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Enhanced Cooling of VLSI Circuits Using Heat Sinks Nanofluids

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Abstract: Electronic devices and chips are an integral part of the technological development in all sectors and are helpful to accelerate their growth. Due to the continuous miniaturization and developments of design of VLSI Chip (Very Large-Scale Integration), the amount of heat generation is increasing per unit volume. The increase in thermal issues due to some of the few major reasons such as high electro migration and increasing the junction temperature caused by higher performance, current flow, and compact size. This increased temperature in the electronic chip also affects the other electronic components on its neighbor. This leads to failure in the electronic devices. Consequently, poor reliability significantly reduced lifetime of the semiconductor as well as increased power consumption. Therefore, it has become inevitable to develop efficient heat sinks and heat transfer fluids capable of higher thermal conductivity and heat transfer so as to increase the processing speed of the electronic devices and VLSI Chip.In this work, the new design structure and cooling methods have been proposed based on the few research gaps as mentioned. Three different structure of channel heat sink are designed and analyzed by using CATIA v5, and commercial CFD software (ANSYS FLUENT version12) respectively. The Single-channel heatsink with ordinary water, Al_2O_3/water as coolants in the Single-channel heat sink at different volume concentration (0.25%, 0.50% and 0.75%)
Keywords: Heat sink, Heat pipe, VLSI Cooling, Ansys Fluent, Electronics Cooling

I. INTRODUCTION

A. Introduction

The semiconductors have significant applications in many fields such as 3D printing machine, power devices, medical therapy, optical sensors, networking, mobile technology, satellite, digital televisions, military affairs, etc., because of their compactness, high performances and low cost. Moreover, semiconductor devices such as transistors, capacitors, inductors, diode, operational amplifier, and resistors, etc., are integrated into a complex circuit to build-up macro, micro, and nano electronic circuits. The history of digital electronics fully started after the introduction of the vacuum tube. The digital electronics has seen tremendous growth after the invention of the transistor at Bell Telephone Laboratories in 1947.

TTL (Transistor-Transistor Logic) family has been the pioneer of the IC logic family since 1962. Indeed, the manufacturing of TTL components was responsible for the formation of all larger semiconductor companies such as Fairchild, National and Texas Instruments.

A few efforts have been taken gradually to develop an integrated analog and digital circuit in a single chip package. These endeavors have succeeded in producing both analog and digital ICs, as well as mixed-signal ICs. Analog ICs are multipliers, operational amplifiers, modulators/demodulators, etc., while digital ICs are AND, OR, XOR, NOR, NAND gates and so on. Digital ICs are mostly categorized based on the measures, in terms of the number of logic gates or transistors in a single package. Remarkably, the CMOS (Complementary Metal-Oxide-Semiconductor) is a type of semiconductor and belonged to MOS (Metal Oxide Semiconductor) logic gates and continued until the later part of the 1960s.

In 1972, the next revolution has begun by Intel in a digital integrated circuit with the introduction of first microprocessors. Since then the dimension of a single integrated chip has been reduced, which results in the dramatic increase in the density of transistor and electronic components used in the integrated chip. Moreover, the increase in integration and miniaturization of devices lead to Small Scale Integration (SSI) in the 1960s, which contains 1-100 transistors and fabricated on a single chip. Likewise, Medium Scale Integration (MSI) which contains100-1000 number of transistors integrated on a single chip. It was followed by a new development in the technology in1960s is a Large-Scale Integration (LSI) that offers 1000- 10000 transistors per chip (Sohel Murshed *et al.* 2017). Similarly, in 1980 Very Large-Scale Integration (VLSI) accommodated with 10000-1 million components and Ultra Large-Scale Integration (ULSI) with 1 million-10 million components per chip.

Gordon E. Moore, the co-founder of Intel and Fairchild semiconductor, predicted that this innovative technology would grow at a rapid pace. In 1965, Moore proposed that the number of transistors in a complex integrated circuit doubles every two years. His Prediction is commonly known as "Moore's Law". In addition, his prediction has accurately proved and used in semiconductor industry for research and development. VLSI design and microelectronic technologies still adhere to Moore's law such as component density, processing speed, memory capacity, chip performance, power consumption and size of pixels in digital cameras. Figure 1.1 Shows the features of semiconductor that predicted by International Technology Roadmap for Semiconductors (ITRS) (Sohel Murshed *et al.* 2017). Accordingly, the size of the transistor decreases incessantly up to 6nm and the density of transistor increases up to about20 billion transistors/cm^2 by 2020.

