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Analysis Of Thermal Performance of a Graphite Heat Spreader with Design Modifications

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ABSTRACT

A heat spreader is a common cooling method. It is a metal plate or foil that is thermally conductive and is used to transfer and disperse heat. A 20 x 16 mm graphite heat spreader has been designed with 1 mm thick copper strip in between its width. The 5 x 5 mm square copper power of 1mm thickness has been placed on the top face from which heat has to be dissipated. The power device was assigned copper as a material as well as the heat spreader was assigned graphite with a thermal conductivity of 900 W/mK. The cuboidal design of the heat spreader was modified to a circular disc. The thickness of graphite heat spreader was reduced to 4 mm, i.e. 2 mm each and the following cases with different diameters (20, 25, 30, 40mm) of the circular disc have been considered for the thermal analysis. After analyzing the results for all the above cases, the diameter with the best thermal performance has been selected further modifications have been done. The copper power device which was mounted above the surface of the graphite heat spreader has been now embedded inside the thickness of the graphite material and then the results have been analysed further. A graphite heat spreader with circular design and the power device embedded inside the disc has been found to perform better for maximum heat dissipation with a significant drop in the core temperature, i.e. 45.1°C, with the same boundary conditions but greater heat dissipation rate.

Keywords: Heat Spreader, Graphite, Maximum Heat Dissipation, Thermal Performance, Thermal Conductivity

INTRODUCTION

The rising emphasis on the electrification for a greener world has spurred the need for the electric power in many forms. The field of electrical engineering known as "power electronics" deals with the processing of the high voltages as well as currents in order to provide power for a wide range of applications. Stable and dependable electric power is needed in a variety of applications, from domestic electronics to spacecraft. Power semiconductor switches as well as control mechanisms are used to convert one kind of power supply to another, resulting in regulated as well as controlled power. Power semiconductor devices are used in all of these applications to switch the input voltages as well as currents to get the necessary outputs. In order to better tolerate high voltages and currents, fundamental semiconductor devices including diodes, FETs, and BJTs have been modified. Designers have power diodes, "silicon-controlled thyristors" (SCRs), MOSFETs (power "metal oxide semiconductor field effect transistors"), BJTs ("power bipolar transistors"), and more. Devices are chosen depending on the required power, efficiency, switching frequency, and input/output characteristics. The graphic below depicts a common power electronic system block diagram.

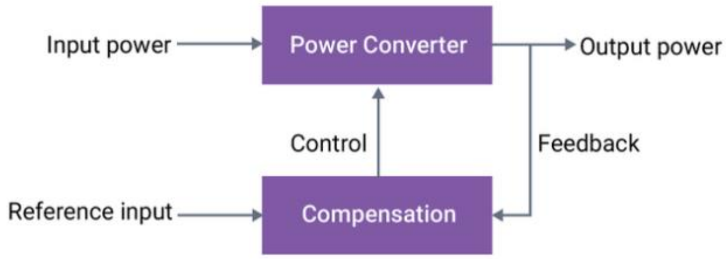

Figure-1 Block Diagram of a typical Power Electronic System

A switching power converter is the most important component of any power electronic system. High-frequency pulses switch on as well as off power semiconductor components in the converter. Using this technique, the devices' voltage as well as current are alternately switched on and off, resulting in a precise amount of output power. You may even regulate the amount of power being pulled from the input. An perfect device changes voltage and current instantly, has zero resistance when switched on, and has infinite resistance when turned off. This is the definition of an ideal device. No gadget can be instantly turned on and off in the real world, though. There are two kinds of power losses connected with the switching converters: (a) Switching Losses, (b) Conduction Losses.

During the on-and-off process, switching losses occur. To provide an example, when an on/off switch is activated, a lower voltage is applied across the switch than when it was off. Also, the current flowing through the device moves from zero to the load current. Power loss occurs because the current and the voltage are constantly changing throughout this operation. When the switch is turned off, the transition is reversed. The switching losses are made up of all of these different kinds of losses. As the frequency of the switch increases, so do the switching losses. The use of extra capacitors and inductors, like "zero voltage switching" as well as "zero current switching", may help reduce these losses.

When current flows through switches, a voltage drop occurs across the switches due to the limited on-state voltage drop. There are newer semiconductor devices as well as improved device architectures that are reducing conduction losses. The switches are managed by a control circuit, also known as a compensation circuit. In order to minimise losses, supply power effectively, and provide excellent output, this block is essential. Reference as well as feedback signals are provided as inputs to the control block, which then outputs signal switching. Nowadays, the majority of game controllers are digital, using a signal processor to take input from an analogue signal and transform it to a digital signal. The software running on the CPU implements compensation logic and generates the relevant switching signals. These signals are sent to the switching devices through drivers, which supply the necessary power. Compensation circuits have traditionally employed operational amplifiers & comparators in analogue form. The control circuits monitor the system's health but also prevent power output when problems arise while delivering suitable gating signals to switches.

