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Performance Investigation of Dye Sensitized Solar Cell using Hybrid Dyes

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Abstract: ***This research uses betalain extract and Spinacia oleracea Dye as a sensitizer source for dye-sensitized solar cell (DSSC) dependent on TiO2, which has entirely different range of absorption. The dye combination displayed a larger absorption range and increasing absorption of light than a single individual dye. As a consequence, Dye sensitized solar cell by the dyes mixture has demonstrated improved efficiency of the cells. Dye sensitized solar cell sensitized by betalain and spinacia oleracea dye yields cell output of 2.45 per cent and 5.03 per cent respectively, according to experimental findings. Dye sensitized solar cell were co-sensitized to find the optimal mixture by combining the dyes at 3 specific volume ratios (1:1 , 1:2 and 2:1). The formulated mixture of betalain and spinacia oleracea dye (at 1:2 ratio) produces 8.02 per cent overall performance.***
Keywords: Natural dye, Dye mixture, betalain, Spinacia oleracea, absorption spectrum.

I. INTRODUCTION

Dye-sensitized solar cells were discovered in the late 1960s that illuminated organic dyes can produce electricity in electrochemical cells at oxide electrodes. In an attempt to understand and model the primary photosynthesis processes the phenomenon was studied with chlorophyll extracted from spinach (bio-mimetic or bionic approach) at the University of California in Berkeley. On the basis of such experiments electric power generation via the dye sensitization solar cell (DSSC) principle was demonstrated and discussed in 1972. The dye solar cell's instability has been described as a principal problem. In the following two decades, its performance could be improved by improving the porosity of the electrode prepared from fine oxide powder, but the instability remained an problem. A typical DSSC consists of a porous coating of nanoparticles of titanium dioxide, coated with a molecular dye that absorbs sunlight, like the chlorophyll in green leaves. The titanium dioxide is dissolved in an electrolyte solution, in which a catalyst centered on platinum is present. An anode (the titanium dioxide) and a cathode (the platinum) are mounted on either side of a liquid conductor (the electrolyte) as in a traditional alkaline battery.

II. LITERATURE REVIEW

Kashyout et al. rendered zinc foils using a zinc oxide colloidal process. The grain size was found to be inversely proportional to the centrifugal velocities. By rising centrifugal speed from 6,000 to 15,000 rpm, it decreased from 150 nm to 50 Nm. Both were sensitized to the cell by artificial and natural dye. Natural dye demonstrated a high open circuit voltage of 0.6 V[1].

Iha and Polo extract blue anthocyanin from various fruits to produce a natural sensitizer for the solar dye. The jaboticaba showed a current density, a fill factor, an open circuit voltage and a maximum output of 9.0 mA / cm2, 0.54, 0.59 and 1.9 mW / cm2. Although Calafate was used as a sensitizer, the current density, fill factor (FF), open circuit voltage and maximum power were less than that of jaboticaba, respectively 6.2 mA / cm2, 0.36, 0.47 and 1.1 mW / cm2[2].

Wu et al. produced solar cell dye using natural sensitizer dyes. Natural dyes derived from black rice, capsicum, variegata flower Erythrina, Rosa xanthina, and kelp. The blue rice extracts and produces best results of all colorants. The current density, open circuit voltage, fill factor and power of the DSSC using blue rice extracts were found respectively as 1.142 mA, 551 mV, 0.52 and 327 µW[3]. Sirimanne et al. extracted juice from pomegranate fruits that contain cyanine (flavylium) used as a natural sensitizer for dyeing. The solid-state solar cell TiO2 (n type semiconductor)/pomegranate piment (natural dye)/CuI (p type) showed maximum absorption at a wavelength of 570 nm, which induced the cell's highest efficiency compared to other natural pigments (cyanidine, tannin, santalin and vitamin C)[4].

Using p-CuI as a hole conductor, Kumara et al. used shisonin, chlorophyll and mixer of both pigments derived from shiso leaves as the dye for a DSSC solid state. The highest cocktail dye efficiency (shisonin and chlorophyll) was 1.31%. The DSSC based on shisonin and chlorophyll showed an efficiency of 1.01 and 0.59 per cent respectively. The open circuit voltage (mV), the current density (mA / cm2), the FF and the shisonin output (percent) are 550, 0.59, 0.51 and 1.01 while chlorophyll is 432, 3.52, 0.39 and 0.59. And the maximum efficiency of the mixed solar dye cell was 1.31 per cent[5].

