ISSN 2515-8260 Volume 09, Issue 06, 2022

# Investigations on Design of Improved Multi Layer Anti Reflecting Coating for Efficiency Enhancement of Solar Cell

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*Abstract-* ***To improve the efficiency of solar cells, an anti-reflective coating was designed and simulated. When incorporated into arrays of devices, anti-reflection coating aids in the development of novel geometrical forms for defining various techniques of light trapping in all directions and enables optimal use of available space. The use of TCAD software for effective module selection and surface texture was suggested as possible enhancement methods. Significant yield gains and loss reductions were made utilizing the system simulation and process simulation platform powered by Silvaco software. To assess the effectiveness of the gadget, a multi-layer anti-reflective coating was created. In simulations using a comparable laser beam, it has been found that the multi-layer coating helps to boost the current that is accessible.***

***Keywords-Anti Reflecting coating, TCAD, Device Simulation, Solar Cell.***

## I. INTRODUCTION

Now a day the planet depends on energy sources from fossil The world now depends on energy sources derived from fossil fuels. The world's consumption of fossil fuels (coal, gas, and oil) is rising despite a growing awareness of the negative environmental effects of their use and the limited supply of these fuels. One of the major contributors to the present economic woes throughout the world is the rise in oil prices. The high total cost of PV installations is the biggest barrier to the expansion of photovoltaics. We have a number of solar cell texture optimization strategies to maximize incident photon absorption and gather photogenerated carriers to increase the performance of solar cells. Solar cell design that sets settings to maximize efficiency. Silicone (si) solar cells' decreased optical and electrical losses have historically represented a historical achievement of higher efficiency. The PV array employs an inverter to convert DC electricity into AC power, which is then sent into the motor and other light loads, among other things. The modules are linked in series and then parallel to the current specification, as shown in Figure 1.1, to get a greater portion of the rated voltage.

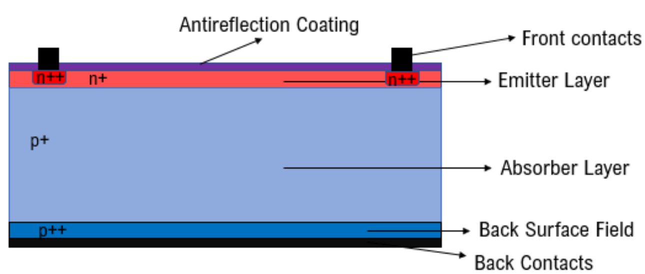


Fig. 1.1. Structure of a PV Cell


Fig. 1.2. Different PV Modules

For this reason, materials with high conductivity and transmittance are frequently utilized, such as conducting nano-cable networks, conductive polymers, and films of indium tin oxide.

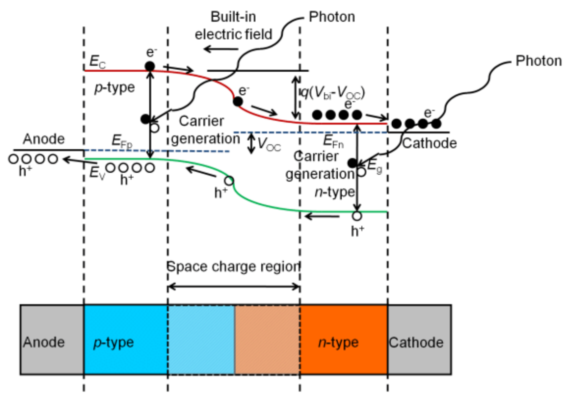


Fig. 1.3. Band diagram

Silicon is a quadruple-coordinating atom that is typically tetrahedrally bonded to four of its neighbors. A single silicone crystal, which can be produced with a band gap near to yet readily amorphous silicon, can be used to create tandem solar cells.

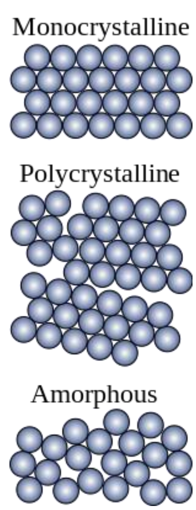


**Fig.** 1.4. Allotropic form of Silicon

## II. SOLAR CELL

The first Photovoltaic module was built by Bell laboratories in 1954.

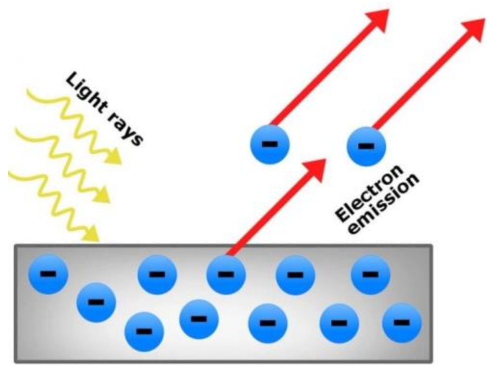


Figure 2.1 Basic diagram of Photoelectric effect

The fundamental diagram of the photoelectric effect is seen in Figure 2.1. When making solar cells, a thin semiconductor wafer is given specific treatment to produce an electric field. Modules are created specifically to generate voltage at a certain volt. The quantity of light striking the module will then determine how much current is produced.