Electronic design has traditionally placed a high value on controlling the amount of heat created by its components. Nowadays, as the power densities continue to rise and individual components like as microprocessors use more power to fulfil the demanding functional as well as computational needs of modern high-powered applications, this is even more true. Excess heat should be removed from important components as well as system hot spots and dispersed into ambient environment in order to guarantee optimal performance and dependability. It is possible for engineers to apply intelligent thermal designs to minimise heat-related failures, to enhance the life expectancy of the systems as well as to decrease noise emissions, energy consumption, costs and time to market. The movement of electrons as well as phonons is responsible for heat conduction. Heat carriers' basic transport and scattering are determined by their bulk characteristics, but interface qualities as well as finite dimensionality are critical in their applicability in the real world.

LITERATURE REVIEW

[1] (Fu et al., 2021) A heat sink made out of graphite film (GF) is believed to be the best option for thermal management. Nonetheless, the use of GF as a heat sink might be severely restricted if it has an ineffective thermal

interface material (TIM). SAC305 (Sn-3.0Ag-0.5Cu wt. percent) solder was used to build the GF heat sink in this experiment. The soldered heat transfer contact has a compact shape due to the ultrasonic effects. The "interfacial coefficient gradient" of the thermal expansion might be improved by the formation of Ag3Sn & Cu6Sn5 nanoparticles at the contact. Soldering-assembled GF heat sinks outperformed standard thermally conducted packaging methods in terms of cooling efficiency, even after 50 thermal cycles from 0 to 100 °C and 48 hours of thermal ageing at 150 °C in air. The "ultrasonic-assisted soldered GF joints" performed well in the mechanical performance testing. "Ultrasonic-assisted soldered GFs" in heat management have been shown to have tremendous promise, as these data confirm.

[2] (Cermak et al., 2020) In terms of heat sinks, "natural graphite sheet" (NGS) might be a viable option. Through–plane thermal conductivity may be improved using heat pipes, as we demonstrate. This NGS heat sink has the same thermal resistance as a geometrically similar aluminium one in the tested configuration. 37 percent of the weight was lost as a result of this treatment. Soft and compliant NGS does not need thermal grease at the contact between the heat source as well as the heat sink when the electrical insulation is not required. A drop in common mode conducted emissions is not caused by the poor electrical conductivity of NGS; nevertheless an analogy with antennas showed a reduction in radiated emissions of 12 to 97%. NGS heat sinks are not advised for the practical applications since they restrict the thermal performance, weight, as well as cost gains that may be achieved. An alternative method for determining the most effective heat sink shape involves utilising an optimization algorithm.

[3] (Gurpinar et al., 2020) Power modules for the next generation must have improved heat extraction capabilities while still being lighter and smaller. The "thermally annealed pyrolytic graphite" (TPG) utilised in the power modules for the thermal control is analysed and compared in this research with standard materials. Fundamental TPG characteristics are described and contrasted with those of typical heat spreaders as well as substrates for power module. TPG encapsulated heat spreaders are made and compared to bulk copper in modelling and experimentation. More than 50% decrease in thermal resistance and 48% weight reduction in the heat spreader layer were achieved by using an encapsulated TPG based thermal conductor.

[4] (D. Fan et al., 2020) Miniaturization as well as integration have made thermal dissipation a critical concern in electronic systems that are more small and integrated. Graphite, which has a high heat conductivity, has been commonly employed in these devices. Nevertheless, graphite's low thermal radiation as a heat sink limits its ability to dissipate heat. Graphite-silver-polyimide sandwich structure composite foil with high heat conductivity and outstanding selective emission property is shown in this study, which is appealing for outdoor space use. It was determined mathematically and empirically how well the foil dissipated heat. To prevent the object surface from overheating in direct sunlight, our simulations showed that incorporating a selective thermal emitter in the sandwich structure augmented the heat lost by heat source, reducing local high temperatures on the surface. Researchers used a solar simulator as well as an infrared camera to show experimentally that the sandwich structure's heat dissipation performance is superior than graphite.

[5] (Birbarah et al., 2020) In order to increase power density, thermal management of the power electronic systems must be addressed. Hydrodynamic instability makes two-phase cooling, like flow boiling, difficult because of the high heat transfer coefficients required for it. By boiling a cooling fluid directly from the electronic components, immersion cooling may bypass these obstacles, reducing thermal interface materials as well as packaging limits that are faced in the previously stated technologies. When compared to higher performance fluids like water, the immersion cooling systems use "dielectric heat transfer liquids" due to the electrical consideration, that presents the fundamental disadvantages due to the relatively low critical heat flux (20 W/cm2), low boiling point, and relatively poor thermophysical properties like thermal conductivity as well as latent heat. Immersion cooling in water is proposed as a method of cooling in this research. The "printed circuit board" (PCB) as well as electronic equipment are water-resistant thanks to Parylene C coatings, which are electrically insulating. Using a 200-volt system, we show experimentally that conformal coatings of Parylene C as thin as 1 lm are effective at preventing leakage of the current between electronic components as well as the surrounding water. For both natural convection as well as nucleate pool boiling, they provide the heat flux and "convection heat transfer coefficient" as a function of the hot-spot-to-fluid temperature differential in 3 M Novec 72DE as well as 7300 dielectric fluid, water, and even a 50/50 in volume combination of WEG & water. A variety of board-mounting techniques including the "thermal pad locations" are available for GaN transistors, which are employed as heat sources. Water has been shown to have heat fluxes as high

as 562 W/cm2. For the purpose of demonstrating the feasibility of the water immersion cooling, an efficient deionized water-cooled 2-kilowatt power converter was used as a proof-of-concept. High-power density electronic devices may be cooled by immersing them in water using innovative electrically insulating coatings paired with "attractive electrically conducting cooling medium", according to this research.

