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Review on Implementation of Dye-sensitised Solar Cells (DSSC)

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***Abstract:** Solar cells give better power conversion efficiency (PCE) compared to conventional solar cells made of Silicon in terms of low materials and manufacturing costs. Materials required for the manufacturing of DSSCs such as titanium oxide are inexpensive, abundant and environmentally friendly. DSSC materials are contamination resistant and processable at room temperature, a roll-to-roll process can be used to print DSSCs in a mass production facility. DSSCs have been found to perform better under low light conditions and so they are a great choice for indoor applications, especially in powering of low powered objects such as IoT devices. A lot of work has also been done to make coloured and semi-transparent thin film DSSCs to use indoors and in window modules and enhance their aesthetic values. This review is a report about some selected works done in manufacturing of DSSCs, especially the transparent cells and their integration in buildings, both outdoors and indoor [1].*
***Keywords:** Construction, Working, Advantages, Disadvantages, Types and Conclusion*.

I. INTRODUCTION

It has been reported that buildings consume forty percent of the energy generated in the world and as industrialization advances, the portion of building's energy consumption is expected to increase [2]. Dye sensitized solar cells are second generation solar cells which unlike conventional solar cells, primarily consists of photosensitive dye and other substances. This cell was first invented by Michael Gratzel and Brian O'Regan in 1991 and since then has seen a lot of development and increase in Power Conversion Efficiency (PCE). A DSSC is a thin film, low-cost solar cell with price/performance ratio high enough to compete with fuel electricity generation [3-6].

II. CONSTRUCTION

DSSC consists of a layer of titanium dioxide nanoparticles which is covered by molecular dye that absorbs sunlight. Titanium dioxide only absorbs a very small number of photons that falls on it but it is the preferred material due to its resistance to continuous electron transfer. The molecular sensitizers of the dye molecules on the semiconductor surface absorbs a large portion the incident solar light, hence intensifying the absorption.

III. WORKING

As sunlight falls on the dye layer, the dye absorbs energy and enters an excited state. In the excited state it emits electrons which are absorbed by the Titanium dioxide.

Then by diffusion the electrons flow towards the electrode where they are collected for powering a load. After the electrons go around the circuit, they are reintroduced into the cell on a metal electrode on the back of the cell. These electrons then flow into the electrolyte, which then transports the electrons back to the dye molecules. Generally, a DSSC contains a combination of dye-sensitised transparent conducting substrate, semiconductor film, electrolyte and counter electrode. The DSSC is made of a mesoporous oxide containing TiO2 nanoparticles which is essentially its middle layer, that is deposited on a transparent conducting oxide (TCO) or fluorine-doped tin oxide (FTO) coated on a glass. This setup acts a path from cathode to anode for the electrons [7]. The diameter of these particles ranges from 10nm to 30nm while the thickness of the film is 10 micro meter which is doped with a dye for absorbing the photons. The dye gives out electrons, after getting hit by the photons, to the conduction band which results in oxidation of the dye [8].

By iodide/triiodide redox system, the dye then recovers lost electrons from the electrolyte. Triiodide(3I3) is formed as I- loses electrons to the dye.

By gaining electrons from the cathode, which is covered with platinum as catalyst, the Triiodide again becomes iodide, resulting in electrons flow from the semiconductor side to the counter electrode side, forming a flow of current [9].

I- + 2e- = 3I-

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IV. ADVANTAGES

1) Among all other thin-film solar cells, with 5 percent to 13 percent efficiencies, DSSC are the most efficient third generation solar cells showing efficiency of around 11 percent.
2) Among all other thin-film solar cells, with 5 percent to 13 percent efficiencies, DSSC are the most efficient third generation solar cells showing efficiency of around 11 percent.
3) To increase strength a traditional solar panel is encased in a glass with a metal back, which results in increase in temperature and hence decrease in efficiency. Whereas only a thin layer of conductive plastic on the front to build a DSSC which allows heat and radiation to pass much easily and quickly, resulting in low internal temperatures, which leads to higher efficiencies [10].

V. DISADVANTAGES

1) For large scale implementation higher cost higher efficiency solar cells are preferable to DSSCs. The price cut in traditional solar cells has lead to manufacturing of DSSCs and other thin film technologies taking a back seat.
2) A major concern in DSSCs is its liquid electrolyte, which contains organic solvents that has to be properly sealed. Scientists are working on replacing the liquid electrolyte with a solid one.
3) Another drawback of the liquid electrolyte is that it is unstable at varying temperatures. While the electrolyte might freeze at low temperatures (causing power cuts), at higher temperature sealing of the electrolyte becomes a difficult task as it might expand [10].

