interface material call for the development of analytical or numerical models to estimate the effective thermal and mechanical properties so they may be optimized by formulating the appropriate particle size distribution

The length of heat sink fin is varied with different conductivities and convection coefficient. The optimum length is chosen in the analysis. The velocity of fan which is used to cool the microprocessor is varied with the values of 1.2 m/s, 2.2 m/s and 3m/s. This will consider as inlet boundary conditions. Composite materials with different combination are analysed in this journal. The composite materials were Alumina fillers in silicone matrix, Silver fillers in silicone matrix, Alumina fillers in epoxy matrix, Silver fillers in epoxy matrix and Copper filler in Silicone matrix.

II. LITERATURE REVIEW

The purpose of this literature review is to provide background information on the issues to be considered in this thesis and to emphasize the relevance of the present study. This treatise embraces some related aspects of polymer composites with special reference to their thermal analysis characteristics in heat sink. The topics include brief review:

- 1) On Variable Fin Length of Heat Sink
- 2) On Velocity of Cooling Fan.
- 3) On Thermal Analysis of different composite materials

Estimation of effective thermal and mechanical properties of Particulate thermal interface materials (TIMS) by a random Network model

Classical analytical models in literature such as the Maxwell's model [3], Rayleigh's model [4] and Bruggeman Differential Effective Medium (DEM) model [5] are valid only for isolated fillers and/or regularly arranged particles. Full-field simulations of particle ensembles were performed for high volume fractions [6] and were found to capture the near-percolation thermal transport in these materials accurately. However, these simulations were computationally expensive. A less expensive alternative using Batchelor's analytical approximation for two particles in near contact [7] was developed by Kanuparthi et al. [1] and termed Random Network Model (RNM). This model was based on the observation that heat transport in the interface is predominantly through the particles when the particle to matrix conductivity ratio is very high.

An improvement to the RNM was subsequently proposed by Dan et al. [2] and shown to model heat transport within a particle more accurately. Several analytical and empirical models have been proposed in literature to estimate the effective elastic modulus of particulate systems [8]. One of the earliest analytical models was developed by Einstein [9], in which inter-particle interactions were neglected and the modulus was obtained as a linear function of the volume fraction. Consequently, the model is applicable only for dilute concentrations (<10%) where the particles are well separated. Extensions to Einstein's model have attempted to incorporate particle interaction through higher order terms [10]. Kerner [11] derived an analytical expression for the effective modulus using an averaging scheme due to Bruggeman [5]. These analytical models are found to be inaccurate at high volume fractions. Semi-empirical models have also been proposed, such as the Halpin-Tsai's relation [12] and Mooney's equation [13], which require fitting parameters that depend on the composite system being studied. A numerical alternative is to conduct full-field simulations [6], but the computational cost involved is very high.

