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Improving Energy Conversion of Photovoltaic Modules with Optimum Anti-Reflective Coating

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Abstract: The photons of sunlight are converted into electricity is done with a solar cell using the photovoltaic effect. At the time of solar beams fall on the solar cell, the light may be reflected, transmitted or absorbed, whereas the absorbed lights can only produce into electricity. The attracted photons are moved to electrons in the solar cell. According to their newborn energy, the electrons are running away from their usual positions in the semiconductor PV material and become part of the electrical flow, or current, in an electrical circuit. Most of the solar cells are interconnected together with a defending glass cover on top to make one PV module, which is affixed on a roof. The energy conversion determined the amount of sun's light energy is converted into electrical energy, whereas it is a significant measure of the success for a PV module. Avoiding the reflection and to increase the energy conversion efficiency, it is necessary to select a best Nano-particle as an anti-reflective coating on the solar module cover glass. The anti-reflective coating maximizes the light availability by avoiding the reflection of sunlight to improve the converted electrical energy. In this paper, two main works are taken to improve energy conversion. The first work is to select a best Nano-particle for anti-reflective coating and the second work is to consider the thickness of the anti-reflective coating layer to improve the energy conversion.

Key words: Energy Conversion · Solar Panel · Photovoltaic Model · Anti-reflective coating

INTRODUCTION

Though, before the sun's light reached for the solar cell, the PV modules suffer from minimum conversion efficiency. This is due to the protective cover replicates certain amount of the incident sunlight. A normal solar panel glass cover lost 15% to 25% of the daytime light and not able to generate electricity. By applying an anti-reflective coating to the solar cover glass, it will reduce the reflection of the sunlight fall on the solar PV module and maximize the amount of energy conversion. Commercial PV techniques used in industries convert more than 35% of the incoming sunlight into electricity. Incase of adding anti-reflective coating on these commercial PV modules, it increases an additional 0.9% of the power conversion [2]. It is more affordable to make the solar modules which can achieve higher conversion efficiency in a cost effective manner. Anti-reflective coating minimizes the reflection and increases the energy conversion efficiency. Selecting an effective Nano-particle as an ARC, for solar PV module improves the light availability for converting into electrical energy. The best anti-reflective coating is having the capabilities of increasing transmission power over the entire solar spectrum [1] as well as over the sun's juncture angles also it is appropriate for large surface areas within an affordable cost.

A best cancellation happened at the time of refractive index is tuned with the glass, where the glass thickness is controlled as ¼ of the targeted wavelength. Designing an ARC for one wavelength is very simple. Whereas a broad range of wavelengths are from the sunlight and they are

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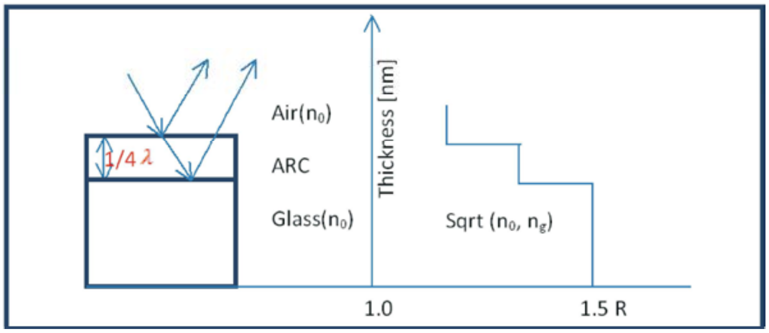


Fig. 1: Change in refractive index and reflection angle based on ARC

used to generate the energy. The existing solutions use multi-layer coating, where multi-layer can provide desired effective in terms of energy but not in terms of cost. So it is necessary to introduce a cost effective ARC to improve the energy conversion across a wide range of wavelengths and angles, to capture as much as possible amount of sunlight for energy conversion. The anti-reflective coating makes interference among the two reflected waves from the bottom and top of the thin film coating. In case the waves go out of phase and they cancel each other, which reduces the reflection of light. It is very easy to design an ARC for a single wavelength. But the sunlight has a wide range of wavelengths to generate electrical energy. The applications of the ARC are more durable and effective for solar panels in terms of improving the energy conversion which is unique and low-cost planting. The advantages of this research are: It reduces reflection of sunlight, Increase the energy conversion, The basic manufacturing material is mostly combined with native material, the anti-reflecting coating essentially more stable and durable and the ARC uses new Nano-fabrication techniques, increasing the energy conversion with low cost.

In this paper, it is motivated to improve the performance of the ARC for PV modules within a budget. To do this a stepwise process is applied for increasing the energy conversion rate. For this reducing the reflection on the whole day and light incident from various angles instead of when the sun is overhead. It has a valued refractive index for maximizing the solar energy availability for conversion. If the refractive index is changed from glass to air does gradually maximizing the solar energy conversion according to the conditions of the day.

