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ENHANCING SI SOLAR CELLS EFFICIENCY BY ADDING SiO_2/TiO_2 THIN FILMS USING TRANSFER MATRIX METHOD[†]

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Thin film silicon solar cells are nowadays the best choice to get electricity due to their low cost compared to the crystalline solar cells. However, thin film silicon solar cells have weak absorption of incident light. To deal with such a weakness and get better efficiency of these cells, an efficient back reflector composed of multilayer thin films (Silver, Silicon dioxide (SiO2) and Titanium dioxide (TiO2)) will be used. The transmitted light from the first silicon layer will be reflected by the next layer, and the reflected light will go back to the first silicon layer. By this way, the absorbance of the silicon solar cell can be increased by an increase in the probability of the light reflection from the SiO2, TiO2 and Ag. The transfer matrix method (TMM) by Matlab program will be used to analyze the results of the reflectance, transmittance and absorbance of the thin film layer and these results can prove the efficiency of the cells by using MATLAB codes.
Keywords: SiO2, TiO2, TMM, Efficiency, Optical Properties, Thin Film, Matlab.
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The need for clean energy sources has increased lately due to the increasing demand for cheaper and cleaner energy. The solar cell itself relies primarily on thin film and it is often made of semiconducting materials because of the scholars' ability to control the energy gap of these materials in the first place. The theoretical side is very important for the engineers interested in manufacturing the solar cells because theoretical calculations provide the optimum conditions for manufacturing such important devices and the electrical and optical properties of these materials.

Many studies were done to improve the solar cells efficiency. One of these studies was conducted by Saravanan, Dubey, Kalainathan, More and Gautam (2015). They used in their research the ultra film solar cells of 40 nm thickness and discovered that the efficiency of the solar cells increased by 15%, and the current density increased by 23mA/cm2. Another study was done by Xu, Chen, Ding, Pan, Hu, Yang, Zhu and Dai (2018). They controlled the recombination of the charge carriers in the interface in material of the different layers of the solar cells. As a result of this control, a positive change happens in the efficiency and current density when using SiO2; the efficiency increased from 3% to 3.9%, Voc from 0.523v to 0.558v and FF from 56.5% to 68.1 %.

For Sheng, Johnson, Broderick, Michel and Kimerling (2012), they recommended to employ the reflection idea in the form of DBR by using materials like SiC in the energy researches. These materials have small absorption coefficient α and big reflection. In comparison, Yang, Lien, Chu, Kung, Cheng and Chen (2013) used ARCs to increase both the reflection and efficiency. The results show that there was an increase in the reflection by 9% and in efficiency by 16.3%. Additionally, there are several mathematical methods to analyze the equations and the easiest one is TMM. Perez (2007) used TMM to find the transmittance and absorbance because this method is easy in studying a model of multilayers.

The specific scope of this research is numerical modeling for thin film solar cells. Photovoltaic array systems are familiar and are widely utilized in electric power generation. They are very important and useful devices, and the attempts to improve them and to get higher efficiency have not been stopped until now.

The research aims at getting solar cells of higher efficiency. To achieve this aim, a-Si, SiO2 and TiO2 will be used. Thin film silicon solar cells are the best choice to get power due to their low cost as compared to other types of solar cells. However, thin film silicon solar cells suffer from the problem of weak absorption of incident light. To solve this problem and improve the performance of solar cells, an efficient back reflector composed of layer thin film (SiO2/TiO2/Ag) will be used in this research

The properties of Si/SiO2/TiO2/Ag compounds will be examined by using TMM and their analysis will take place by Matlab code. The parameters will give information on the efficiency of the solar cells and this efficiency can be improved by putting layers of SiO2 and TiO2 under the first silicon's layer and analyses by using Matlab program.

The model used in this research consists of a glass substrate and a thin layer of thickness 50 nm from silver (Ag) is put on the substrate. The sliver does like a reflector of the incident light to the upper layers made of TiO2 and SiO2, which in turn, do like charge carrier collectors in addition to their role as reflectors for the light to the upper effective layer of silicon a-Si. The SiO2 & TiO2 layers collect the charge carriers faster than the process of the carrier's recombination effects. This research has found that the best thickness of Si is 100nm to absorb the charge carriers well, while it is 90 nm for SiO2 and TiO2. Consequently, better efficiency and current density can be got.

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MATHEMATICAL METHOD

A. TMM for Thin Film Optics

TMM can be used for the analysis of the wave propagation of quantum particles, such as electrons and electromagnetic, acoustic, and elastic waves. In this research, a simulation of transfer matrix equations will be employed to examine the transmission and reflectance as functions of wavelength. The reflectance transmittance characteristics of optical thin-film will also be analyzed and visualized.