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Yamazaki et al. used a natural sensitizer called carotenoid, crocetin and crocin. It was observed that carotenoid and crocetin containing carboxylic group could adsorb the cell's best output effectively on the semiconductor. While crocin showed less efficiency due to the lack of a carboxylic group. DSSC 's specific performance parameters using crocetin and crocin extracts[6].

Wong charee et al. collected rosella dye, blue pea and mixed water extract that was used as a solvent at 100 ° C. Rosella extract obtained the maximum efficiency of 0.37 per cent. The dye solar cell based on blue pea and mixed dyes showed respectively an efficiency of 0.05 per cent and 0.15 per cent. It was found that when the temperature of extraction was reduced to 50 °C and the pH of the dye was adjusted from 3.2 to 1.0, the efficiency using rosella was improved and reported as 0.70%. Therefore the solvent temperature and pH value affects the efficiency of the cells[7].

Senadeera et al. extracted various natural pigments (Sesbania grandiflora scarlet, hibiscus rosainensis, hibiscus surattensis, Nerium oleander, Ixora macrothyrsa and rhododendron arboretum zeylanicum) from tropical flowers. With current densities ranging from 1.1 to 5.4 mAcm−1, the total performance ranged from 0.2 percent to 1.1 percent. Hibiscus-Hibiscus The highest efficiency of surattensis was 1.14 per cent[8].

Teoh et al. used gold nano-particles on working electrode (TiO2), where Ce4+/3 + water based electrolyte was used and sensitized with rhoeo spathacea stream extracts. This updated technique showed best results at 1.49 per cent cell efficiency[9].

McHale et al. produced natural solar dye cells from red beet roots, using betalain pigments. Present density and open circuit voltage respectively measured as 2.42 mA / cm2 and 0.44 V. Betanin (I), betanidin (II), betanine and betalamine derivatives of betanine pigments showed maximum wavelength absorbance of 535 nm, 542 nm, 482 nm, and 424 nm respectively[10].

Girtu et al . synthesized DSSCs using anthocyanin extracted from red cabbage and red onion extracts with different solvents and recorded highest efficiency of 0.173 per cent with red cabbage using water as solvent while using red onion extract using MeOH extract DSSC produced an efficiency of 0.141 per cent[11].

Furukawa et al. assembled two different solar dye cells with different molecular weight added into the oxide paste using polythene glysol (PEG). Dye was prepared using Curcumin and Red Cabbage. Cell efficiency with PEG of 2,000,000 molecular weight was reported high (0.99 percent) compared to cell with 50,000 (0.42 percent) molecular weight[12].

III. EXPERIMENTAL SETUP

A. Components

Figure 1 Components of DSSC

1. DYE
2. TITANIUM DI-OXIDE
3. ELECTROLYTE
4. GRAPHITE
5. GLASS PLATES
6. PIPETTE
7. BURNER
8. SAFETY GOGGLES
9. DIGITAL MULTIMETER
10. WIRE GAUZE
11. PETRI DISH
12. PAPER CLIPS
13. SET OF CLIPS
14. SCOTCH TAPE
15. MICROSCOPE SLIDE GLASS

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IV. PROCEDURE

A. Anode Preparation

Commercially available TiO2 paste (avg. particle size = 20 nm) crystal structure: > 99 percent anatase (cat. no.- 791547 from Sigma-Aldrich) glass substrate (cat. no.- 735183 from Sigma-Aldrich) was bladed on the conducting side of the FTO (surface resistivity = 8 /sq. and transmittance = 80–81.5 percent). The FTO / TiO2 was permitted to dry at 40 ° C for 60 minutes and then to sinter at 450 ° C. The active cell area was 1 cm2 . The single layer TiO2 film thickness was around 8–10 μm

B. Dye Extraction

Red (betalain) and green (Spinacia oleracea) colours, respectively, were derived from local (Bangladesh) beetroot (Beta vulgaris) and turmeric (Curcuma longa).

The beetroot derived dye was obtained by cutting it into small pieces and adding 100 ml of ethanol (99.5 percent purity, Merck cat. − 8187602500).

Beetroot to ethanol had a ratio of 3 g: 10 ml. Strong residues were filtered out and used as a source of DSSC sensitizers. For dye extracted from turmeric, it was thickly sliced after peeling off and dried for 72 h in the absence of sunlight. Such forces submerged in ethanol after they squashed the turmeric into powder using a mortar grinder. The ratio of turmeric-powdered to ethanol was 1 g: 10 ml. Strong residues were filtered out and used as a source of DSSC sensitizers.