Literature Survey: Several research people already discussed about the Nano particles used for anti reflective coating. Some of them are: A.Ibrahim *et al.* [1] examines the etching process in solar cell for reduce the reflection, where the author used silicon oxide (SiO) & titanium dioxide (TiO_2) coatings for reducing the reflection loss. Vitaly *et al*. [2] used TWM (Three-wave mixing) and negative group velocity in dielectric crystals. Alexander K. Popova *et al.* [3] uses three and four wave mixing and this process is called by second harmonic generation. Mihaela Girtan *et al*. [4] studied about electronics and Photonics which are benefits for solar energy conversion. Alexander D. Dolgov *et al.* [5] shows the resonance photon production is higher than non-resonant gamma rays are created in isotropic background. Gowrishankar Seshadri *et al.* [6] uses to analyze the energy conversion from hydraulic pressure to electric energy.

Alexander O. Govorov *et al.* [7] discuss these results shows size, design and field direction in plasmonic carriers. Andreas Pospischil *et al.* [8] uses 2D optoelectronics, the photovoltaic solar cells and light emissions applications are implemented. Svetlana V. Boriskina *et al.* [9] in low energy photons, the intrinsic thermodynamic is limited via thermal up conversion. Alexander V. Uskov *et al.* [10] study about photo electron emission and its two mechanisms like surface and volume photoelectric effects of plasmonic Nanoparticles. Sameer Chhajed *et al.* [11] discussed about AR (anti-reflecting) coating for solar cells and its characteristics of broadband and omnidirectional in Nano-structured multi layer graded-index. Barbara swatowska *et al.* [12] uses PECVD (plasma enhanced chemical vapor deposition) is the most effective methods of anti-reflecting coating in silicon solar cells.

Coping Liu *et al.* [13] using the hydrothermal method, the photovoltaic conversion energy of dye-sensitized solar cells (DSSCs) which was improved. I.A. Kuznetsov *et al.* [14] uses transition metal-oxide Nano-rods particles the output power of solar cells are increased. Qiuping Liu *et al.* [15] study about the hydrothermal method Ca^{2+} ions can be dopped into TiO_2. And which can be used to increase the efficiency of dye-sensitized solar cells. Yin-Cheng Yen *et al.* [16] study to improve the performance of solar cells using solid and liquid state dye-sensitized method. Guiqiang Wang *et al.* [17] study to enhanced electrochemical property which is improving the efficiency of dye-sensitized solar cells. Fengjuan Miao *et al.* [18] study to increasing the efficiency of DSSC with high order Pt and Si electrodes. PravinChopade *et al.* [19] discuss about reactive power management and voltage control using SVC. Ying Guo *et al.* [20] analysis of global research, enhanced the thin-film solar cells in Nanotechnology. Andrew J. Leenheer *et al.* [21] study to efficiency estimates and conversions of solar energy through hot electron intend photon emissions in metallic Nanostructures.

Reflection Theory: Because of the coating, two optical effects can be created in such a thin film and thick film effects. Due to the variation in the refraction index of the refraction among the layers above and below the coating, thick film effects arise, example, between the layers of the air, the coating and the glass. In case of thick film coating, it does not depend on the thickness of the coating material. The thick film coating effects, when the thickness of the coating is merely similar to the thickness of the wavelength of the light. The number of layers can improve the energy conversion of the PV modules. Generally silicon has the highest refractive index (***n***). Refractive index is the number of photons purely reflected from its surface. The ratio of photons reflected in the interface between two refractive indices is

$$\left[\frac{n_t - n_i}{n_t + n_i}\right] \quad (1)$$

The value of (***n***) of vacuum is 1.0, glass is 1.46, water is 1.33 and silicon is 3.6. From equation –(1), 3.5% of the reflection happens between window glass in the air and 32% reflection happens silicon in the air. When considering elimination of reflection portion, silicon is the best one. The solution is to reduce the thickness and place a transparent dielectric material on the surface of the silicon. The RI of the dielectric material, should follow the silicon and air combination where the thickness should be ¼ wavelength of the sunlight. The reflection can also be reduced by adding a steady source of light using any other mechanisms. The thin film coating depends on the angle in which the light assaults on the coated surface. During the time of light moves from one layer to the other layer [mediums like glass to air] a portion of the light is reflected from the surface that is the place between the two media. It can be noted through the backside of the window. This amount of reflection depends on the RI of the two media and angle to the beam of sunlight. The amount of reflection can be calculated using Fresnel equation – (2), is given as:

