Optimization of Double Anti-Reflective Coating SiO_x / SiN_x on the Solar Cells with Silicon Conventional.

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Abstract

In this study a single anti-reflective layer like a double anti-reflective coating of silicon nitride (SiN_x) and oxide of silicon (SiO_x) will be presented. The object of this study and the optimization of the antireflective coatings on the solar cells with silicon, it was noted that the minimal reflection losses are obtained on the double anti-reflective coating of SiO_x/SiN_x with refractive index n2=2.08 and n1=1.45 studied on 600 nm respectively. The effect of the thickness and the refractive index will be also studied. The optimization procedures and the various results will be presented.

Keywords*:*

Anti-Reflective Coatings, Thickness, SiN_x, SiO_x. Double Anti-reflective Layer,

1. INTRODUCTION

During the last years, several anti-reflective coatings deposited for the theoretical and experimental optimization of the solar cells to silicon have been studied.

Y. Lee and K. Choi [1]-[2] have extended their work on the double anti-reflective layers or various types of materials exploited like: SiO_2 / TiO_2, ZnS/MgF_2 and SiOx /SiO_x N_Y.

They are used as anti-reflective coatings thanks to their weak absorption and adjustable optical properties. The reflectance rays or the incidental photons on the surface of the substrates which are silicon constitutes a significant source of loss for photovoltaic conversions.

M. Lipinski and al [3] have presented that the anti-reflective coating is vital to adapt the refractive index and the thicknesses between the air or a corpuscle (glass) and the substrate in order to minimize the reflection for wavelengths given, for that a good choose of the refractive index of ARC (anti-reflective coating) and the thickness and to be exploited the phenomenon of interference destructives are necessaries, the dephasing between the considered wave has the interface ARC/Substrate are in phase opposition in the case of the incidental wave is completely transmitted or absorbed . The ARC can be seen as a cutting glass of a wave quarter which will make it possible to eliminate the reflection for a specific wavelength.

M. A. Green and W. Lijuan [4]-[5] have studied the photovoltaic application phenomenons, the refractive index and the thickness of the anti-reflective layers are used to minimize the reflection with the wavelength of 600 nm, near to the maximum of the sunlight emission and allows an acceptable penetration of the photon light in the silicon.

M. Lipinski and al [6] have shown that the anti-reflective coating is an advantages due to a broad range by the fact of the solar spectrum made for the use of double anti-reflective coating constituting two different materials is possible.

In this study, we succeeded a simulation program which enabled us to find the best combinations of the SARC (single anti-reflective coating) and DARC (double antireflective-coating) to minimize the reflection.

As can be seen we have varied the thickness values of the ARC and to calculate their reflection.

2. THEORY

The Fig. 1 shows the boundary conditions, the tangential components of the resultant electric and magnetic fields are continuous across the interface.

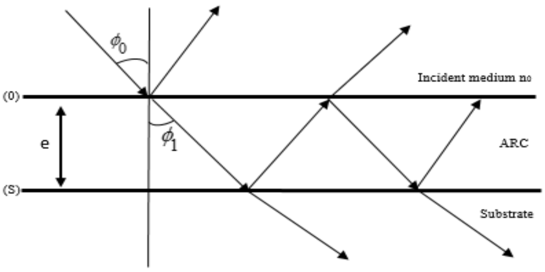

Fig. 1: Model of anti-reflective coating

The field components at the first boundary (0) are related to those of the next boundaries (S) by the first expressions.

M. C. Troparevskry and P. Kossoboutskyy [7]-[8] studied on that, the tangential components of the fields electric and magnetic on the two successive diopters (0/ARC and ARC/S) are linked.

Firstly, we'll describe the characteristic matrix of a single layer. As mentioned earlier, the matrix illustrated two components, tangential and electric, respectively H(x) and E(x) at the layer boundaries (diopter) x=0 and x=S.

$$\begin{pmatrix} E_o \\ H_o \end{pmatrix} = M \begin{pmatrix} E_s \\ H_s \end{pmatrix} \quad (1)$$

The field components to the first border are related to those of the next by the following expressions:

$$E_O = E_S \cos(\phi) + H_S \left(\frac{i \sin(\phi)}{Y} \right) \quad (2)$$

$$H_O = E_S \left(iY \sin(\phi) \right) + H_S \cos(\phi) \quad (3)$$

$$M = \begin{pmatrix} \cos(\phi) & \frac{i \sin \phi}{Y} \\ iY \sin(\phi) & \cos(\phi) \end{pmatrix} \quad (4)$$

