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A THEORETICAL INVESTIGATION INTO THE PERFORMANCE OF SWCNTs AS AN ANTIREFLECTION COATING LAYER FOR SILICON SOLAR CELL

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ABSTRACT

In this paper optical simulations based on Transfer Matrix Method (TMM) is developed to investigate the performance of Carbon nanotube on silicon solar cells. Reflection of the incident photons by the silicon surface is a major source of losses for photovoltaic solar cell. However, these losses can be minimized by depositing an antireflection layer. Recently, antireflective coatings (ARCs) attract critical consideration for both their fundamental aspects and wide practical applications. The TMM solutions permit us to plot the optical reflectivity versus wavelengths and layer thicknesses. The optical refractive index and thicknesses of considered materials, which allowed us to have the lowest reflection, can be used to simulate the electrical properties of the cell with PC1D and Silvaco software in the future.

Keywords: carbon nanotube, photovoltaic solar cell, antireflection coating layer.

INTRODUCTION

Solar energy plays an important role as a vital type of renewable energy, owing to its inexhaustible nature, environmental friendliness, and the potential for power conversion efficiency of solar energy harvesting devices [1, 2]. Enhancing the power conversion efficiency is an essential research subject in the manufacture of photovoltaic (PV) advances, as it makes them more cost-competitive compare to traditional sources of energy [1, 3, 4]. Solar cells with heterojunction arrangements incorporating carbon materials have generated a lot of enthusiasm in experimental essentials and great applications in different innovative optoelectronic devices, e.g. photovoltaic solar cells [5]. There are many reports that have investigated different contents, especially transparent conductive films of CNTs, graphene and semiconducting polymers that can be conveniently deposited on commercial Si wafers to improve efficiency of solar cells [6-9]. Numerous experiments predicted to new advances related to photovoltaic cells with the intention of expanding the enthusiastic yields of such environmentally friendly energy generation tools.

However, there is a need to produce economical optical coatings to permit the maximum solar emission to achieve semiconductor intersection. Applying an Anti-Reflective layer, with an advanced refractive index and thickness to cover device can mostly eliminate this issue [10, 11]. Mostly, the current coatings have problem for stability in water, they have higher adsorption of contaminants from the outdoor environment, therefore, problem in light trapping will be created follows by decreasing of efficiency in solar cells [12]. To solve the issues and increase efficiency, thin film coating should be used with wide spectrum of light trapping ranging from visible to near-infrared wavelengths, the existence of reachable pores in the nano meter range helped to the adsorption of contaminations from the environment. This is one of the important issues and it leads to higher antireflection layer refractive index. Water up-take can be significantly decreased by making the thin film's pores, hydrophobic [12, 13]. Because of the incredible mechanical, electrical and thermal properties and substance steadiness of CNTs, they have been involved in much research through the previous decades [14]. In the solar energy area, it is conceivable to utilize CNTs films as transparent electronic materials and to utilize nanotube composites for solar cells applications.

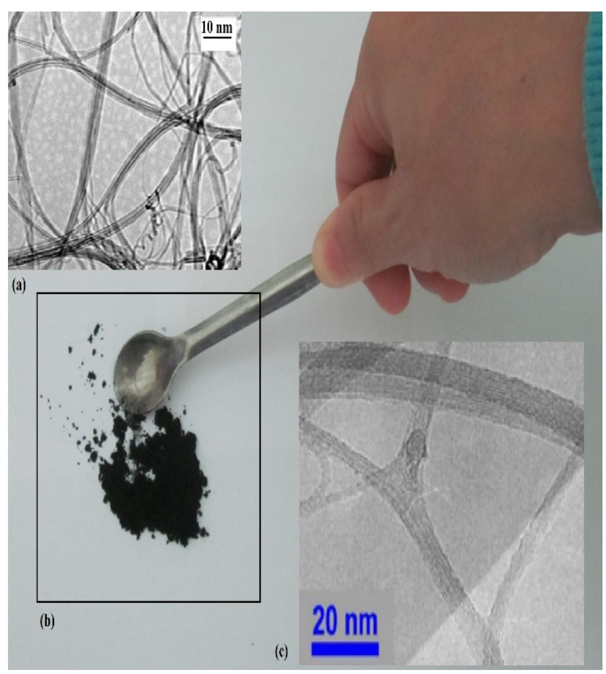

Figure-1. (a) TEM of SWCNTs, (b) Macrograph of SWCNTs, (c) HRTEM of SWCNTs.