TMM in electromagnetics and optics is a powerful and convenient mathematical formalism for determining the plane wave reflection and transmission characteristics of an infinitely extended slab of a linear material. While the TMM was introduced for a homogeneous uniaxial dielectric-magnetic material in the 1960s, and subsequently was extended for multilayered slabs, it has more recently been developed for the most general linear materials. By means of the rigorous coupled-wave approach, slabs that are periodically nonhomogeneous in the thickness direction can also be accommodated by TMM.

Calculating the optical properties for the thin films paves the way to build a simulation for a solar cell system based on the results from TMM by using Matlab programming algorithms.

B. The Reflectance of a Thin Film

As it has been said before, the research method is TMM which will be used to analyze the propagation of waves in thin film which, in turn, will be studied for calculating transmission and reflection amplitude and their properties. Accordingly, it is supposed that there is one layer or two layers made of homogeneous substances, more particularly (Si, SiO_2 and TiO_2). The indexes of refraction of every medium will be different from each other, and changes with wavelength. The incident waves on the boundaries will be analyzed in electric and magnetic fields. Then, the equations will be solved to get the transmission and reflection. TMM has been applied to a single layer and multilayers.

a. The Single Layer Film

It can be noticed from Figure (1) that there is one layer film on a substrate. If this film is thin, the interfaces of the wave will increase. The occurrence of these interfaces of monochromatic leads to the existence of transmission and reflectance of the waves when analyzing them in their electric and magnetic fields. In this process, it should be taken into consideration the boundaries between the thin film, the air and the substrate. To go back to Maxwell's equations, the new equation will be used to describe the magnetic and electric fields at separating boundaries.

Some symbols are used in the Figures below to refer to the directions of the fields which make up waves. It is assumed that the sign (+) refers to the direction of incidence and the sign (-) refers to the direction of the light reflection. Besides, the boundary between the air and the first medium is named (a), the boundary between the second medium and the substrate is named (b), whereas the boundary between the third medium and the substrate is named (c). After the analyses of the research data, the following equations are got:

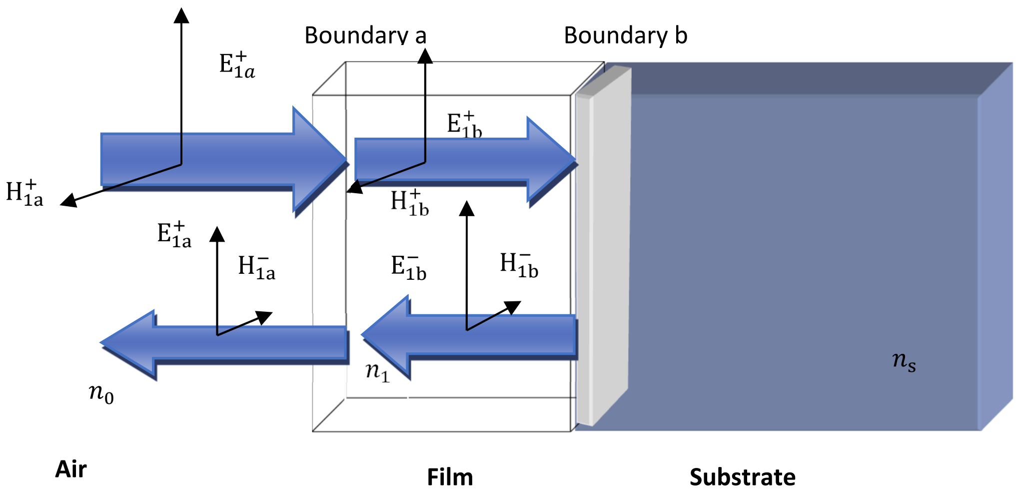


Figure 1. The wave incident on one layer thin film.