$$R = [(n_0 - n_s)/(n_0 + n_s)]^2 \quad (2)$$

where, n_0, n_s are the RI values of the two media. The RI value changes from 0 to 1. Where 0 means no reflection and 1 means there is a reflection. Corresponding with *R, T,* is the transmittance. It is observed that, absorption and rejection are rejected, when *T* is 1–*R*. From this, it is clear and well known that the intensity of the light is *I*, fall on the surface, then *RI* is reflected and *TI* is transmitted. It is described by Lord Rayleigh; it is possible to reduce the reflection by deploying a thin film on the top of the glass on the surface. It can be seen that the thin layer material having RI is n_1, between the air having RI is $n_0$and the glass having RI n_s. Because of these three layers, the light reflects twice, one is from glass interface and the other is from thin layer. The RI, reflectivity of the two interfaces can be estimated and indicated R_{01} and R_{1s} respectively. Then T can be calculated for the two layers is $T_{01} = 1 - R_{01}$ and $T_{1s} = 1 - R_{1s}$. So the total transmittance can be calculated as T_{01} T_{1s}. By changing the value of n1, an optimum RI of the layer can be obtained when the T01 and T1s are equal and it provides the maximum T into the glass. This optimum value can be fetched from mean of the two RI values as:

$$n_1 = \sqrt{n_0 n_s} \quad (3)$$

Proposed System: The proposed approach has three stages. 1: Pattern of ARC, 2: the thickness of the solar panel and 3: Nano particle used for ARC.

Stage-1: Pattern of ARC: One of the essential components in PV module is ARCs. There are various types of ARC, more expensive and a large portion of solar energy is happening due to the reflection of lights. In this paper, moth-eye structured ARC [3] is used as the outline in the substrates. One of the non-reflective PV structures is moth's eye and it is used to see the available light even it is less in the dark. In this research the moth eyes include a new structure which cuts down the reflection in thin-film interfaces. The direct pattering eradicates the necessity for overseas materials, manufacturing the final product is more durable. It is engraved the ARC directly into the multi-crystalline silicon substrates and it is not necessary to include additional coatings are deployed on

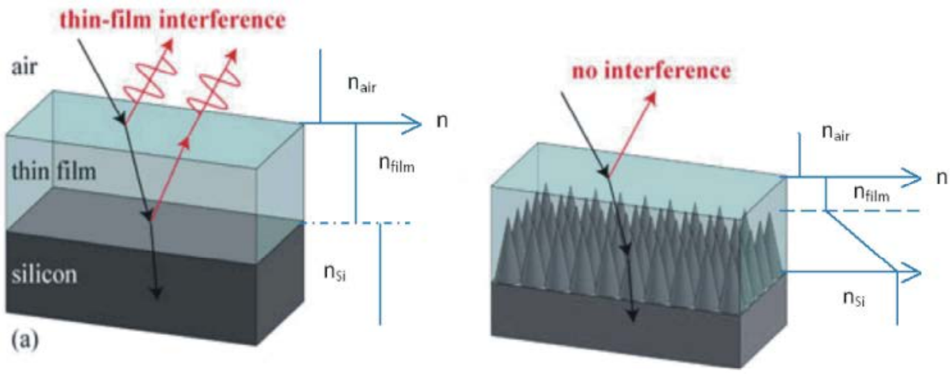


Fig. 2: Moth's Eye Pattern of the Nano-Structure

the substrate surface. Due the ARC is moth-eye structured, the water communication angle of the patterned silicon surface is sloped and considerably increased. This makes the solar panel cells to be self-cleaning. The inexpensive template the Nano-fabrication procedure that makes the sub-wavelength-structured moth-eye broadband anti-reflection gratings works faster than standard lithography equipment and is much easier to use.

From Fig. 2, the schematic of (a) thin-film interference, where reflections from the film–silicon interface and top of the film interfere. (b) A Nano structured interface can be integrated between the film–silicon stack to suppress the interfacial reflection and eliminate thin-film interference effects. The gradient-index profile is qualitatively illustrated. The structure of the Nano particle based PV module is arranged in such a manner that the thin film is placed on the top of the silicon. The Nano particles are shaped in a cone structure [25] and placed in thin film layers shown in Fig. 2. The Nano structures are shaped like tiny cones which can project into the thin film layer on top, much like the structures found in moths' eyes and limit the light reflection at the interface of the layers by meshing the two layers together. It is well known that the Nano structure device reflected 100 times less light than a thin-film device without the Nano structures. The next step is to produce a solar cell using where the Nano structure layer would be added to the thin film device and test the results. If successful, then the researchers will look to scale up the technology for commercialization.