[6] (Jung et al., 2019) Micro channel cold plates implanted in silicon (25 parallel channels: 75 micro metres by 150 micro metres) are studied for their single-phase thermal-fluidic performance utilising water as the working fluid, with six inlets and vapour extraction conduits. A monolithic micro cooler (-cooler) is made from a silicon 3D manifold attached to a silicon micro channel substrate. For the electrical Joule-heating as well as thermometry, a metal serpentine bridge with a 52 mm^2 footprint and numerous RTDs are employed. Flow rates of 0.03, 0.06 & 0.1 l/min as well as heat fluxes of 60, 100 & 250 W/cm^2 were used to measure the chip's maximum and average temperatures, pressure drop, thermal resistance (down to 0.68 K/W), average "heat transfer coefficient" (30,000–50,000 W/m^2K) and other parameters. At a flow rate of 0.1 litres per minute, the integrated microchannel-3D manifold -cooler device can remove 250 W/cm^2 at a maximum temperature of 90 °C with less than 3 kPa pressure loss. Over a broad range of heat fluxes and flow parameters, the numerical findings from the conjugate thermal-fluidic simulations match well with the actual data. With the same pressure drop as well as flow rate, the computer simulations suggest that single-phase water may remove up to 850 W/cm^2 at a maximum temperature of 166°C. Single-phase water cooling of the "high heat flux power electronics" is now an appealing method and choice.

[7] (Qian et al., 2018) PEs are becoming more popular in different energy systems as the focus shifts to the sustainable development of the energy and the environment. There are several applications for the "insulated gate bipolar transistor" (IGBT), a PE with numerous benefits and potentials for developing greater voltage as well as current ratings. Nevertheless, as IGBTs continue to become smaller and more powerful, they need a more complicated thermal management system because of their tremendous heat flow. Thermal management on thrIGBTs is discussed in this work, including comparing, evaluating, and categorising the findings of previous investigations. There are three main types of heat dissipation models: analytical models, thermal network models, as well as numerical models. Current IGBT modules' thermal resistances are also being investigated. Our present products on a variety of IGBTs show us that the thermal resistance between the junction and the casing reduces inversely with the overall thermal output. Also evaluated and compared are the different cooling techniques for IGBTs, as well as their respective performance. IGBTs' thermal management may now be judged by their junction-to-case thermal resistance as well as "equivalent heat transfer coefficient, which we've presented as a rapid, efficient assessment method.

[8] (Patel & Zhao, 2017) Copper heat spreaders and vapour chambers (with and without graphite foam) were subjected to ANSYS numerical heat transfer simulations. The impacts of heat flow from the power electronics, "heat transfer coefficient" at the heat sink, vapour chamber thickness, and graphite foam on vapour chamber thermal performance were all examined. Ultra-thin vapour chambers with very "high effective thermal conductivities" were shown to have superior "heat transfer performance" than thicker ones with less effective thermal conductivity, according to the simulation tests. This is in contrast to other studies, which found that graphite foam had a considerable impact on thermal performance in thick vapour chambers. In the 5-mm thick vapour chamber, the GF might assist lower the junction temperature by 15-30%. For power electronics, a 250-400 W/cm2 local heat removal efficiency may be achieved by using a GF integrated vapour chamber.

MATERIALS AND METHODOLOGY

1. Design of the Model

When employed as a heat spreader, graphite, with its thermal conductivity in the basal plane of 1,500 W/mK, is an excellent choice. Furthermore, graphite has a reduced fracture toughness, hardness, and mechanical strength, that makes it easier to machine. Because of its high thermal conductivity, graphite is not suitable for use in densely packed high-power electronics with high heat flux, such as high-speed telecommunications as well as inverters used in the electric vehicles, even though these characteristics make it an ideal candidate for the two-dimensional heat dissipation. When using a planar heat spreader with a typical device, as shown in Figure 2, a low cross-plane thermal

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conductivity results in poor overall heat dissipation and cooling, even if the heat loss rate near the device-side surface is high. This is despite the high heat loss rate near the device-side surface of the heat spreader.

