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The Comparison Between Thermal Pad Made of Nano-Silver and Silicon ElastomerUsing Computational Fluid Dynamic (CFD) Software, FLUENT^{TM}

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Abstract: This paper presents the comparison between thermal pad made of nano-silver and silicon elastomer by using three dimensional numerical analysis of heat and fluid flow in computer. 3D model of microprocessors is built using GAMBIT and simulated using FLUENT software. The study was made for four microprocessors arranged in line under different types of materials, inlet velocities and package (chip) powers. The results are presented in terms of average junction temperature and thermal resistance of each package The junction temperature is been observed and it was found that the junction temperature of the microprocessors is not exceed 70º C. It also found that the type of material in producing thermal pad and inlet velocities are the most important elements to control and manage the junction temperature. The strength of CFD software in handling heat transfer problems is proved to be excellent.

Key words: Thermal pad, Thermal Management, Nano-silver, Silicon Elastomer.

INTRODUCTION

Nowadays, the major trend in electronic industry is to make the products smarter, lighter, and highly compact, at the same time can reduce the heat of electronic component. This trend has necessitated stringent packaging requirements and using nanotechnology is a promising option to tackle this issue. However, a serious issue in electronic packaging is the thermal management. The electronic components made using silicon chip and the organic substrate, which generates heat and causes malfunction for some electronic components when the temperature above 70ºC. This problem is effectively solved by using thermal pad as a medium interface between microprocessor and PLCC. Two types of materials used in order to produce the thermal pad power and been tested in mini wind-tunnel and air inlet velocity used as cooling device. Conventionally the thermal pad was made by silicon elastomer as main material in the electronic components in chip manufacturing. Nano-silver was used to improve the thermal resistance in thermal pad in order to reduce the junction temperature of PLCC. In normal case, when electronic components operate in long period, the temperature of chip in electronic components will easily exceed 70ºC.This will cause electronic components malfunction or overheated. That why there are a lot of researchers doing study on thermal management over 30 years ago.

In electronic industries, the continuing increase of power densities in microelectronics and simultaneous drive to reduce the size and weight of electronic products have led to the increased importance of thermal management issues in electronic industry. The temperature at the junction of an electronic package has become the important factor that determines the lifetime of the package. The thermal management had been started over 30 years ago. Initially, the studied had been conducted by experiment only. The heat transfer and pressure drop for airflow in arrays of heat generating rectangular module had been studied by Sparrow (1982). Later Sparrow (1983) made an experimental investigation of heat transfer and fluid flow characteristics of arrays of heat-generating block-like modules affixed to one wall of a parallel-plate channel and cooled by forced convection airflow. They also investigated the convective heat transfer response to height differences in an array of block-like electronic components. Gupta and Jaluria (1998) carried out experiments to study forced convection water cooling of arrays of protruding heat sources with specified heat input. Hwang (1998) investigated forced convection from discrete heat sources mounted flush on a conductive substrate in a rectangular duct. Molki and Faghri (2000) made an experimental investigation of forced convection air-cooling of a 4 by 3 copper rectangular block positioned along the lower wall of the test section in an in-line arrangement. Ramadhyani, Moffat and Incropera (1985) made a 2D numerical study on the conjugate analysis of forced convection heat transfer from discrete heat sources mounted on a solid substrate and exposed to fully developed laminar flow.

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Davalath and Bayazitoglu (1987) considered a conjugate heat transfer for two-dimensional, developed flow over array rectangular blocks representing finite heat sources on parallel plate using the cooling fluid as air.