The efficiency of a solar cell is given by

$$\eta = \frac{FFV_{OC} J_{SC}}{P_{in}} \quad (2.1)$$

Where

$P_{in}$ = incident power

FF = fill factor

$J_{sc}$ = short-circuit current density

$V_{oc}$ = open circuit voltage.

The solar cell's efficiency must be increased by optimizing all three parameters (FF, Jsc, and Voc). These variables control how well a solar panel produces power.

The electron is excited by incoming light photons that have energy levels equivalent to or higher than the band gap that the p-n bond creates, resulting in e-h pairs. the incident light energy's photons

Incoming light photons, whose energy content is equal to or greater than those of the band gap created by the p-n bond excite the electron and produce e-h pairs. The photons of incident light energy

$$E_{ph(\lambda)=\frac{hc}{\lambda}} \quad (2.2)$$

Where:

$E_{ph}$ = photon energy of light (J),

h = Planck's constant = $6.626\times10^{-34}$ (Js).

c = speed of light in a vacuum = $2.998\times10^{8}$ (m/s).

λ = wavelength (m).

A photon with a wavelength of 1.13 m corresponds to the silicon band gap of 1.1 eV. The arriving photons of light that have a higher energy than the band gap will release this extra energy as heat. Electricity cannot be created by photons having wavelengths longer than 1.13 micrometers. The relationship of light absorption on wavelength is described by the silicon absorption coefficient. The wavelength and extinction coefficient are connected by the formula () = 4Ke/ for the absorption coefficient (2.3)

$$\alpha (\lambda) = \frac{4\pi Ke}{\lambda} \quad (2.3)$$

Where: $\alpha$ = absorption coefficient ($m^{-1}$).

$k_e$ = extinction coefficient.
As the light propagates through the material light intensity (I), at any point or depth in material is given

$I_0 e^{-ax}$I = (2.4)
)
Where: $I_o$ = light intensity.
x = path length of light.
Thus, when light is absorbed and generated electron hole pairs then $G_{e-h}$ generation rate at any depth of material can be given by a differentiation equation.

$$G_{e-h} = \alpha N_0 e^{-ax} \quad (2.5)$$

The solar cell's surface texturing not only lessens the impact but also aids in light trapping, extending the route of light into absorbent materials by causing rays of light to be reflected by the sloped surface at considerably broader angles. In actuality, the rise in light angles has led to a higher internal reflection power in silicon. These lengthenings of the light's journey inside solar cells greatly raise the likelihood of absorption. The front surface, the back reflector, or both can be texturized [19] [25]. The silicon solar cell's spectral response is related to its internal and external quantum efficiency. It provides incident solar cell energy with the currents produced under non-load or ISC. This value is crucial since it both indicates and defines the maximum efficiency of solar cells.
The external quantum efficiency of the solar cell is correlated with the spectral characteristic.
The spectral characteristic SR (λ) in (A/W) of the solar cell is related to the external quantum efficiency by:

$$SR(\lambda) = \frac{I_{SC}}{P_{in(\lambda)}} = \frac{qn_e}{\frac{hc}{\lambda}n_{ph}} = \frac{q\lambda}{hc}EQE(\lambda) \quad (2.6)$$

Where:
$I_{SC}$ = short circuit current (A).
$P_{in}(\lambda)$ = power of spectral incident light (W).
q = electron elementary charge = $1.602\times10^{-19}$ C.
$n_e$ = flux of electrons per unit time.
$n_{ph}$ = incident flux of photons wavelength
λ = per unit time.
EQE = external quantum efficiency.
External quantum efficiency includes reflection losses while internal quantum efficiency excludes reflection losses. This reflection as a function of the wavelength, R (λ), is given by:

$$R(\lambda) = \frac{[n(\lambda)-1]^2}{[n(\lambda)+1]^2} \quad (2.7)$$

Where n is the silicon refractive index and the medium from which light is transmitted is air with a refractive index equivalent to 1. The light transmitted in the solar cell will then be the amount of light that does not affect the upper surface, by subtracting the light transmitted by the T to the back of the cell the EQE is given as follows:

$$EQE = IQE\,(1-R-T) \quad (2.8)$$

IQE = number of e-h pairs generated for photon of incident that are not reflected or transmitted through the cell. The standard way to find out the maximum output power $P_{mp}$ of PV modules is given by:

$$P_{mp} = FF I_{SC} V_{OC} \quad (2.9)$$

Where:
FF = fill factor of the.
$V_{OC}$ = open circuit voltage.