Figure 2 betalain Dye (Red)

Figure 3 Spinacia oleracea Dye (Green)

Figure 4 betalain Dye (Red)

Figure 5 betalain Dye (Red)

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C. *Dye Loading:* 30 ml red and green coloring solution used for single dye-based DSSC sensitizer. The combination of red dye + green dye with 1:1 (15 ml: 15 ml), 2:1 (20 ml: 10 ml), 1:2 (10 ml: 20 ml) was used as the basis of DSSC co-sensitization. In the dye solutions, anode (FTO / TiO2,) was soaked at room temperature for 12 h in the absence of light. After the anode was consumed, air was dried for the workplace photoanodes for 60 min.

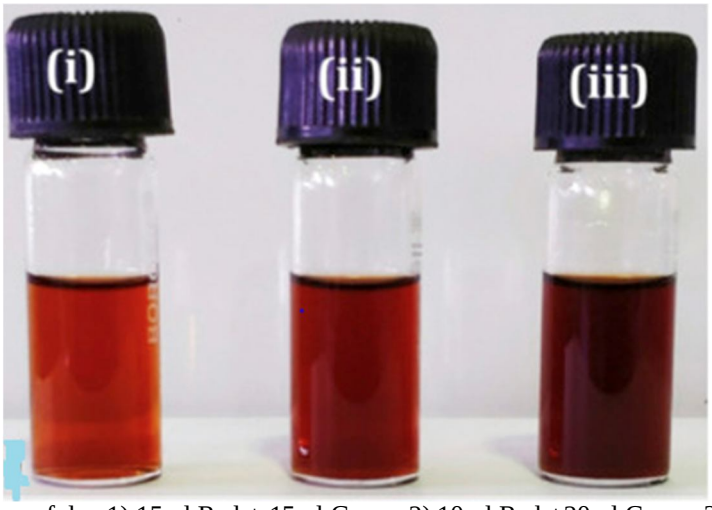


Figure 6 Combination of dye 1) 15ml Red + 15ml Green, 2) 10ml Red +20ml Green, 3) 20 Red + 10ml Green

D. *Electrolyte Preparation*

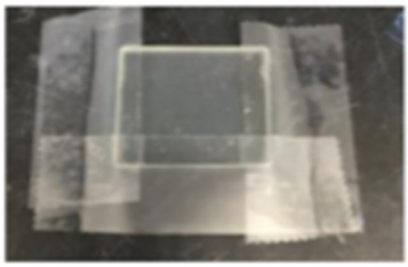
To prepare the Iodide electrolyte solution, 0.127 g I2 (Merck cat. no.- 1047610500), 10 ml of ethylene glycol (Merck cat. no.- 1009492500) and 0.83 g KI (Merck cat. no.- 1050430500) were combined in a volumetric flux. Both chemicals were used with no additional alternation.

E. *Cathode Preparation and cell Fabrication*

The cathode was prepared using the graphite-printing process. The graphite paste was prepared by making a homogeneous 3 ml sodium silicate mixture and 4 g graphite powder mix. The "Doctor Needle" printing technique casted the graphite paste onto polished FTO glass. The graphite-coated film had been allowed to dry off in the air for 60 min. To mount the DSSC, both electrodes were clamped together and produced into a cell style sandwich, and electrolyte solution redox I−/I3 − was injected into the cell.

F. *Assembling the Cell*

The conductive sides of the glass slides were calculated by using a multimeter to take resistance from each slide. It was found that the conducting sides had a resistance of between 17-26 ohms. A single cell was made from two slides with the same initial resistance. One slide was covered with graphite leaving about 0.5 cm on one side, with the conductive side facing up. The other slide 's conductive hand was covered with suspension TiO2. Pieces of tape were mounted on the slide to test the TiO2 location and thickness as shown in figure 7.



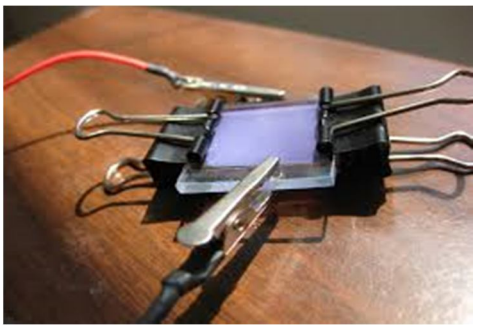


Figure7: Solar cell coating preparation Figure 82 Prepared Cell

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V. WORKING

When the sunlight strikes on the surface of the DSSC, the dye molecules collect photons and produce the excited electrons. The sensitizer injects excited electron into the conduction band of nanoporous semiconductor film. The dye molecules that lost electrons are then oxidized. The injected electron travels through the nono-porous TiO2 thin film toward the transparent conductive electrode (working electrode), and reaches to a load where work is performed and delivered in the form of electrical energy. The electrons now travel back through an external load and reach the counter electrode and thus complete the whole circuit.