Utilization of CFD as thermal prediction tool was employed by Plotnik and Anderson (1995) and Tucker and Paul (1998) as part of design for heat transfer enhancement in electronic devices. The laminar and the turbulent forced convective flows over two sequentially heated blocks mounted on one principal wall of a channel were experimentally and numerically studied by Chen and Wang (1998). Hong and Yuan (1997) proved that a constant and uniform heat transfer coefficient across the whole package was inadequate in the accurate prediction of thermal stresses, due to the significant effect of local temperature distribution resulted from the variation of local heat transfer coefficient. Thus, they demonstrated the importance of considering the conjugate problem for electronic packages. Jayakanthan et al. (1997) carried out simulations of conjugate heat transfer associated with single and two packages mounted on printed circuit board (PCB) which was situated in a wind tunnel, using FLUENT™ for various flow conditions. This work was numerical investigation of heat transfer in plastic leaded chip carrier continued by Huat (1998) who simulated multiple chips using a 2D model. Hung and Fu (1999) designed a two-dimensional model for numerical prediction of viscous laminar flow, mixed convection and conjugated heat transfer between parallel plates with uniform block heat source and with opening on the integrated circuit board. The interest in the determination of junction temperature and thermal resistance continued to grow as is evident from the works of Tso et al. (1999), Young and Vafai (1999), and Kim and Kim (1999).

In year 2007, the development of electronic industries increase rapidly because development of electronic packaging and nanotechnology.Yusof et al. (2009) has studied the PLCC packaging by using 2 PLCC in the PLCC packaging. After that, the studied about electronic packaging about PLCC has been improved by Mazlan et al. (2010). Futhermore, nano-silver is used in electronic components to decrease temperature and increase the performance of chip processor. Nano-Silver can decrease the junction temperature of chip compare with others material like epoxy compound moulding (EMC) and Composite polymer. As the modern electronic industry is driving towards more compact systems, further research is needed to increase the performance of electronic devices.Mazlan et al. (2013) had studied the electronic packaging by using thermal pad as a medium interface between PLCC and motherboard. The thermal pad was made by using nano-silver because of high thermal resistance and thermal conductivity. Accordingly, the present study is focused on simulations of thermal pad applied on PLCC packages by using new material, nano-silver compare to the traditional one using silicon elastomer by using several inlet air velocities with different chip powers. Factors affecting the chip temperature such as coolant velocity, chip power and thermal conductivity of materials are studied and presented.

2.0 The Numerical Method:

2.1 Governing Equations:

The basic equations describing the flow of fluid are conservation of mass, conservation of momentum and conservation of energy. The governing equations are expressed as:

Continuity equation:

$$\frac{\delta u}{\delta x}+\frac{\delta v}{\delta y}+\frac{\delta w}{\delta z}=0 \tag{1}$$

Dimensionless continuity equation:

$$\frac{\partial \hat{U}}{\partial X}+\frac{\partial \hat{V}}{\partial Y}+\frac{\partial \hat{W}}{\partial Z}=0 \tag{2}$$

Momentum equation:

x-direction

$$(u\frac{\delta u}{\delta x}+v\frac{\delta u}{\delta y}+w\frac{\delta u}{\delta z})(\rho) = -\frac{\delta p}{\delta x}+\mu\left(\frac{\delta^2 u}{\delta x^2}+\frac{\delta^2 u}{\delta y^2}+\frac{\delta^2 u}{\delta z^2}\right) \tag{3}$$

y-direction

$$(u\frac{\delta v}{\delta x}+v\frac{\delta v}{\delta y}+w\frac{\delta v}{\delta z})(\rho) = -\frac{\delta p}{\delta y}+\mu\left(\frac{\delta^2 v}{\delta x^2}+\frac{\delta^2 v}{\delta y^2}+\frac{\delta^2 v}{\delta z^2}\right) \tag{4}$$

z-direction

$$(u\frac{\delta w}{\delta x}+v\frac{\delta w}{\delta y}+w\frac{\delta w}{\delta z})(\rho) = -\frac{\delta p}{\delta z}+\mu\left(\frac{\delta^2 w}{\delta x^2}+\frac{\delta^2 w}{\delta y^2}+\frac{\delta^2 w}{\delta z^2}\right) \quad (5)$$

Energy equation:
Energy balance equation with negligible radiation and distribute energy source in the fluid field is given as:

$$\rho c_p(u\frac{\delta T}{\delta x}+v\frac{\delta T}{\delta y}+w\frac{\delta T}{\delta w})=k\nabla^2 T \quad (6)$$