From the Figure (1), the tangential components of E and H are:

$$\pounds_b = \pounds_{1b}^{+} + \pounds_{1b}^{-}, \quad (1)$$

$$\mathcal{H}_b = \eta_1 \pounds_{1b}^{+} - \eta_1 \pounds_{1b}^{-}, \quad (2)$$

where

£ – total tangential electric field amplitude, that is, the field parallel to the thin film boundaries
$\mathcal{H}$ – total tangential magnetic field amplitude, that is, the field parallel to the thin-film boundaries.
The formulation of the optical admittance at oblique incidence angle according to Ahmed (2006) is

$$\eta_1 = n_1\eta_0 \cos\theta_1 \text{..............for S-polarization} \quad (3)$$

$$\eta_2 = \frac{n_1\eta_0}{\cos\theta_1} \text{...................... for p-polarization} \quad (4)$$

where
η_1 – Characteristic admittance of a material thin film layer
η_0 – Characteristic admittance of the incident medium.
η_m – Characteristic admittance of the emergent medium
η_{sub} – Characteristic admittance of substrate.
θ – The angle of incidence in the thin film layer
From the Snell's law (Kolle, 2011):

$$n_0 \sin\theta_0 = n_1 \sin\theta_1, \quad (5)$$

$$n_1 \sin\theta_1 = n_{sub} \sin\theta_{sub}, \quad (6)$$

$$\therefore \ £_{1b}^{+} = \frac{1}{2}\left[\frac{\mathcal{H}_b}{\eta_1} + £_b\right], \quad (7)$$

$$£_{1b}^{-} = \frac{1}{2}\left[\frac{-\mathcal{H}_b}{\eta_1} + £_b\right], \quad (8)$$

$$\mathcal{H}_{1b}^{+} = \eta_1 £_{1b}^{+} = \frac{1}{2}[\mathcal{H}_b + \eta_1 £_b], \quad (9)$$

$$\mathcal{H}_{1b}^{-} = -\eta_1 £_{1b}^{-} = \frac{1}{2}[\mathcal{H}_b - \eta_1 £_b]. \quad (10)$$

The phase factor of the positive wave will be multiplied by ($e^{i\delta}$), while the phase factor the negative wave will be multiplied by ($e^{-i\delta}$) by using

$$\delta = 2\pi n_1 d \frac{\cos\theta_1}{\lambda}, \quad (11)$$

where:
δ – phase retardation in the thin film layer, d – the thickness of thin film, n – the refraction index for medium, λ – the wavelength of incident light .

$$\therefore \ £_{1a}^{+} = £_{1b}^{+} e^{i\delta} = \frac{1}{2}\left[\frac{\mathcal{H}_b}{\eta_1} + £_b\right] e^{i\delta} \quad (12)$$

$$£_{1a}^{+} = £_{1b}^{-} e^{-i\delta} = \frac{1}{2}\left[\frac{-\mathcal{H}_b}{\eta_1} + £_b\right] e^{-i\delta} \quad (13)$$

$$\mathcal{H}_{1a}^{+} = \mathcal{H}_{1b}^{+} e^{i\delta} = \eta_1 £_{1b}^{+} = \frac{1}{2}[\mathcal{H}_b + \eta_1 £_b] e^{i\delta} \quad (14)$$

$$\mathcal{H}_{1a}^{-} = \mathcal{H}_{1b}^{-} e^{-i\delta} = -\eta_1 £_{1b}^{-} = \frac{1}{2}[\mathcal{H}_b - \eta_1 £_b] e^{-i\delta} \quad (15)$$

The result of the field in boundary a is

$$£_a = £_{1a}^{+} + £_{1a}^{-} = £_{1b}^{+} \quad (16)$$

By using eqs (12) and (13), the following is produced:

$$£_a = \frac{1}{2}\frac{\mathcal{H}_b}{\eta_1} e^{i\delta} + \frac{1}{2} £_b e^{i\delta} - \frac{1}{2}\frac{\mathcal{H}_b}{\eta_1} e^{-i\delta} + \frac{1}{2} £_b e^{-i\delta} \quad (17)$$

$$£_a = £_b \left[\frac{e^{i\delta} + e^{-i\delta}}{2}\right] + \mathcal{H}_b \left[\frac{e^{i\delta} - e^{-i\delta}}{2\eta_1}\right] \quad (18)$$

The relationships:

$$\cos\theta = \left[\frac{e^{i\theta} + e^{-i\theta}}{2}\right] \quad (19)$$

$$i \sin\theta = \left[\frac{e^{i\theta} - e^{-i\theta}}{2}\right] \quad (20)$$

are used in eq. (18), so the result is

$$£_a = £_b \cos\delta + \mathcal{H}_b \frac{\mathrm{i}\sin\delta}{\eta_1} \quad (21)$$