These parameters, needed to find the output power of the solar cell under standard test conditions (STC) that are:

- Solar spectrum AM- 1.5, standardized at 1000 W / $m^2$
- Operating temperature of 25° C
- Normal irradiance

$V_{OC}$, $I_{SC}$ and FF are usually defined under normal radiation and these are valid for a very short period during the day time. Short-circuit current $I_{SC}$ is considered the most critical parameter in the optical modeling of photovoltaic panels because it is directly related to the number of pairs e-h produced and therefore to the number of incoming photons and thus to the optical transmission of the panel. Isc is the current flowing through the solar cell when a short circuit and the cell voltage is zero. This is the maximum current that tested solar cells can produce at specific lighting. The active area of the short circuit current per unit area or the density of the short-circuit current $J_{SC}$ (A / m$^2$) can be expressed by

$$J_{SC} = \int_{\lambda 2}^{\lambda 1} SR(\lambda)F(\lambda)T_g(\lambda)\left(1 - R_g(\lambda)\right)T_{EVA}(\lambda)d\lambda \quad (2.10)$$

and

$$I_{SC} = J_{SC}A_{Cell}$$

Where:

$\lambda_{1-2}$ = spectral range of wavelengths (nm).
$F(\lambda)$ = spectral irradiance per unit area (W/m$^2$/nm).
$T_g(\lambda)$ = transmission of the covered glass, or portion of light not absorbed.
$R_g(\lambda)$ = reflectivity of the covered glass.
$T_{EVA}(\lambda)$ = transmission of the encapsulated EVA.
$A_{cell}$ = area of the solar cell (m$^2$).
$V_{OC}$ = maximum voltage, i.e. when no load is attached to the cell or zero current, and increases logarithmically with increasing daylight.

$$0 = I_{SC} - I_{D,0}\left(\frac{qv}{e^{KT_{CELL}n_{ideal-1}}}\right) \quad (2.11)$$

and

$$V_{OC} = \frac{KT_{CELL}}{q}\ln\left(\frac{I_{SC}}{I_{D,0}} + 1\right) \quad (2.12)$$

Where:

$n_{ideal}$ = ideality factor =1.
k = Boltzmann's constant = $1.381\times10^{-23}$ (m$^2$kg s$^{-2}$).
$T_{CELL}$ = absolute temperature (K).
$I_{D,0}$ = dark saturation current.

Photon Refraction Off the Solar Cell Surface: The goal of all solar cell designs is efficiency. The efficiency of the solar cell is affected by a number of factors. Therefore, only 30% of the input power is produced by solar cells, even the greatest ones. Before transferring its energy to the electrons in the material, the light that strikes the surface of the solar cell may simply reflect off of it. The solar cell surface can waste up to 36% of the energy if the angle of propagation is far from being at a 90 degree angle and the material has a very reflecting surface. Anti-reflection coatings are created and applied to the surface of solar cells to address this issue. [26] [27].

Insufficient Energy Photons: The energy levels of the photons vary. For every material, the energy needed to overcome the band gap difference is unique. Although the photon can overwhelm the electron, it lacks the energy to pass from the valence band to the conduction band, and another problem associated with this is that the interaction of a poorly guided photon with electrons only causes a warming since it cannot do so. This rate is typical, and it causes an increase in losses as a result of the solar cell warming and heating. Losses brought on by thermal effects can considerably reduce generation.

Photons with excessive energy: Photons are actually capable of carrying a great deal of intensity. The photon's action on the overburdened electron allows the electrons to traverse the band's space. The excess energy that isn't cross the band dissipates like heat and produces thermal effects that are difficult to differentiate from an onslaught of helpless photons. The remarkable wonders that enable solar cells to generate power are another explanation for the high temperature of the cell. The charge on the opposite side of the cell and the heat produced by internal recombination are sent through the electrostatic field of the exhausted district. The cell's temperature is crucial for effective task completion. Cell cross section structure prevents growth of the charge carriers across the cell when the cell is at or below its operating temperature, reducing the power production.

Production Errors: The semiconductor materials used to create solar cells, the inherent flaws, and the degree of doping affects are included into the finished result (solar cell). These crystalline structures are affected by these doped impurities' flaws and defects, which lowers their efficiency. The solar cell's metal contacts are often opposed, which results in a reduction in intensity yield and an increase in cell temperature. Similar connections over the solar cells and the conductive network prevent light from shining through them and have the effect of shading them. The incoming light is significantly reduced in the cell by the effects of shadows and shading.