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Nanotechnology has become very popular, and many researchers are working on projects related to solar cells and solar energy methods incorporating CNTs. There have been reports about applications of Nano fluids in solar energy, applications of nanotechnology in solar cells a solar collector using nanotechnology and electro catalysis using CNTs. Carbon materials were introduced into flat cells in 1996, and CNTs were incorporated into energy conversion systems beginning in 1999. In particular, there have been several reports on high efficiency energy conversion. The extraordinary properties of CNTs, such as their light weight, excellent mechanical strength, three-dimensional flexibility and outstanding electro catalytic properties can be used to improve the performance of solar cells. In addition to applications in solar energy conversion, CNTs can be used in Dye-Synthesized Solar Cells (DSSCs) that have been studied as part of damage sensing and structural health monitoring (SHM) systems. At a minimum, there must be a technique for financially realistic energy conversion efficiency, and

CNTs are the most likely technology to significantly contribute to renewable electricity generation by 2020. One of the most recent PV solar cells to be introduced that uses CNTs for photocurrent generation is the nanotube-silicon heterojunction (NSH). It is similar to a single intersection crystalline silicon solar cell, but the emitter layer is replaced by a thin film of SWCNTs or MWCNTs.While the reduction of reflection is an essential part of achieving a high efficiency solar cell, it is also essential to absorb all the light in the silicon solar cell. The amount of light absorbed depends on the optical path length and the absorption coefficient.

Transfer matrix method (TMM)

In this paper the transfer matrix modelling of antireflective coating using nanomaterial will be reviewed. For the modeling of antireflective nanostructure researchers have reported several methods, however the most attractive and common methods which are suitable for thin films are transfer matrix method (TMM) and finite-difference time-domain (FDTD). Each of these methods have their own advantages and drawbacks. Maxwell's equation and its mathematical explanation have so many advantages, for instance, Time-based solution such as FDTD have the benefits of computing reflectance for numerous wavelengths of light per recreation. Diagnostic methodologies answer for Maxwell's equation such as TMM are suitable for extremely basic thin films [15, 17-19]. One approach to make a cost effective solar cell is diminishing light reflection at surface and interfaces. It is reported that TMM are fitted out for representing the geometry of subwavelength structures. In spite of the fact that these methods are viewed as accurate and comprehensive answers for Maxwell's comparisons, it is recommended that investigation of arrangements through numerous modeling techniques is generally powerful. In solar cells, improving the thickness of each thin-film layer in view of the optical impedance influences, which allows us to maximize the optical absorption in the active region, is fundamental to acquire the best quantum proficiency [19, 20]. One of the most attractive model for thin film is TMM method and it is a simple way to deal with modeling sunlight going through layered media. A beam of light with its associated electric and magnetic fields undergoes an external reflection at (R) and transmitted portion at (T) as shown in Figure-4.

Below a summary of the TMM mathematical derivation is demonstrated. We consider an external environment refractive index n0 and N thin layers Cn. The refractive indexes of these layers are: ni, ni+1,ni+n. the refractive index of a substrate S is ns. Here we demonstrate the characteristics matrix of one layer. [15].

$$\left(\frac{E(0)}{H(0)}\right) = M\left(\frac{E(s)}{H(s)}\right) \qquad (1)$$

The matrix itself is obtained which relates the fields at two adjacent boundaries [16].

$$M = \begin{bmatrix} Cos\emptyset & j\,Sin\,\emptyset/n_c \\ j\,n_c\,Sin\,\emptyset & Cos\emptyset \end{bmatrix} \qquad (2)$$

The characteristic matrix of a multilayer is a product of corresponding single layer matrices. If i is the number of layers, then the field at the first (z=z0) and the last (z=zi) boundaries are related as follows:

$$M_i = \prod_{i=1}^{N} \begin{bmatrix} Cos\,\emptyset_i & j\,Sin\,\emptyset_i/n_i \\ j\,n_i\,Sin\,\emptyset_i & Cos\emptyset_i \end{bmatrix} \qquad (3)$$

With j2= -1, ni the refractive index of the its layer, ϴ is dephasing between the reflected waves of layers i and i+1

$$\emptyset_i = \frac{2\pi}{\lambda} n_i\, d_i\, Cos\,\theta \qquad (4)$$

ϕ is the angle of wave propagation in the layer. The detailed derivation of coefficients of reflection (r) and transmission (t) are given in Equations 5 and 6.