A dye sensitized solar cell consists of two electrodes, an anode or photo or working electrode and a cathode or counter electrode, generally made up of specially designed transparent conductive glass coated with transparent conductive oxide i.e. indium or fluorine doped thin oxide. The transmittance of the indium doped tin oxide (ITO) is higher than that of the fluorine doped tin oxide (FTO) while the sheet resistance of the FTO is less than that of the ITO

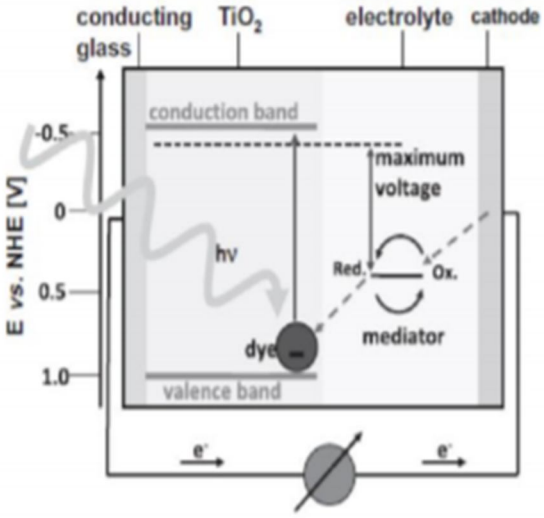

Figure 9 Working of dye solar cell [13]

VI. PERFORMANCE PARAMETERS OF DSSC

The performance of dye solar cell is generally evaluated by the different parameters of the cell such as open circuit voltage, short circuit current, fill factor, maximum voltage and maximum current of the cell. Each parameter is discussed in detail as follows [39]:

A. Open Circuit Voltage

The open circuit voltage (Voc) of the solar cell is defined at the open terminals of the cell. As the temperature of the cell increases, the Voc decreases. The Voc of the cell is expressed as follows:

$$Voc = \frac{Vt * Im}{(Isc / Io) + 1}$$

B. Short Circuit Current

The short circuit current (I_{SC}) can find at the short circuit terminals of the cell. The short circuit current increases with increase temperature. Following expression shows the I_{SC}:

$$Isc = Im + Io \{\exp(Vm/Vt) - 1\}$$

C. Fill Factor

The fill factor (FF) of the solar cell can be defined as the ratio of actual power (product of maximum voltage; Vm and maximum current; Im) to the dummy power (product of Voc and Isc).

$$FF = \frac{Vm * Im}{Voc * Isc}$$

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D. Efficiency

The efficiency of the solar cell can be defined as the ratio of electrical power to the optical power incident on the cell. It can be expressed as follows:

$$\eta = \frac{FF * Voc * Isc}{\text{Incident optical power}}$$

Voc – Open-circuit voltage,
Isc – Short-circuit current,
Vm – Maximum value of voltage,
Im– Maximum value of current,
Vt– Terminal voltage of the cell
η – Efficiency of the cell
I_o- Output current

VII. RESULTS AND DISCUSSION

A. Combination of Dyes

1) 30ml Betalain(Red)
2) 30ml Spinacia oleracea(Green)
3) 15 ml Betalain(Red) + 15ml Spinacia oleracea(Green)
4) 10 ml Betalain(Red) + 20ml Spinacia oleracea(Green)
5) 20ml Betalain(Red) + 10ml Spinacia oleracea(Green)

The current–voltage (I-V) characteristics of the DSSC was determined by a calibrated solar simulator with lamp and a light intensity of 100 mW/cm^2

a) For 30ml Betalain(Red)

Table 1 30ml Betalain(Red)

Sr. No	Time(hr)	Voc(mV)	Isc(mA)	FF	η%
1	1	371.6	1.21	0.48	2.15
2	2	372.8	1.25	0.48	2.23
3	4	373.5	1.27	0.49	2.24
4	10	375.5	1.31	0.50	2.45
5	24	393.2	0.883	0.498	1.72

b) For 30ml Spinacia Oleracea (Green)

Table 2 30ml Spinacia oleracea(Green)