By using eqs (14) and (15), the following will exist:

$$\mathcal{H}_a = \mathcal{H}_{1a}^{+} + \mathcal{H}_{1a}^{-} = \mathcal{H}_{1b}^{+} e^{i\delta} + \mathcal{H}_{1b}^{-} e^{-i\delta} \quad (22)$$

$$\mathcal{H}_a = \eta_1 £_{1b}^{+} - \eta_1 £_{1b}^{-} \quad (23)$$

$$\mathcal{H}_a = \mathcal{H}_{1a}^{+} + \mathcal{H}_{1a}^{-} = \frac{1}{2}[\mathcal{H}_b + \eta_1 £_b]e^{i\delta} = \frac{1}{2}[\mathcal{H}_b - \eta_1 £_b]e^{-i\delta} \quad (24)$$

$$\mathcal{H}_a = \frac{1}{2}\mathcal{H}_b\, e^{i\delta} + \frac{1}{2}\eta_1 £_b e^{i\delta} + \frac{1}{2}\mathcal{H}_b e^{-i\delta} - \frac{1}{2}\eta_1 £_b e^{-i\delta} \quad (25)$$

$$\mathcal{H}_a = \eta_1 £_b \left[\frac{e^{i\delta} - e^{-i\delta}}{2}\right] + \mathcal{H}_b \left[\frac{e^{i\delta} + e^{-i\delta}}{2}\right] \quad (26)$$

By using the relationships (19) and (20), the result will be

$$\mathcal{H}_a = \eta_1 £_b \ \mathrm{i}\sin\delta + \mathcal{H}_b \cos\delta \quad (27)$$

$$£_a = £_b \cos\delta + \mathcal{H}_b \frac{\mathrm{i}\sin\delta}{\eta_1} \quad (28)$$

$$\mathcal{H}_a = \mathrm{i}\, \eta_1 £_b \ \sin\delta + \mathcal{H}_b \cos\delta \quad (29)$$

Now, eq. (28) and eq. (29) are changed to matrix notation which is between the boundaries a and b:

$$\begin{bmatrix} \cos\delta & \frac{\mathrm{i}\sin\delta}{\eta_1} \\ \mathrm{i}\,\eta_{1_b} \ \sin\delta & \cos\delta \end{bmatrix}$$

$$\therefore \begin{bmatrix} £_a \\ \mathcal{H}_a \end{bmatrix} = \begin{bmatrix} \cos\delta & \frac{\mathrm{i}\sin\delta}{\eta_1} \\ \mathrm{i}\,\eta_{1_b} \ \sin\delta & \cos\delta \end{bmatrix} = \begin{bmatrix} £_b \\ \mathcal{H}_b \end{bmatrix} \quad (30)$$

By supposing that the transfer matrix M has the following matrix notation:

$$M = \begin{bmatrix} \cos\delta & \frac{\mathrm{i}\sin\delta}{\eta_1} \\ \mathrm{i}\,\eta_{1_b} \ \sin\delta & \cos\delta \end{bmatrix} \quad (31)$$

$$\begin{bmatrix} £_a \\ \mathcal{H}_a \end{bmatrix} = M \begin{bmatrix} £_b \\ \mathcal{H}_b \end{bmatrix} \quad (32)$$

It is supposed that the symbol Y stands for input optical admittance to compare it with this eq.:

$$\eta = \frac{\mathcal{H}}{£} \quad (33)$$

So, according to Ahmed (2006):

$$\therefore Y = \frac{\mathcal{H}_a}{£_a} \quad (34)$$

To find the reflectance of a sample interference between an incident medium of admittance η_0 and the medium of admittance Y (Macleod, 2010):

$$r = \frac{\eta_0 - Y}{\eta_0 + Y} \quad (35)$$

$$R = \left[\frac{\eta_0 - Y}{\eta_0 + Y}\right]\left[\frac{\eta_0 - Y}{\eta_0 + Y}\right]^{*} \quad (36)$$

Now eq. (30) is changed by dividing it by $£_b$, so the following is produced:

$$\begin{bmatrix} £_a/£_b \\ \mathcal{H}_a/£_b \end{bmatrix} = \begin{bmatrix} B \\ C \end{bmatrix} = \begin{bmatrix} \cos\delta & \frac{\mathrm{i}\sin\delta}{\eta_1} \\ \mathrm{i}\,\eta_{1_b} \ \sin\delta & \cos\delta \end{bmatrix} \begin{bmatrix} 1 \\ \eta_2 \end{bmatrix} \quad (37)$$

