DATE: 16 Oct 2023

MAE 3314 – Heat Transfer – Design Assignment 1 Report.

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❖ Problem Statement:

To create a Heat Sink attached to a CPU chip with all system surfaces being convectively cooled. With the given dimensions of the system, the goal is to perform a steady-state temperature distribution analysis for the given boundary conditions and material properties. Ultimately, the maximum temperature must not exceed 85°C. Then, various thermal parameters are changed on the ANSYS model and the effect of the results are observed.

❖ Boundary conditions:

- Volumetric heating rate $\dot{q} = 5 \cdot 10^6\ W/m^3$
- Convection heat transfer coefficient $h = 50\ W/m^2$-K
- Temperature $T_\infty = 40°C$

❖ Procedure:

The heat sink and silicone chip are first modelled using SolidWorks. The following Fig. 1 shows the initial assembly. The bottom plate is the silicone chip and the top plate with 121 fins is the heat sink.

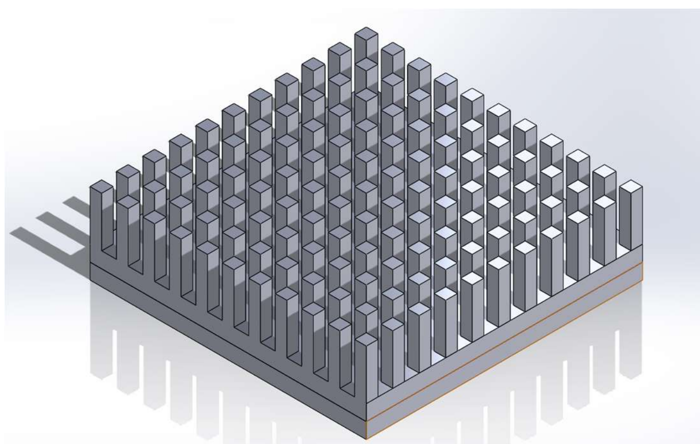


Fig. 1 Heat sink and silicone chip assembly in SolidWorks.

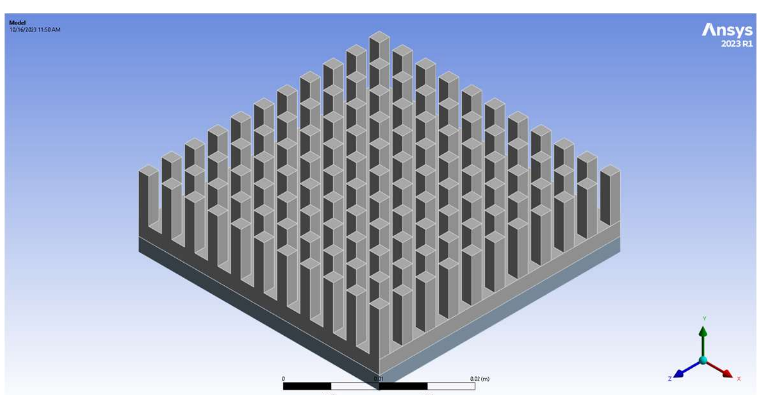


Fig. 2 Heat sink/CPU imported in ANSYS.

For the initial analysis, the meshes chosen are very coarse to reduce processing time. The heat sink has tetrahedron mesh shapes and the bottom chip has standard square shaped mesh. The tolerance level for sizing is set to 0.005.

Two separate materials are given to the parts. The bottom chip is selected with pure silicone, whereas the top heat sink is selected with Aluminium alloy. These materials are later changed to see the 3D temperature heat map.

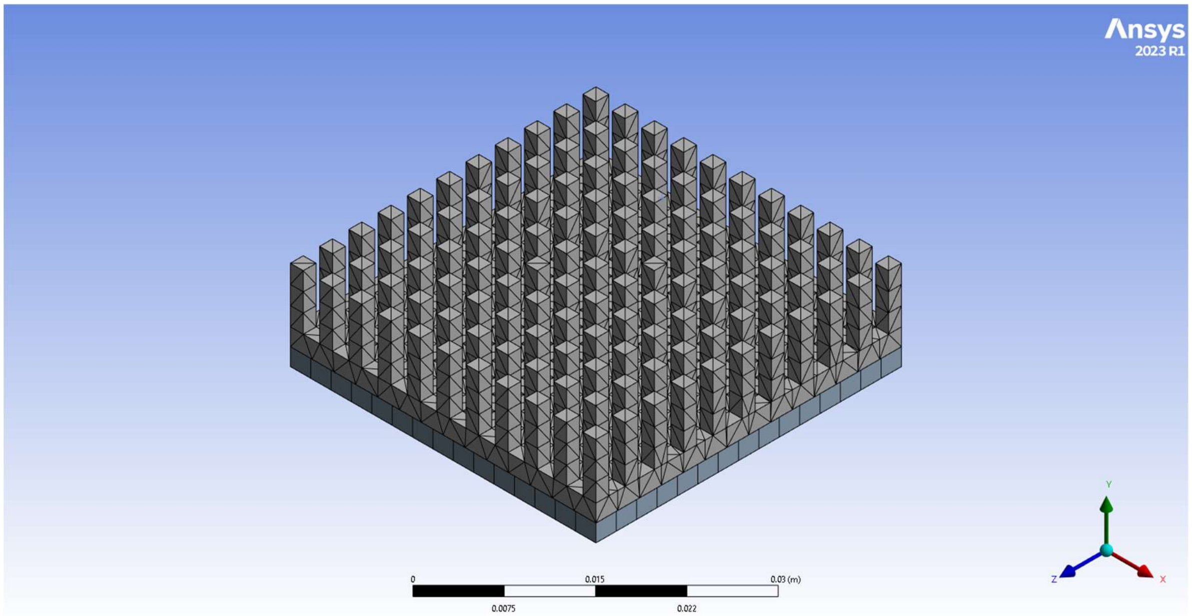


Fig. 3 Meshes added to the CPU/Heat sink model.