A. Advancement in Dye Sensitized Solar Modules

Over the last two decades DSSMs had a large amount of advancement and got remarkable attention and is currently considered the most suitable alternative to conventional photovoltaic solar cells [16-17].

As they are thinner in structure, they are more lightweight, flexible and partly transparent which makes them applicable on curved surfaces such as glass buildings and window modules.

While their low cut-off makes them usable indoors for powering small devices/sensors. Various progressions have been made in the fabrication of various kinds of DSSCs with uses of various nature. In this paper we will explore how DSSCs have been used to made transparent PV modules and BIPVs such as:

B. Transparent DSSC for Building Integrated Photovoltaic (BIPV) systems

As stated above, one of the biggest features of DSSCs are their low cut off which makes them a perfect candidate to be used for Building Integrated Photovoltaic (BIPV) modules.

And to use them inside buildings, especially as window modules, one of the most important features they need to have been their transparency [11].

Sanghoon Yoon et al. made a study to find the relationship between efficiency and transparency on a series of DSSCs, whose transparencies were controlled by changing the thickness of TiO_2 photoelectrodes.

When it comes to window modules not only efficiency but transmittance has also to be considered as it effects the building's energy consumption.

In BIPV systems the decrease in transmittance results in increase in heating loads but also leads to decrease in cooling loads. Moreover, zone orientation influences the effects of transmittance on energy consumption. Including zone orientation, factors such as solar radiation and heat flow also need to be considered carefully [12].

In the simulation it can be seen that total energy use of a normal window without DSSC is inversely related to transmittance, that is the increase in heating load is larger than cooling load.

This is due to reduction in solar heat gain results in an increase of heating load. At 60 percent transmittance lowest energy consumption is seen.

However, when DSSC is applied to the windows, excess energy is produced which leads to lowest energy consumption at 25 percent transmittance (Fig 2a, 2b) [12].

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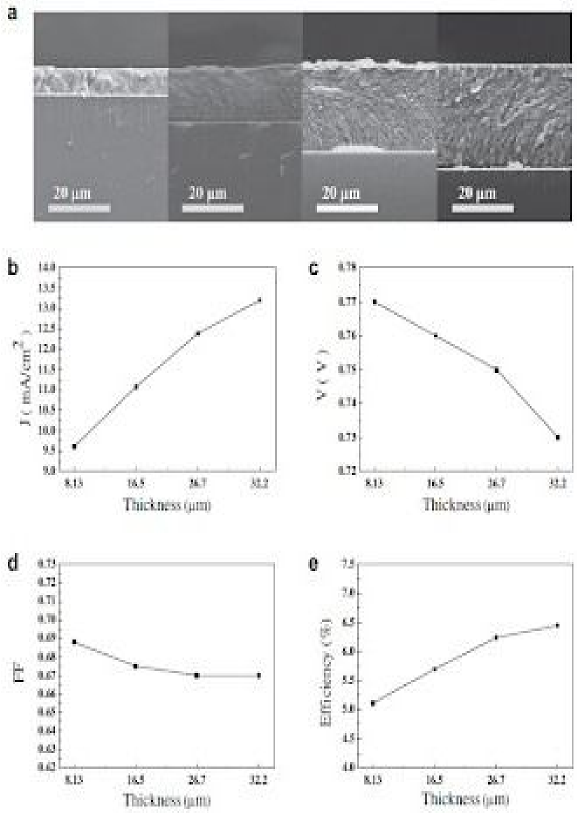