$$r = \frac{n_0 M_{11} + n_0 n_s\, M_{12} + M_{21} - n_s M_{22}}{n_0 M_{11} + n_0 n_s\, M_{12} + M_{21} + n_s M_{22}} \qquad (5)$$

$$t = \frac{2n_0}{n_0 M_{11} + n_0 n_s\, M_{12} + M_{21} + n_s M_{22}} \qquad (6)$$

Mij are the elements of the characteristic matrix of the multilayer. The energy coefficients (reflectivity, transmissivity, and absorptance) are given by:

$$R = |r|^2 \qquad (7)$$

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$$T = \frac{n_s}{n_0}|t|^2 \tag{8}$$

$$A = (1-R)\left[1 - \frac{R_e\,(n_s)}{R_e\,[(M_{11} + n_s M_{12})(M_{21} + n_s M_{22})^*]}\right] \tag{9}$$

With Re the real part, ns and no is refractive index of the silicon and vacuum respectively.

$$R + T + A = 1 \tag{10}$$

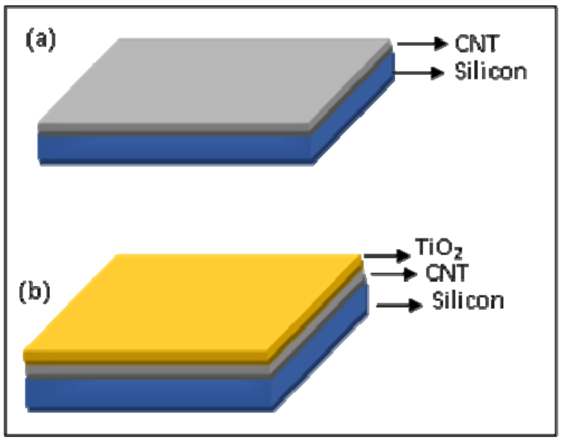


Figure-2. Projected view of the ARCs layer, (a) Investigation of reflection for SWCNT with different thickness, (b) Investigation of reflection for double layer ARCs (SWCNT and TiO_2) with different thickness.

RESULTS AND DISCUSSION

In this paper, a single layer and double layer antireflection coating has been designed and simulated. The presented structure is shown in Figure-2. In this research single and double layer antireflection coatings are used on top of the silicon substrate.

Single layer antireflection coating

A good antireflective coating (ARC) is vital for solar cell performance as it ensures a high photocurrent by minimizing reflectance. Unlike many other optoelectronic devices, solar cells operate at a range of wavelengths, from 300 – 1200 nm, which means they need a broadband ARC. Figure-3. shows the effect of SWCNT as an ARCs with different thickness. It can be seen that, SWCNT can be used as a single layer antireflection coating with a thickness of 300nm and 400 nm which in these range of thickness minimum reflection is observed. The minimum reflection is because of specific semiconductor properties of CNT. As we suppose they are transparent, they transmit the light to substrate and as they are in nano size and thickness the absorption is almost zero.

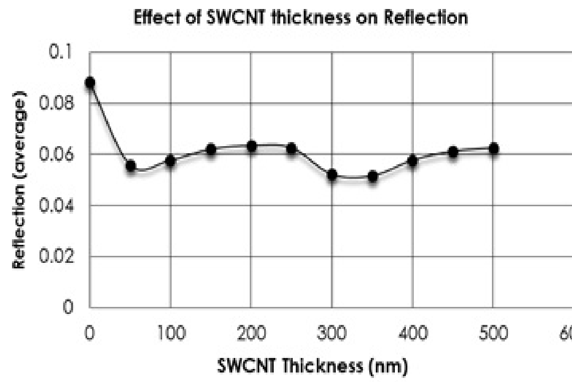


Figure-3. Effect of SWCNT thickness on reflection.

As can be seen in Figure-3, there is a considerable improvement in the performance of the sample by using an antireflection coating in comparison with the case of 'no ARC' (Thickness = 0). The reflectance was recorded on Si samples for two different antireflection coating SWCNT and TiO_2 (Figure-4). CNT is a promising semiconductor material which can used for high efficiency thin film solar cells and other optoelectronic devices due to its suitable properties. It is clear higher reflection in single layer TiO_2 compare to single layer SWCNT.