Stage-2: Optimizing the Anti-Reflective-Coating Thickness: Another major concept in solar based energy conversion is the effect of the thickness of the anti-reflective coating with the refractive index of the number of layers used as an anti - reflection coating. ARC's thickness is chosen according to the wavelength of the dielectric material is ¼ of the wavelength of the incoming wave. For ¼ wavelengths anti-reflective coating is the chosen according to the ARC's refractive index n_1 and light incident wavelength λ_0/, thickness d_1, the minimum reflection can be computed by:

$$d_1 = \lambda_0/4n_1 \tag{3}$$

where n is the RI in ARC. For the PV cell, the equation (2) can be written as:

$$n_1^2 = n_0 n_2 \tag{4}$$

n_0 is the RI of air and is 1, n_2 is the RI of the base material, d is the thickness of the ARC and λ is the wavelength obtained from photo-sensitivity area is 400 nm to 1100 nm. During the time of reflection for a specific thickness, RI, it is easy to reduce the wavelength is to 0 by utilizing the equation (4). Since the RI depends on the wavelength, the reflection is also 0 at one wavelength. For PV modules, the RI, thickness is chosen to minimize the amount of reflection for a specific wavelength [ex. 0.6 µm]. For this the wavelength is selected when it closes to the highest power of the solar spectrum.

Stage-3: Nano-Particle used for ARC: In this paper an optimization technique is applied to find out the Nano-particles can be used as a best Nano-particle and used as the anti-reflective coating for improving the energy conversion. An Artificial Immune System is used to optimize the behavioral attributes and choose the best one. AIS algorithm is given below.

AIS Algorithm:

1. Generate a random population P is 50, represents each individual
2. List all the attributes of the individuals as *Ai* = {*rh, rf,*

nc, sf, sr}
3. Compute OFV is less reflection and more production
4. For I = 1 to N
5. List the attribute values of P
6. Compute affinity value and rate of cloning
7. For day=1 to K
8. Compare the attribute values
9. If the values, reduce the reflection rate
10. End day
11. Mutate the attribute combination
12. Compute and compare the OFV for mutated attributes
13. Repeat the above for various Materials with various Ai until get the least reflection
14. End I

where $\mathbf{A}_i$ denotes the set of all attributes of the anti-reflective coating

Rh *– denotes relative humidity testing*
Hf *– denotes humidity freezing testing*
Nc *– denotes number of cycles*
Sf *– Salt – fog testing*
Sr *– denotes spectrum range*

The artificial immune system also optimizes the properties of the materials and chose the best one for ARC doping.

The most important properties of the materials are

- Material Melting temperature
- Crystal Structure
- PV applications
- Band structure
- Electrical properties
- Optical properties
- Acoustic Wave speed