❖ Steady-state temperature distribution analysis:

For the boundary conditions, the volumetric heat generation of Adding volumetric heat generation of $\dot{q} = 5 * 10^6\ W/m^3$ is added to the bottom (exposed) plane of the silicon chip. The heat sink is added with the temperature $T_\infty = 40°\text{C}$ and $h = 50\ W/m^2$-K. The following Fig. 4 is the 3D colour temperature map.

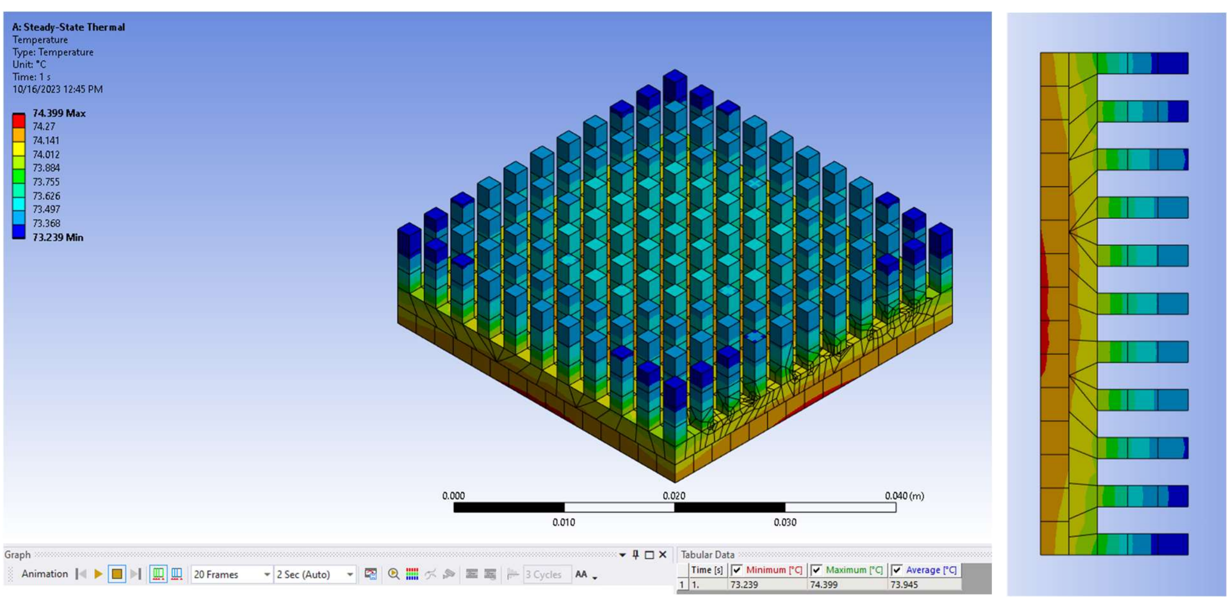
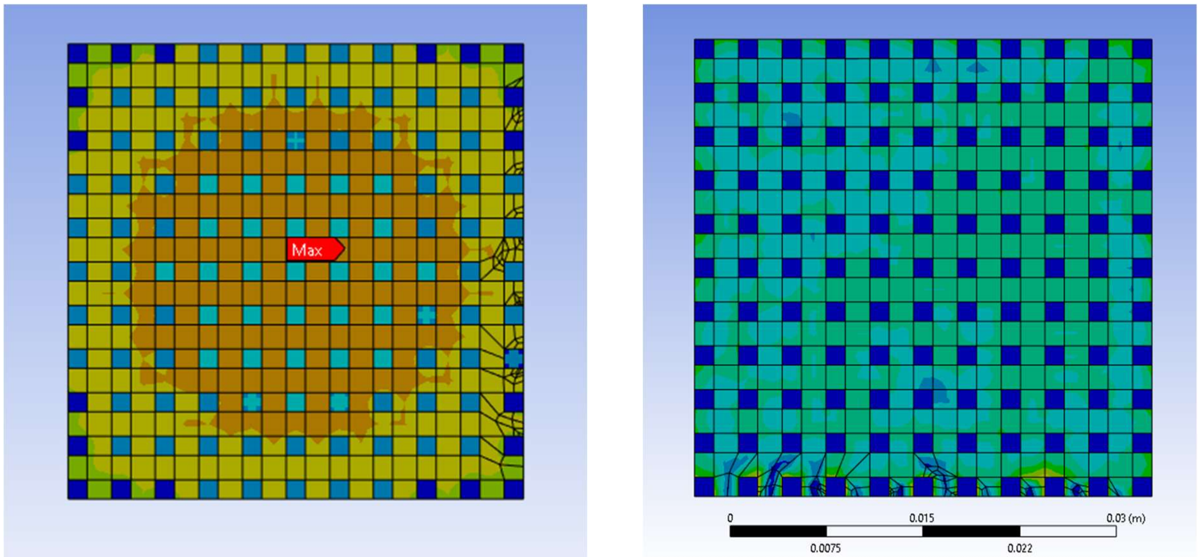