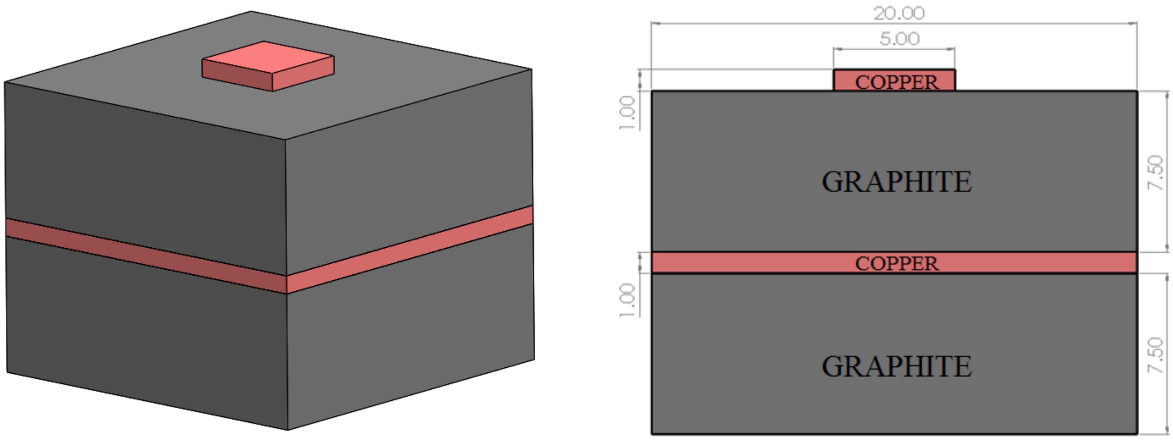

Figure-2 The designed model of the graphite heat spreader

The detailed dimensions of the heat spreader have been shown in the figure 2. A 20 x 16 mm graphite heat spreader has been designed with 1 mm thick copper strip in between its width. The 5 x 5 mm square copper power of 1mm thickness has been placed on the top face from which heat has to be dissipated.

2. Software Used

The **COMSOL Multiphysics** software package is a vital resource for a broad range of computer simulations in both R&D and education throughout the globe. In the domains of manufacturing, engineering, and scientific research, it is a general-purpose simulation software suite. Fully connected multiphysics and single-physics modelling capabilities are provided by the COMSOL Multiphysics® simulation platform. Every stage of the modelling process is covered by Model Builder, from specifying geometry and material attributes to solving models and doing postprocessing to get correct results.

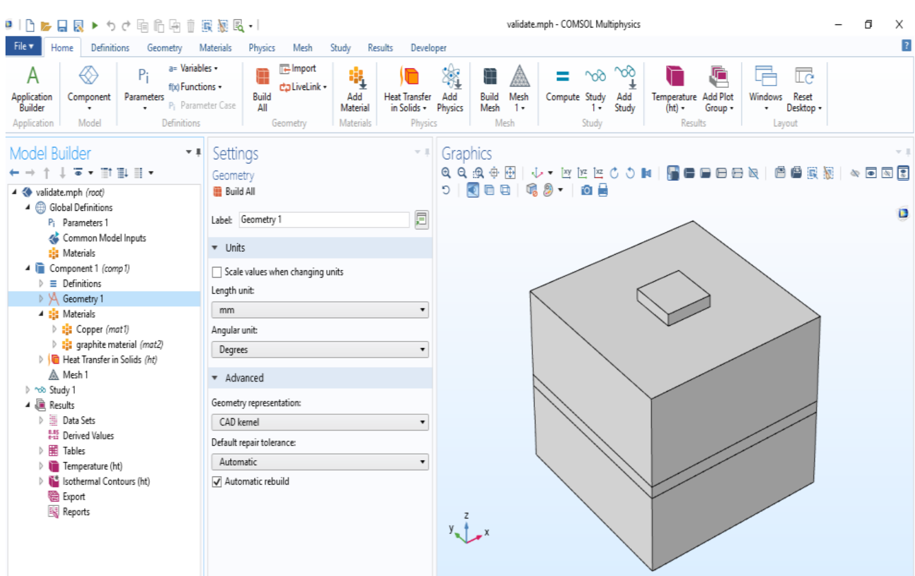

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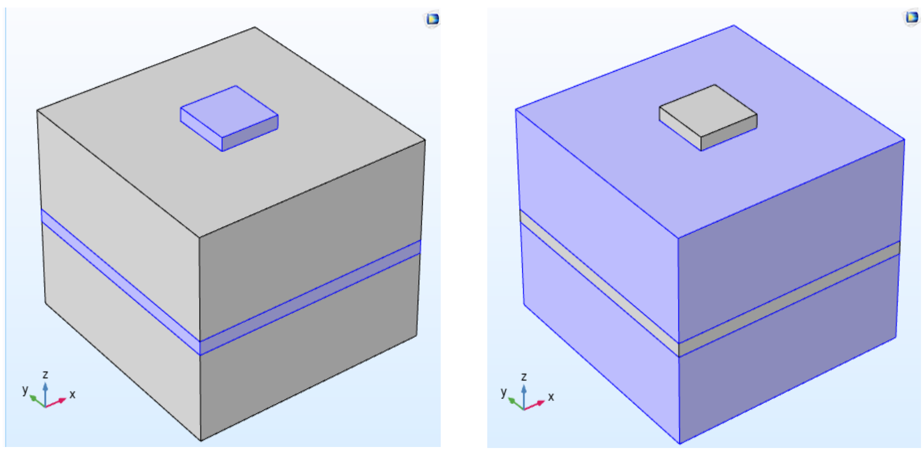
Figure-3 The COMSOL Multiphysics Software Suite

Using the Application Builder, you can transform your model into a simulation application with a specialised user interface that can be used by colleagues and clients who are not specialists in simulation software. The Model Manager in the COMSOL Multiphysics® platform is a modelling and simulation management tool that offers version control and efficient storage to help you keep your models and applications organised.

3. Materials Assigned

The power device was assigned copper as a material as shown in the figure 4(a) below. Copper has a density of 8960 kg /m^3, a specific heat capacity of 385 J/kgK and a thermal conductivity of 400 W/mK.