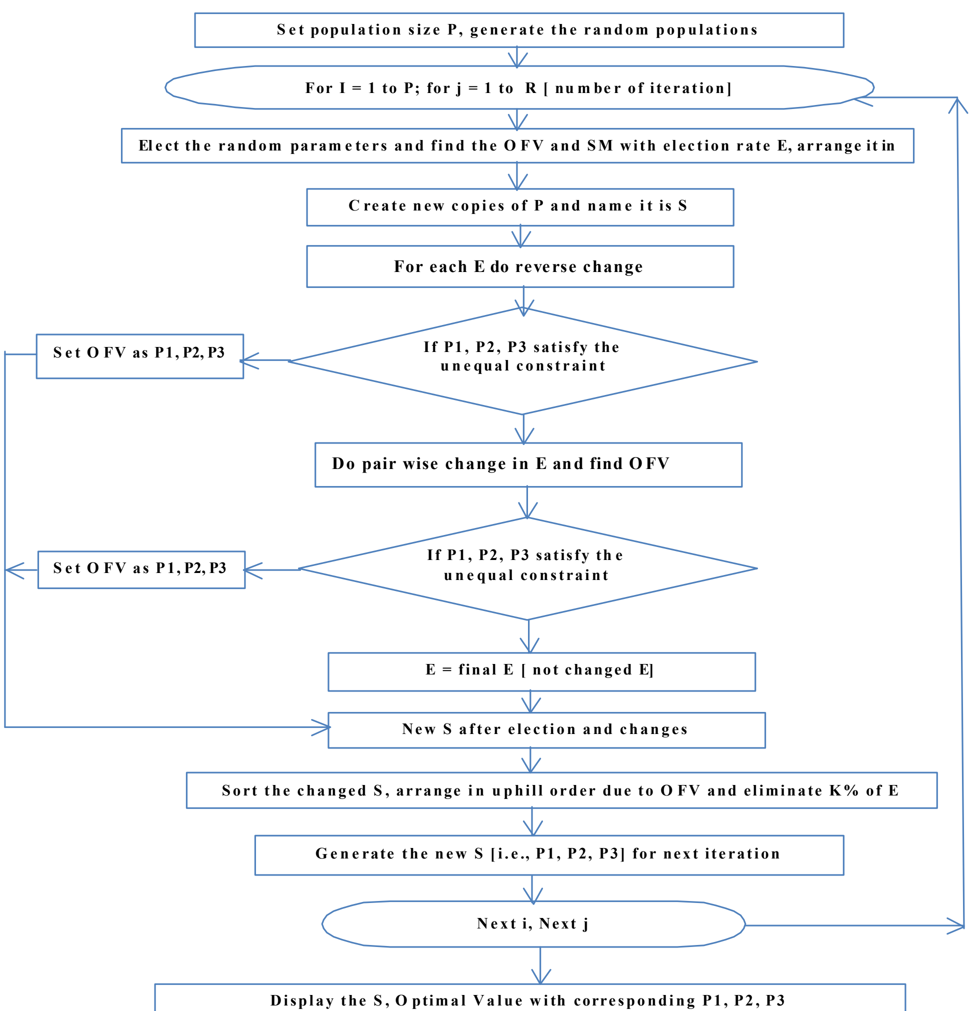


Fig. 2: Flowchart for AIS

Numerical Illustration: Since utilizing the nano-particle as the ARC is drastically growing in terms less reflection and more energy conversion, it is necessary to optimize the attributes of the nano-particle to select the best nano-particle as the best ARC.

Initialization:

$$P=50,\ R=100 \tag{15}$$

$$P = \{rh,\ hf,\ nc,\ sf,\ sr\} \tag{16}$$

In the initialization phase, all the parameters belongs to the nano-particle are initialized in order to compute the OFV. The overall population is taken into account of the initial population. Example, a String S = { 4, 7, 2, 3, 1, 11, 8, 5, 9, 12, 6, 10} the attribute number as the index and P holds all the parameters relevant to the S.

Objective Function: The key objective of this paper is to select a minimizing the total distance for obtaining the best data transmission with less cost. Compute the Objective function value as:

$$OFV = \sum_{i=1}^{N}\sum_{i=1}^{N} A_i \forall A_i \text{ is the set of attributes of the nano particles}$$

For all populations, compute the affinity value using OFV and it can be written as:

Affinity value = **1/OFV**

It is noted that the affinity value is inversely proportional to the OFV value.

Clonal Selection: The strings are selected for cloning can be applied directly proportionally according to the affinity value with the ROC. The rate of cloning for each string is computed by the following equation as:

$$Rate\ of\ cloning\ [ROC] = \frac{affinity\ value\ *\ Population\ Size}{Total\ of\ affinity\ value\ of\ the\ solution}$$

Clonal Expansion: One clone indicates the original copy of one string. According to the ROC value, new clones are generated. Example, if the ROC value is 1.4, the number of new clones is 2. This process increases the temporary population of the clones.

Mutation: Mutation process can make new clones of the population. Mutation can change the clone using reverse mutation and pairwise mutation. The following Fig. 3 illustrates the inverse mutation of the string S, where the numbers of nodes chosen as neighbor nodes are 12 and the inverse mutation starts at location 3 to 8.

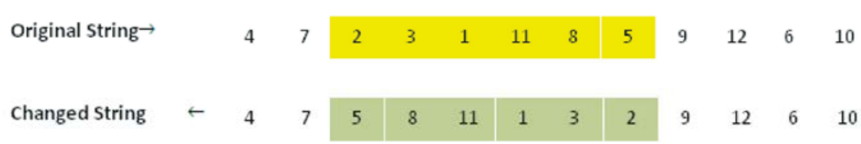


Fig. 3: Inverse Mutation

For each mutated string, the OFV is calculated and compare with parent clone OFV. Replace the original string by mutated string, if the OFV of the mutated string is less than the OFV of the original string, else retain the same string. The following Fig. 4 illustrates the pairwise mutation of the string S, where the numbers of neighbor nodes are 12 and the pairwise mutation starts at location 3 and 8.

Fig. 4: Pairwise Mutation

For each mutated string, the OFV is calculated and compared with parent clone OFV. Replace the original string by mutated string, if the OFV of the mutated string is less than the OFV of the original string, else retain the same string. Once the mutation process completed, the number of strings in the improved string is higher than the population size. For maintaining the size of the initial population, arrange all improved strings in ascending order and remove the strings having highest OFV.

Receptive Editing Process: R=20%, where 20% of the highest OFV based clones are replaced by newly generated population and repeat the same process described above to obtain the best OFV. Repeat the above steps until the number of iterations mentioned.