Sr. No	Time(hr)	Voc(mV)	Isc(mA)	FF	η%
1	1	518.5	1.492	0.536	4.14
2	2	507.2	1.857	0.503	4.73
3	4	509.1	1.92	0.508	4.96
4	10	513.2	1.93	0.509	5.03
5	24	521.1	1.96	0.513	5.23

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c) For 15 ml Betalain(Red) + 15ml Spinacia oleracea(Green)

Table 3 15 ml Betalain(Red) + 15ml Spinacia oleracea(Green)

Sr. No	Time(hr)	Voc(mV)	Isc(mA)	FF	η%
1	1	511.5	1.797	0.527	4.84
2	2	495.5	2.319	0.508	5.83
3	4	498.1	2.33	0.519	6.02
4	10	501	2.49	0.528	6.58
5	24	504.2	2.56	0.540	6.96

d) For 10 ml Betalain(Red) + 20ml Spinacia oleracea(Green)

Table 4 10 ml Betalain(Red) + 20ml Spinacia oleracea(Green)

Sr. No	Time(hr)	Voc(mV)	Isc(mA)	FF	η%
1	1	515.8	1.883	0.541	5.25
2	2	502.3	2.494	0.518	6.49
3	4	508.1	2.59	0.524	6.89
4	10	514	2.62	0.531	7.15
5	24	528.9	2.81	0.543	8.07

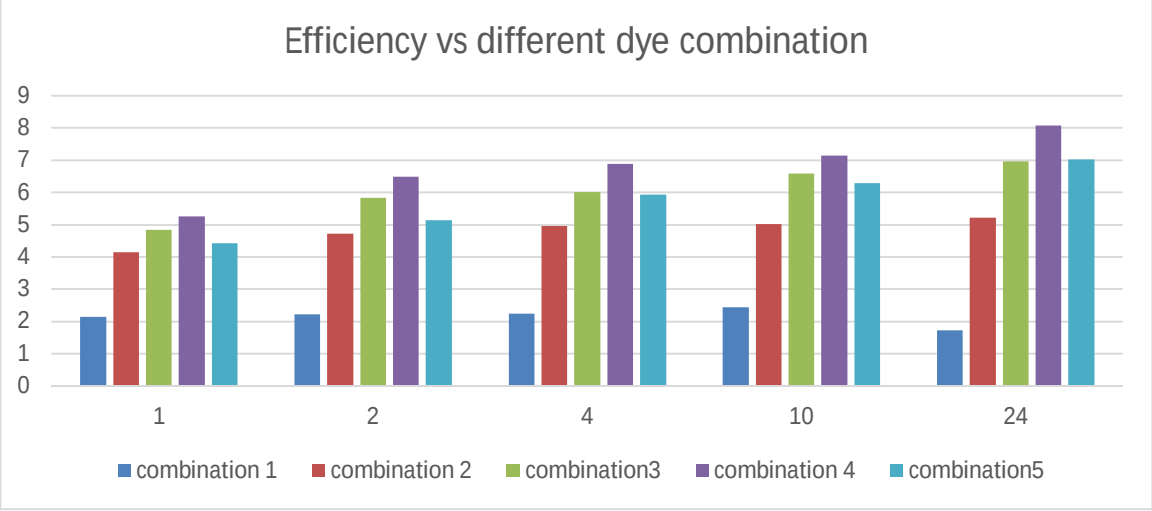
e) For 20ml Betalain(Red) + 10ml Spinacia oleracea(Green)

Table 5 20ml Betalain(Red) + 10ml Spinacia oleracea(Green)

Sr. No	Time(hr)	Voc(mV)	Isc(mA)	FF	η%
1	1	515.3	1.618	0.532	4.43
2	2	497.1	2.041	0.508	5.15
3	4	505.8	2.26	0.529	5.93
4	10	518.3	2.31	0.527	6.30
5	24	520.1	2.50	0.541	7.03

B. Efficiency vs Different dye Combination

Table 6 Efficiency vs different dye combination



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VIII. CONCLUSION

The cell efficiency of DSSC has increased with increase in time. By combining the red and green dye that has a higher and wider absorption spectrum than both single individual dye. Also, the optimized combination of red and green (at the 1:2 vol ratio) has the highest cell efficiency 8.07%, which was higher than single individual red (η = 2.45%) and yellow (η = 5.23%) dye-sensitized DSSC's cell efficiency, respectively.

