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# Gamma Rays Induced Effects on the Quality Performance of Silicon based Solar Cells

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***Abstract: At the present work mono-crystalline silicon solar cells were irradiated with 1.25 MeV and 0.662 MeV gamma photons with different doses for different periods of time. The degradations of the photovolatic parameters of solar cells were described in terms of the variation of the maximum voltage ($V_{max}$), maximum current ($I_{max}$) and maximum power ($P_{max}$), the results obtained that the gamma exposure doses have a significant effect on the photovolatic parameters of the solar cell and it controls the quality and performance of the solar . Moreover different gamma photons energy and doses can affect the solar cell photovolatic parameters differently.***

***Keywords: Gamma rays, Mono-crystalline silicon solar cell, $^{60}$Co γ-irradiation, $^{137}$Cs γ-irradiation, Photovolatic parameters***

## I. INTRODUCTION

The electrical characteristics of silicon solar cells are affected by environment condition. During operation of photovoltaic solar cells, they are exposed to radiation such as used in space systems and satellites.

The irradiation of solar cells by high-energy levels of radiation in the form of gamma rays, neutrons, charged particles, etc. leads to radiation defects and electrical damage in the solar cells bulk and results in a significant degradation of the electrical parameters of silicon solar cells [1,2].

The lifetime and performance of the solar cells is limited by the amount of radiation damage in solar cells. When silicon solar cells are irradiated with gamma rays, two types of radiation damage occur within it. These defects mostly act as recombination points that decreased the diffusion length and lifetime of minority carrier as well as increased internal parameters of cells. Output parameters of solar cell such as maximum output power, fill factor, efficiency, short circuit current, and open circuit voltage strongly depend on internal parameters of solar cells such as series resistance RS, saturation current I0 and ideal factor n. it has been proved that increasing each of above internal parameters of solar cell causes that the output characteristics of solar cells to be decreased [3-5].

When gamma rays interact with material, two types of radiation damage effects occur, the first effect is Ionization effect, which is the generation of electron-hole pairs within the material which can be caused by either Photoelectric effect, Compton scattering, or pair production where they eject electrons from the atoms of the material [6] .These ejected electrons can create secondary reactions. The result is a track of ionized atoms in the bulk of the material. The second effect is atomic displacement which is known as the movement of atoms from their normal position in the lattice to another placement, causing a defect in the lattice material. Sometimes the atom receives so much kinetic energy at the site of interaction that it leaves its initial location in the material. This displacement creates additional atomic movement on its track that may result in a cluster of defects into the atomic lattice. The immediate and long-term results of ionization and atomic displacement strongly depend on the material [6]. After electron-hole generations, electrons and holes travel in the bulk under the influence of the local electric field. the mobility of electrons is much higher than the mobility of holes, but both charge carriers may get into defects of the lattice called traps. Charge carriers accumulate around traps and create a local charge build-up. These traps can be single point defects or a mismatch of interface surfaces [7,8]. High-energy photons give rise to clusters of defects and low-energy photons only produce single point defects. The interstitial atoms are not such electrically active as a complex of defects. Defects introduce intermediate energy levels in the gap between the conducting band and the valence band. These band-gap defects disturb the transport of electrical charges by several reactions [9]. First, generation and recombination of electron-hole pairs degrade the minority carrier lifetime. Second, the trapping and compensation effects change the majority carrier density and decrease the carrier mobility [10].

The permanent damage in solar cell materials is caused by the collisions of incident radiation particles with atoms in the crystalline lattice, which are displaced from their positions. These defects degrade the transport properties of the material and particularly the minority carrier lifetime.

The interaction between vacancies, self-interstitials, impurities, and dopants in Si leads to the formation of undesirable point defects such as recombination and compensator centers which affect performance of solar cells, especially in space. The introduction of radiation-induced recombination centers reduces the minority carrier lifetime in the base layer of the p-n junction increasing series resistance [11]. Radosavljevi´ candVasi´ c[12]show that the generation of electron-hole pairs due to ionization effects usually results in the generation and increase of noise and the minimum signal that can be detected. All of these effects lead to the decrease of the output current.

The objective of this work is to examine a suitable (light source –solar cell) geometry and describe a series of measurements carried out and compared to characterize the $^{60}$Co, $^{137}$Cs γ-induced displacement damage on a mono-crystalline silicon solar cell in terms of variation of mono- -crystalline silicon solar cell photovoltaic parameters with respect to $^{60}$Co, $^{137}$Cs γ-ray exposure doses .