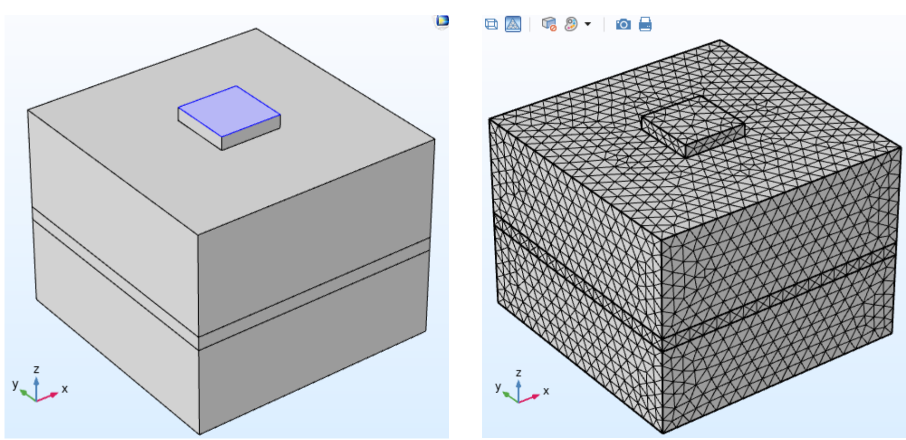
(a) **(b)**

Figure-4 Material assigned (a) Copper (b) Graphite

The heat spreader was assigned graphite as a material as shown in the figure 4(b). Graphite has a density of 2150 kg /m^3, a specific heat capacity of 750 J/kgK and a thermal conductivity of 900 W/mK.

4. Assigning the Heat Flux

A heat flux of 150 W has been assigned to the topmost surface of the copper device as shown in the figure 5(a) below.



(a) **(b)**

Figure-5 (a) Heat Flux assigned to the power device (b) Mesh generation in the COMSOL Multiphysics

5. Mesh Generation

The mesh generated in the COMSOL Multiphysics software has been shown below in the figure 5(b). Triangular meshing has been selected with finer element size in order to simulate the heat dissipation through the heat spreader. By constructing graphite blocks into a three-dimensional (3D) structure, we illustrate the effect of thermal routing on the performance of heat spreaders. Using a finite element technique (FEM), we discover the best design for the construction: a double-decker structure of graphite layers with varied graphite axis orientations. Using a carefully regulated high-temperature method, the double-decker structure with two graphite blocks and copper as a binder layer may be experimentally assembled to achieve ultrahigh and isotropic heat conduction comparable to 900W/mK thermal conductivity.

6. Design Modifications

A circular disc design of the heat spreader have been generated instead of the cuboidal one, as shown in the figure 6 below.

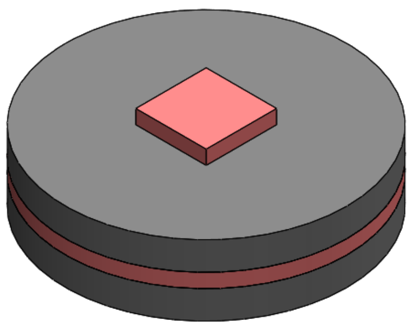
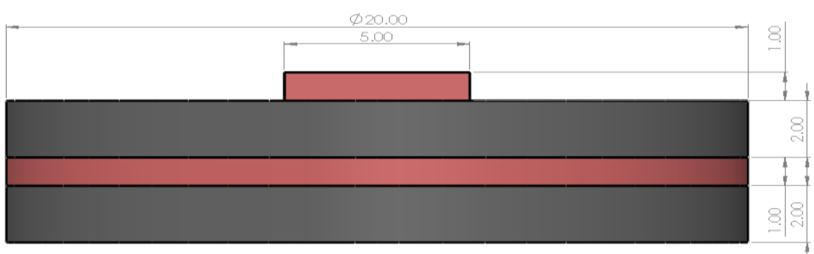


Figure-6 Modified design of the heat spreader

The thickness of graphite heat spreader was reduced to 4 mm, i.e. 2 mm each and the following cases with different diameters of the circular disc have been considered for the thermal analysis as shown in figure 7 below.



(a)

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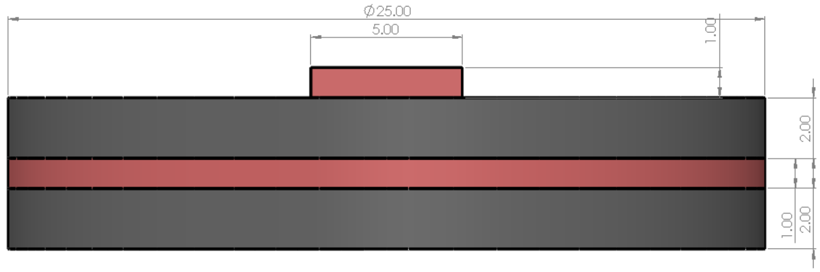