2.2 Description of Model:

The model used in this simulation consists of a wind tunnel which encompasses the whole computational domain with a motherboard, 4 PLCC and 4 thermal pad made by nano-silver andsilicon elastomer.The isometric view, plan view, and front view of the simulation setup for 4 PLCC packages are shown in Figure 1. The motherboard (PCB) is set up 9 cm from the inlet of wind tunnel to make sure that the flow is fully developed when it reaches the outlet of the wind tunnel. The 4 PLCC packages, each having 2 cm × 2 cm face were mounted with 3 cm gaps on the PCB in a symmetrical manner as show in Figure 1. The setup is kept at a height of 7 cm from the bottom surface of the wind tunnel. The motherboard thickness is 0.015 cm and the thickness of chips is 0.3 cm each, meanwhile the thickness of thermal pad is set at 0.1 cm and both made from nano-silver and silicon elastomer.

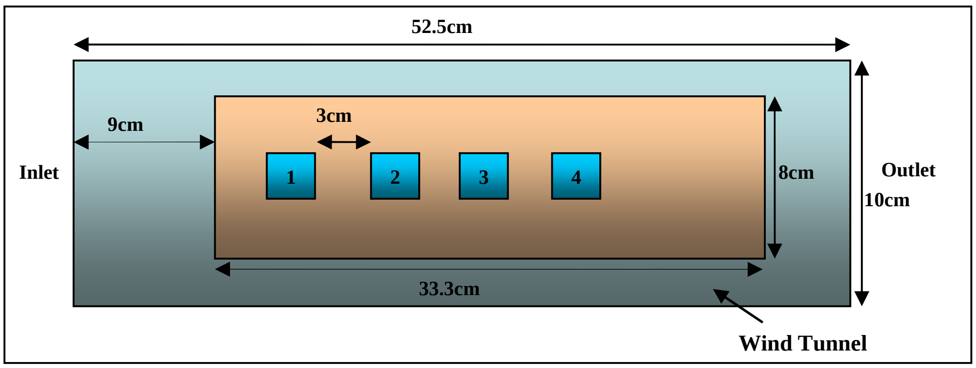


Fig. 1: Simulation Setup for 4 PLCC Packages.

Table 1: Dimension of Components Used in Simulation.

Component	Quantity	Size (cm^3)
Wind tunnel	1	52.5 cm × 10 cm × 10 cm
Motherboard	1	33.3 cm × 0.15 cm × 8 cm
Chip	4	2 cm × 0.3 cm × 2 cm
Thermal Pad	4	2 cm × 0.1 cm × 2 cm

RESULTS AND DISCUSION

The results are presented in terms of average junction temperature and thermal resistance for the packages under different operating conditions. The results of thermal pad made by nano-silver are comparable with silicon elastomerwhere 3-D analysis of the heat and fluid flow are similar and having same model dimensions. The difference bynano-silver material is enable to optimize and at the same time was able to decrease junction temperature for each PLCC packages with different values of input velocity.

3.1 Differences between Thermal Pad using Nano-Silver andSilicon Elastomeron average Junction Temperature by Using CFD Software

3.1.1 Chip Power 0.5W:

Thermal pad proves to be an effective method to reduce the junction temperature for all PLCCs. The result above has shown the difference between the PLCC using the nano-silver thermal pad and PLCC not using the thermal pad. Thermal pad made of nano-silver was able to reduce the junction temperature of the PLCC from 10-30 %. In this sub-chapter, the nano-silver thermal pad will be compared to the other thermal pads available in the current market to see the difference and to see which thermal pad is better to reduce the junction temperature of the PLCC. The thermal pad made of silicon elastomer strives to be the most popular thermal pad available in the current market in light of electronic applications. The same parameters were used in this simulation, where the air inlet velocity used starts from 0.01 m/s until 2 m/s. The chip power for the PLCC used is 0.5 W, 1 W and 2 W or the same as previous ones.