**III. METHOLODOGY**

A suitable thickness anti-reflective coating (ARC). Nanoscale texture surface may also be used. Trap a higher incident light ratio effectively to enhance optical absorption. Layer optimization by ZnO single coat thicknesses and SiO2/Si3N4 double coatings for minimum coatings were measured. reflectivity with the former cultivated by magnetron sputters and characterised by specular deposition. Measurements of X-ray reflectivity. Based on geometric rays and semiconductor solutions Photovoltaic theoretical performance was simulated and compared for a series of incidents equations Optical intensity angles 1.5 am. Angles. Most people in the world So far, photovoltaic commercial silicon relied on the use of single products TIO2, Si3N4 or SiO2, however we look at the SLARC and SiO2/Si3N4 anti-Reflective double-layer ZnO. Coating and surface texturizing benchmark (DLARC). A clear conducting oxide anti-reflective (ARC) coating or thin films such as ZnO or SiO2/Si3N4, if not Made on the surface with a suitable refractive index not just increase the existing short circuit and thickness of the film optical absorption and photo generation density, but similar SiO2 or SiNx:H (Kluska and Al., 2016) ITO (ITO) Panek, 2016) can layers passivate and increase recombination sites The fill factor and open circuit voltage. The ZnO thin in particular The film has high radiation tolerance and is non-toxic and flexible In the visible region, high temperature is transparent (Godlewski et al., 2009), the synthesis of which concerns an existing industry Manufacturing method norm. As a consequence, there are several ZnO ARCs Promise to be adopted in modern solar cells technology. Sans. ZnO's experimental SLARC was a costly thermal budget Grown by RF magnetron sputter deposition to an optimised thickness the layer thickness on the crystalline silicon solar cell Measured using the technique of specular radiation reflection (XRR). The emerging thin film SiO2/Si3N4 is known for its double layer, delivering a high degree of absorption at wavelengths shorter. Crystalline silicone surface is also available micro/nano-scale texturing can be used to increase light striking on surface. In this article, the efficiency of the above antireflective structures are examined and contrasted numerical simulations that provide useful insights into Ideal parameters for architecture. The results demonstrate that there is a potential to increase the absorption to 30% rise in contrast with bare silicon solar normally on the surface cell for light incident.

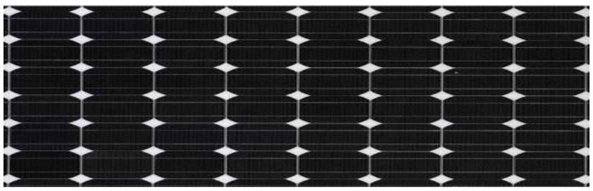

Fig.3.1 Mon crystalline Solar Cell

By using larger cells the module cost will be lower, because less number of cells is used. Figure 3.2 shows a polycrystalline cell.

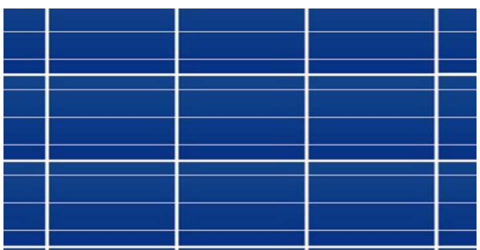

Fig. 3.2 Polycrystalline Solar Cell

A solar cell made of a p-n junction is called a p-n solar cell. It is able to absorb photons and convert them into electricity.
The total p-n junction current I is

$$I=I_L - I_F \qquad (3.1)$$

The block diagram of p-n junction solar cell is shown in Fig.3.3.

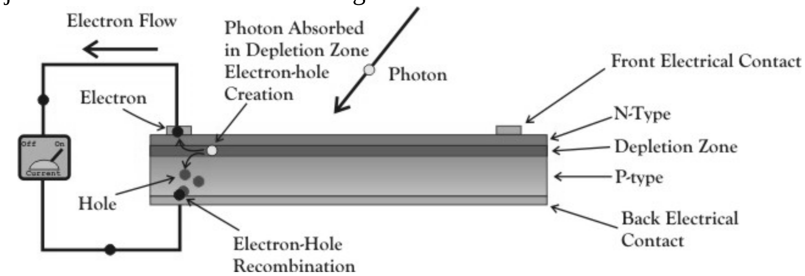


Fig. 3.3: PN Junction Solar Cell

The efficiency of a solar cell is given by

$$\eta = \frac{FFV_{OC}Jsc}{P_{in}} \quad (3.2)$$

where Pin = incident power FF = fill factor Jsc = short-circuit current density Voc=open circuit voltage.

The photons of incident light energy

$$E_{ph(\lambda)=\frac{hc}{\lambda}} \quad (3.3)$$

Where: Eph = photon energy of light (J), h = Planck's constant=$6.626*10^{-34}$ (Js). c = speed of light in a vacuum= $2.998*10^{8}$ (m/s). λ = wavelength (m).

The absorption coefficient is related to the extinction coefficient and the wavelength given by

$$\alpha\,(\lambda)=\frac{4\pi Ke}{\lambda} \quad (3.4)$$

Where: α = absorption coefficient ($m^{-1}$). ke = extinction coefficient. As the light propagates through the material the light intensity (I), at any point or depth in the material is given.

$$I=Io\; e^{-ax} \quad (3.5)$$

Where: $I_o$ = light intensity. x = path length of light.