## II. MATERIALS AND METHODS

Experimental measurements in this paper were carried out on commercially available mono-crystalline silicon solar cells. In this experiment the following were used :

*A.* Two mono-crystalline silicon solar cells with an active area of 10cm×5cm .
*B.* 500 W halogen lamp with 100 mW.cm$^{-2}$ light intensity.
*C.* Pyranometer type HT303N of sensitivity 19.8μV/W.m$^{-2}$
*D.* solar systems analyzer type HTSolar300.
*E.* Two digital multimeters.
*F.* Variable resistor.
*G.* $^{60}$Co, $^{137}$Cs γ-ray source

The light source was fixed at y=20 cm above the active surface area of the solar cell. The halogen lamp bulb is inexpensive, uncomplicated and convenient to operate and require only easy power supply units. The halogen lamp bulb is widely used in solar beam experiments (SBE) for solar simulator applications because it provides a very stable and smooth spectral output [13]. The light source intensity was measured to be 100 mW.cm$^{-2}$. using a pyranometer type HT303N of sensitivity 19.8μV/W.m$^{-2}$, connected to a solar systems analyzer type HTSolar300.

First for γ-ray irradiation, a $^{60}$Co γ-ray source of activity 1mCi and average energy of 1.25MeV was utilized. Two digital multimeters were used to record the output voltage and current while varying the value of a variable resistor (0-1KΩ).

After gathering the results of the $^{60}$Co γ-ray exposure, the $^{60}$Co γ-ray source was replaced with a $^{137}$Cs γ-ray source with energy of 0.662 MeV and a new mono-crystalline silicon solar cell with an active area of 10cm×5cm was instrumented and the output voltage and current were recorded using Two digital multimeters while varying the value of a variable resistor (0-1KΩ).

## III. MEASUREMENTS PROCEDURE

The forward bias I(current) –V(voltage) characteristics of mc-Si solar cells, before and after gamma ray irradiation, were measured at room temperature for different periods of time. The light source was used to uniformly illuminate the solar cell under test and the measurements were performed within 15 minutes in room temperature. It is important to carry out the measurements within a short time scale (~0.25 % hour) to avoid elevating the cell temperature, as this will result in a decrease of $V_{oc}$, with a relative reduction in light conversion efficiency of about 0.4% K$^{-1}$ [14]. The variable resistor, R was set to its maximum value (1KΩ) and both the current (I) and the voltage (V) were recorded. At R=1KΩ, within our measurement conditions, the voltage will approximate the open-circuit value $V_{oc}$. The resistance was then decreased in steps. Both I and V were recorded for different settings, including the short-circuit current $I_{sc}$ corresponding to R=0. At this point, the light source was turned off and the $^{60}$Co γ-source was located at the y=5cm above the active area of the Si solar cell. The cell was irradiated for 1 hr, 2hrs and 3 hrs. The corresponding exposures were calculated to be 532 mR, 1064 mR and 1596 mR, respectively. At the end of each exposure time, the $^{60}$Co γ- source is removed and the light source is turned on. The data for I and V including $I_{sc}$ and $V_{oc}$ were recorded following the measurements procedure before $^{60}$Co γ-ray irradiation.

The I-V characteristics, before and after $^{60}$Co γ-irradiation were used to determine the point of maximum power ($V_{mp}$, $I_{mp}$) . At this point, the maximum power were calculated and (P(power) -V) characteristics were generated.

A new (light source- solar cell) geometry was instrumented and all the steps mentioned above was repeated using a $^{137}$Cs γ-source for irradiation. The gamma source was located at y=5cm above the active area of the Si solar cell. The cell was irradiated for 1hr, 2hrs and 3hrs. The corresponding $^{137}$Cs gamma exposures were calculated to be 280 mR, 560 mR and 837 mR, respectively.