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III. MODELLING

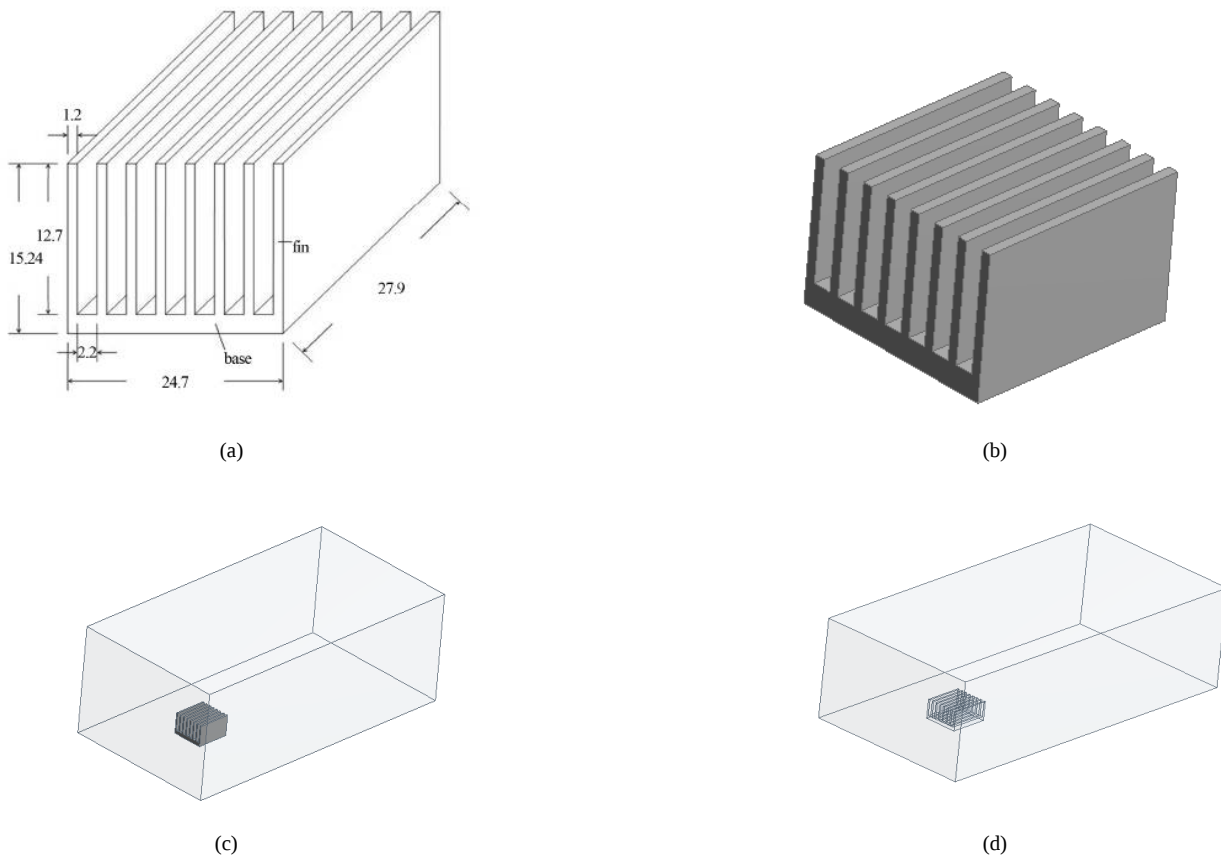


Fig. 1 Dimensions and Geometry (a) Heat sink Dimensions (b) CAD Model of Heat Sink (c) Combined Fluid and Solid Domain (d) Fluid Domain

IV. MESHING

Meshing is the process in which your geometry is spatially discretized into elements and nodes. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of your structure.

Your model is automatically meshed at solve time. The default element size is determined based on a number of factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature.

The following mesh model was created by using Ansys 19.0R1 Academic

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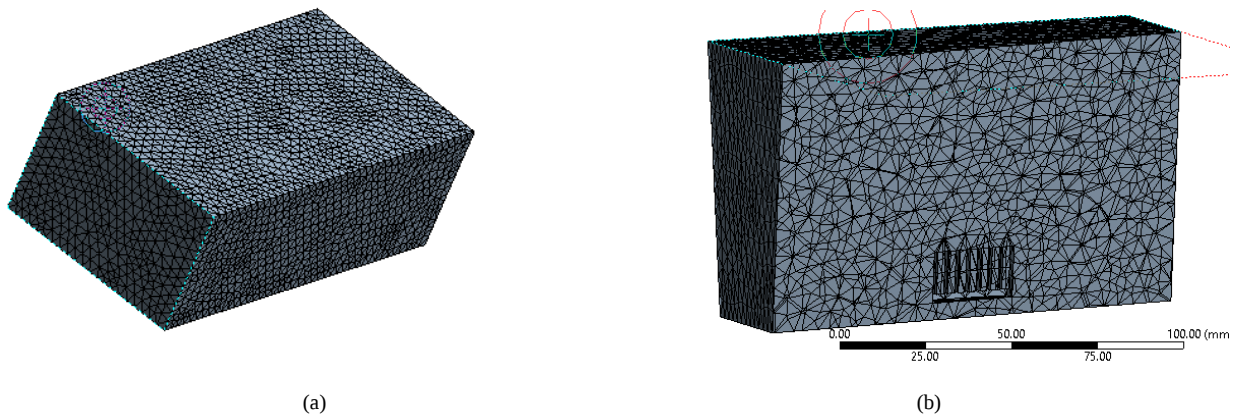


Fig 2 Meshing Details (a) Meshed Geometry (b) Section of discretized geometry

- No of Nodes : 18766
- No of Elements : 100535

V. BOUNDARY CONDITONS

The following are the boundary conditions that are applied to the given model

- Velocity of fan – 1.2 m/s, 2.2 m/s and 3 m/s
- Fin Length – 27.9mm to 36mm.
- Solid geometry is suppressed for the CFD Simulation
- Steady Flow Energy equation and Viscous laminar flow is assumed for the simulation