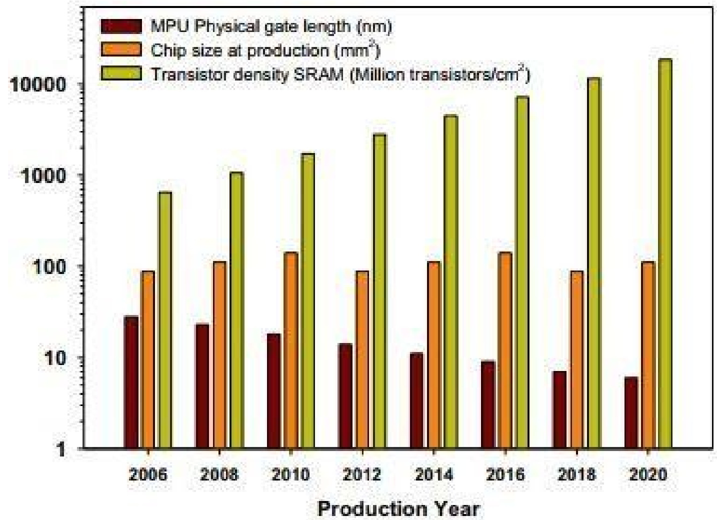

Figure 1.1 ITRS projections of chip size, transistor density and physicalgate length of high-performance microprocessor chips

B. Issues in VLSI Design

For the past several years, the modern semiconductor industries have developed the miniaturized semiconductor components to perform effectively in the compact electronic circuit board. The semiconductor has been contributing more in the development of the high-performance electronic chips. Similarly, the development in VLSI technology had a dramatic impact on the growth and significant improvement of wireless communication systems. In this view, wireless technology advances which have integrated both the baseband digital circuits and the RF analog circuits onto a signal monolithic integrated circuit (system on chip). Because of this some issues still remain to be unresolved such as thermal effect, noise interferences and etc. The high-density chips in MOS VLSI technology are based on scaling i.e. reduction in the size of transistors, so that high packing density can be achieved. Thus, scaling of MOSFET transistors is concerned with systematic reduction of overall dimension of the device as allowed by available technology, while at the same time preserving the geometric ratios found in the larger devices. Some of the most exciting benefits of scaling is that it not only helps to increase the switching speed but also reduce the chip size and power dissipation. However, because of scaling there is a thermal issue arising due to increase in carrier flow in the small channel length.

Even though the modern electronic chips are being designed on a miniaturized scale, their performances and operational speeds are much better than in the past. However, still, there is a drastic increase in the rate of heat also. Therefore, increase in the rate of heat generation are the leading cause of failure of these devices. In fact, the failure rate of the VLSI Chip (electronic chip) increases almost exponentially with increasing operating temperature. Consequently, there is a significant decrease in the reliability and lifetime of the semiconductor as well as its power consumption increased. Because of this impact, thermal management has become critical in the present and future generation semiconductor devices.

The heat flux of the electronic chip increased from 330 W/cm^2 in 2007 to 520 W/cm^2 in 2011 reported by the international technology road map for semiconductors (Bayomy et al. 2016). Simcha Gochman et al. (2003) revealed that the dissipation of heat from desktop and mobile processors is about 100W and 30W, respectively. Pedram et al. (2006) reported that most of the Integrated Circuit (IC) failures are associated with 50% of thermal issues. Thus, cooling of high heat flux in electronic devices effectively is one of the challenging tasks.

C. Use of Ansys-CFD in Electronic Cooling

Ansys CFD (Computational Fluid Dynamics) is a high-performance simulation software which provides reliable and accurate solutions quickly to evaluate the physical characteristics of design products. The three main elements in the CFD code algorithm that used to tackle the fluid flow design are preprocessor, solver, and post processor. It is a commercial CFD software package and used for different applications like 3D modelling, fluid dynamics, structural mechanics, electromagnetics, multi-physics and system simulations etc.

Consequently, it is observed that the excessive development and miniaturization of the electronic chip are still facing thermal issues, which in turn reduces the performance, reliability, and lifetime. Therefore, it is very important to develop an electronic chip cooling system to operate in the ambient temperature. Very limited research work has been carried out on the electronic chip cooling using microchannel heatsink and nanofluids.