Fig.1

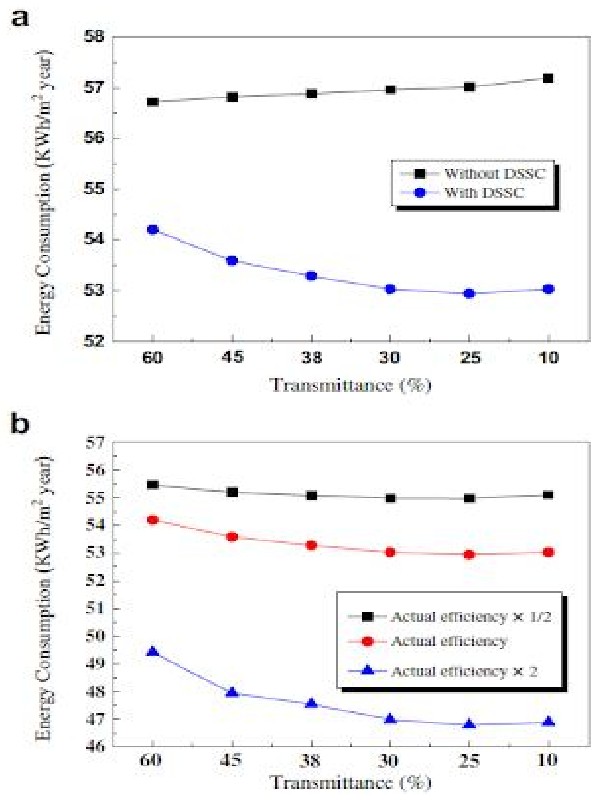

Fig. 2a ,2b

C. Digital printing of efficient DSSCs

Mahfoudh Raissia et al. investigated the fabrication of a semitransparent DSSC by digital printing method. This new digital printing method is called Digital Materials Deposition (DMD), and results from scanning electron microscopy shows that DSSC films printed by this method are more porous than conventional screen-printing deposited films. It has also been found that DMD films have higher Power Conversion Efficiency (PCE=7.4 percent) than conventionally printed DSSCs (PCE=5.48 percent) (Fig 5) [13]. Using the same dye and surface area, screen printed DSSCs show better performance than previously reported ones by other groups. While independent of surface area of the solar cell, DMD printed DSSCs give better performance than the screen printed DSSCs [13].

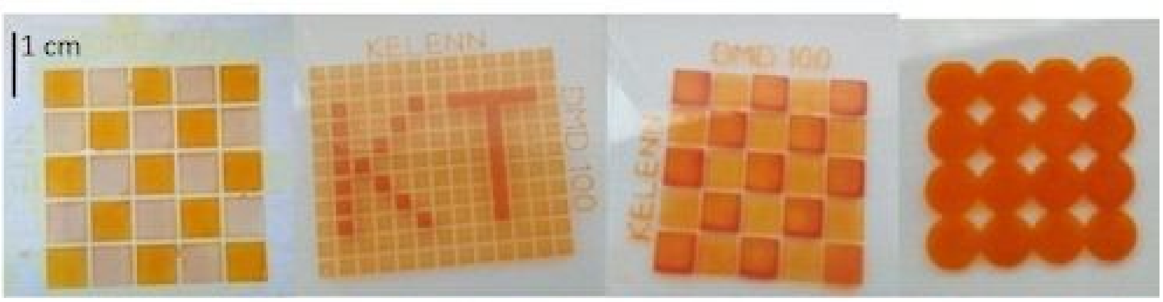

Fig.3 Some patterns printed on a FTO substrate using DMD

The time required to fabricate a DSSC with the DMD process is just 10 mins which is significantly lower than conventional printing method which usually takes overnight. DMD fabrication process also results in reduction of material consumption and provides an alternative to inkjet printing technology and spray coating. DSSCs also have the advantages of tenable colours, transparency, lightweight and higher performance under low light [14-15]. Fig 4: Structure of the D35 dye and picture of 1 sq. cm DSSC prepared by KELENN digital printing technology [12].

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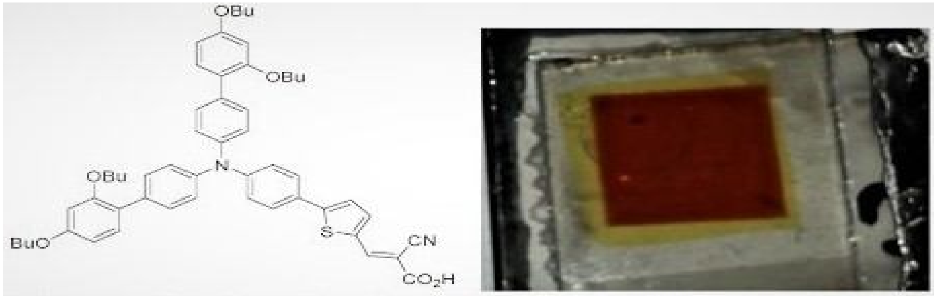

Fig. 4

Metrics of the solar cells fabricated either by digital printing or screen printing using D35 as sensitizer and illuminated with calibrated AM1.5 (100 mW/cm^2).