Thus, when light is absorbed and generated electron hole pairs then $G_{e-h}$ generation rate at any depth of the material can be given by a differentiation equation.

$$G_{eh=\alpha No}e^{-ax} \quad (3.6)$$

Where: $N_0$= photon flux of the top surface (photons/unit-area/sec). The spectral characteristic SR (λ) in (A / W) of the solar cell is related to the external quantum efficiency by:

$$SR(\lambda)=\frac{I_{SC}}{P_{in(\lambda)}} = \frac{qn_e}{\frac{hc}{\lambda}n_{ph}} = \frac{q\lambda}{hc}EQE(\lambda) \quad (3.7)$$

Where: $I_{SC}$ = short circuit current (A). $P_{in}(\lambda)$ = power of spectral incident light (W). q = electron elementary charge = $1.602*10^{-19}$ C. $n_e$ = flux of electrons per unit time.

$n_{ph}$ = incident flux of photons wavelength λ =per unit time. EQE = external quantum efficiency. The reflection as a function of the wavelength, R (λ), is given by:

$$R\,(\lambda) = \frac{(n(\lambda)-1)^2}{(n(\lambda)+1)^2} \quad (3.8)$$

Where n is the silicon refractive index and the medium from which light is transmitted is air with a refractive index equivalent to 1.

$$EQE=IQE(1-R-T) \quad (3.9)$$

IQE = number of e-h pairs generated for photon of incident that are not reflected or transmitted through the cell. The standard way to find out the maximum output power Pmp of PV modules is given by:

$$P_{mp=FFI_{SC}V_{oc}} \quad (3.10)$$

Where: FF = fill factor of the.

$V_{OC}$ = open circuit voltage.

The active area of the short circuit current per unit area or the density of the short-circuit current JSC (A / m2) can be expressed by

$$J_{SC=}\int_{\lambda 2}^{\lambda 1} SR(\lambda)F(\lambda)T_g\,(\lambda)\left(1-R_g(\lambda)\right)T_{EVA}(\lambda)d\lambda \quad (3.11)$$

$$I_{SC} = J_{SC}A_{Cell} \quad (3.12)$$

Where: $\lambda_{1-2}$ = spectral range of wavelengths (nm). F(λ) = spectral irradiance per unit area ($W/m^2/nm$). Tg(λ) = transmission of the covered glass, or portion of light not absorbed. Rg(λ) = reflectivity of the covered glass. $T_{EVA}(\lambda)$ = transmission of the encapsulated EVA. $A_{cell}$ = area of the solar cell ($m^2$). $V_{OC}$ = maximum voltage, i.e. when no load is attached to the cell or zero current, and increases logarithmically with increasing daylight.

$$0 = I_{SC} - I_{D,0}\left(\frac{qv}{e^{KT_{CELL}n_{ideal-1}}}\right) \qquad (3.13)$$

$$V_{OC} = \frac{KT_{CELL}}{q}\ln\left(\frac{I_{SC}}{I_{D,0}} + 1\right) \qquad (3.14)$$

Where: $n_{ideal}$= 2562Ideality factor =1. K = Boltzmann's constant = 1.381*$10^{-23}$ ($m^2kg\ s^{-2}$). $T_{CELL}$ = absolute temperature (K). $I_{D,0}$ = dark saturation current

Steps followed for Device Implementation:

**Step 1:** semiconductor material is used to design crystalline silicon solar cells.
**Step 2:** Mesh is defined in order to specify the x and y co-ordinates of device structure.
**Step 3:** Regions are define including region number and materials of the region.
**Step 4:** Electrodes are defined along its position and materials of the electrodes.
**Step 5:** Material properties are defined.
**Step 6:** Doping type (n or p- type) and doping concentration in each region is specified.
**Step 7:** Models are added for simulation process.
**Step 8:** Contact and interface provided and using SOLVE statement conditions for obtaining solution is defined.
**Step 9:** LOG File is created and saved the I-V characteristics of the device.
**Step 10:** Electrical and optical properties are simulated.
**Step 11:** Output is plotted in Tony plot and extracted for analysis.