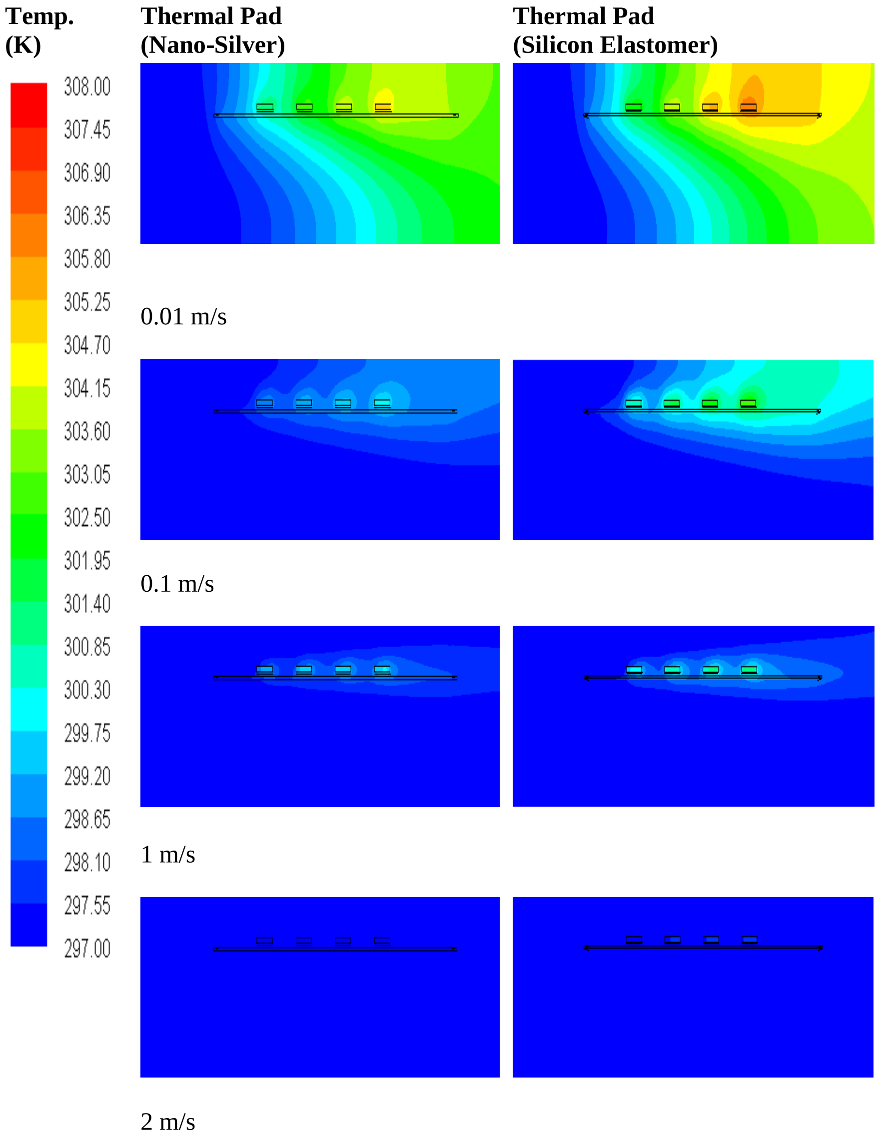


Fig. 2: The comparison between thermal pads made of Nano-Silver and Silicon Elastomer for 4 PLCC at 0.5 W

From figure 3, the differences between junction temperatures at 4 PLCCs using the thermal pad made of nano-silver with thermal pad made of silicon elastomer at 0.5 W are shown. The maximum percentage of the temperature reduction between PLCC is 10.14% and the maximum temperature for the PLCC using thermal pad made of nano-silver with thermal pad made of silicon elastomer are 31.42 ºC and 33.22 ºC. The differences between thermal pads (nano-silver) with thermal pads (silicon elastomer) at PLCC 1 are smaller compared to that made of nano-silver with EMC where the differences exceed 30%. For these two thermal pads, the differences are 5.55%, 3.25%, 3.67% and 0.91%, respectively. Meanwhile, the differences at PLCC 2 are 5.44%, 2.67%, 3.86% and 1.03%, respectively. For PLCC 3, the differences between the PLCC using thermal pad (nano-silver) and thermal pad (silicon elastomer) are 3.95%, 2.62%, 7.13% and 1.36% respectively. Finally, at PLCC 4, the differences between the PLCC using thermal pad (nano-silver) and thermal pad (silicon elastomer) in terms of the junction temperatures are 5.42%, 2.25%, 10.14% and 0.32% respectively.