Printing techno.	TiO_2 mp	Surface area (cm^2)	Jsc (mA/cm^2)	Voc (mV)	ff (%)	PCE (%)
Screen printing	Without scattering layer	0.25	10.03 (± 0.21)	760 (± 5)	72(± 1)	5.48 (± 0.15)
		1	10.50 (± 0.1)	750 (± 10)	64(± 1)	5.05 (± 0.05)
Digital printing	Without scattering layer	0.25	12.65 (± 0.20)	775 (± 5)	75 (± 1)	7.40 (± 0.15)
		1	12.70 (± 0.10)	750 (± 2)	70 (± 1)	6.80 (± 0.15)

Fig. 5

D. Using Concentrated Light to Increase Efficiency of Transparent DSSC

It is true that the loss of performance during the scaling up of DSSCs are a massive and hence solar concentrators are used to compensate for the losses by generating more power from small devices. A light concentrator can be used with a small DSSC to compensate for the performance loss because it has been found that concentrated light absorbed by the solar cell can increase the performance several times [19-21]. A small parabolic compound concentrator was used which increased power conversion efficiency by 67 percent observed at 36 °C which was partly due to a rise in temperature. Maximum Jsc (current density) of 25.55 mA/cm2 is achieved at 40 °C for the concentrated coupled device compared with the Jsc of 13.06 mA/cm2 for the bare cell at the same temperature [22]. Thickness of TiO2 nanostructured materials influences the transparency of DSSCs a lot. Hence it is important that the perfect combination of transparency, thickness of TiO2 layer and the performance efficiency of DSSC is found. Fig 7[22] Table shows the relationship between TiO2 thickness, transparency and current density.

(a) Fabricated Bare DSSC **(b) Scaled up DSSC**

Fig. 6

Photovoltaic parameters of the bare cells based on different TiO_2 thicknesses under an illumination of 1000 W/m^2 (AM 1.5G).

Device	TiO_2 thickness (μm)	J_{sc} [mA/cm^2]	V_{oc} [mV]	ff [%]	P_{max} [mW/cm^2]	η [%]
L2	3.5	7.36	733	46.6	2.48	2.51
L3	6.0	11.14	756	54.0	4.46	4.49
L4	8.0	12.42	746	56.2	4.99	5.02
L5	10.0	12.75	793	58.7	5.87	5.93
L6	12.0	11.81	763	59.0	5.10	5.15
L7	14.0	8.28	742	56.6	3.22	3.24

Fig. 7

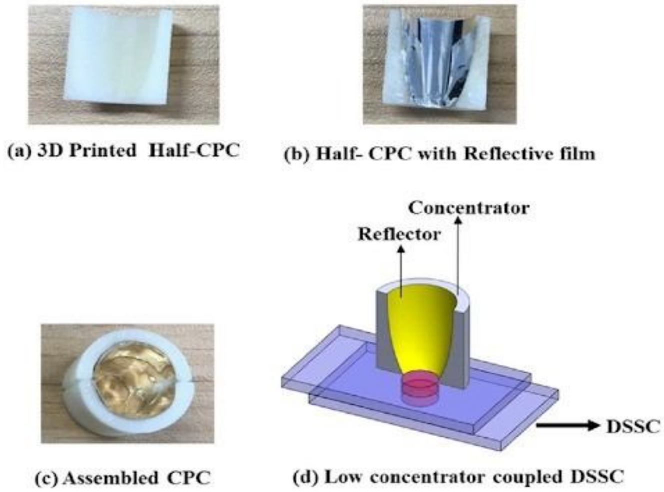

Fig. 8

Lots of different works are being done on DSSCs and solar concentrator for implementing them on buildings. One of the most notable one is by Barbera et al. who proposed a hybrid silicon-DCCS system with separate filters for IR and UV radiation to achieve up to 20 percent efficiency [23]. Increased device efficiency from 2.5 percent to 8.3 percent by using condenser lens for a vertically stacked DSSC with 8nm separation between lens and the cell [24].