Where $\begin{bmatrix} B \\ C \end{bmatrix}$ means the characteristic matrix

$$\frac{\mathcal{H}_a}{£_b} = \eta_2 \quad (38)$$

where

$$B = \frac{\pounds_a}{\pounds_b} \tag{39}$$

$$C = \frac{\mathcal{H}_a}{\pounds_b} \tag{40}$$

B and C are the normalized electric and magnetic fields at the interface.
From eqs (34) and (35), the following is got:

$$Y = \frac{\mathcal{H}_a}{\pounds_b} = \frac{\pounds_a/\pounds_b}{\pounds_a/\pounds_b} = \frac{B}{C} = \frac{\eta_2 \cos\delta + i\eta_1 \sin\delta}{\cos\delta + i\left(\frac{\eta_2}{\eta_1}\right)\sin\delta} \tag{41}$$

From eqs (36) and (37), the reflectance can be found.

b. The Reflectance of a (Assembly) Multilayers Film

The matrix notation of the film is near the substrate:

$$\begin{bmatrix} \cos\delta_2 & \frac{i\sin\delta_2}{\eta_1} \\ i\,\eta_2 \sin\delta_2 & \cos\delta_2 \end{bmatrix}$$

$$\begin{bmatrix} \pounds_a \\ \mathcal{H}_a \end{bmatrix} = \begin{bmatrix} \cos\delta_2 & \frac{i\sin\delta_2}{\eta_1} \\ i\,\eta_2 \sin\delta_2 & \cos\delta_2 \end{bmatrix} \begin{bmatrix} \pounds_c \\ \mathcal{H}_c \end{bmatrix} \tag{42}$$

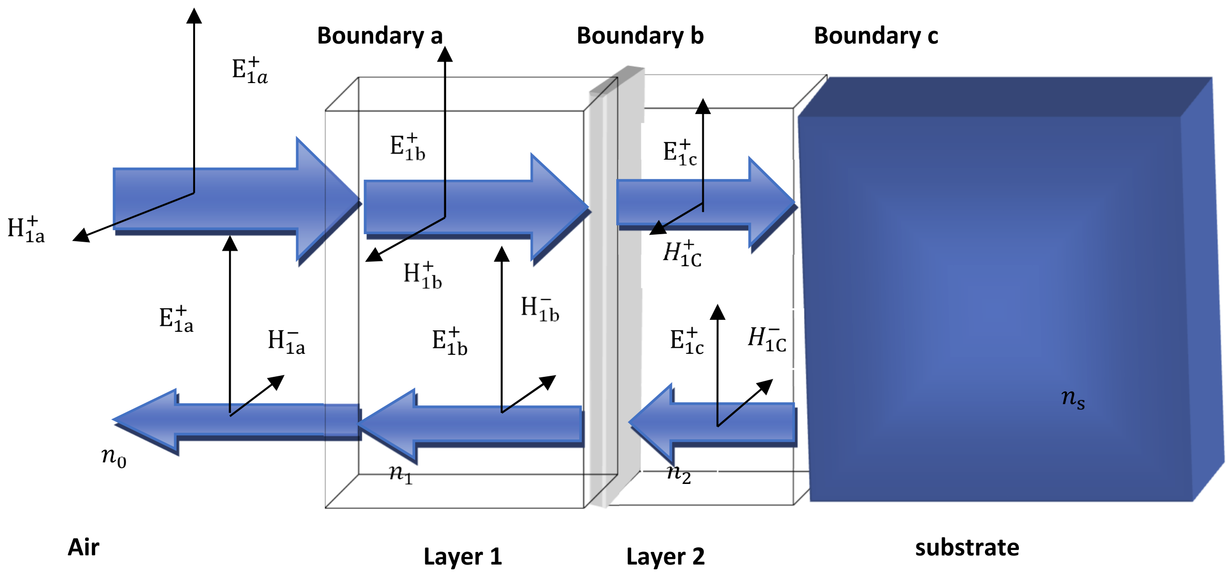


Figure 2. The incident wave on the two layer thin film.

For two layer films, the following equations exist:

$$\begin{bmatrix} \pounds_a \\ \mathcal{H}_a \end{bmatrix} = \begin{bmatrix} \cos\delta_1 & \frac{i\sin\delta_1}{\eta_1} \\ i\,\eta_1 \sin\delta_1 & \cos\delta_1 \end{bmatrix} \begin{bmatrix} \cos\delta_2 & \frac{i\sin\delta_2}{\eta_2} \\ i\,\eta_2 \sin\delta_2 & \cos\delta_2 \end{bmatrix} \begin{bmatrix} \pounds_c \\ \mathcal{H}_c \end{bmatrix} \tag{43}$$

$$\begin{bmatrix} B \\ C \end{bmatrix} = \left\{ \prod_{r=1}^{q} \begin{bmatrix} \cos\delta_r & \frac{i\sin\delta_r}{\eta_r} \\ i\eta_r \sin\delta_r & \cos\delta_r \end{bmatrix} \right\} \begin{bmatrix} 1 \\ \eta_{sub} \end{bmatrix} \tag{44}$$

$$\text{Where} \quad \delta_r = 2\pi d \frac{\cos\theta}{\lambda} \tag{45}$$

$$\begin{bmatrix} B \\ C \end{bmatrix} = [M_1][M_2][M_3] \ldots \ldots [M_q] \begin{bmatrix} 1 \\ \eta_{sub} \end{bmatrix} \tag{46}$$