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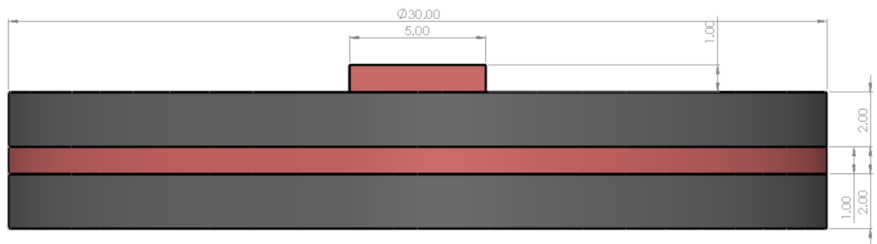
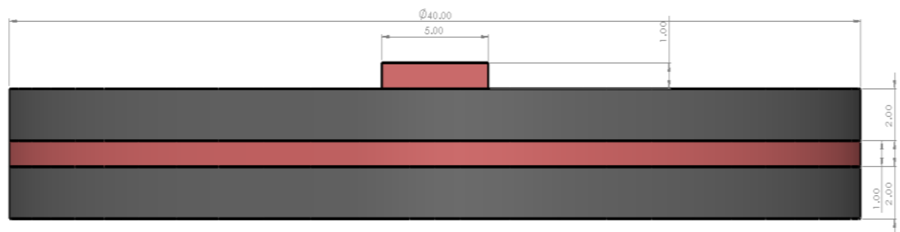


(c)



(d)

Figure-7 (a) CASE 1: Diameter- 20mm, (b) CASE 2: Diameter- 25mm, (c) CASE 3: Diameter- 30mm, (d) CASE 4: Diameter- 40mm

After analyzing the results for all the above cases, the diameter with the best thermal performance has been selected further modifications have been done as shown in the figure 8 below. The copper power device which was mounted above the surface of the graphite heat spreader has been now embedded inside the thickness of the graphite material and then the results have been analysed further.

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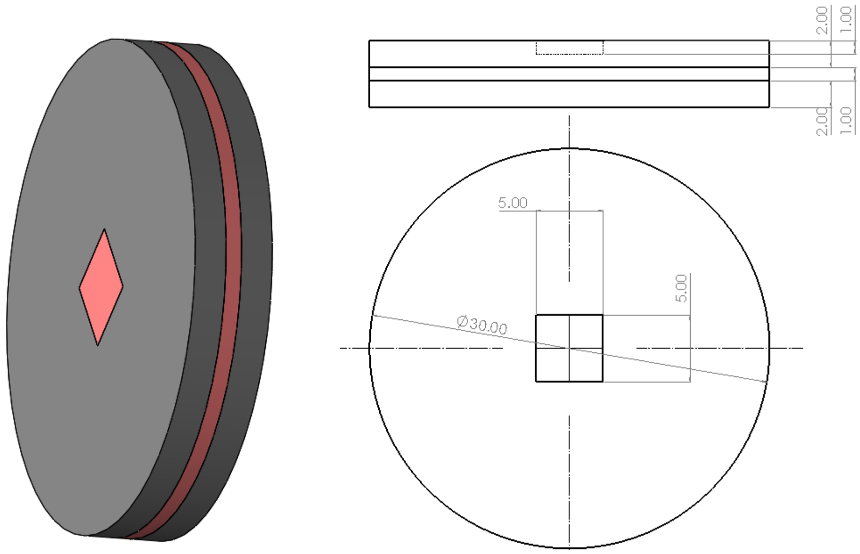
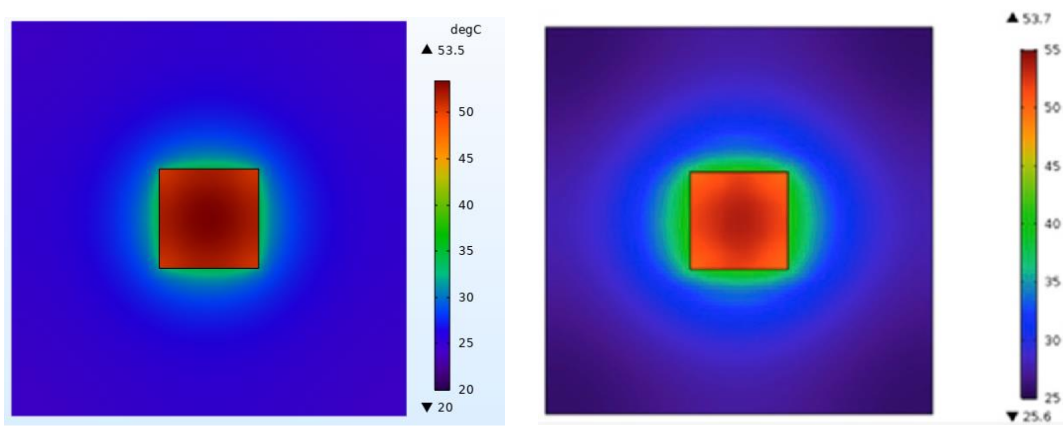


Figure-8 CASE 5: With the Copper device inside the circular disc

RESULTS AND DISCUSSIONS

1. Result Validation

The results of the generated for the cuboidal base paper design has been shown in the figure 9 below. These results have been then validated through the base paper results.