E. Self-powering Internet of Things (IOTs) using DSSCs

The Internet of Things (IoTs) is a system made by an intelligent blend of interrelated physical “things” - electronic and communication devices, sensors, actuators and computational systems for networking, data handling and artificial intelligence for advanced automation.

1) Working of IoTs

IoTs requires exceptionally low electrical power to function and so it is possible that they can be driven by power generating systems located indoors. Hence DSSCs are a great option to produce power indoors due to their low cut off which helps them generate power in low lighting conditions. It has been estimated that by 2025 we will be using 75 billion IoT devices, majority of which will be located indoors [25]. First the IoT devices will collect information and data from their surrounding environment. Then these collected data is sent to IoT platform or their cloud storage infrastructure via various networking systems such as Wi-Fi, Bluetooth, Ethernet, etc. These data sent are stored and analysed by artificial intelligence and fed back to the user interface which communicates between the IoT devices and the users [26].

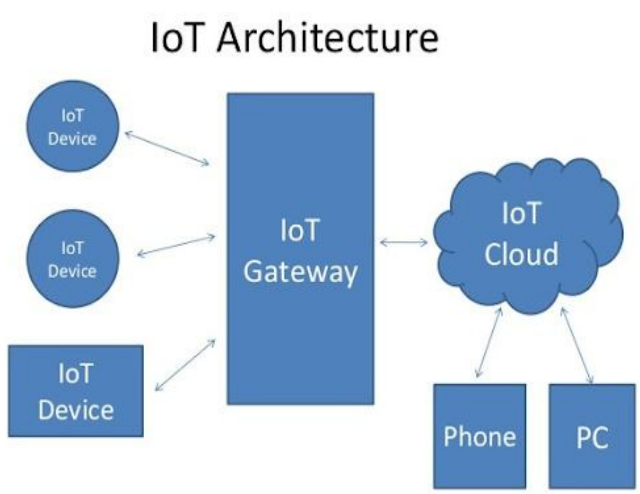

Fig. 9

2) Powering the IoT Devices

An uninterrupted power supply is very important for proper functioning of IoT devices. Hence a power supply with low maintenance is preferable and one solution for that are indoor DSSCs which have enough potential to power sensors, actuators and various communication devices[27-28]. DSSCs can be made multi-coloured, semi-transparent and very thin, while maintaining exceptional performance at low light conditions. This makes them perfect for self-powering application of IoT devices. DSSCs are also relatively cheap to fabricate, have roll-to-roll compatibility, using already available materials and easy processing ability.

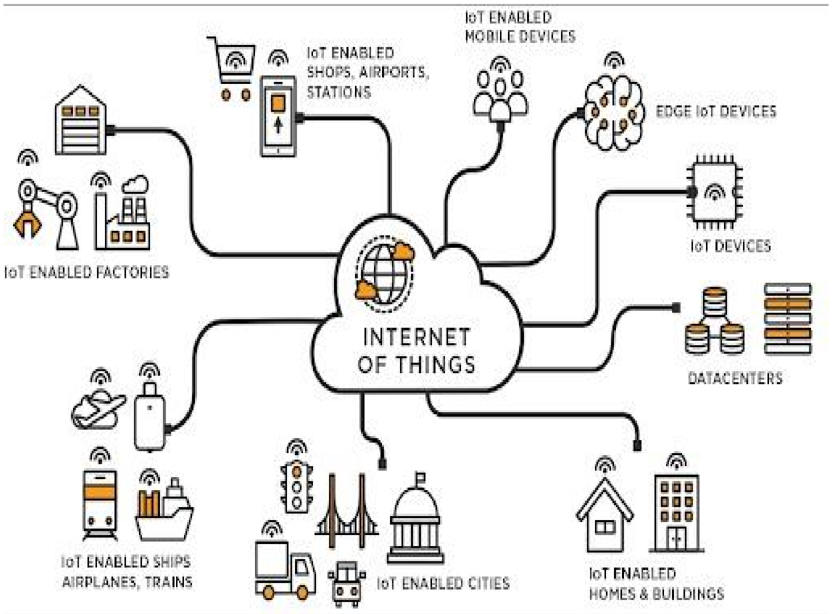

Fig. 10

VI. CONCLUSIONS

To commercialize and make the DSSC technology more competitive it is very important to improve the efficiency, stability and also reduce the material and manufacturing cost. And to achieve these goals more research and development should be done to identify and manufacture better dyes, electrolytes, surface substrates along with their assembly [29]. After development of a good model, we have to find practical uses and techniques to harvest them in both small and large scale applications. While it is true that conventional solar cells are a better option for large scale deployment, DSSC is a better option as Building Integrated PV(BIPV) cell, that is as window modules and indoor power sources. Life of DSSC is also a factor that is holding back its commercialization, so a lot of work has to be done in enhancing the life of DSSCs [30].