The reflectance R, transmission T and absorbance A will be got by the following eqs (Macleod, 2010):

$$R = \left[\frac{\eta_0 B - C}{\eta_0 B + C}\right]\left[\frac{\eta_0 B - C}{\eta_0 B + C}\right]^* \tag{47}$$

$$T = \frac{4\eta_0 \mathrm{Re}(\eta_m)}{(\eta_0 B + C)(\eta_0 B + C)^*} \tag{48}$$

$$A = \frac{4\eta_0 \mathrm{Re}(BC^* - \eta_m)}{(\eta_0 B + C)(\eta_0 B + C)^*} \tag{49}$$

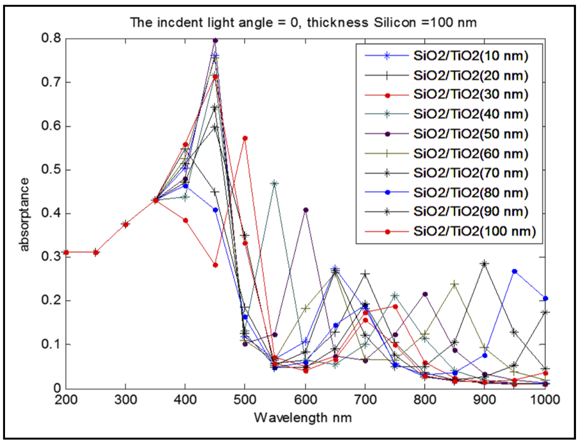
Where adding these parameters is equal to 1 according to Al-Shadidi & Falih (2019, p.77):

$$R+T+A=1 \tag{50}$$

THE RESULTS

To design a model for the silicon solar cell in this research, a set of thin film layers has been assumed. The thickness of each layer has been calculated, taking into consideration the interference between the incident and the reflected rays from each layer. These calculations have been done by using Matlab code for TMM, to investigate the higher possible absorption to be obtained.

As in equation (46), the M matrices have been calculated for different thickness of each layer and different angles of incident rays. The thickness of Si layer has varied from 100 nm to 1000 nm, with 100 nm steps, while the SiO2 & TiO2 thickness has been changed from 10 nm to 100 nm with 10 nm steps, for each layer thickness of Si. These calculations have been repeated for three angles of incident (0°, 45°, 90°).



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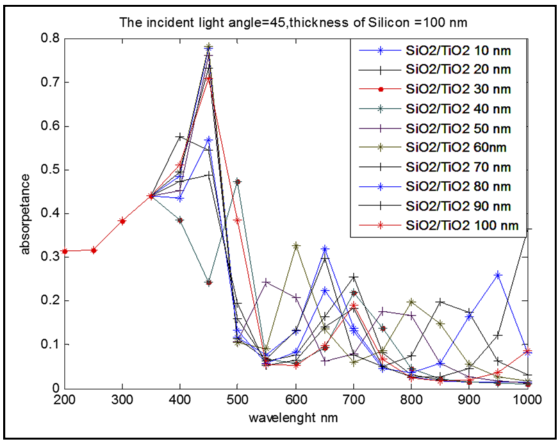

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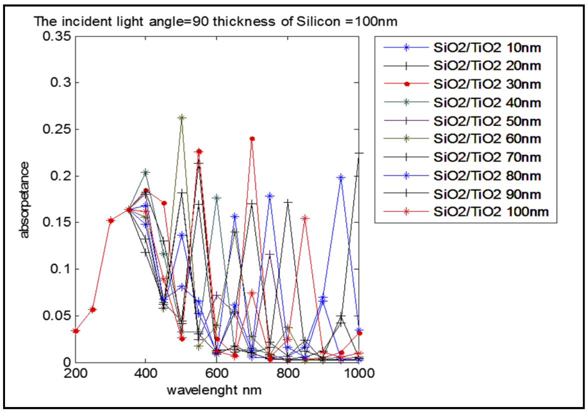