From the results above, it has been shown that the PLCC using thermal pad made of nano-silver has a lower junction temperature compared to thermal pad made of silicon elastomer. By using the nano-silver thermal pad, the temperature of the PLCC should be able to reduce up to 10.14% for 4 PLCC applications at 0.5 W. Although the PLCC using thermal pad made of silicon elastomer has higher junction temperature, it still turns out better than the PLCC without using the thermal pad.

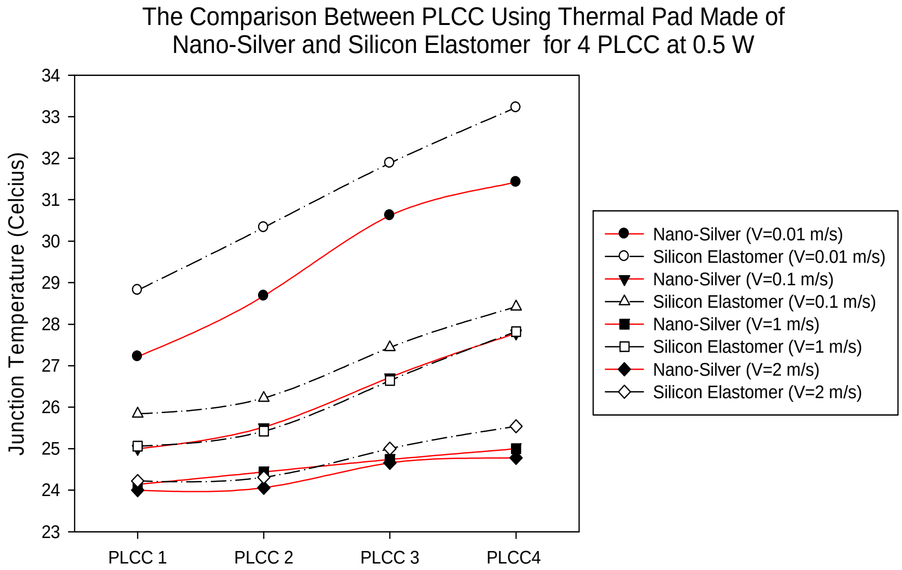
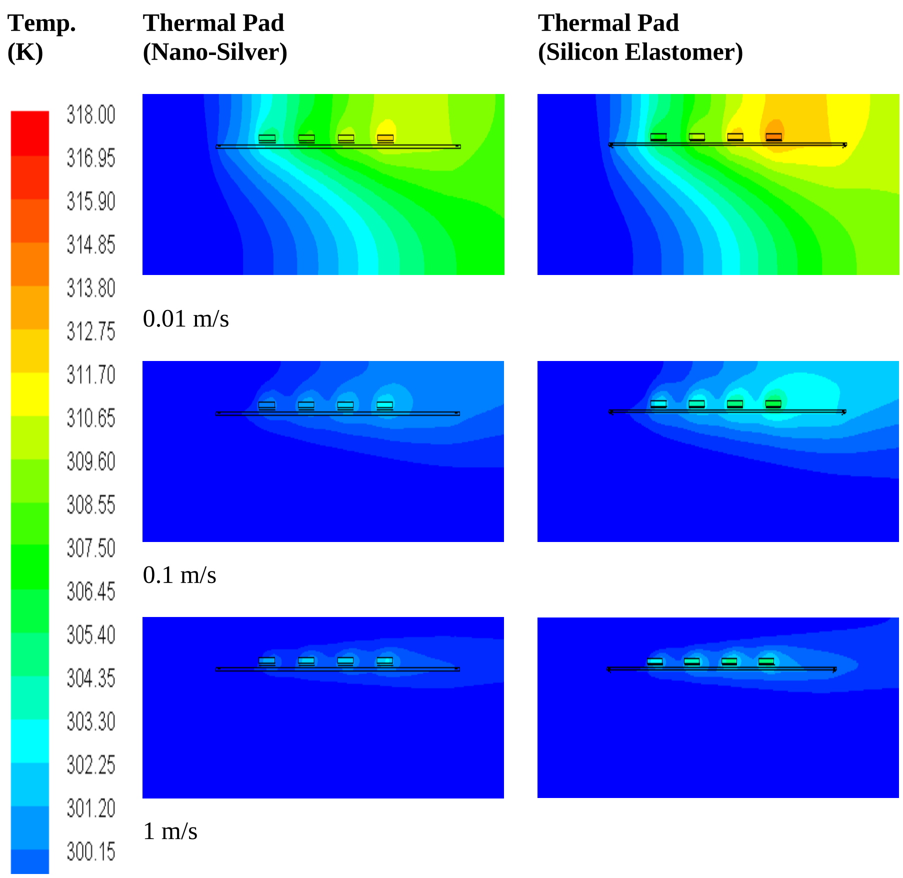
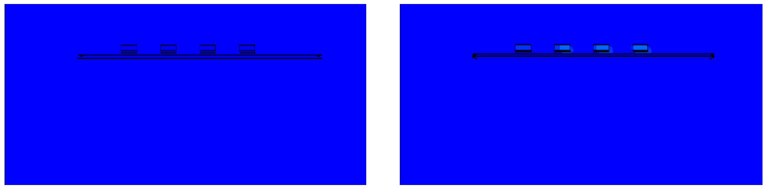