ϕ between two waves are dephasing and reflecting, which are given by the following relation:

$$\phi = \frac{2\pi\delta}{\lambda} \quad (5)$$

$$\delta = 2ne\cos(\varphi) \quad (6)$$

the expression (3) becomes:

$$\phi = 4\pi \frac{ne\cos(\varphi)}{\lambda} \quad (7)$$

Y is the optical admittance of radiation with a parallel polarization Y $^{(P)}$ is a perpendicular polarization Y $^{(S)}$ are given by:

$$Y^{(s)} = \sqrt{\frac{\varepsilon_o}{\mu_o}} n \cos(\varphi) \quad (8)$$

$$Y^{(P)} = \sqrt{\frac{\varepsilon_o}{\mu_o}} \frac{n}{\cos(\varphi)} \quad (9)$$

for a stacking of several layers, instead of a matrix there will be a product of matrix those which can be applied for a double layer studied by C. C. Katsidis and L. Remache [9] - [10]:

$$M_i = \sum_{i=1}^{m} \begin{pmatrix} \cos \phi_i & \frac{i \sin \phi_i}{Y_i} \\ iY_i \sin \phi_i & \cos \phi_i \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \quad (10)$$

The reflection coefficient and the total reflection can be expressed as:

$$r = \frac{Y_0 M_{11} + Y_0 Y_s M_{12} + M_{21} - Y_S M_{22}}{Y_0 M_{11} + Y_0 Y_S M_{12} + M_{21} + Y_S M_{22}} \quad (11)$$

$$R = \frac{R_s + R_p}{2} \quad (12)$$

$$R = |r|^2 \quad (13)$$

Considering a non-encapsulated structure (n0=1) SiO_X/SiN_X/Substrate, with variable refractive index, SiOx ($1.45 \le n2 \le 1.5$), SiNx ($1.9 \le n1 \le 2.3$) for the photovoltaic cells performance improvements.

Y. Lee and A. Mahdjoud [11]-[12] illustrated that the deposit of silicon nitride and silicon oxide is a promising method for obtaining a better electric current cells performances.

3. Results and Discussions

S. A. Boden and D. Bouhafs [13]-[14] presented that a good anti- reflective coating is essential for the execution of solar cells because it ensures the increaseness of the photocurrent by reducing the reflectivity to the minimum, with the difference of other optoelectronic devices, the solar cells function with a range of wavelength used up, starting from 300 –1100 nm, that means they need an ARC with wide strip. We have developed a numeric digital code of simulation with a software where we employed the method of transfer-matrix to solve the optical equation and that to have different reflectivity for each thickness and refractive index to non-encapsulated materials. These simulations were made with a surface before punt. The Fig.2 shows the spectrum of reflectance for a Si-blank without ARC and a SARC of SiOx /Si calibrated to 600 nm.

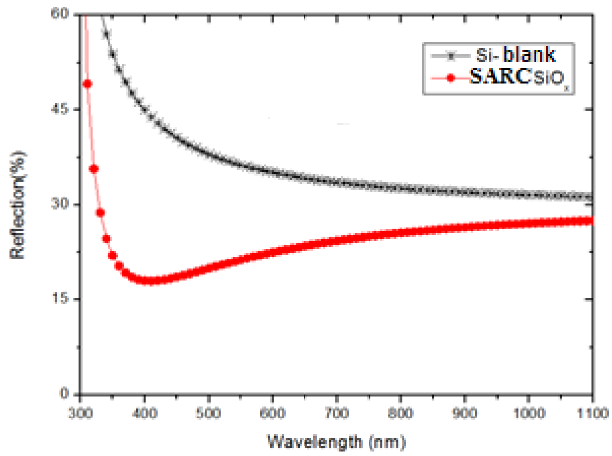

Fig. 2: Reflectance spectra for SiOx SARC under normal incidence and Silicon-blank according to the wavelength.

As can be seen, for a SARC the reflectivity is V-shape which means that the reflectivity minimum can be only achieved in one specific wavelength. The reflectivity of silicon-blank is 35 % being definitely higher than that of a SARC of silicon oxide has 17 % however showing an increaseness in the efficiency of the photovoltaic cells. However, the necessary thicknesses to make this significant reflectivity and those which to bring about problems at the time of manufacturing of the contacts have through this one. It is thus interesting to be able to also minimize the DARC thickness. The Fig. 3 goes in that direction.

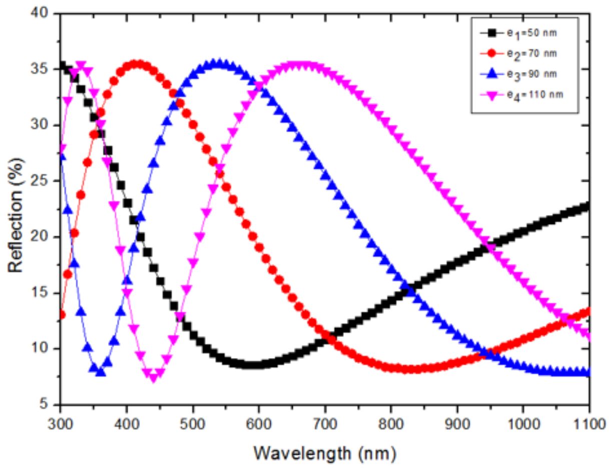

Fig. 3: Reflectance spectra for SiNx SLAR under normal incidence by the thickness variation according to the wavelengths.