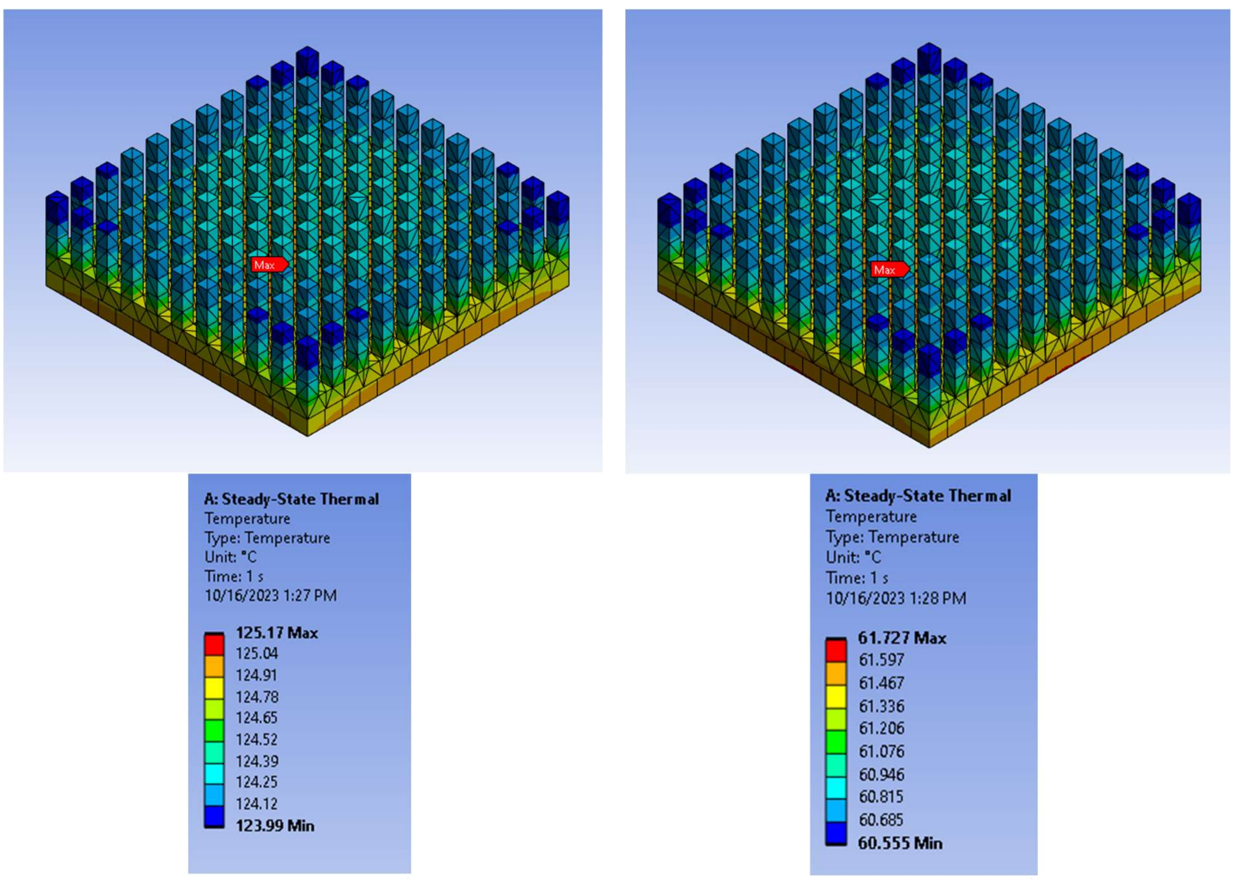
Fig. 4 3D colour map of temperature distribution for original boundary conditions.



(a) Temperature map (Top view) (b) Heat flux map (Top view)

Fig. 5 Temperature and heat flux distribution colour map from top.

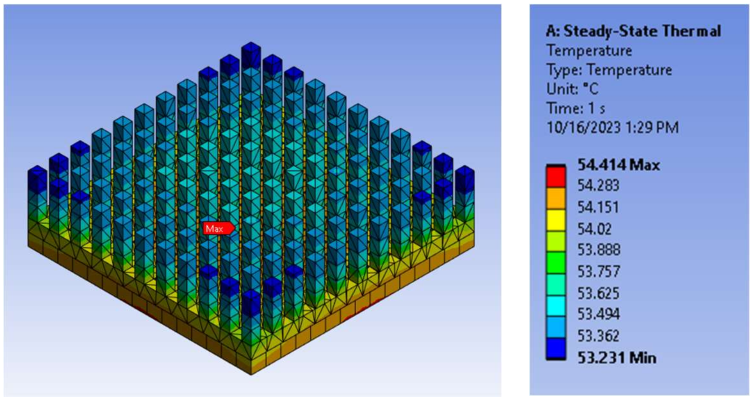
- **Part (d): 1 – increasing (or decreasing) convection heat transfer coefficient, *h* of air.**



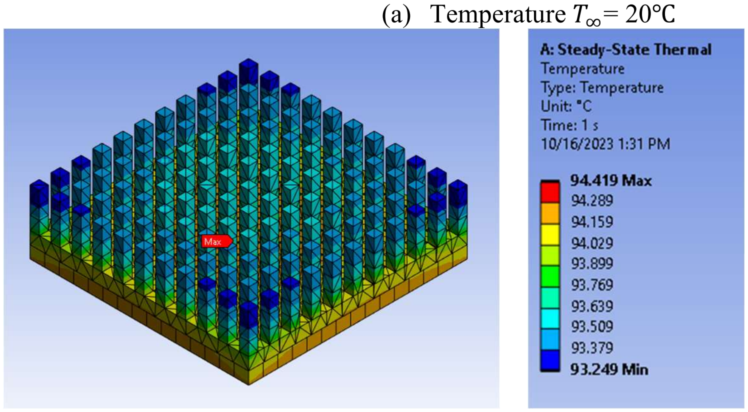
(a) $h = 20\ W/m^2\text{-}K$ (b) $h = 80\ W/m^2\text{-}K$

Fig. 6 New temperature colour maps with temperature ranges for revised coefficient.