Fig. 3: The graph show the comparison between thermal pads made of Nano-Silver and Silicon Elastomer for 4 PLCC at 0.5 W

3.1.2 Chip Power 1 W for 4 PLCCs:





2 m/s

Fig. 4: The comparison between thermal pad made of Nano-Silver and Silicon Elastomer for 4 PLCCs at 1 W.

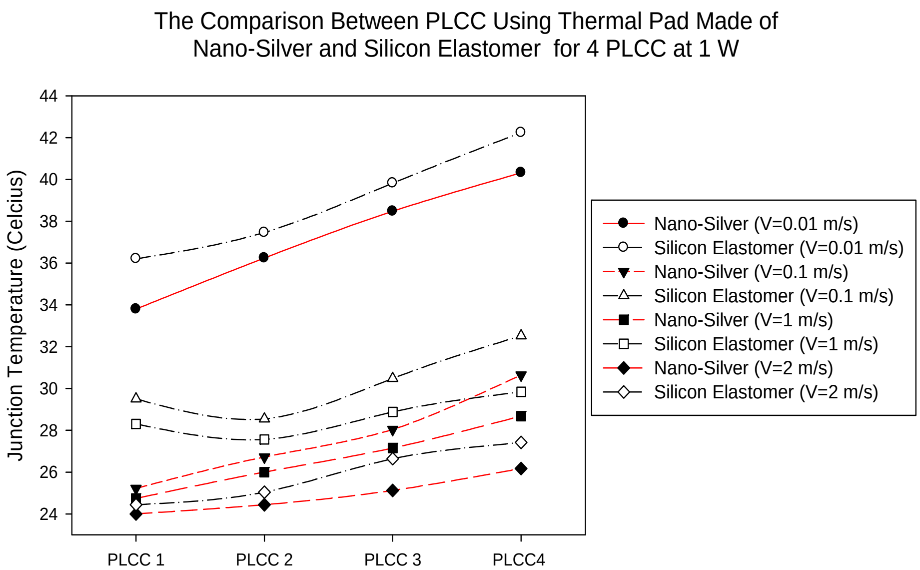


Fig. 5: The graph show the comparison between thermal pads made of Nano-Silver and Silicon Elastomer for 4 PLCC at 1 W.

From figure 5, the differences between junction temperatures at 4 PLCCs using thermal pad made of nano-silver with thermal pad made of silicon elastomer at 1 W are highlighted. The maximum percentage of the temperature reduction between the PLCC is 14.51% and the maximum temperature for the PLCC using thermal pad made of nano-silver with thermal pad made of silicon elastomer are 40.32 ºC and 42.24 ºC. For these two thermal pads the differences are 6.63%, 14.51%, 12.58% and 1.80% respectively. Meanwhile, the differences at PLCC 2 are 3.26%, 6.38%, 5.66% and 2.40% respectively. For PLCC 3, the differences between the PLCC using thermal pad (nano-silver) and thermal pad (silicon elastomer) are 3.37%, 8.01%, 5.99% and 5.71% respectively. Last but not least, at PLCC 4 the differences between the PLCC using thermal pad (nano-silver) and thermal pad (silicon elastomer) in terms of the junction temperature are 4.55%, 5.78%, 3.89% and 4.56% respectively.