The maximum of solar radiation is for a wavelength of approximately 600 nm and it appears logical (R=20.7%).

The results of simulation of the maximum capacity shows that the best performances are obtained for thicknesses of anti-reflective layer slightly more significant.

The results showed that the absorption of the thickness of anti-reflective layer SiOx/Si impacts on the performances of a conventional photovoltaic cell.

The variation of the factor of reflection with the various values thickness shows that for a SARC also increases with the thickness with the wavelengths.

The Fig. 4 shows the variation of SiOx/SiNx/Si DARC and SiOx/Si SARC under various values for the wavelengths to minimize the cells reflectivity.

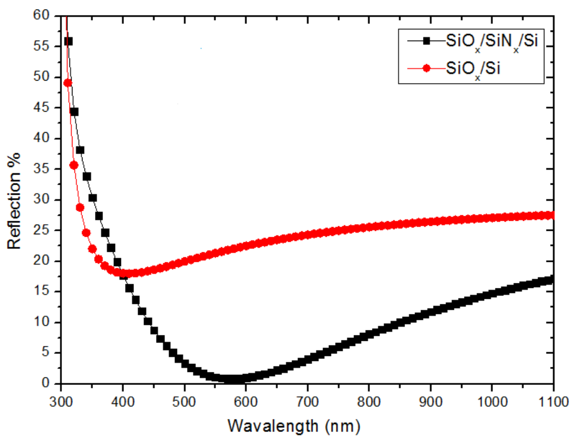

Fig. 4: Reflectance spectra for SiOx/SiNx/Si DARC under normal incidence and SiOx/Si SARC according to the wavelength.

This Fig. 4 makes it possible to observe the impact of the DARC compared to that SARC, the anti-reflective layer SiOx presenting an average reflection (R=17 %) is seen being more reduced if a DARC is with the lower part of the latter which is having a higher refractive index (nsubstrat > n2 > n1).

It appears logical according to those which precede to obtain the minimum of reflectivity (R=0) for a DARC around 600 nm because the maximum of radiation is the curve in V-shape and thus a reflectivity cannot take place for only one wavelength and it depends on the wavelengths.

The development of a DARC would allow the reflectivity conditions for several wavelengths entraining a lower average reflectivity. We note that to minimize optical losses a DARC is more advantageous and has a curve in V-Shape reflectivity (DARC, Fig. 4) is a reflectivity improvement compared to SLAR. As sight previously Fig. 5 shows impacts of the thickness on the efficiency of solar cells.

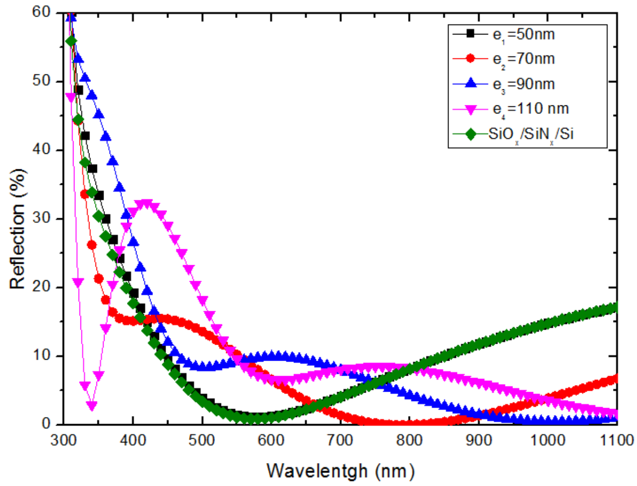

Fig. 5: Reflectance spectra for SiOx/SiNx/Si DARC under normal incidence and SiOx/Si SARC by the thickness variation according to the wavelengths.

The solutions of the DARC go in the direction of the previously studies showing the reflectivity minimization and the increaseness of the photovoltaic cells electric efficiency due to the low of reflectivity.

The improvement of this last parameter is mainly due to a better transmission of the light photons and by the various thickness wavelengths.

It is noted that the reflectivity has reduced itself related to the different values of wavelengths for an average reflectivity of (R = 5.10 %) those being more minimal than a SARC.

The best results are obtained on the DARC where we have a very success by having an interest profit at the Fig. 4 and 5.

It is obvious to specify that the refractive index of silicon and the anti-reflective thickness layers vary with the visible wavelengths and that it be necessary by knowing, in our case one have taken some refractive index and thickness of ARC for the which the best result optical and electric it is obtained without taking notice for all wavelengths.

4. CONCLUSION

It was found that the antireflection effect of SiOx/SiNx double-layer ARC is better than that of a single anti-reflective layer SARC. For DARC, the optimal antireflection effect is obtained with thicknesses e4=110nm and e3=90 nm.

The results reported in this study can be used as a significant tool for efficiency improvement in thin film silicon solar cells on glass.

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