From the AIS, the best shortest path is selected and used for data transmission. After the route discovery of optimized shortest path, the source node can send data into the primary path. To maintain the QoS of the path, some of the additional paths are taken for AIS output. Once the primary path gets any violation, the secondary paths can be chosen for maintains the QoS.

Simulation Results: The entire simulation is obtained from the online ARC thickness calculator and all the attribute values are iteratively changed and verifies the efficiency in terms of reflection reduction. The RI value for Si with wavelength $\lambda = 600nm$ and it is equal to $n_2 = 3.6$. The effect of R for the mono-crystalline Si is in the range of 30-35%, while for the multi-crystalline Si is in the range of 25-30%. The wavelength=600 *nm* and the RI of Si's n = 3.6, then the optimal thickness of the ARC=80 *nm*. According to the equation (4), the optimum RI n for the ARC layer coated on the Si solar PV cell should be around 1.9.

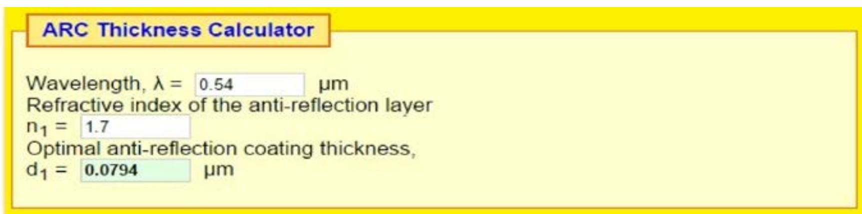


Fig. 3: Result obtained from the online ARC thickness calculator

The Fig. 3 shows the effect of the single layer ARC on Si. For simplicity, it is assumed a constant RI for Si is 3.5. In real the RI of Si and the ARC is a function of wavelength. During the reflection for a given specific thickness, RI and wavelength are reduced to 0 using the equation (4). Since the RI depends on wavelength sometimes it makes reflection 0 in a single wavelength. For PV applications, the RI and the thickness are chosen especially for minimizing the reflection for a specific wavelength is 0.6 µm. This special wavelength is selected for the highest power of the solar spectrum. From the existing resources studied form sun power corporation, USA, STC standard test condition, the flash power gain, according to ARC glass is on average 2.7%. Then it is verified that the energy production can be improved 3.5 to 5%, according to the location and installation type by changing the values in an AIS based implementation.

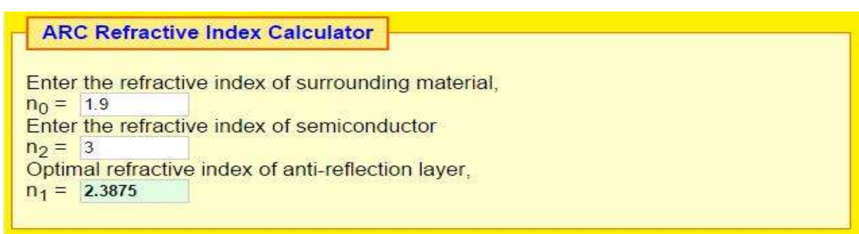


Fig. 4: Result obtained from online ARC- RI calculation

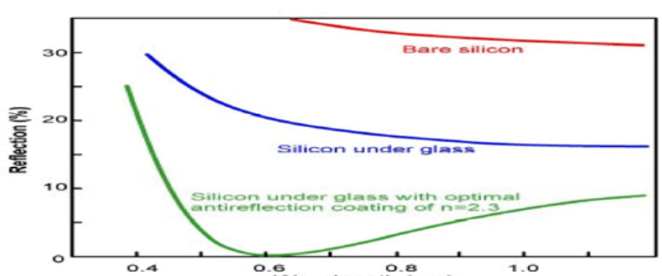


Fig. 5: Comparison of surface reflection from a silicon solar cell, with and without a typical anti-reflection coating

In this paper, the improved energy production is compared between the various ARC materials under optimized thickness of the thin film layer is chosen. The RI, light scattering and the angle of the ARC affects the energy production. The real environment data are simulated and the results are agreed. It is also proved that the reflection can be reduced in a big manner by increasing the Nano-particles used as ARC under various wavelengths [3] but it is highly expensive. Also the mathematical representation to solve the multi ARC is more complicated than a single ARC for single layer. The Fig. 4 shows the multi-layer ARC result. By changing the RI and thickness within a range of values, it is possible to get more energy production by obtaining reflection lesser than 3.