From the results above, the same pattern has shown that the PLCC using thermal pad made of nano-silver has lower junction temperature compared to thermal pad made of silicon elastomer. By using the nano-silver thermal pad, the temperature of the PLCC was able to be reduced up to 14.51% for 4 PLCC applications at 1 W. This time, the differences between these two thermal pad have increased due to the increase in the chip power from 0.5 W to 1 W. These phenomena occur due to the increasing junction temperature in all PLCCs that had led the difference to increase.

3.1.3 Chip Power 2 W for 4 PLCCs:

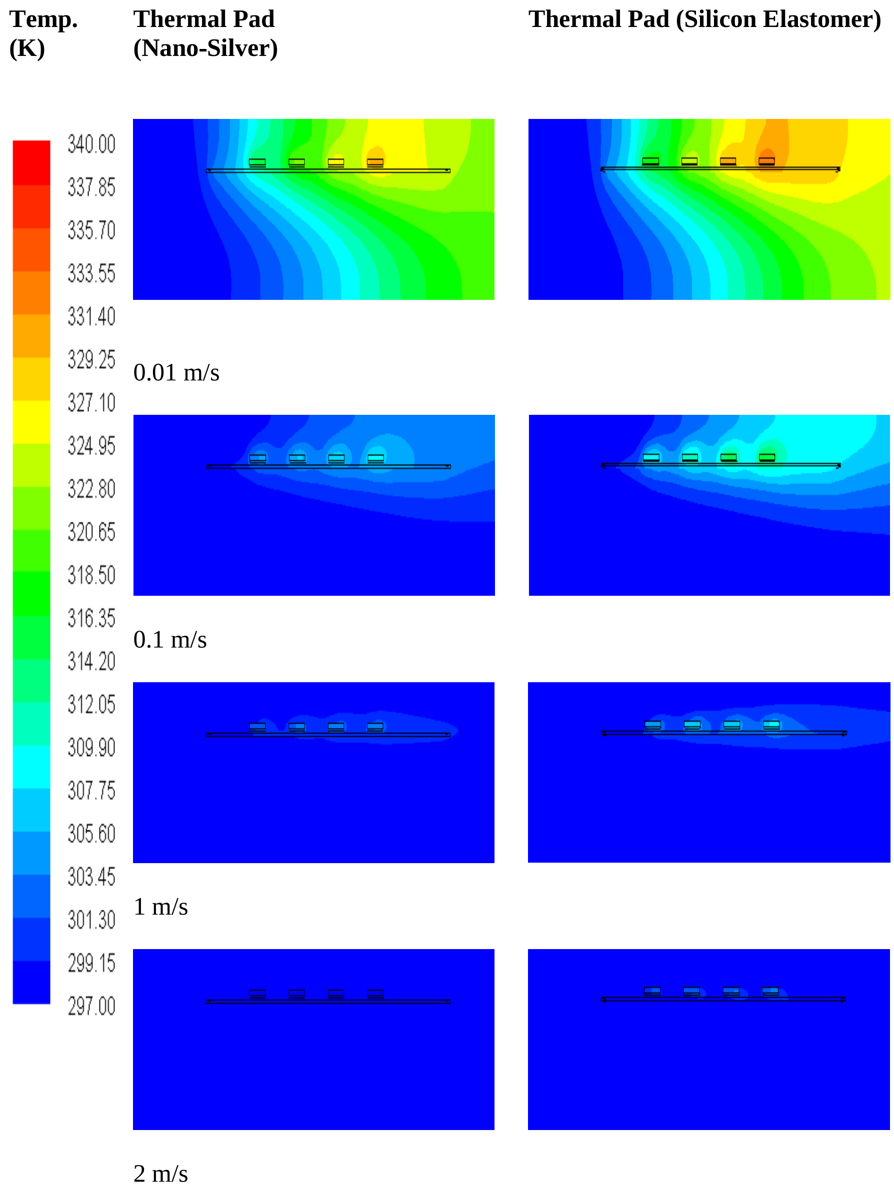


Fig. 6: The comparison between thermal pads made of Nano-Silver and Silicon Elastomer for 4 PLCCs at 2 W.