II. MATERIALS AND METHODS

A. Materials

In this work, Distilled water and Al_2O_3/water nanofluids coolants were carried out to examine the heat transfer performance of single channel heat sink.

The heat transfer analysis of the channel heatsink for the electronic chip cooling was carried out with the nanofluids at different volume concentrations (0.25%, 0.50% and 0.75%). Seyed Ebrahim Ghasemi *et al.* (2017c) examined the heat dissipation in the micro channel heatsink based on the thermo physical properties of nanoparticles such as CuO and TiO_2 as shown in the Table 2.1.

Table 2.1 Thermo-physical properties of Al_2O_3, CuO and TiO_2 nanoparticle and distilled water

Properties	TiO_2 nanoparticle	CuO nanoparticle	Al_2O_3 nanoparticle	Distilled Water
Density ρ [kgm^{-3}]	4250	6500	3970	997.1
Specific heat Cp [$J\ kg^{-1}K^{-1}$]	686.2	540	765	4179
Thermal conductivity k[$Wm^{-1}K^{-1}$]	8.953	18	40	0.613
Dynamic Viscosity μ [Nsm^{-2}]				0.001003

B. Single Channel Heatsink

The schematic diagram of the single-channel heatsink with fins, inlet, and outlet are shown in the Figure 2.1.

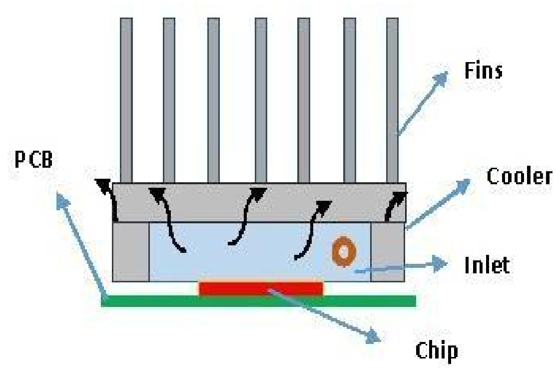

Figure 2.1 Schematic diagrams of single channel heatsink

Here, the heatsink is designed with a channel inlet and outlet and it's placed above the PCB integrated with the VLSI chip. Figure 2.1 showsthe modeling of single-channel heat sink using CATIA v5 software.

In this modeling, the single-channel heat sink with a length of 49 mm, the width of 45 mm and a total height of 29 mm with 7 fins are designed. Here, the hydraulic diameter of the inlet and outlet of the single channel heatsink is 9 mm. In this the coolants such as Al_2O_3/water and distilled water are circulated through the inlet.

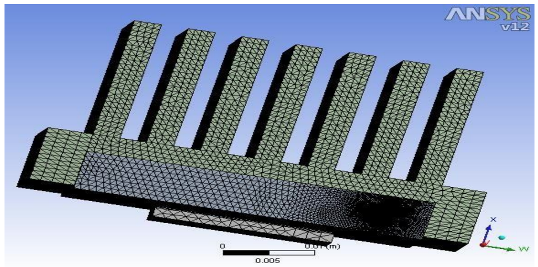

Figure 2.2 Computational mesh of single-channel heatsink using theANSYS

III.RESULTS AND DISCUSSIONS

The commercial CFD software, ANSYS FLUENT version12.0 was used to study and analyse numerically the different structure of channel heat sink. CATIA v5 is the tool of multi-platform 3D software modelling that was used to design three different structure channels heat sink. The three different channel heat sinks are the single-channel heat sink, six-channel heat sink and wave channel heat sink. It should be noted that the effectiveness of the coolant and performance of the chip is examined by the different volume flow rates of 0.02 m/s to 0.10 m/s under different boundary conditions.

A. Heat Transfer Coefficient Using Al_2O_3/Water Nanofluid

In the Figure 3.1, the numerical data illustrated the heat transfer coefficient of the channel heat sink for Reynolds number using Al_2O_3/water nanofluids. It can be seen that increase in heat transfer coefficient with increasing particle volume concentration. Consequently, Al_2O_3/water nanofluids have a higher heat transfer coefficient compared to the distilled water in a single-channel heat sink and the heat transfer coefficient enhancement of Al_2O_3/water nanofluids is 51%, 61%, and 68% increased than the water respectively. This is due to the presence of nanoparticles with high thermal conductivity.