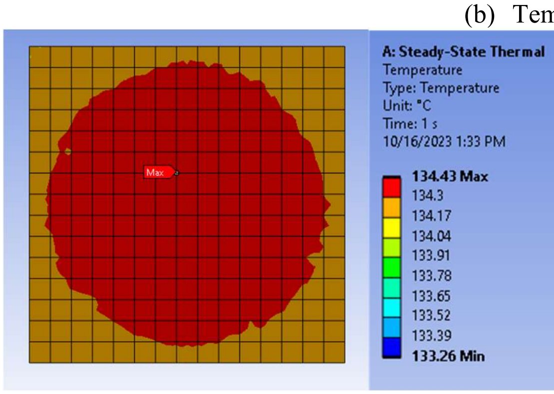
❖ **Part (d): 2 – increasing (or decreasing) air temperature, T_∞**



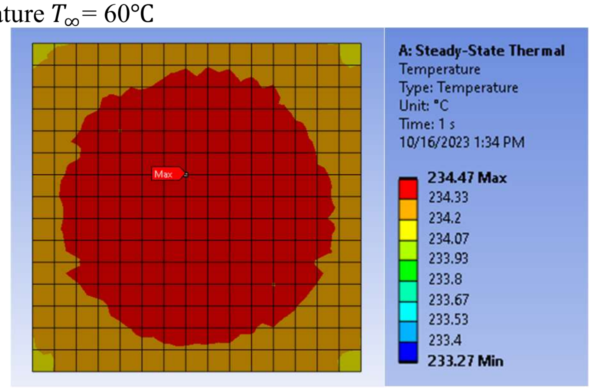
(a) Temperature T_∞= 20°C



(b) Temperature T_∞= 60°C



(c) Temperature T_∞= 100°C



(d) Temperature T_∞= 200°C

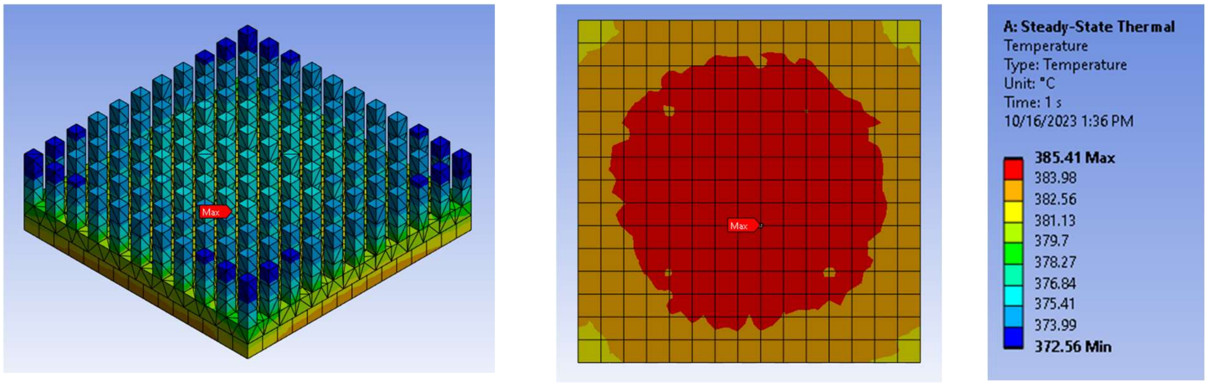
Fig. 7 New temperature colour maps with temperature ranges for revised air temperatures.

Upon plotting the temperature distribution maps for the original set of boundary conditions, the maximum temperature resulted in 74.399 °C (Fig. 4). Additionally, the total heat flux map was also generating for the given conditions (Fig. 5, b). The bottom of the chip has the most amount of heat, while the top portions are relatively cooler. The system is well below the safety limit of 85 °C.

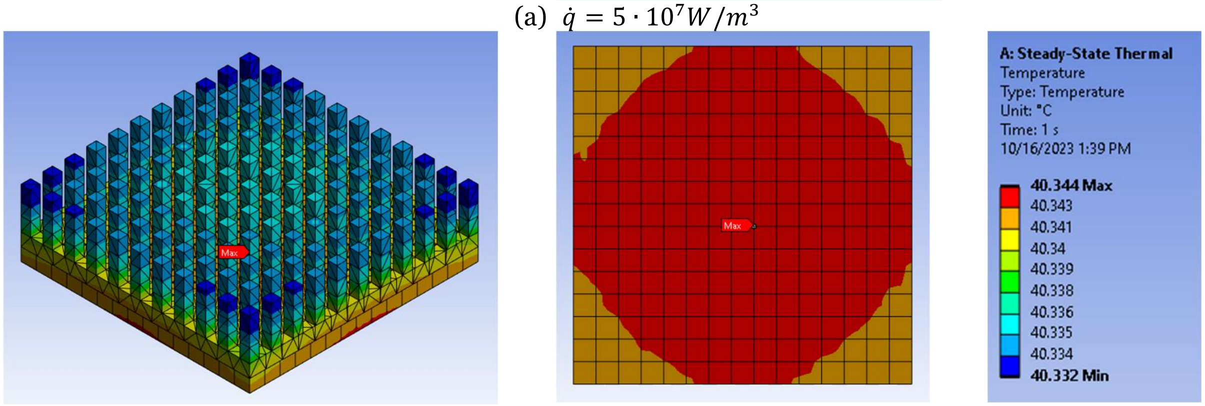
When the heat transfer coefficient was decreased, the maximum temperature spiked to 125.17 °C. However, when the heat transfer coefficient was increased, the maximum temperature is 61.73 °C. This intuitively makes senese because with a higher rate of heat dissipation, the system is able to cool faster thereby lowering its maximum temperature (Fig. 6, b).

Four different ambient temperatures were tested as seen in Fig. 7. The trend seen is that with the increase in ambient temperature, the maximum temperature increases. To add, the temperature range is very small.

- **Part (d): 3 – increasing (or decreasing) chip generation density, $\dot{q}$**



(a) $\dot{q} = 5 \cdot 10^7 W/m^3$



(b) $\dot{q} = 5 \cdot 10^4 W/m^3$

Fig. 8 New temperature colour maps with temperature ranges for revised heat generation.