VII. ACKNOWLEDGMENT

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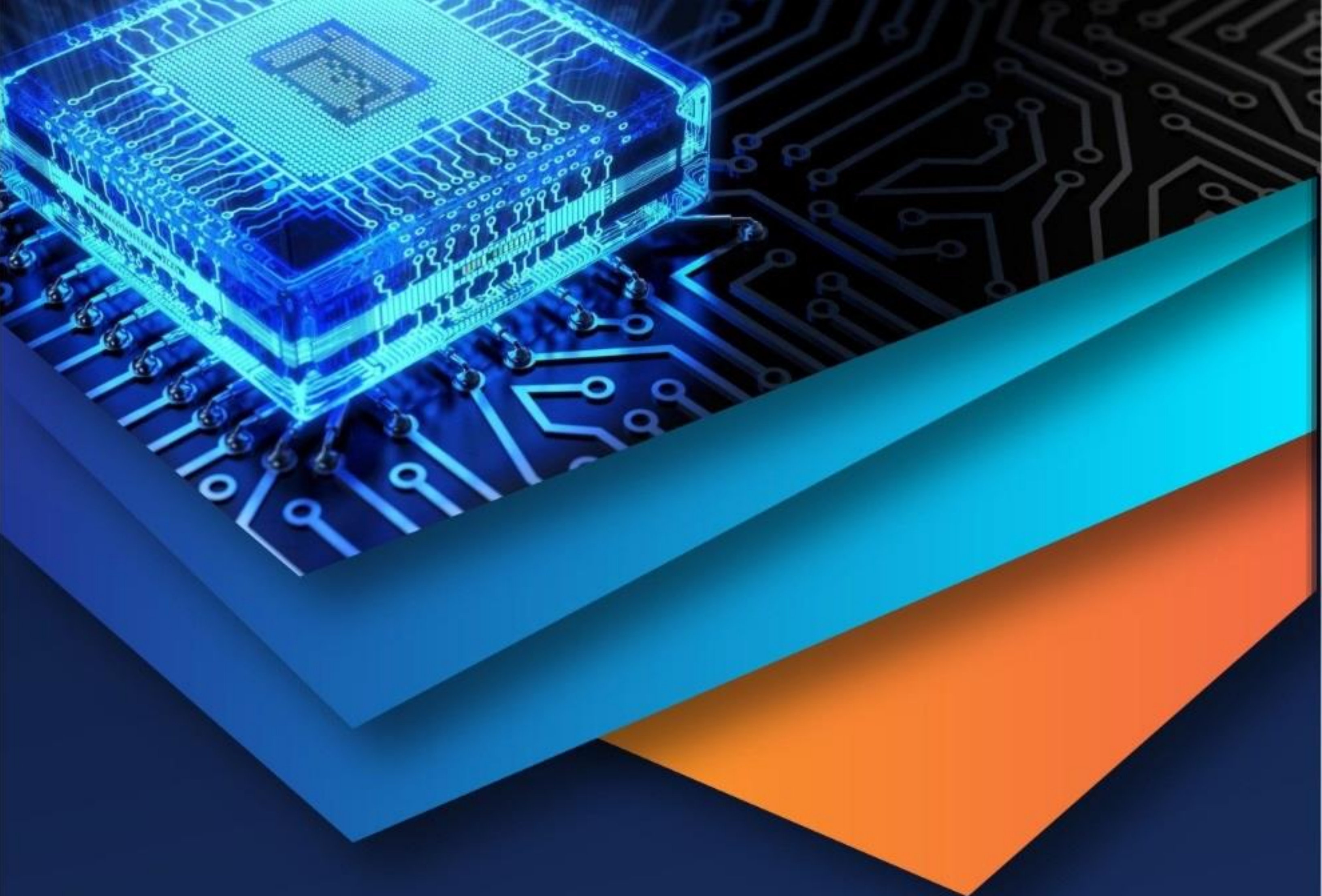

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