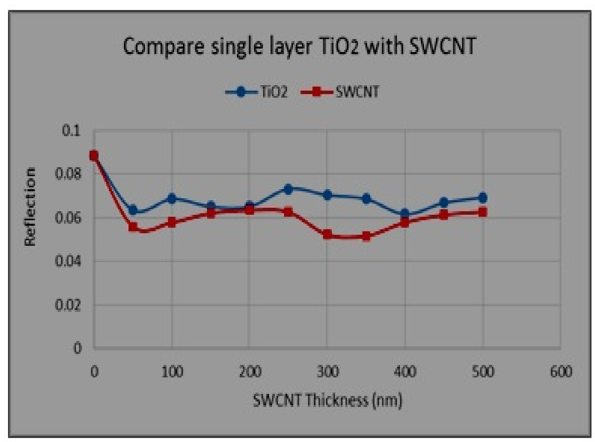


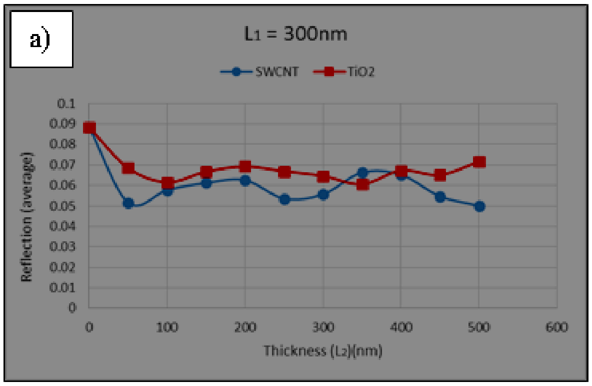
Figure-4. Effect of thickness on two different ARC.

Double layer antireflection coating

After optimization of one-layer ARC, we will go for two layers. The result of modeling for two layers demonstrate that the thickness of 300nm and 400nm are the best thickness fir first layer. Figure-5 shows the results of effective reflectivity (R_{eff} average across a wavelength range 300-1200 nm) of double layer SWCNT compare to double layer TiO_2. In this research we investigate the double layer of SWCNT and double layer of TiO_2 separately to compare the reflectivity. It is clear that there is no difference between two layer SWCNT and one single layer at same thickness in Figure-3. For instance, in double layer SWCNT, at L_1=300nm (thickness of first layer) with

ARPN Journal of Engineering and Applied Sciences

L_2=100 nm (thickness of second layer), the reflection is R_{eff}=0.057717, and we can see in total thickness 400nm for single layer SWCNT the reflection is same R_{eff}=0.057717.



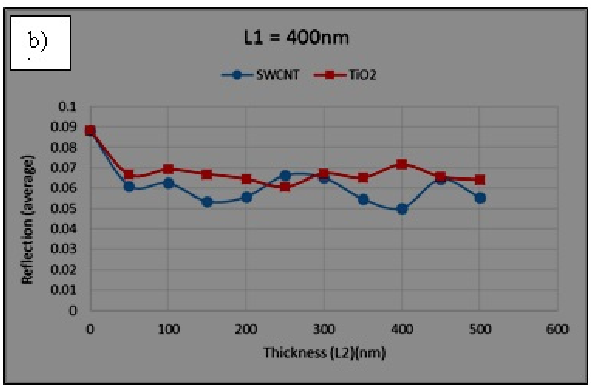


Figure-5. Investigation the effect of layer (300nm and 400nm) on reflection. a) Reflection for different thickness of second layer SWCNT (red), TiO2 (blue) when the thickness of their first layer is 300nm b) Reflection for different thickness of second layer SWCNT (red), TiO2 (blue) when the thickness of their first layer is 400nm

CONCLUSIONS

A simple method to determine the thicknesses of very thin films by using reflectivity was described here. A procedure based on the TMM is used to determine its thickness film values. The TMM method needs only to know usual optical constants, that is, refraction indices and absorption coefficients as a function of wavelength for the film and the substrate. CNTs and TiO_2 are remarkable materials for the photovoltaic applications with silicon. Combination of these three materials can be exploited to reduce both the optical losses and the losses related to the recombination of the minority carriers. The present modeling approaches are capable of predicting antireflection properties of thin films such as CNTs film for different thickness in all wavelength. Finally, for predicting the solar properties of our model we can use solar simulator such as Atlas software and Silvaco. In conclusion the findings of application of CNTs in solar cells in the future research are crucial factor to improve a simple, cost-effective solar cell with high efficiency and it provides new concepts and ideas for the development of high-performance antireflective and self-cleaning surface.