With the increase in chip power generation density, the maximum temperature skyrockets. Notice from Fig. 8 that the highest temperatures are concentrated in the middle of the chip for part (a). As the power is decreased, the maximum temperature is drastically lower and the temperature difference between minimum and maximum is very small.

The type of material also has an effect on the temperature distribution of the heat sink. As seen in Fig. 9-10 below, four different materials were chosen specifically for the heat sink: pure silicon, stainless steel, copper alloy and glass fiber. All the original boundary conditions were used for all these materials. Upon obersving, pure silicon has the most similar effect to the originally chosen Aluminium alloy – with a slightly higher maximum temperature.

The highest temperature difference is seen for the glass fiber (Phenolic (PF) matrix, E-glass fiber woven prepreg, quasi-isotropic laminate) ranging from 44.2 ℃ to 114.3 ℃. However, this heat quickly dissipates before reaching the surface of heat sink (Fig. 9 (d) top view) when compared to stainless steel material. Additionally, copper alloy has similar temperature map to pure silicon. Finally, stainless steel has a high surface temperature at the heat sink. Therefore, stainless steel and glass fiber are not good materials for heat sink or the chip. Copper alloy can be a good material for the system.

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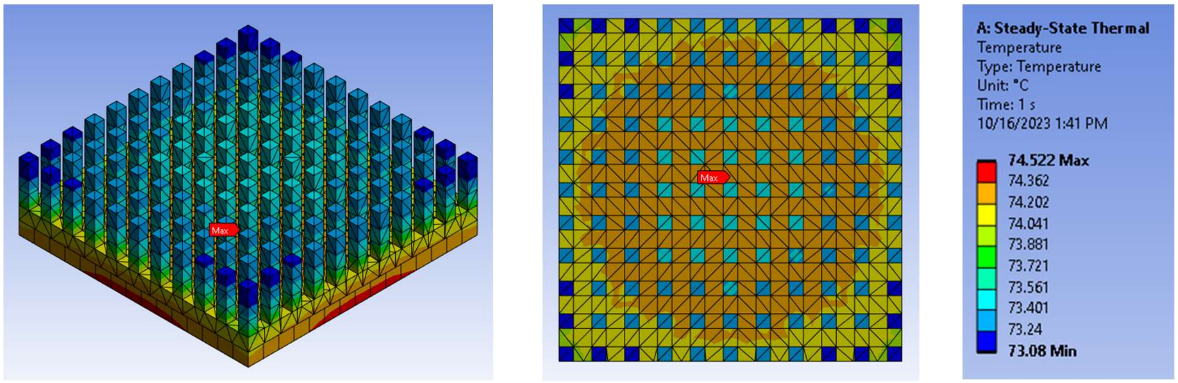
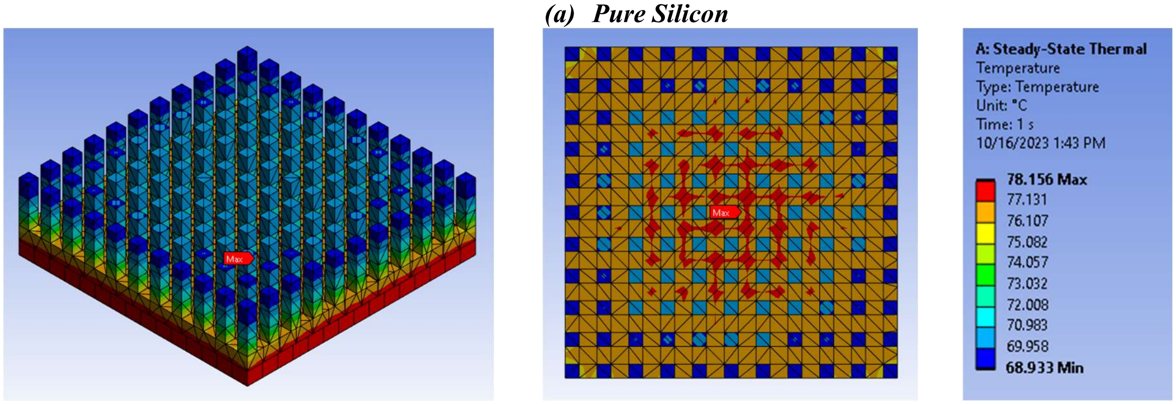
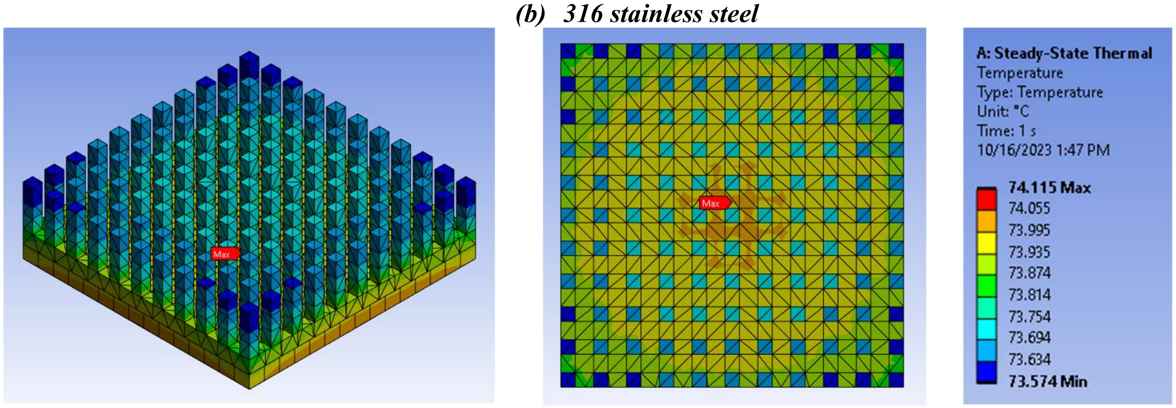
❖ Part (d): 4 – Changing heat sink materials.