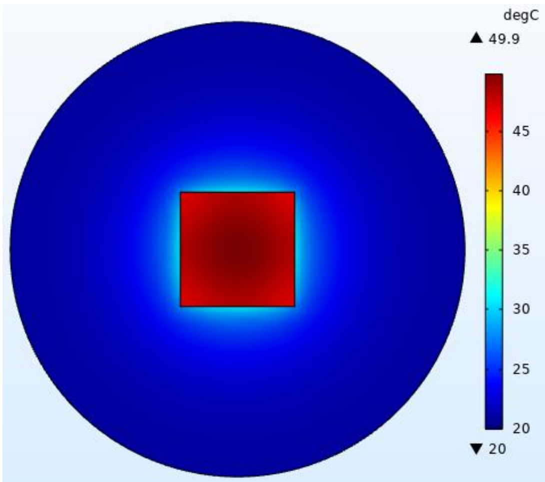


(a) **(b)**

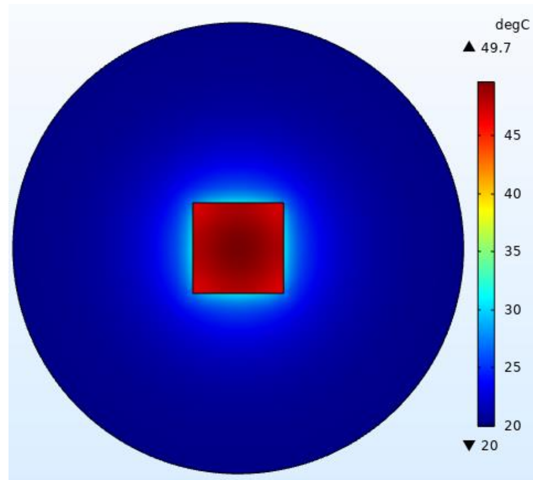
Figure-9 (a) Results of the analysis (b) Base Paper Results

The maximum temperature obtained in the thesis model 53.5° C which is very close to the base paper temperature of 53.7° C. Hence, the approach is quite correct.

2. Results For The Modified Design



(a)



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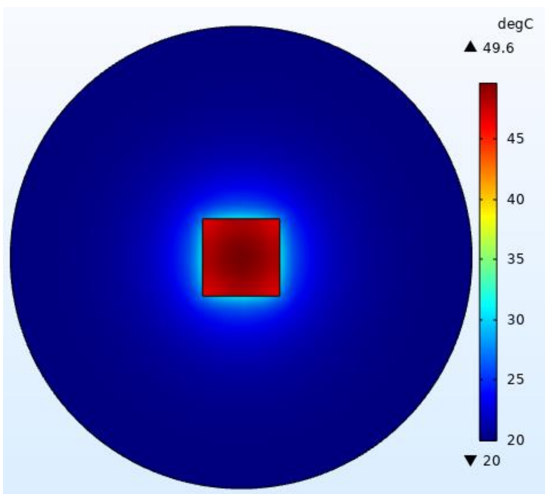

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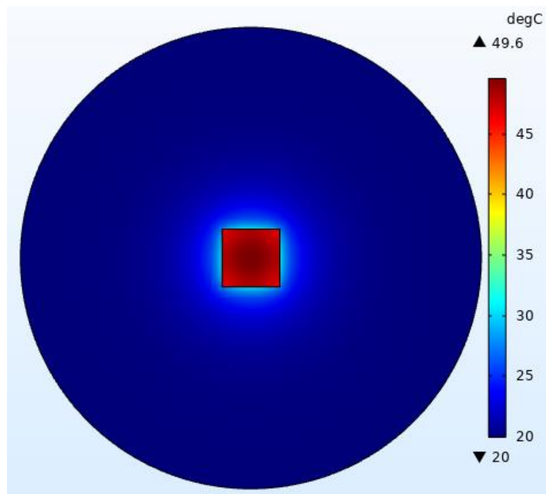

(d)

Figure 10 (a) CASE 1: Diameter- 20mm, (b) CASE 2: Diameter- 25mm, (c) CASE 3: Diameter- 30mm, (d) CASE 4: Diameter- 20mm

Figure 10 shows the heat dissipation from the copper core to the graphite heat spreader for all the four cases with different diameters. In the figure 11 below, it can be observed that the minimum temperature of copper core has been obtained in the case 3 and 4 with 30 mm and 40 mm diameters, i.e. 49.6º C. However, due to economic considerations and an optimal design solution with minimum material used has been considered and case 3 with 30 mm diameter of the graphite circular disc has been selected for further analysis.

Design type	Temperature (ºC)
Rectangular	53.5
20 mm Dia	49.9
25 mm Dia	49.7

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30 mm Dia	49.6
40 mm Dia	49.6