## IV. RESULTS AND DISCUSSIONS

A schematic of a fabrication layer for a silicon solar cell structure is shown in Figure 4.1 below

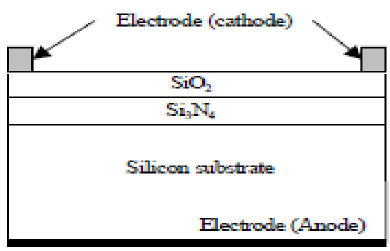


Fig.4.1. Schematic Diagram of Proposed Structure

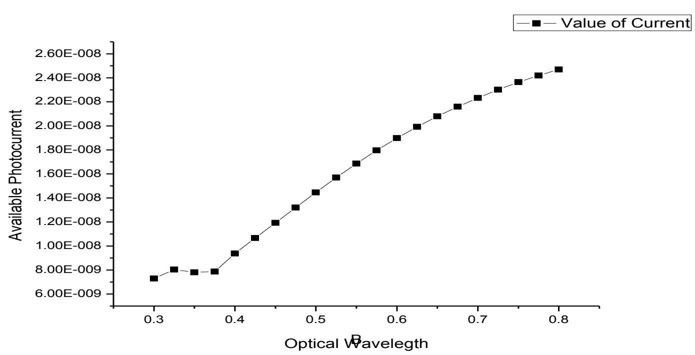


Fig.4.4. Photocurrent with respect to optical wavelength with two layer coating

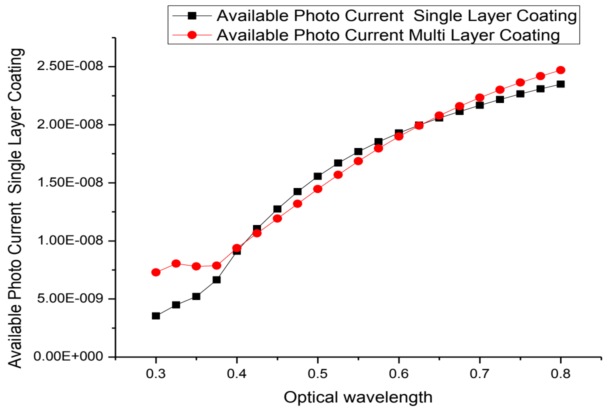


Fig.4.5. Comparative Analysis of photocurrents with single layer and Multi-Layer coating.

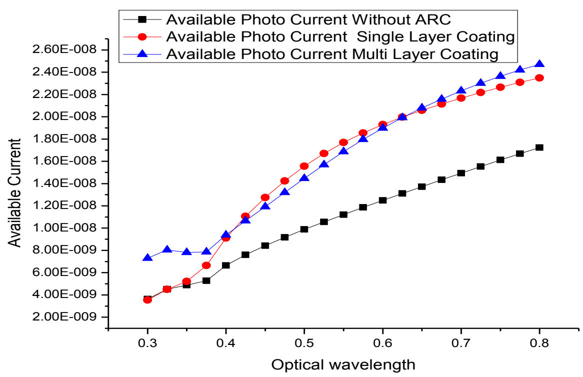


Fig.4.6. Photocurrents without coating and with single layer and Multi-Layer coating.

Figure 4.8 indicated the comparative analysis of absorption coefficients of all three proposed structure. The value of absorption coefficient of multi-layer coating is superior as compared to that of single layer coating and uncoated silicon cell in low wavelength and higher wavelength spectrum.

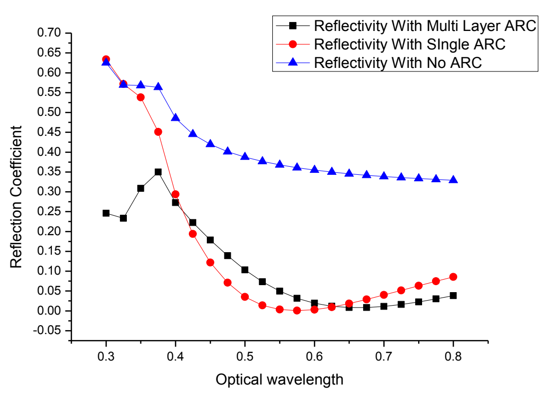


Fig.4.7. Analysis of reflection coefficient with respect to anti reflecting coating

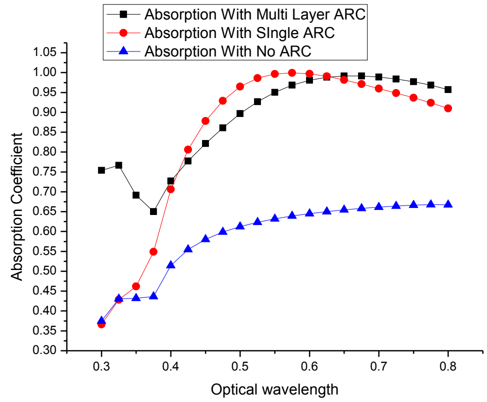


Fig.4.8. Analysis of Absorption coefficient with respect to anti reflecting coating

The Silvaco Software package was used to conduct the planned research on TCAD software. A 2D model of the structure of a solar cell was created. With the aid of the ATHENA tool and the ATLAS toolbox, the device's structure was created. In this study, we simulated three alternative solar cell structures with integrated anti-reflective coatings. On factors such available photocurrent, absorption coefficients, reflection coefficients, and transmission coefficients, the performance of anti-reflecting coatings was compared. By exposing a light beam to spectrum wavelengths of various lengths, the suggested structure's spectral analysis was performed. A two-layer anti-reflective coating that has been proposed has improved overall outcomes with regard to light beams and may be used to increase solar cells' spectral efficiency. Table 1 shows a comparison of the performance metrics for single layer and multi-layer ARC in solar cells. One can see that the two layer anti-reflective coating has increased current density, maximum power, and efficiency values. Figures showed a comparison of the photo generation rates of ARC solar cells with single and double layers. The effective rate of solar spectrums causes an increase in photo generation, which is what causes the creation of new charge carriers.