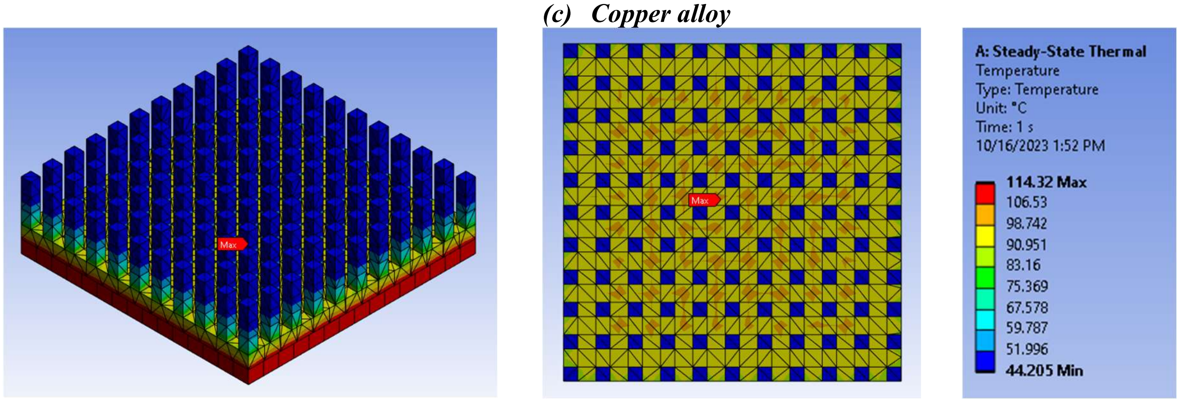
(a) Pure Silicon



(b) 316 stainless steel

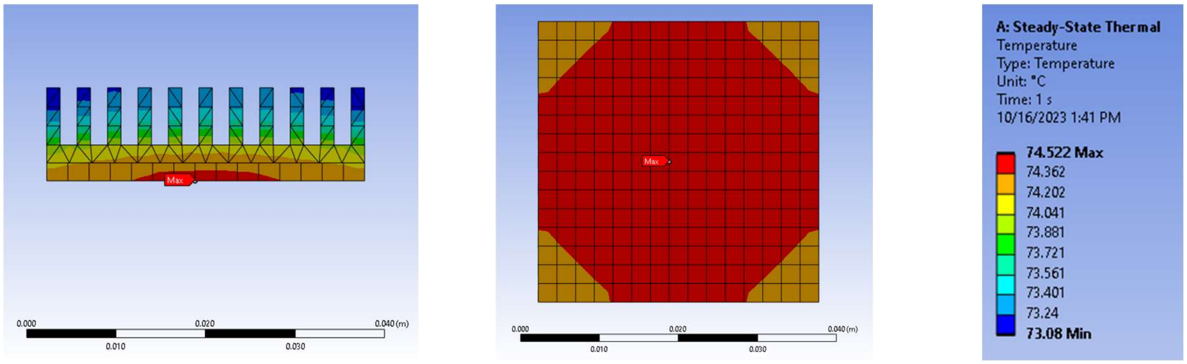


(c) Copper alloy

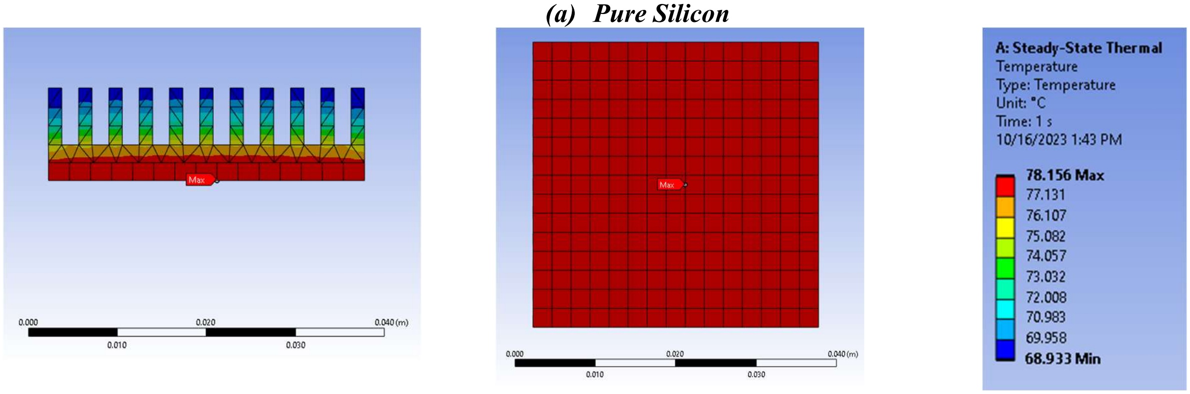


(d) Glass fiber

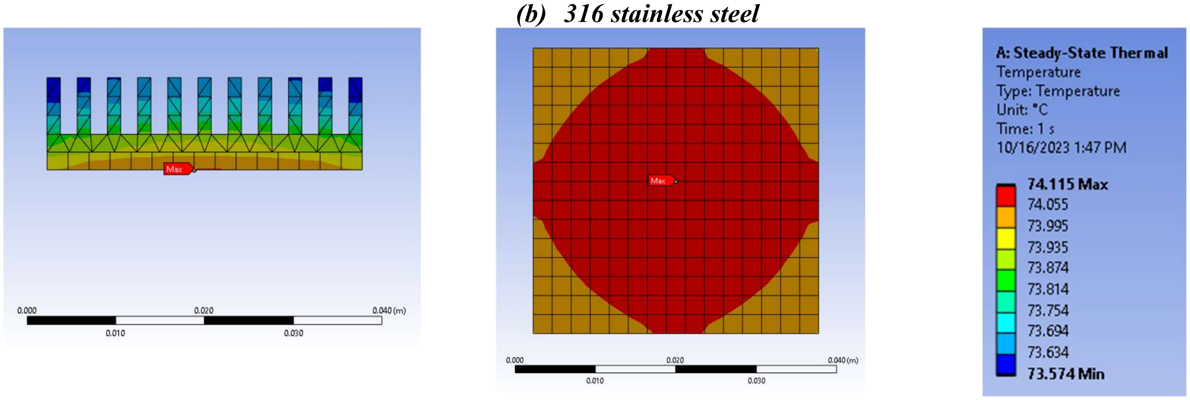
Fig. 9 Temperature distribution for changed materials.