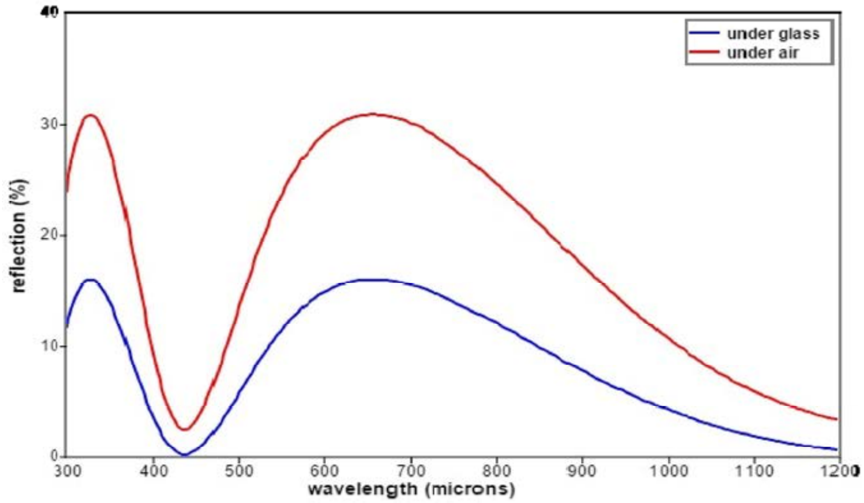


Fig. 6: No reflection at the optimum refractive index and thickness values for ARC at wavelength of 600 NM.

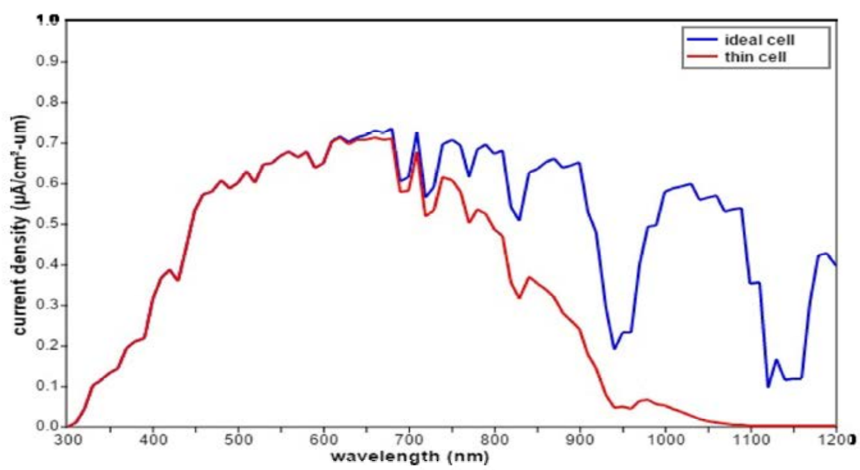
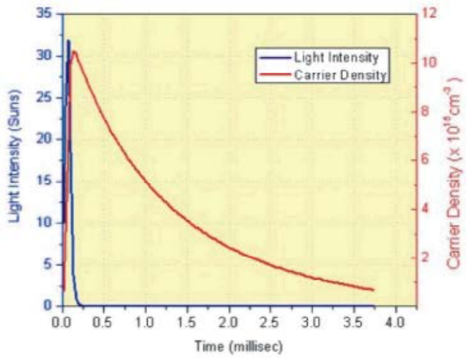


Fig. 7: Cell Thickness: 15.1 microns Actual JSC: 29.7 mA / cm^2

During the time of improving energy efficiency of the solar cell by reducing the reflection rate, it is necessary to intake all the light in the solar cell. The amount of energy production completely depends on the amount of light absorbed. Mathematically, it can be said that the light absorbed rate depends on the optical length and coefficient. Fig. 7 shows the dependence of photon absorption on device thickness for silicon solar cell.

The simulation is carried out without any front surface reflection losses, whereas all incident light enters the cell. It is assumed that the diffusion length is perfect due to improve the collection capability of the carriers generated from the light. At last, the light passed through the cell only. Commonly, the thin cells are attached by a reflector in the rear, so that it can have multiple passes across the cells and increasing the cell absorption power. Here, it is assigned that the silicon RI value is 3.5.



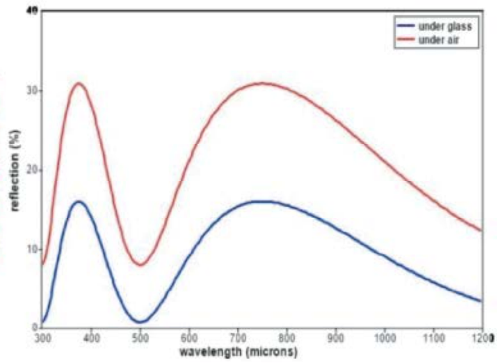


Fig. 8: Time Vs. Intensity Comparison Fig.9: Refractive index n: 2.5 vs. ARC thickness 150 mm

Illumination time and minority carrier density. The pulse of light is very short and the carrier density typically follows an exponential decay. Move the mouse over the graph to see that the carrier density decay is a straight line on log scale.