VI. RESULT ANALYSIS

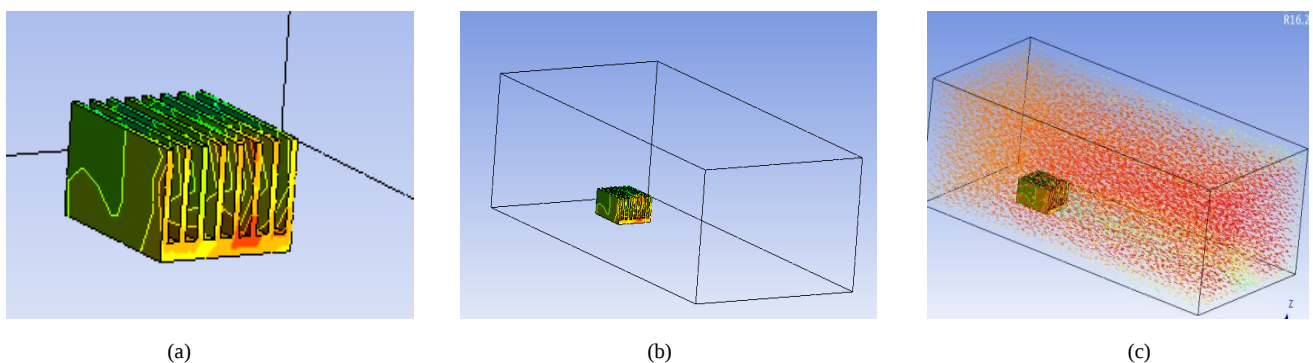


Fig. 4. CFD Analysis and Output (a) Temperature Distribution (b) Velocity Profile for air (c) Heat flux for heat sink

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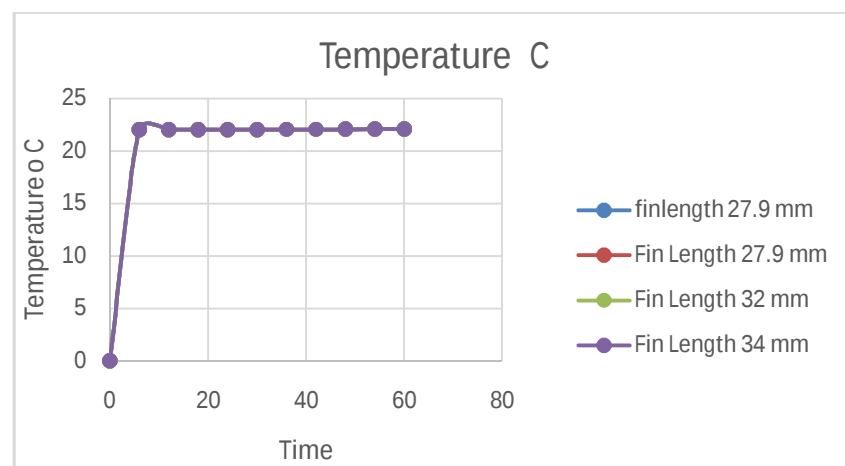
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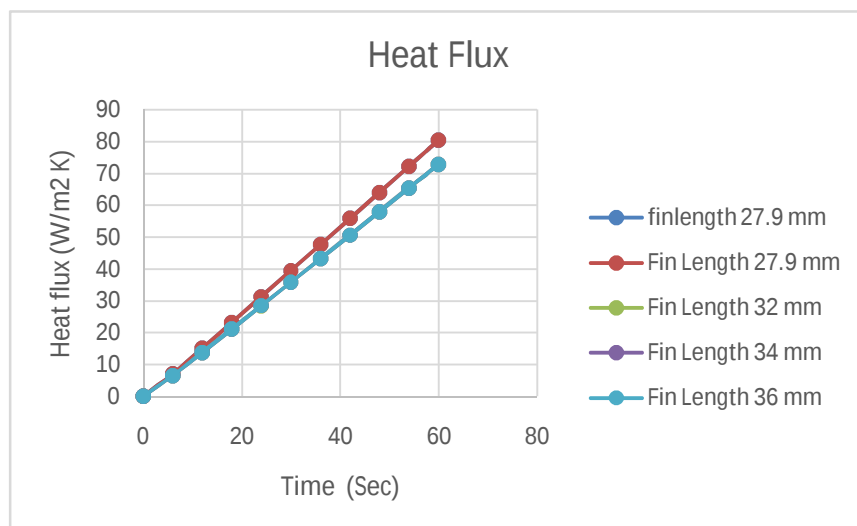
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VARIATION OF FIN LENGTH

The fin length is varied with the range of 27.9 mm to 36 mm. The graph of Temperature, Heat Flux and Thermal Resistance versus Time is plotted in different fin length.



(a)



(b)

Fig. 5. Graph (a) Temperature Vs Time (b) Heat Flux Vs Time

Optimum Conditions

Optimum velocity of fan with 1.2 m/s. Optimum composite from analysis silver filler with silicon matrix. This were found out through analysis.