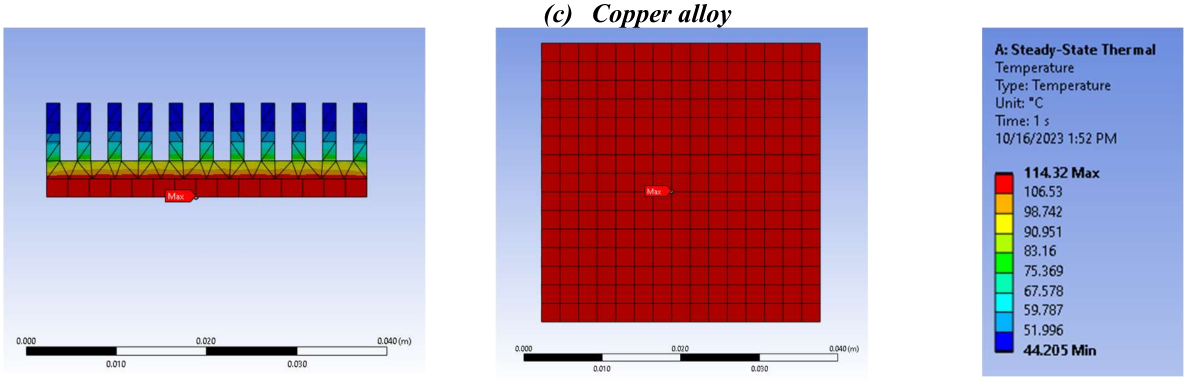
(a) Pure Silicon



(b) 316 stainless steel



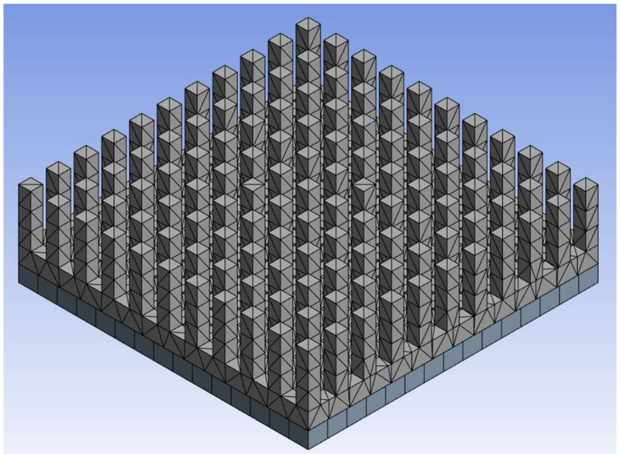
(c) Copper alloy



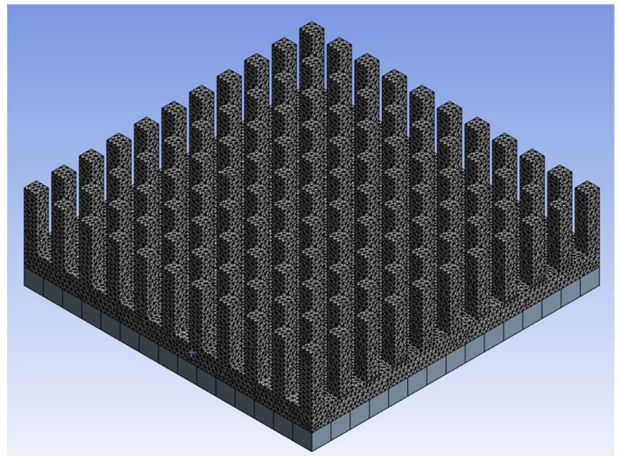
(d) Glass fiber

Fig. 10 Temperature distribution for changed materials.

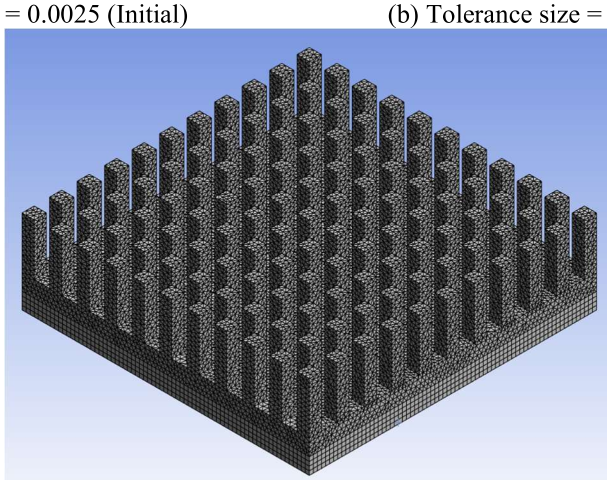
❖ Part (d): 5 – Changing mesh sizes.



(a) Tolerance size = 0.0025 (Initial)



(b) Tolerance size = 0.0005 (heat sink only)



(c) Tolerance size = 0.0005 (heat sink + silicone chip)

Fig. 11 Meshes chosen.