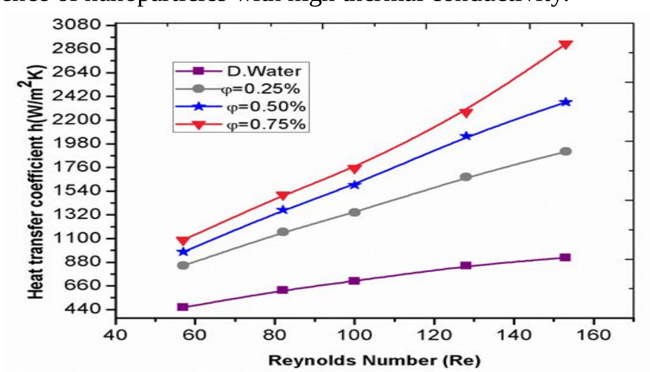

Figure 3.1 Variation of heat transfer coefficient of the single-channel heat sink using Al_2O_3/water nanofluid at different Reynolds numbers

B. Nusselt Number

Nusselt number (Nu) is the dimensionless parameter that represents the convective heat transfer. The Nusselt number for single-channel heatsink was examined by circulating the nanofluids and distilled water at different inlet velocity. Figure 3.2 illustrates the variation in Nusselt number which depends on different

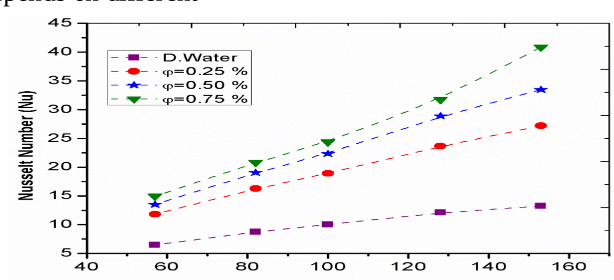

Figure 3.2 Nusselt number Vs Reynolds number for single channel heatsink using Al_2O_3/water Nanofluid

It has been found that the Nusselt number of both Al_2O_3/water nanofluids and distilled water is increasing with increase in Reynolds number. It is observed that the Nusselt number of Al_2O_3/water nanofluids at 0.25%, 0.5%, and 0.75% volume concentration increases by 51%, 60%, and 67% when compared with water.

C. Effect of Power Dissipation of the Electronic Chip

The power consumption and dissipation are one of the most important factors for reliability and lifetime of electronic chip circuits. Power dissipation increases with a decrease of thermal resistance and surface temperature. Figure 3.3 shows the variation of power dissipation with respect to the surface temperature of electronic chip in the single-channel heatsink using Al_2O_3/water nanofluid as a coolant. These results show that power dissipation is significantly increased at lower surface temperatures and decreased at higher surface temperatures.

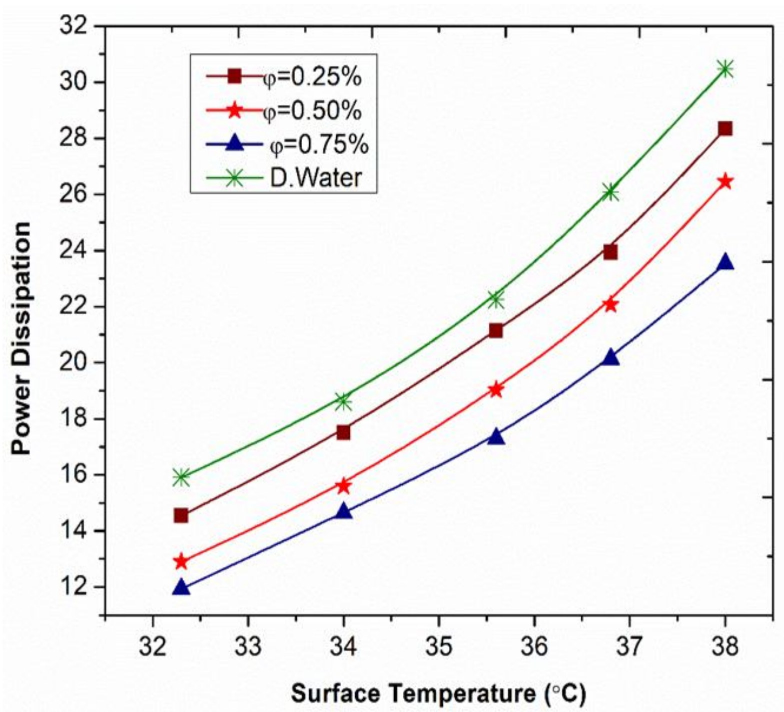

Figure 3.3 Variation of power dissipation using nanofluid and basefluid with a single-channel heat sink