**Table 1 Comparative Analysis of Performance Parameters for Single Layer and Multi-Layer ARC in Solar Cell**

| **Parameter** | **Values** | | **Percentage Change** |
|---|---|---|---|
| | **Single Layer ARC** | **Double Layer ARC** | |
| **Voltage at Maximum Power** | **0.33 V** | **0.34 V** | **3.03 %** |
| **Current Density** | **26.3261 mA/cm2** | **32.933 mA/cm2** | **25.11 %** |
| **Fill Factor** | **75.138 %** | **76.21 %** | **14.31 %** |
| **Efficiency** | **12..31 %** | **15.41 %** | **3.1 %** |

## V. CONCLUSION

Silvaco software package was used to do research on the TCAD program. The study was suggested. For the structure of solar cells, 2D models have been produced. Using the Athena tool, the ATLAS toolbox was utilized to construct the system's structure and simulate its operation. The output of the antireflective coating has been compared to variables including photocurrent availability, absorption coefficients, reflections, and transmission coefficients. The two-layer anti-reflective coating that was suggested produced superior overall outcomes for the light beam and may be combined to increase the spectrum efficiency of solar cells. Surface roughness with an anti-reflection layer on a photovoltaic cell not only lessens the effect but also aids in light trapping, increasing the lift direction of light in the absorbing material and causing the advance of light to be reflected at much larger angles by the sloping surfaces. In reality, silicone has a higher internal reflection power due to the increase in light angles. Multi-layer coating has a greater value of the reflection coefficient than single layer coating and untreated silicon cell.

**REFRENCES**

[1] Lennie, A., et al. "Modelling and Simulation of SiO2/Si3N4 as Anti-reflecting coating for silicon solar cell by using silvaco software." World Applied Sciences Journal 11(7) 786-790, (2010).

[2] Rahul Dewan, Ivaylo Vasilev, Vladislav Jovanov, and Dietmar Knipp "Optical enhancement and losses of pyramid textured thin-film silicon solar cells." *Journal of Applied Physics* 110, 013101 doi:10.1063/1.3602092, (2011).

[3] Chen, Chun-Wei, et al. "Effects of advanced dual anti-reflection layer coating on crystalline silicon solar cell efficiency." Photovoltaic Specialists Conference (PVSC), 37th IEEE, (2011).

[4] Jianping, Sun. "An optimum layout scheme for photovoltaic cell arrays using PVSYST." International Conference on Mechatronic Science, Electric Engineering and Computer (MEC), (2011).

[5] Duttagupta, Shubham, et al. "Optimised antireflection coatings using silicon nitride on textured silicon surfaces based on measurements and multidimensional modelling." Energy Procedia 15, 78-83, (2012).

[6] Sepeai, Suhaila, et al. "Enhanced light absorption in bifacial solar cells." Semiconductor Electronics (ICSE), 10th IEEE International Conference on. IEEE, (2012).

[7] Kim, Jinkuk, et al. "Double antireflection coating layer with silicon nitride and silicon oxide for crystalline silicon solar cell." Journal of Electroceramics 30.1-2, 41- 45, (2013).

[8] S. Zhou et al., "Acid texturing of large area multi-crystalline silicon wafers for solar cell fabrication," International Conference on Materials for Renewable Energy and Environment, Chengdu, pp. 31- 34, (2013).

[9] Lee, In-Ji & Paik, Ungyu & Park, Jea-Gun. "Solar cell implemented with silicon nanowires on pyramid-texture silicon surface." Solar Energy. 91. 256-262. 10.1016/j.solener. (2013).

[10] Ilaiyaraja, R., and P. Gopi. "Performance modeling and assessment of different photo voltaic arrays for Indian climatic conditions." Renewable Energy and Sustainable Energy (ICRESE), International Conference on. IEEE, (2013).

[11] Al Ali, Mona, and Mahieddine Emziane "Performance analysis of rooftop PV systems in Abu Dhabi." Energy Procedia 42 689-697, (2013).

[12] Choi, Young-Kwan. "A study on power generation analysis of floating PV system considering environmental impact." International Journal of Software Engineering and its Applications 8.1 75-84, (2014).