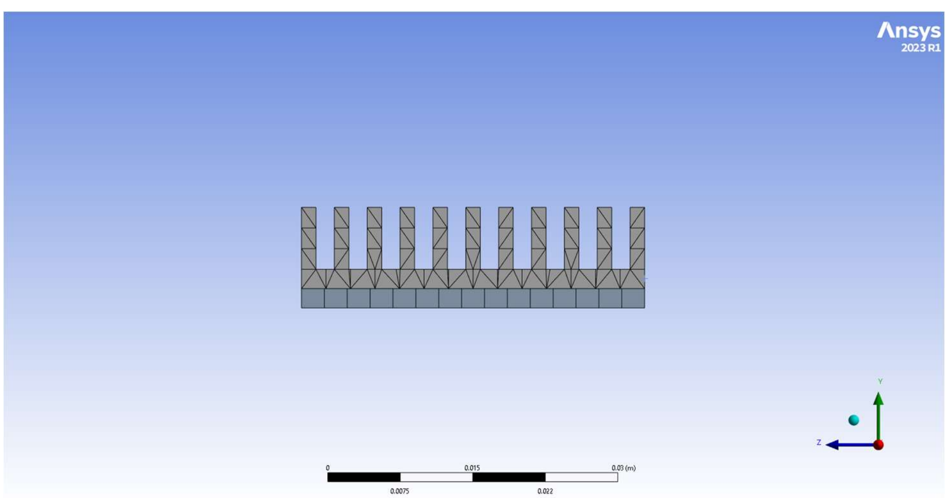
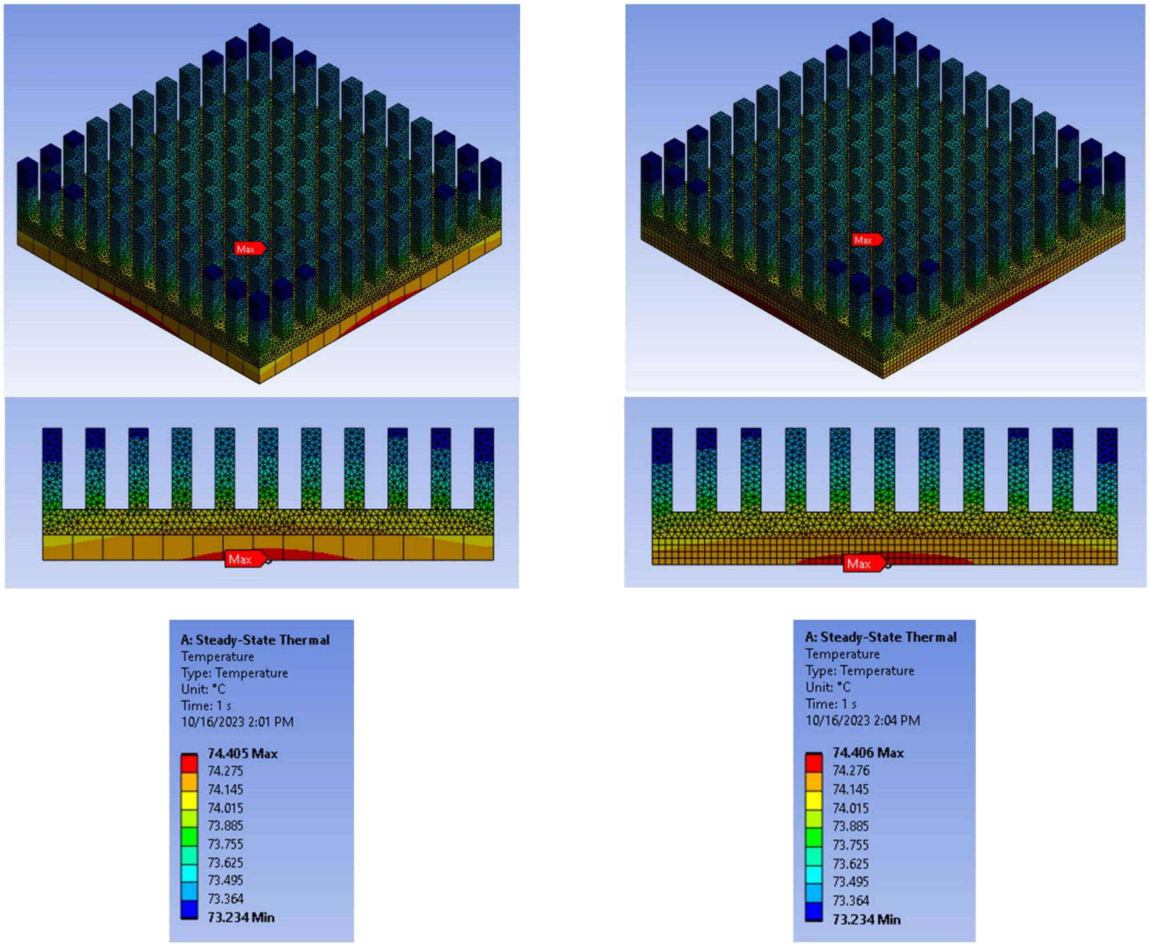


Fig. 12 Initial mesh side profile.



(a) Heat sink with finer mesh (b) Heat sink plus chip with finer mesh

Fig. 13 Temperature distribution for different meshes used.

Two extra meshs were created for testing if the size of the mesh has any significant effect on the temperature distribution results. For the original mesh, with initial boundary conditions the maximum temperature was 74.399 °C. By adding a finer mesh to heat sink only and keeping the chip mesh coarse (seen in Fig. 11, b), the maximum obtained is slightly higher at 74.405 °C. By adding a finer mesh of 0.0005 size to chip, whole model yielded in a similar result of 74.406 °C. There is not a drastic difference seen by increasing the mesh size for this case.

❖ **The End**