For 1st hour the combination of Red and green (1:2) ratio has the highest efficiency with 5.24%. after that combination with ratio 1:1, 2:1 has 4.84% and 4.43% respectively. Now for 2,4,and 10 hour combination of red and green 1:2 ratio has highest efficiency with 6.49%, 6.89%, and 7.15%.

Now for after 1 day (24 hours) the combination of Red and green (1:2) ratio has the highest efficiency with 8.07%. so after 1 day efficiency of dye-sensitized solar increases.

Here we conclude that combination of 10 ml Betalain(Red) + 20ml Spinacia oleracea(Green) has the high efficiency as compare to other combination. We also conclude that the efficiency of hybrid solar cell increases, so that DSSC can be used for long time.

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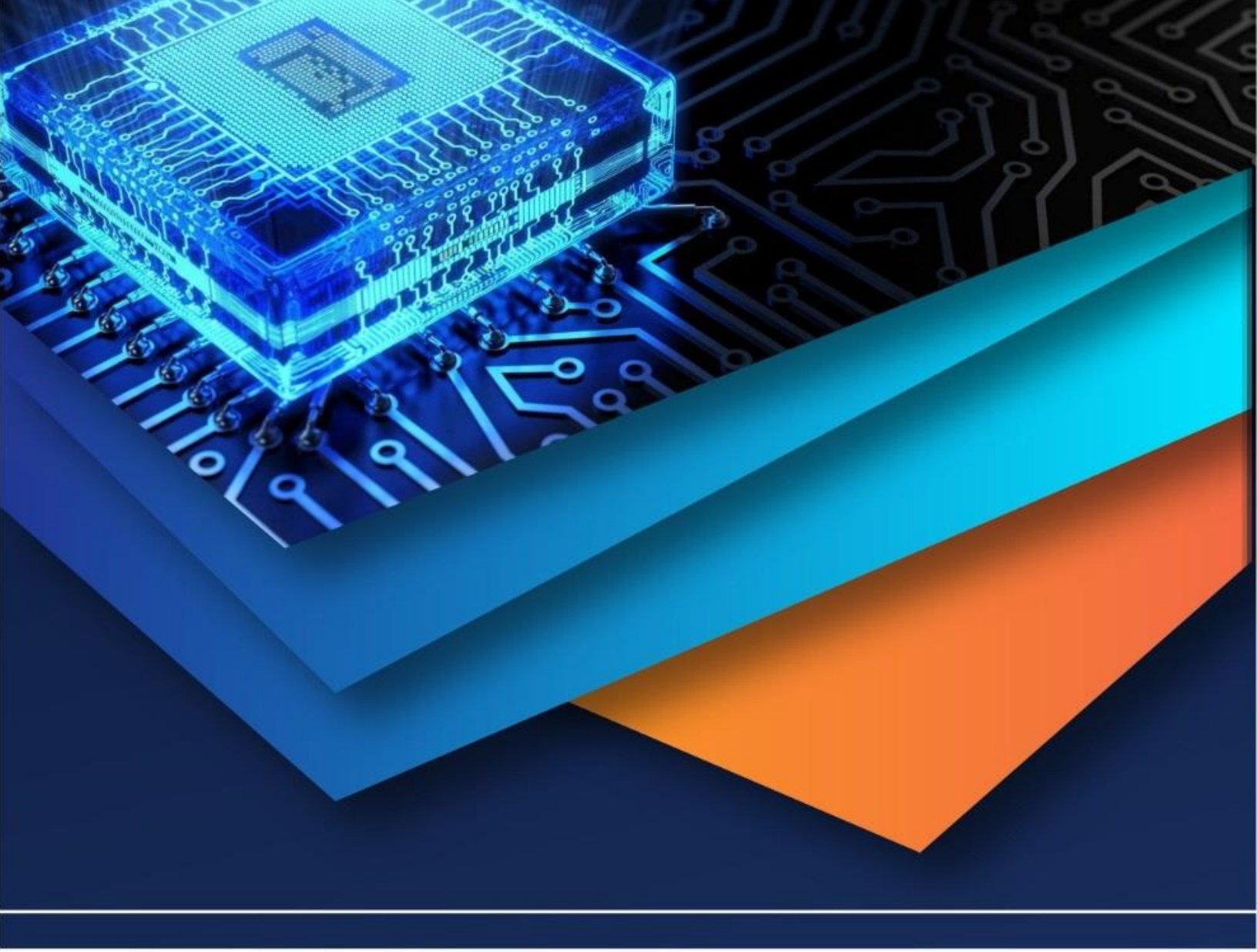

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