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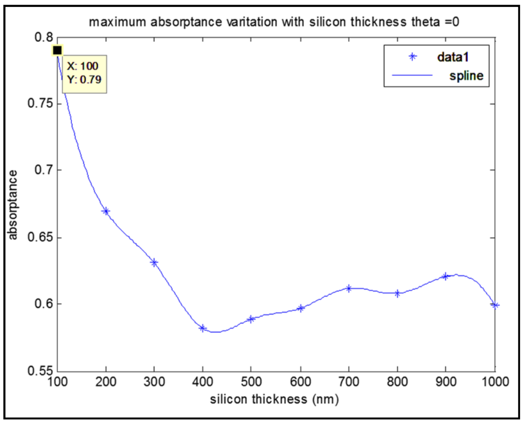
Figure 3. Absorbance as a function of wavelength (nm), the thickness of Silicon 100(nm) by different light incident angles (a) angle = 0^0,(b) angle = 45^0,(c) angle = 90^0

As shown in Figure (3), maximum absorbance has occurred at wavelength equal to 450nm which belongs to the interface between blue and violet color from the visible spectrum region. In Figure (3a) & (3b), many other peaks can be seen at different frequencies. At an angle of incident equal to zero, there are several peaks for absorption at other wavelength within the visible spectrum. It is possible to control the increase in absorbance within the whole light spectrum through controlling the thin films thickness. From Figure (3)a, a distinctive peak can be seen at wavelength equal to 900nm, when the (SiO2/TiO2) thickness is equal to 90nm, which is in the IR region.

At the angle of incident equal to 45°, it can be observed many peaks of absorbance within the visible and infrared spectrum. The highest absorbance is at wavelength equal to 450nm which is the interface between the violet and blue color region in the visible spectrum. Then, the absorbance decreases. Moreover, there are many other peaks can be distinguished within the Visible- IR spectrum. One noticeable peak is at the end of IR region and it belongs to the SiO2/TiO2 90nm thickness.

Figure (3)c shows the absorbance at the angle of incident equal to 90°. The absorbance at average is less than that at another angle of incident. In detail, the absorbance reaches (0.8) at the highest peaks for other angles of incident, while the highest peak equal to (0.28) at angle of incident equal to (90°). In general, the absorption rate in this case is close to each other. The highest peak is at wavelength equal to 450nm. Other peaks of absorption have been seen at wavelength equal to (550, 700, 800, 900 and another high peak at the end of the infrared region 1000nm).

The above calculations have been repeated for different silicon thickness levels (100, 200,….100nm). The best absorbance has happened when Silicon thickness was equal to 100nm, while the SiO2 & TiO2 thickness was equal to 90 nm. These calculations have been done by using a 50 nm Ag layer thickness. The Ag has worked as a reflector to return the rays to the effective Silicon layer.



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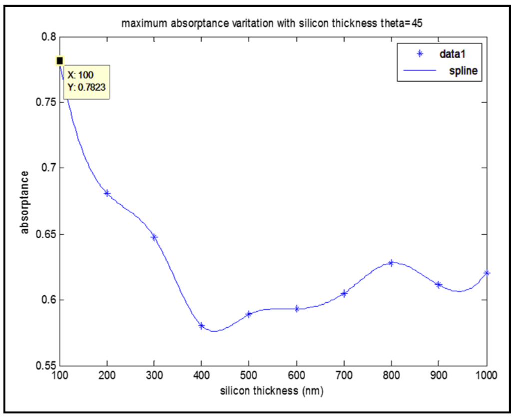

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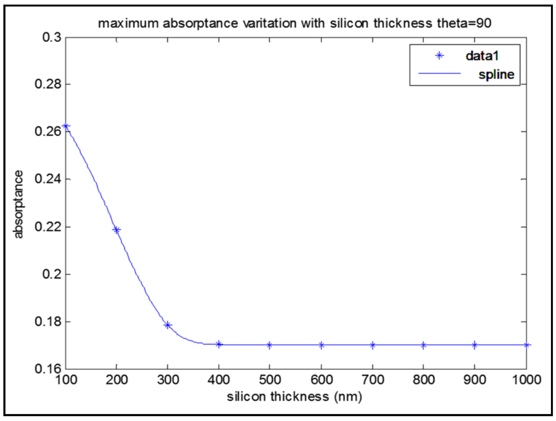

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Figure 4. Absorbance of the solar cell as a function of Silicon thickness (nm) by different light incident angles (a) angle=0°, (b) angle=45°, (c) angle= 90°.

In Figure (4), the maximum absorbance from each layer, and the relationship between the absorbance and the thickness of silicon layers have changed according to the change in silicon layer thickness.