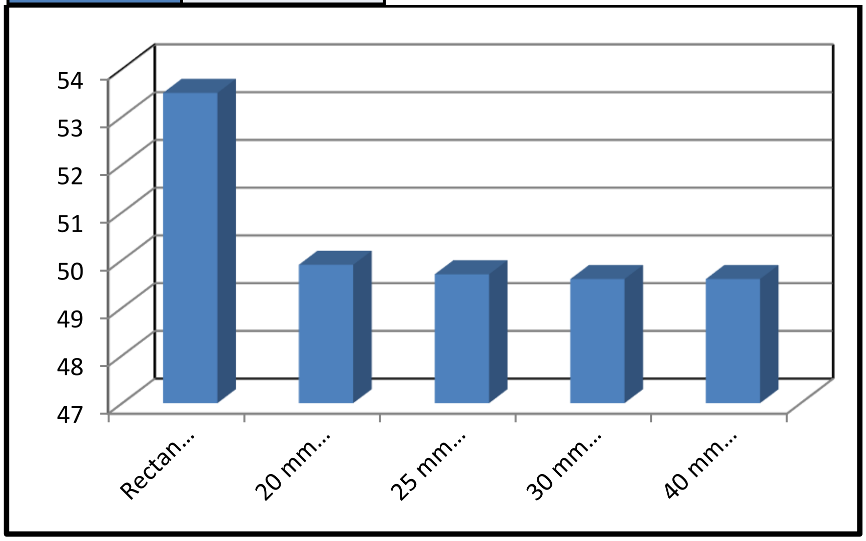

Figure-11 Graphical representation of the maximum temperatures obtained in all the cases.

3. Results For Case 5 With Inside Copper Device

The circular disc with 30 mm diameter has been further analysed with the copper device embedded inside the graphite heat spreader and the results obtained have been shown in the figure 4-5 below.

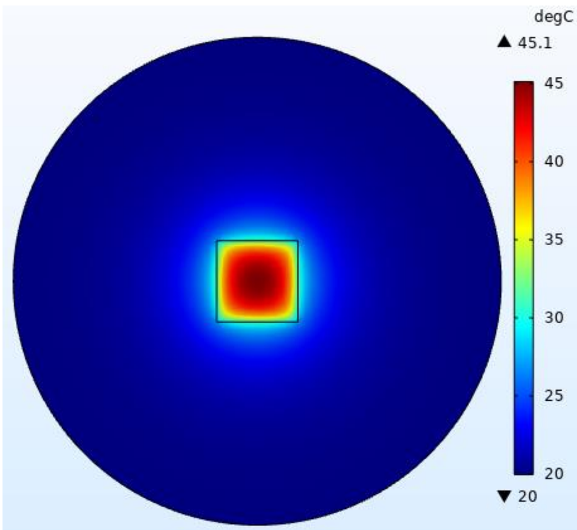

Figure-12 Heat distribution with inside copper device

As can be observed, the temperature at the core is further reduced to 45.1°C as compared to the previous design with the copper device mounted on the outer surface.

Design type	Temperature (°C)
30 mm Dia	49.6
Inside covered	45.1

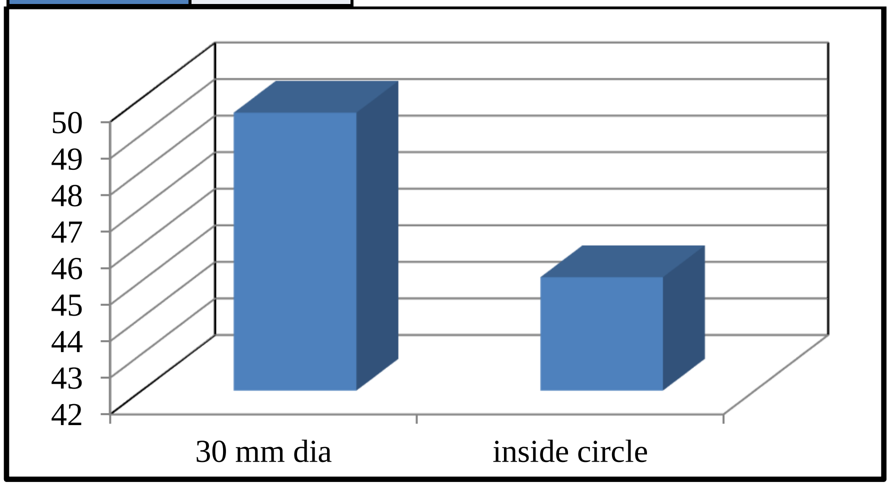

Figure-13 Graphical comparison of the temperatures obtained for the two cases

The design with the copper device embedded inside the circular graphite disc has proven to perform better for dissipating the heat than the cuboidal design as well as designs with the copper device outside on the surface.

CONCLUSION

By constructing graphite blocks into a three-dimensional (3D) structure, we illustrate the effect of thermal routing on the performance of heat spreaders. A 1 mm thick copper strip is sandwiched between two cuboidal graphite heat spreaders measuring 20 x 16 mm. The top face from which heat must be dispersed has a 5 x 5 mm square copper power of 1 mm thickness. The cuboidal design of the graphite heat spreader has been modified to form two circular discs of 2 mm thickness with a 1 mm sandwiched layer of copper. Four different cases with different diameter of the circular disc, i.e. 20mm, 25mm, 30mm and 40mm, have been considered for the thermal analysis under the same boundary conditions. In the analysis, the circular disc design with 30mm has been observed to display an optimum thermal performance with a minimum temperature of 49.6°C at the copper core. The circular disc with 30mm diameter has again been selected for the thermal analysis but with the copper core embedded inside the graphite disc rather than being mounted on the outside on the surface. This design achieved a significant drop in the core temperature, i.e. 45.1°C, with the same boundary conditions but greater heat dissipation rate. Hence, a graphite heat spreader with circular design and the power device embedded inside the disc has been found to perform better for maximum heat dissipation.

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