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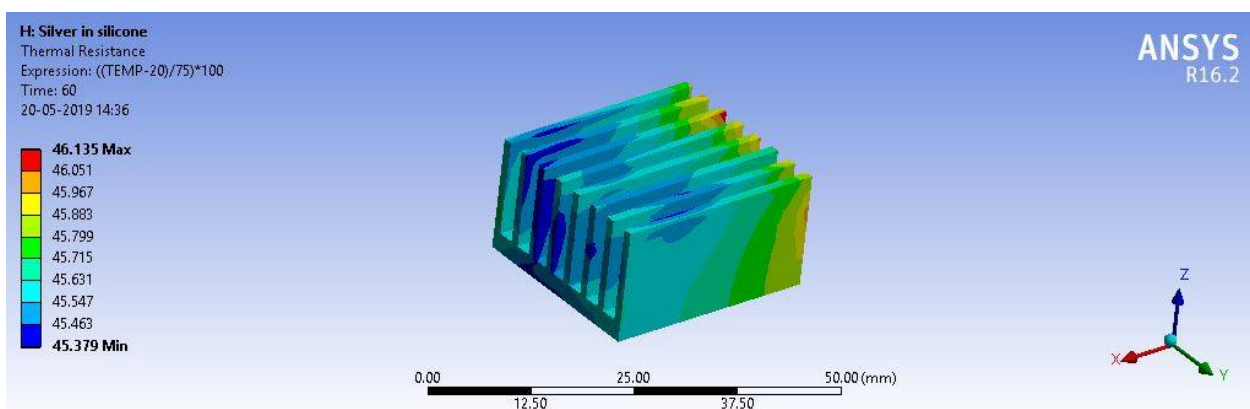
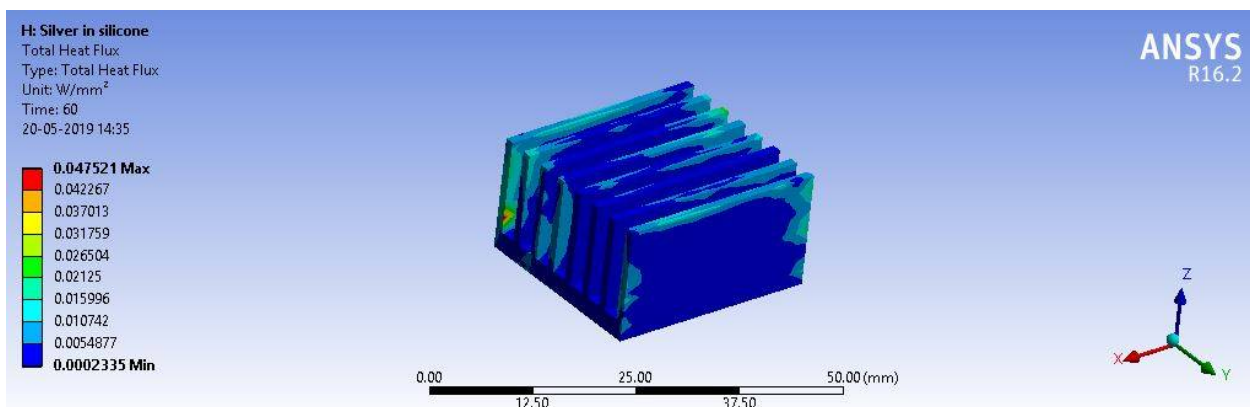
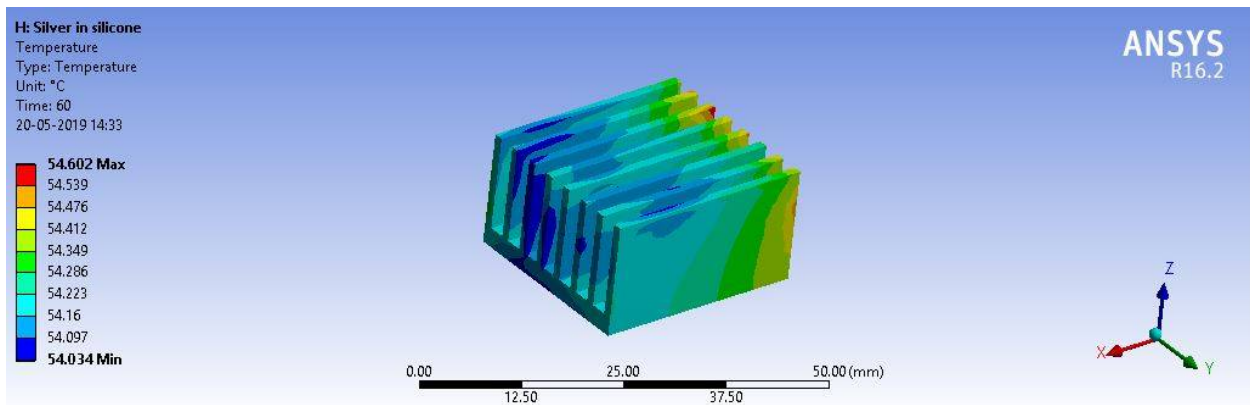