Figure 7, shows the differences between junction temperatures at 4 PLCCs using thermal pad made of nano-silver with thermal pad made of silicon elastomer at 2W. The maximum percentage of the temperature reduction between the PLCC is17.65% and the maximum temperatures for PLCC using thermal pad made of nano-silver with thermal pad made of silicon elastomer are 43.35 ºC and 52.64 ºC.For these two thermal pads the differences are 8.32%, 17.65%, 14.43% and 4.2% respectively.Meanwhile, the differences at PLCC 2 are 5.52%, 7.62%, 7.22% and 4.2% respectively. For PLCC 3, the differences between the PLCC using thermal pad (nano-silver) and thermal pad (silicon elastomer) are 5.12%, 9.42%, 8.12% and 7.64% respectively. Finally, at PLCC 4 the differences between the PLCC using thermal pad (nano-silver) and thermal pad (silicon elastomer) in terms of the junction temperatures are 6.23%, 8.52%, 6.32% and 6.97% respectively.

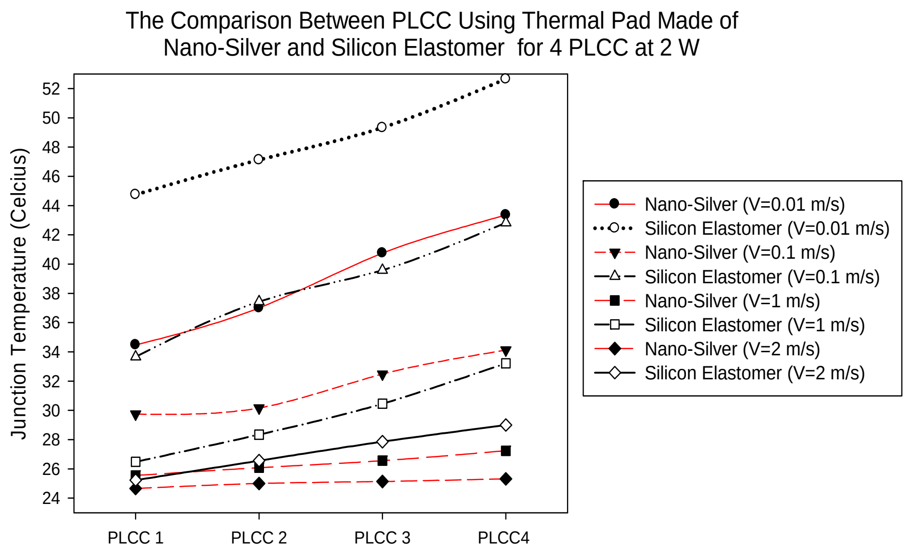


Fig. 7: The graph show comparison between thermal pads made of Nano-Silver and Silicon Elastomer for 4 PLCCs at 2 W

4.0 Conclusion:

From the results above, shown that the junction temperature of PLCCsdecreases with increase in inlet velocity, at a constant chip power. The junction temperature thermal pad made of nano-silver is lower than silicon elastomer for air inlet velocity at 0.01 m/s and 2 m/s. The junction temperature of PLCC reduces from 10-20 % by using nano-silver compare to silicon elastomer. This happen due to the characteristic of nano-silver that had good thermal absorption and thermal resistance. The junction temperature for PLCC 1 is the lowest compared to the other packages whereas PLCC 4 has highest junction temperature. This phenomenon happens due to the flow resistance offered as the air passes over successive PLCC packages. In the simulation model, the arrangement of the packages begins with the PLCC 1 located in front of motherboard followed by 2, 3 and 4. This makes the inlet air velocity to be minimized for PLCC 4 and hence maximum junction temperature.

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