The results revealed that the power dissipation of Al2O3/water nanofluids is 17 %, 39 %, and 51% higher than base fluids at 0.25%, 0.5%, and 0.75% volume concentrations respectively. By using the coolant and heatsink has lower power dissipation and thus reduces the power consumptionof the electronic chip and increases the credibility.

D. Effect of Reliability and Lifetime of the Electronic Chip

In the absence of a proper cooling system, the miniaturized VLSI Chip is subject to an increase in the junction temperature. Under these conditions, the mobility of carriers is also being increased and thereby there is an increase in the rate of electro-migration. Consequently, this can lead to the failure of electronic components in relatively short times and also reducing the circuit lifetime to an unacceptable level.

Figure 3.4 shows the variation of reliability with respect to temperature in the single-channel heatsink. It can be seen from the results that the reliability of the electronic chip is high at low temperatures and low at a higher temperature.

The numerical results also illustrate that the lifetime of the electronic chip using the coolant Al_2O_3/water nanofluids is higher than the water as a coolant. The reliability of an electronic chip has increased up to 70%, by using Al_2O_3/water nanofluids at 0.75% volume concentration, which is higher than the use of water as a coolant. The reason behind the higher reliability of an electronic chip is because it uses the nanofluids with high thermal conductivity properties and makes it an effective heat transfer.

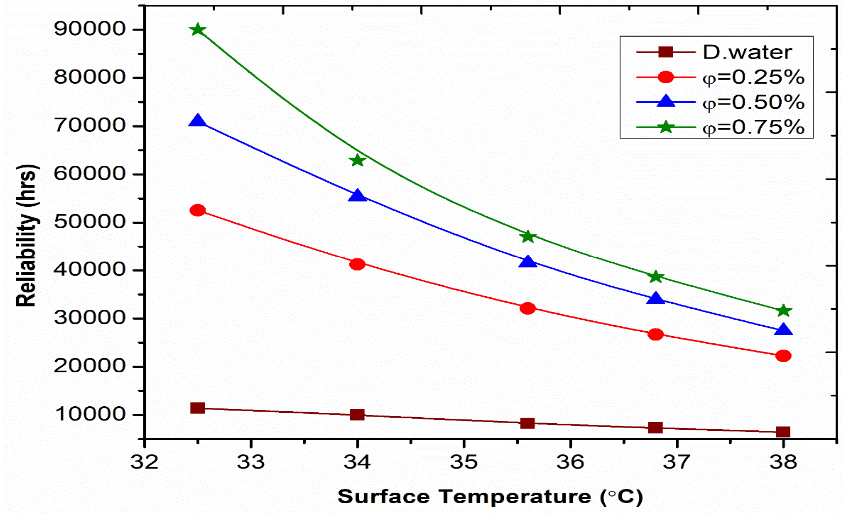

Figure 3.4 Reliability and lifetime versus surface temperature in a single-channel heat sink

IV. CONCLUSIONS

The following conclusions have been drawn from the proposed work:

1) It has been found that the heat transfer coefficient of nanofluids is significantly 74%, and 81% higher at 0.50% when compared to distilled water.
2) It was found that the viscosity and thermal conductivity increased with the increase of particle volume concentration.
3) It was observed that the heat transfer coefficient of the Al_2O_3/water nanofluids is increased by 18%, 47%, and 51% at 0.25% when compared with distilled water.
4) It was clearly observed that the heat transfer coefficient of Al_2O_3/water nanofluids increases by 27 %, 55 % and 61 % at a volume concentration of 0.5% when compared with distilled water.
5) It was found that the heat transfer coefficient of Al_2O_3/water nano fluids increased by 33%, 61% and 68% at a volume concentration of 0.75%when compared with distilled water.
6) It is observed that Al_2O_3/water nanofluid has a higher heat transfer coefficient than other coolants because of higher thermal conductivity.
7) The obtained results show that the heat transfer coefficient of a single channel heat sink increased by 74%, and 81% at 0.50% nanofluid. These results also show that single channel heat sinks have a better thermal performance than other channel heatsinks.
8) It is found that this high heat transfer coefficient can effectively reduce the surface temperature of the VLSI Chip.