## IV. RESULTS AND DISCUSSION

*A. Comparison between the Effects of illumination of $^{60}$Co and $^{137}$Cs γ-ray irradiation on the I–V and P-V characteristics.*

The forward bias (I-V),(P-V) characteristics of the mc-Si solar cell, before and after various $^{137}$Cs γ-ray exposure doses; 280 mR, 560mR and 837 mR, were measured at room temperature and shown in table (1)

Table (1):The illuminated I-V ; P-V characteristics of mc-Si solar cell irradiated with 0.662 MeV $^{137}$Cs photons at various doses collectively.

| Condition | Parameters | | |
|---|---|---|---|
| Pre irradiation | $I_{mp}$ | $V_{mp}$ | $P_{mp}$ |
| | 0.937753 | 0.5401944 | 0.506569 |
| After irradiation | $I_{mp}$ | $V_{mp}$ | $P_{mp}$ |
| $^{137}$Cs (Dose 1) 280 mR | 0.863672 | 0.53807927 | 0.464724 |
| $^{137}$Cs (Dose 2) 560 mR | 0.842181 | 0.52443833 | 0.441672 |
| $^{137}$Cs (Dose 3) 837 mR | 0.812643 | 0.49155533 | 0.399459 |

The forward bias (I-V),(P-V) characteristics of the mc-Si solar cell, before and after various $^{60}$Co γ-ray exposure doses; 532 mR, 1064 mR and 1596 mR, were measured at room temperature and shown in table (2)

Table (2):The illuminated I-V ; P-V characteristics of mc-Si solar cell irradiated with 1.25 MeV $^{60}$Co photons at various doses collectively.

| condition | Parameters | | |
|---|---|---|---|
| Pre irradiation | $I_{mp}$ | $V_{mp}$ | $P_{mp}$ |
| | 0.937753 | 0.5401944 | 0.506569 |
| After irradiation | $I_{mp}$ | $V_{mp}$ | $P_{mp}$ |
| $^{60}$Co (Dose 1) 532 mR | 0.846737 | 0.53784823 | 0.455416 |
| $^{60}$Co (Dose 2) 1064 mR | 0.825667 | 0.52443782 | 0.433011 |
| $^{60}$Co (Dose 3) 1596 mR | 0.773946 | 0.49154851 | 0.380432 |

The forward bias I-V characteristics of two mc-Si solar cells, after various $^{60}$Co γ-ray exposure doses; 532 mR, 1064 mR and 1596 mR for the first cell, and $^{137}$Cs γ-ray exposure doses; 280 mR, 560 mR and 837 mR for the second cell, were measured at room temperature at the same acquisition time 1 hr ,2 hrs ,3hrs for both sources individually, compared and shown in Fig(1) (a,b,c,).

As seen in table (1) , table (2) and Fig (1)(a), the maximum (I-V) point for $^{137}$Cs peaks at (0.863672, 0.53807927) where for $^{60}$Co it appears at (0.846737, 0.53784823), in Fig (1)(b), the maximum (I-V) point for $^{137}$Cs appears at (0.842181, 0.52443833) where for $^{60}$Co it peaks at (0.825667, 0.52443782), in Fig (1)(c), the maximum (I-V) point for $^{137}$Cs peaks at (0.812643, 0.49155533) where for $^{60}$Co it appears at (0.773946, 0.49154851), In comparison to the voltage $V_{mp}$ values after $^{137}$Cs γ-ray irradiations the $V_{mp}$ values of $^{137}$Cs γ-ray irradiations exceeds those of $^{60}$Co γ-ray irradiations by 0.04% for 1hr exposure , 0.0001% for 2hr exposure and 0.001% for 3hrs exposure. In comparison to the current $I_{mp}$ values after $^{137}$Cs γ-ray irradiations the $I_{mp}$ values of $^{137}$Cs γ-ray irradiations exceed those of $^{60}$Co γ-ray irradiations by 1.96%, 2% and 4.8 %, respectively.

The variation of the output power with voltage (P-V) characteristics are reported in table (1), table (2) and Fig (2) (a,b,c,). As shown in table (1), table(2) and Fig (2) (a), the maximum (P-V) point for $^{137}$Cs peaks at (0.464724, 0.53807927) where for $^{60}$Co it appears at (0.455416, 0.53784823), in Fig (2)(b), the maximum (P-V) point for $^{137}$Cs top out at (0.441672, 0.52443833) where for $^{60}$Co it peaks at (0.433011, 0.52443782), in Fig (2)(c), the maximum (P-V) point for $^{137}$Cs peaks at (0.399459, 0.49155533) where for $^{60}$Co it appears at (0.380432, 0.49154851), , in comparison to the output power values after $^{137}$Cs γ-ray exposure , the $P_{mp}$ values of $^{137}$Cs γ-ray irradiations exceeds those of $^{60}$Co γ-ray irradiations by 2%, 1.9% and 4.7 %, respectively.