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REFERENCES

[1] Hyo Jin Gwon, Y.P., Cheon Woo Moon, Sahn Nahm, Seok-Jin Yoon, Soo Young Kim, and Ho Won Jang, Superhydrophobic and antireflective nanograss-coated glass for high performance solar cells. Nano Research, 2014. 7(5): p. 670.

[2] Dincer, I., Renewable energy and sustainable development: a crucial review. Renewable and Sustainable Energy Reviews, 2000. 4: p. 157.

[3] Ye, L., *et al.,* Sol–gel preparation of SiO2/TiO2/SiO2–TiO2 broadband antireflective coating for solar cell cover glass. Solar Energy Materials and Solar Cells, 2013. 111: p. 160.

[4] Raut, H.K., *et al.,* Anti-reflective coatings: A critical, in-depth review. Energy & Environmental Science, 2011. 4(10): p. 3779.

[5] Zhu, H., *et al.,* Applications of carbon materials in photovoltaic solar cells. Solar Energy Materials and Solar Cells, 2009. 93(9): p. 1461.

[6] Shi, E., *et al.,* TiO (2)-coated carbon nanotube-silicon solar cells with efficiency of 15%. Sci Rep, 2012. 2: p. 884.

[7] Mohamed, N.M., *et al.,* Photoelectrochemical behavior of bimetallic Cu–Ni and monometallic Cu, Ni doped TiO2 for hydrogen production. International Journal of Hydrogen Energy, 2015. 40(40): p. 14031.

[8] Hanaei, H., M.K. Assadi, and R. Saidur, highly efficient antireflective and self-cleaning coatings that incorporate carbon nanotubes (CNTs) into solar cells: A review. Renewable and Sustainable Energy Reviews, 2016. 59: p. 620.

[9] Bashiri, R., *et al*., Hydrogen production from water photosplitting using Cu/TiO2 nanoparticles: Effect of hydrolysis rate and reaction medium. International Journal of Hydrogen Energy, 2015. 40(18): p. 6021.

[10] Mathew, S., *et al*., Dye-sensitized solar cells with 13% efficiency achieved through the molecular engineering of porphyrin sensitizers. Nat Chem, 2014. 6(3): p. 242.

[11] N. Benzekkour1, F.Z. Ghomrani1, 3, N. Gabouze1, S. Kermadi1, M. Boumaour1, K. Ferdjani2, Formation of rough TiO2 thin films on glass and porous silicon by sol-gel method. Materials Science Forum, 2009. 609: p. 139.

[12] Faustini, M., *et al*., Hydrophobic, Antireflective, Self-Cleaning, and Antifogging Sol−Gel Coatings: An Example of Multifunctional Nanostructured Materials for Photovoltaic Cells. Chemistry of Materials, 2010. 22(15): p. 4406.

[13] Garnett, E. and P. Yang, Light trapping in silicon nanowire solar cells. Nano Lett, 2010. 10(3): p. 1082.

[14] Li, X., J. He, and W. Liu, Broadband anti-reflective and water-repellent coatings on glass substrates for self-cleaning photovoltaic cells. Materials Research Bulletin, 2013. 48(7): p. 2522.

[15] Sahouane, N. and A. Zerga, Optimization of antireflection multilayer for industrial crystalline silicon solar cells. Energy Procedia, 2014. 44: p. 118.

[16] González-Ramírez, J.E., *et al*., Evaluation of the thickness in nanolayers using the transfer matrix method for modeling the spectral reflectivity. Physics Research International, 2009. 2009.

[17] Zhan, F., *et al*., Design Multilayer Antireflection Coatings for Terrestrial Solar Cells. The Scientific World Journal, 2014. 2014.

[18] Kosarian, A. and P. Jelodarian. Numerical evaluation and characterization of single junction solar cell based on thin-film a-Si: H/a-SiGe: H hetero-structure. in Electrical Engineering (ICEE), 2011 19th Iranian Conference on. 2011. IEEE.

[19] Katsidis, C.C. and D.I. Siapkas, General transfer-matrix method for optical multilayer systems with coherent, partially coherent, and incoherent interference. Applied optics, 2002. 41(19): p. 3978.

[20] Jung, S., *et al*., Optical modeling and analysis of organic solar cells with coherent multilayers and Incoherent glass substrate using generalized transfer matrix method. Japanese Journal of Applied Physics, 2011. 50(12R): p. 122301.