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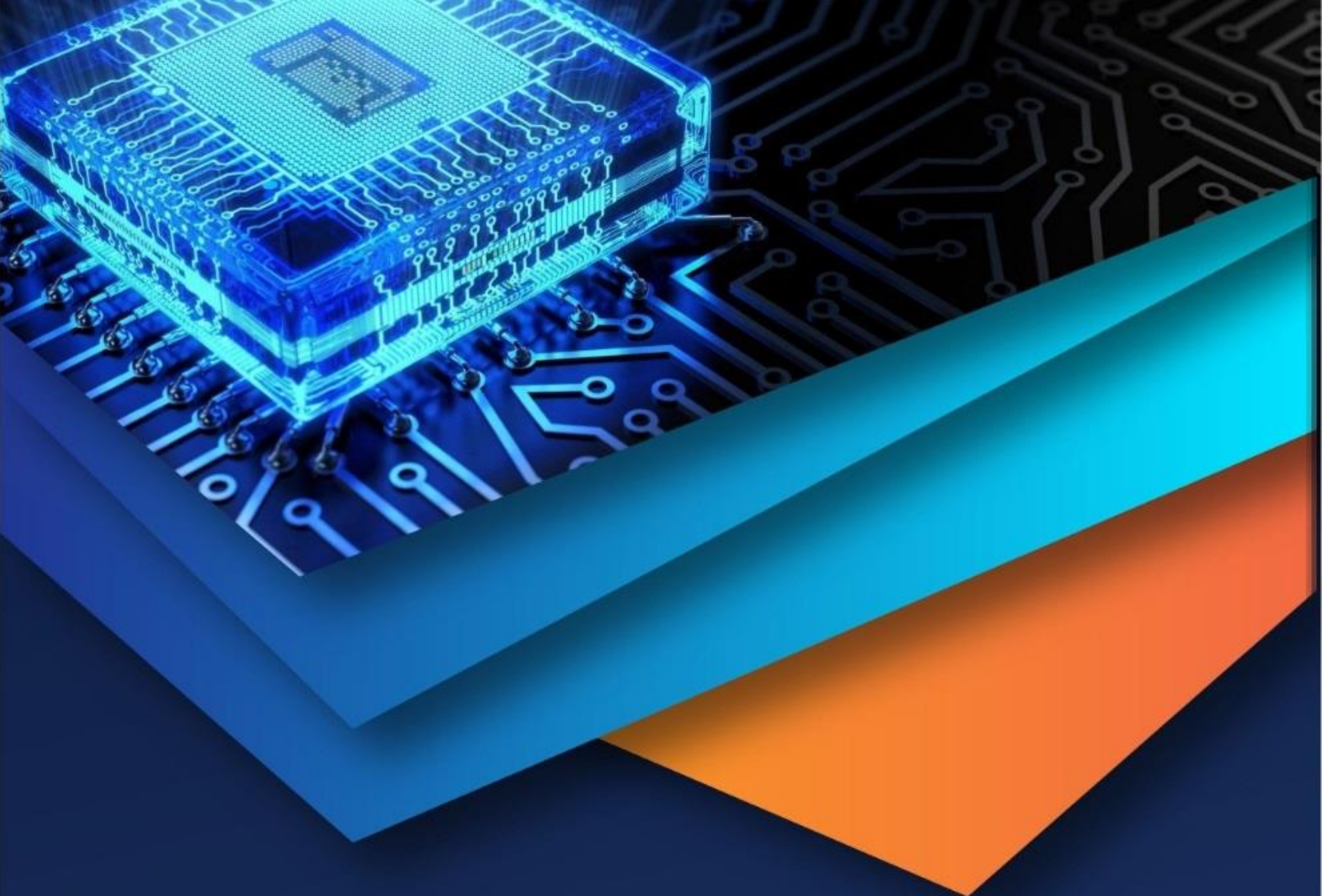

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