It is obvious that the deterioration of the photovoltaic parameters caused by $^{60}$Co gamma photons is greater than the deterioration caused by $^{137}$Cs gamma rays .This may attribute to the fact that the average energy of $^{60}$Co (1.25 Mev) is higher than the energy of $^{137}$Cs (0.662 Mev) which can cause extra damage in solar cells.

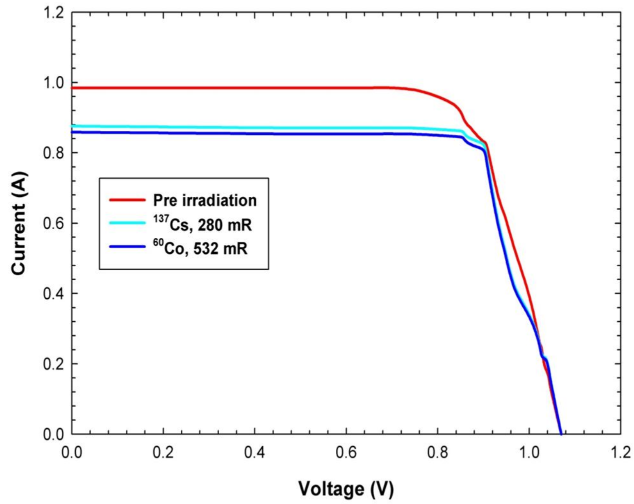


Fig (1.a): The illuminated I-V characteristics of mc-Si solar cell irradiated with 532 mR $^{60}$Co gamma photons VS 280 mR $^{137}$Cs gamma photons.

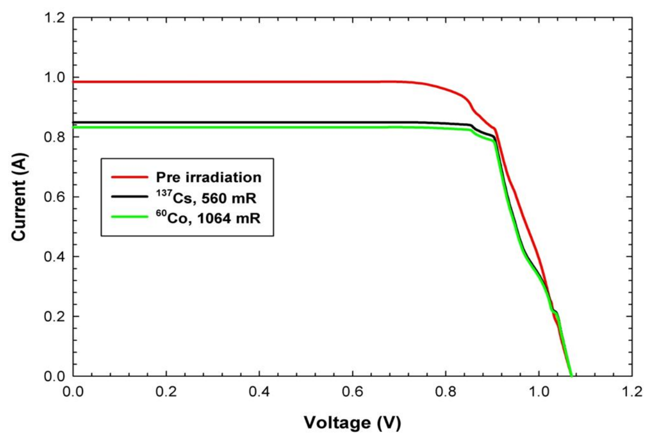


Fig (1.b): The illuminated I-V characteristics of mc-Si solar cell irradiated with 1064 mR $^{60}$Co gamma photons VS 560 mR $^{137}$Cs gamma.

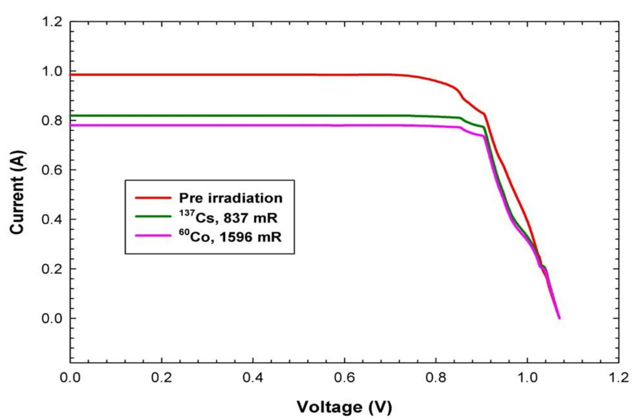


Fig (1.c): The illuminated I-V characteristics of mc-Si solar cell irradiated with 1596 mR $^{60}$Co gamma photons VS 837 mR $^{137}$Cs gamma.