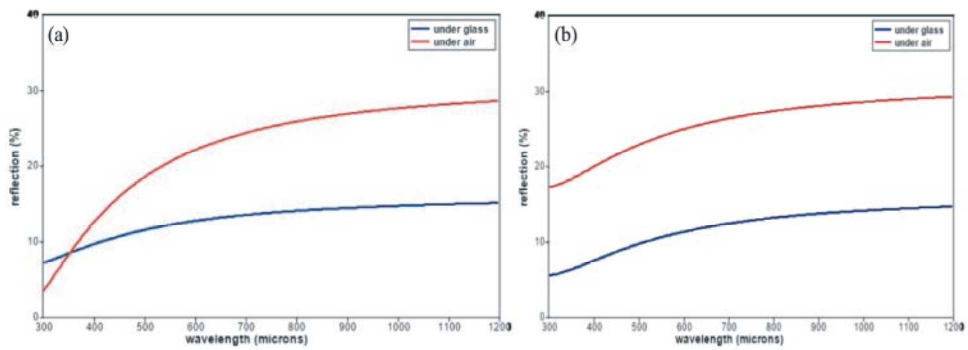


Fig. 9(a): Refractive index n: 1.77 vs. ARC thickness 35 nm; (b) Refractive index n: 2.91 vs. ARC thickness 25 mm

Calculate reflectance due to thin-film interference by entering your films below. The reflectance at wavelengths from 200nm to 2000nm may be calculated. Up to 20 films may be entered. Our Reflectance Calculator uses the same calculation engine that our thin-film measurement systems do, which is based on the complex-matrix form of the Fresnel equations. Also, various nano particles were used as ARC and repeat the simulation at various numbers of times and then choose the best one-particle. In this paper the best nano particle suggested for anti reflection coating is AlSb.

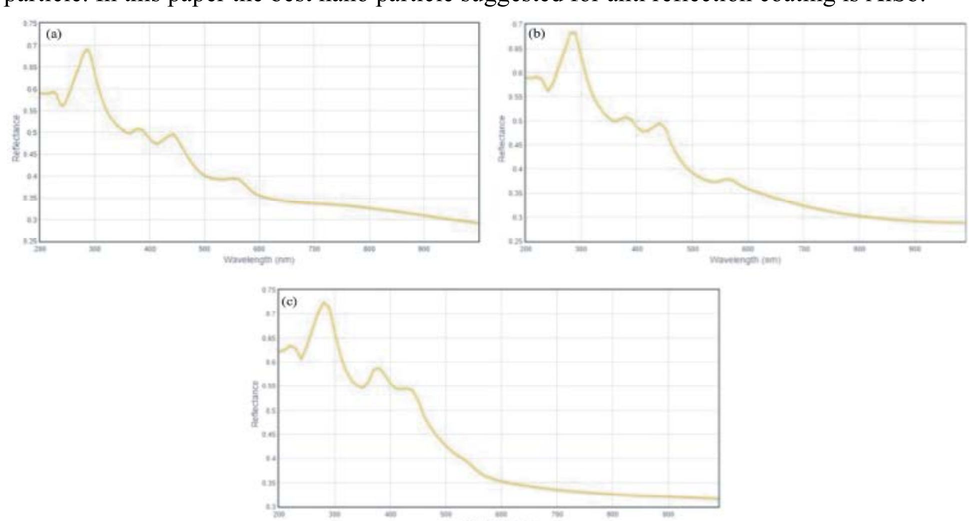


Fig. 10: Reflection Rate Reduction in terms of Thickness (a): 100 *nm* (b): 50 *nm,* (c): 10 *nm*

From Fig. 10, it is clear that the reflection rate is reduced according to the thickness value of the anti reflection coating material on the glass. When the thickness is 100nm the reflection rate is reduced up to 0.3%, when the thickness is 50nm the reflection rate is reduced up to 0.27%, whereas, when the thickness is 10nm the reflection rate is reduced up to 0.2%. Hence the thickness reduced the reflection proportionally due to its coating thickness value and also it is suggested the thickness up to 10nm.

CONCLUSION

A layer on the solar cell used to reduce the reflection of the sunlight is so called anti-reflection coating. Due the thickness, electrical and mechanical behavior with RI, angle the amount reflection reduction occur. One of main concept is this reflection reduction is depends on the wavelength of the sunlight. In this paper, it is discussed, choosing an optimal Nano-particle, optimum thickness and the RI with the wavelength. The simulation results concluded that the AlSb can be used as the best ARC and the coating thickness is up to 10nm.

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