Fig 6. Variation in Silver filler with silicon matrix in 1.2 m/s (a) Temperature (b) Total Heat Flux (c) Thermal Resistance

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Table 6.1 Variation of Total Heat Flux

Sl No.	Velocity of Air	Materials	Total Heat Flux (Maximum)
-	m/s	-	W/m ²
1	1.2	Aluminum filler with silicon matrix	1090.72
2	1.2	Aluminum filler with epoxy matrix	416.19
3	1.2	Silver filler with silicon matrix	432.13
4	1.2	Silver filler with epoxy matrix	1279.47
5	1.2	Copper filler with silicon matrix	1278.81
6	2.2	Aluminum filler with silicon matrix	664.39
7	2.2	Aluminum filler with epoxy matrix	241.16
8	2.2	Silver filler with silicon matrix	250.13
9	2.2	Silver filler with epoxy matrix	756.61
10	2.2	Copper filler with silicon matrix	756.30
11	3	Aluminum filler with silicon matrix	511.12
12	3	Aluminum filler with epoxy matrix	183.02
13	3	Silver filler with silicon matrix	189.51
14	3	Silver filler with epoxy matrix	571.42
15	3	Copper filler with silicon matrix	571.21

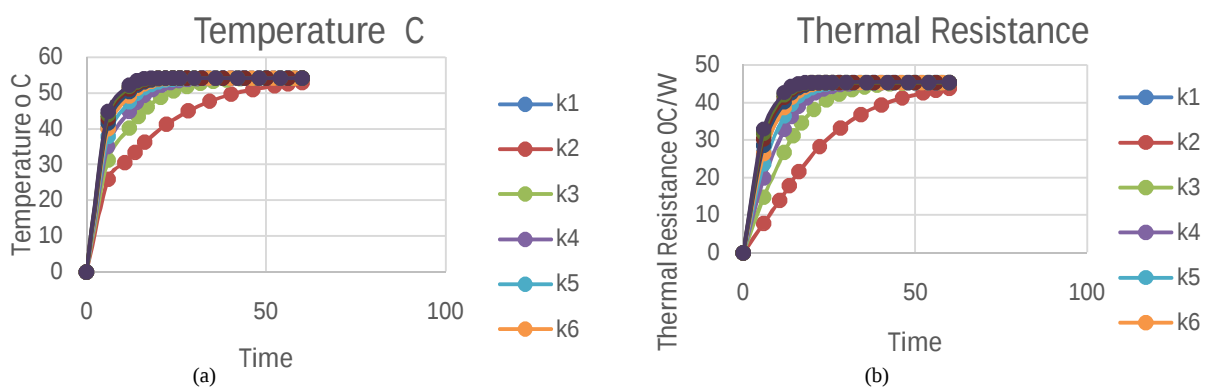


Fig 6. (a) Temperature Vs Time (b) Thermal Resistance Vs Time

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VII. CONCLUSION

Different thermal interface materials are identified for the analysis and is numerically tested for the suitability as a potential replacement for conventional materials. The thermal conductivity of the TIM is calculated from equations. Intra molecular gap is varied to obtain different thermal conductivities for numerical analysis. Three type of analysis is carried out to study about the behavior of TIM as a viable replacement. First by varying the fin length, using different TIM materials and with different velocities. The first we have created atmosphere heat rejection from TIMs. Then we applied a forced air flow by applying three different conditions of velocities using fan. The composite material has set with 5 combination of composite materials. The fin length is varied and the optimum fin length is used in next phase. Temperature, Total Heat Flux, Thermal conductivity and Thermal resistance are calculated and plotted the graph with time. Following observations are obtained from the analysis

- There is no considerable effects on heat flux and thermal resistance due to variations of effective fin length
- Silver filler in Silicon matrix material combination shows better performance in terms of heat flux and thermal resistance.
- Flow velocity is an important determinant of heat transfer in terms of electronic cooling

The future work can be done by changing the materials or by the different combination of composite materials can be analyzed. The turbulent flow can applied over the surface. The particle distance have done with small range. It can be decreased up to microstructure size and be used.

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