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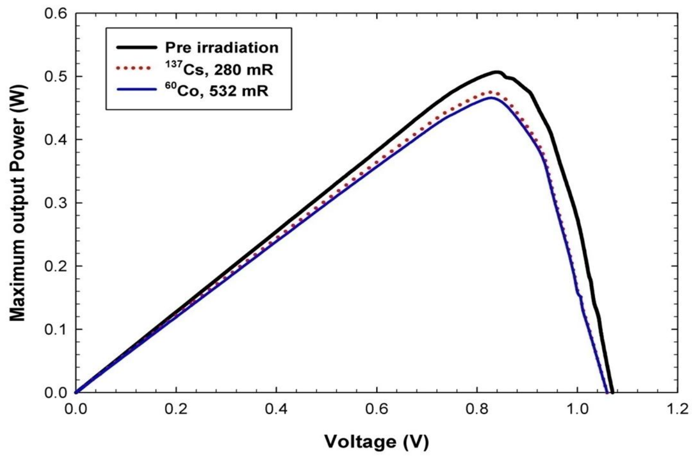


Fig (2.a): The illuminated P-V characteristics of mc-Si solar cell irradiated with 532 mR $^{60}$Co gamma photons VS 280 mR $^{137}$Cs gamma.

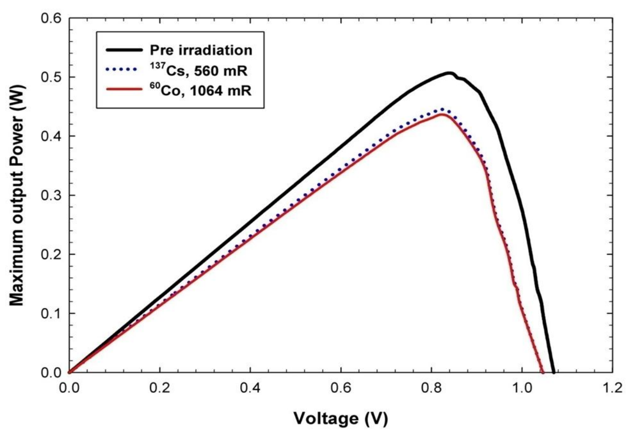


Fig (2.b): The illuminated P-V characteristics of mc-Si solar cell irradiated with 1064 mR $^{60}$Co gamma photons VS 560 mR $^{137}$Cs gamma.

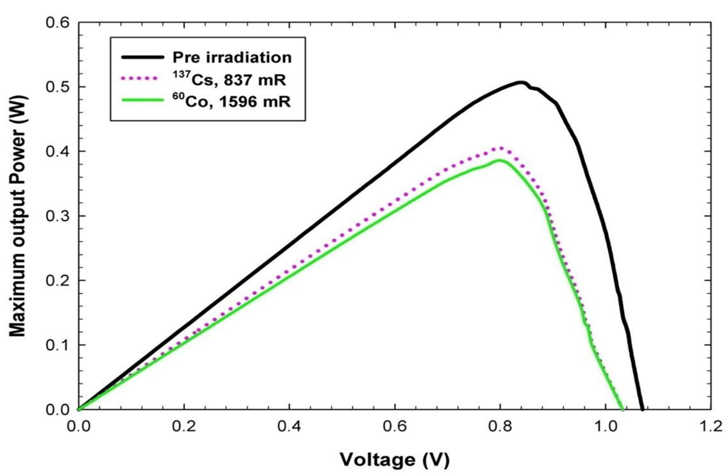


Fig (2.c): The illuminated P-V characteristics of mc-Si solar cell irradiated with 1596 mR $^{60}$Co gamma photons VS 837 mR $^{137}$Cs gamma.

## V. CONCLUSIONS

This work discusses the gamma-induced defects in Silicon-based solar power systems. The experimental methods are used to investigate the impact of $^{60}$Co and $^{137}$Cs gamma ray photons on the electrical properties of Silicon-based solar power systems.

When comparing the I-V characteristics reduction caused by 60Co γ-ray photons to that caused by 137Cs γ-ray photons at the same acquisition time, it was found that the $V_{mp}$ reduction caused by $^{60}$Co γ-ray photons exceeds that of $^{137}$Co γ-ray photons by 0.04% for 1hr exposure,0.0001% for 2hrs exposure. While for 3hrs exposure the $V_{mp}$ reduction by $^{60}$Co γ-ray photons exceeds that of $^{137}$Co γ-ray photons by 0.001%.

Similarly when comparing the $I_{mp}$ reduction caused by $^{60}$Co γ-ray photons to that caused by $^{137}$Cs γ-ray photons at the same acquisition time (1,2,3 hrs), it was found that the $I_{mp}$ reduction caused by $^{60}$Co γ-ray photons exceeds that of $^{137}$Co γ-ray photons by 1.9% , 2% , 4.9% respectively.