[13] Anandhi, S., and S. Salomi Mary Magdalene. "Reduction of reflection losses in solar cell by using tial2 and ZR anti reflective coating." IEEE, (2014).

[14] Yadav, Priya, Nitin Kumar, and S. S. Chandel. "Simulation and performance analysis of a 1kWp photovoltaic system using PVsyst." Computation of Power, Energy Information and Commuincation (ICCPEIC), International Conference on. IEEE, (2015).

[15] Chaïb, Ahmed, Mohamed Kesraoui, and Elyes Kechadi. "PV panel positioning using a robot manipulator." Renewable and Sustainable Energy Conference (IRSEC), 3rd International. IEEE, (2015).

[16] Dong, Yinghua, et al. "Performance test and evaluation of photovoltaic system." 4-4, (2015).

[17] Do Sacramento, Elissandro Monteiro, et al. "Scenarios for use of floating photovoltaic plants in Brazilian reservoirs." IET Renewable Power Generation 9.8, 1019-1024, (2015).

[18] Kumar, Nitin, PriyaYadav, and S. S. Chandel. "Comparative analysis of four different solar photovoltaic technologies." Energy Economics and Environment (ICEEE), International Conference on. IEEE, (2015).

[19] Irwan, Y. M., et al. "Stand-alone photovoltaic (SAPV) system assessment using PVSYST software." Energy Procedia 79,596-603, (2015).

[20] Xiaorang Tian et al., "Pyramid size control and its effects on the performance of silicon heterojunction solar cells," China Semiconductor Technology International Conference, Shanghai, , pp. 1-3.doi: 10.1109/CSTIC.2015.715348, (2015).

[21] Iwahashi, T., et al. "Silicon nitride anti-reflection coating on the glass and transparent conductive oxide interface for thin film solar cells and modules." Journal of Applied Physics 118.14, 145302, (2015).

[22] Pillai, Gobind, et al. "The techno-economic feasibility of providing solar photovoltaic backup power." IEEE International Symposium on Technology and Society (ISTAS). Vol. 20. (2016).

[23] Roy, Sandipta, Arnab Pattanayak, and Siddartha P. Duttagupta. "Enhancement in absorption of amorphous Si solar cell by using conducting anti-reflection coating and plasmonic nano-structured back reflector." arXiv preprint arXiv: 1611.07227 (2016).

[24] Fenqin Hu,; Yun Sun,; JiaweiZha,; Kexun Chen,; ShuaiZou,; Liang Fang,; Xiaodong Su. "Solar Energy Materials and *Solar Cells"*, 10.1016/j.solmat.2016.08.032. ISSN: 09270248,(2016).

[25] Wang, Qiang; Pan, Chengfeng; Chen, Kexun; Zou, Shuai; Shen, Mingrong; Su, Xiaodong; Publish Date: May 2017; Journal: "Solar Energy Materials and Solar Cells". (40 -46),(2017).

[26] Bhatnagar, Abhinav, and Vijay Janyani. "Cost effective and "high" power conversion efficiency ultra-thin film GaAs solar cell." Computer, Communications and Electronics (Comptelix), International Conference on. IEEE, (2017).

[27] Jamil, Majid, and MdEhtesham. "Optimizing PV system performance considering the impacts of non-uniform irradiance and partial shading." Energy Economics and Environment (ICEEE), International Conference on. IEEE, (2015).

[28] Kachhia, Jaivik, R. M. Shereef, and S. A. Khaparde. "Operation and tariff for composite PV-battery system." India Conference (INDICON), Annual IEEE, (2013).

[29] Kim, Jeehwan& Inns, Daniel & Fogel, Keith &Sadana, Devendra. "Surface texturing of single - crystalline silicon solar cells using low density SiO2 films as an anisotropic etch mask. Solar Energy Materials and Solar Cells." 94. 2091–2093. 10.1016/j.solmat.2010.06.026. (2010).

[30] Kymakis, Emmanuel, SofoklisKalykakis, and Thales M. Papazoglou. "Performance analysis of a grid connected photovoltaic park on the island of Crete." Energy Conversion and Management 50.3 433-438, (2009).

[31] Raj, Ashish, Manoj Gupta, and Sampurna Panda. "Design simulation and performance assessment of yield and loss forecasting for 100 KWp grid connected solar PV system." In 2016 2nd International Conference on Next Generation Computing Technologies (NGCT), pp. 528-533. IEEE, 2016.

[32] Ashwini, K., Raj, A., & Gupta, M. (2016, December). Performance assessment and orientation optimization of 100 kWp

grid connected solar PV system in Indian scenario. In 2016 International Conference on Recent Advances and Innovations in Engineering (ICRAIE) (pp. 1-7). IEEE.

[33] Liu, Yanhua, Dayang Yu, and Yaohui Liu. "Potential of grid-connected solar PV without storage." Power System Technology (POWERCON), International Conference on. IEEE, (2010).