The maximum point at the absorbance curve is got at the thickness of 100 nm. For lower absorbance at the other layer thicknesses, it happens because the interference of the light waves. At the thickness of 100 nm in the active material (a-Si), the interference effect is clear and a-Si becomes disordered in its behavior, so the change appears in the absorbance with thickness. As a result, the change of the incident angle of the unpolarized light leads to the best absorbance when the thickness is equal to 100 nm. It can be noticed from Figures (4a) and (4b) that there is a very little difference for the maximum absorbance between the cases of zero and 45° angle of incident. The maximum absorbance is very little in the case of normal incident as shown in Figure (4c). When silicon thickness increases, the recombination for the charge carriers will be done before reaching the SiO2/TiO2 layers. Therefore, the best results will be seen at a thickness equal to 100nm. However, decreasing silicon layer thickness less than 100nm interface effect will be dominant.

From Figure (5), it can be seen the curve of Jsc and the thickness of SiO_2 /TiO_2 layers. Jsc curve increases if the thickness of SiO_2 and TiO_2 layers increases. The highest point of Jsc curve increase occurs when the thickness of SiO_2 / TiO_2 is 90 nm. At this level of thickness, the best absorbance accrued at the effective silicon layer. For, the short circuit current, it was (15.16) mA. The results of this research are similar to the ones of Burkhard, Hoke & McGhee's research (2010) and Sahouane & Zerga's research (2014).

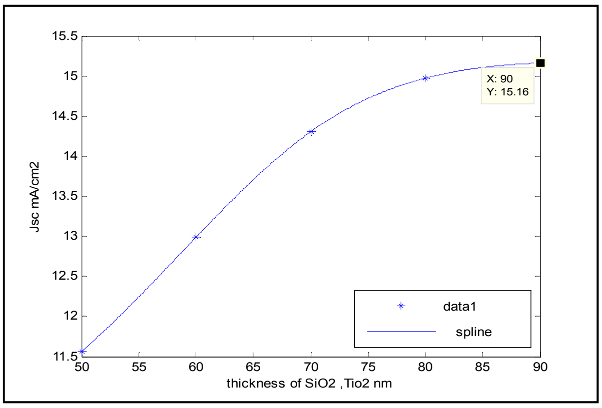

Figure 5. The curve of the thickness of SiO_2,TiO_2 (nm) and Jsc (mA/cm^2)

CONCLUSION

The efficiency of solar cells has been improved by using a multilayer thin film made of different materials. The choice of the thickness of these layers has been determined using the Matlab code to have the best absorbance of first layer (a-Si) and (SiO_2 and TiO_2). The absorbance of the charge carriers happens faster than their recombination. Hence, this model (SiO_2 and TiO_2) has the best efficiency at the thickness of 90 nm and at 100 nm for a-Si.

The novelty of this research is the new combination of thin film layers to build a high efficiency thin solar cell. The cell contains two layers that can collect the charge carriers before reassembly. In addition to an excellent reflector to ensure the use of the most possible radiation falling on the cell.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ КРЕМНІЄВИХ СОНЯЧНИХ ЕЛЕМЕНТІВ ШЛЯХОМ ДОДАВАННЯ ТОНКИХ ПЛІВОК SiO_2/TiO_2 МЕТОДОМ МАТРИЦІ ПЕРЕНОСУ

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Тонкоплівкові кремнієві сонячні батареї сьогодні є найкращим вибором для отримання електроенергії через їх низьку вартість порівняно з кристалічними сонячними елементами. Однак тонкоплівкові кремнієві сонячні батареї мають слабке поглинання падаючого світла. Щоб впоратися з такою слабкістю та отримати кращу ефективність цих батарей, буде використаний ефективний задній відбивач, що складається з багатошарових тонких плівок (срібла, діоксиду кремнію (SiO_2) та діоксиду титану (TiO_2)). Світло, що проходить від першого шару кремнію, буде відбиватися наступним шаром, а відбите світло повернеться до першого шару кремнію. Таким чином, поглинання кремнієвого сонячного елемента можна збільшити за рахунок збільшення ймовірності відбиття світла від SiO_2, TiO_2 та Ag. Метод матриці переносу (TMM) від програми Matlab буде використовуватися для аналізу результатів відбиття, пропускання та поглинання тонкого плівкового шару, і ці результати можуть довести ефективність батарей за допомогою кодів MATLAB.

Ключові слова: SiO_2, TiO_2, TMM, ефективність, оптичні властивості, тонка плівка, Matlab.