On the other hand when comparing the P-V characteristics reduction caused by $^{60}$Co γ-ray photons with that caused by $^{137}$Cs γ-ray photons at the same acquisition time (1,2,3 hrs) for both sources, it was obvious that the $P_{mp}$ reduction caused by $^{60}$Co γ-ray photons exceeds that of $^{137}$Co γ-ray photons by 2% 1.9% 4.7% respectively .

There is no doubt that the degradation of the photovoltaic parameters of the Si solar cell increases proportionally with the radiation dose. The higher the radiation dose, the more degradation on the photovoltaic parameters is caused. Beside radiation energy also plays a major rule in photovoltaic parameters degradation .

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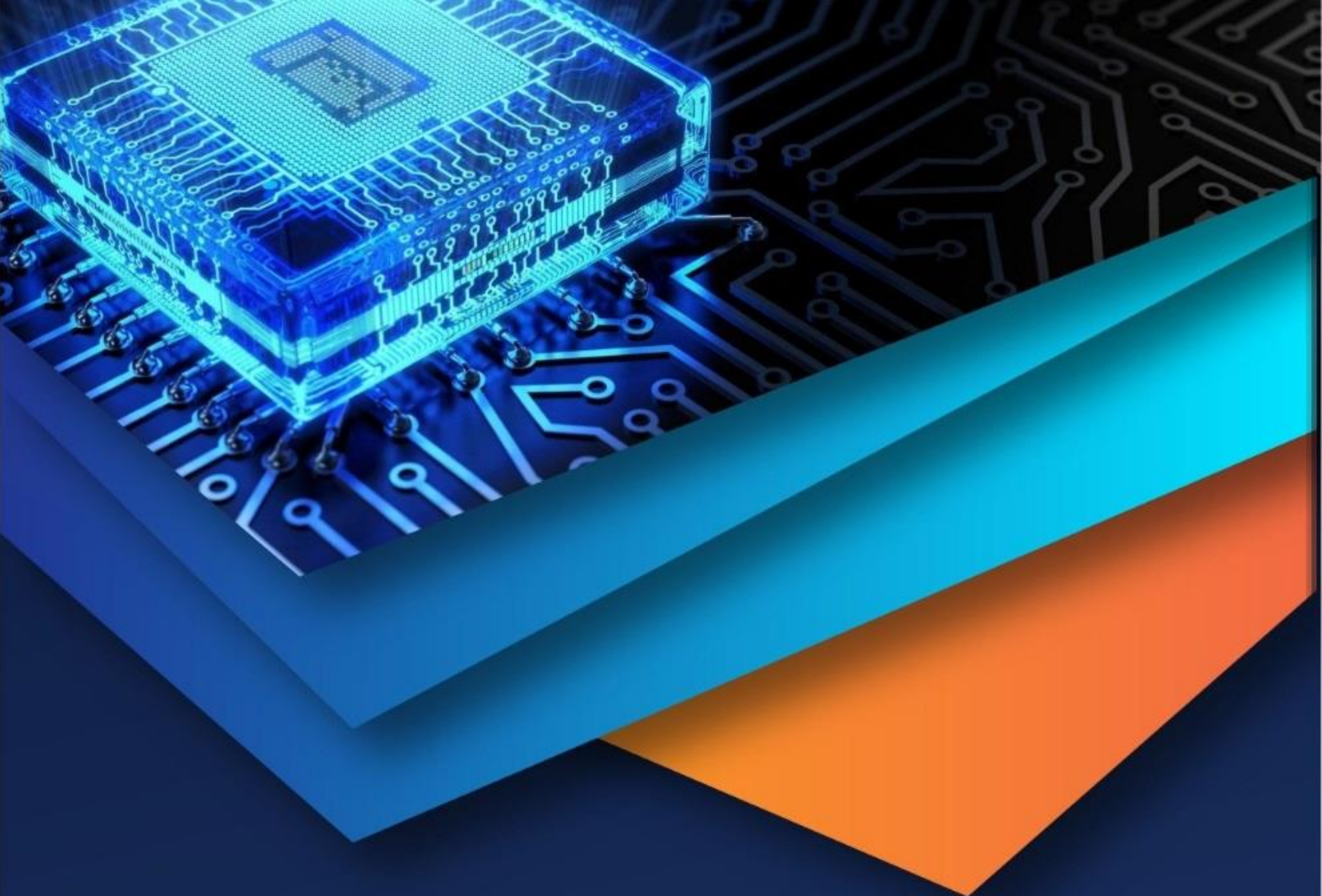


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