Journal of Materials Science & Surface Engineering, 5(8): 729-732
ISSN (Online): 2348-8956; 10.jmsse/2348-8956/5-8.4

Influence of Multi Anti – Reflective Layers on the Silicon Solar Cells

Awa Dieye . Nacire Mbengue . Oumar A. Niasse . Fatou Dia . Moulaye Diagne . Bassirou Ba

Laboratoire des Semi-conducteurs et d'Energie Solaire, Faculté des Sciences et Techniques,
Université Cheikh Anta Diop, Sénégal.

ABSTRACT
The deposition of an antireflection coating (ARC) is an efficient way to ensure low reflectivity of silicon photovoltaic cells. With an ARC, the zero reflectivity takes place only for a given wavelength since this layer acts as a quarter-wave plate. The application of a double antireflective coating (DARC) combining the deposition of two layers on the front of the cell is a way to improve the reflection properties on the conversion efficiency [1].This work tries to find the better configuration of the double anti-reflective layers to effectively improve the electrical performance of the silicon solar cells[2].

ARTICLE HISTORY
Received 29-07-2017
Revised 27-10-2017
Accepted 28-10-2017
Published 16-11-2017
KEYWORDS
Solar Cell,
Reflection coefficient,
ARC, DARC, MARC

Introduction

The reflection of the incident photons on the interface of substrates is an important source of losses for photovoltaic conversion, in addition to those transmitted through the cell without being absorbed.

For mass production of solar cells, more efficient solutions must be found to limit photons lost at the front of the cell. The idea is to make the deposition of one or more anti-reflective layers.

For that, the hydrogenated silicon nitride SiNx:H (SiN) and silicon oxide SiOx:H are interesting materials since they can act as anti-reflection coating due to their low absorption and their adjustable optical properties [3].

Experimental

Theory

Study of a Single Anti-reflective Coating

Figure 1 shows the configuration of a substrate material coated by an anti-reflective coating of refractive index n_2.

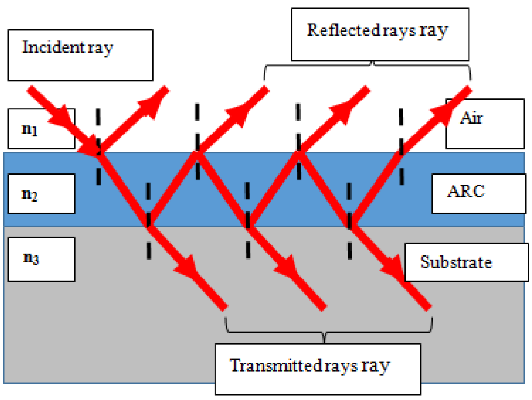

Figure 1: Incident reflected and transmitted light radiations through three different refraction indices environments

Incident light ray is falling on the top the ARC and is submitted to multiple reflection and transmission on both air-ARC and ARC-substrate interfaces. The incident wave is defined by the maximum amplitude of the electric field E_0.

The path difference between two consecutive reflected rays is:

$$\delta = 2\, e\, n_2 \cos i_2 \qquad (1)$$

where e is the ARC thicknesses, i_2 the refractive angle. The corresponding phase difference is:

$$\Delta\varphi = \frac{2\pi\delta}{\lambda} \qquad (2)$$

The resulting amplitude E_r of reflected electric field is expressed in terms of E_0, r_{12}, r_{23}, t_{12}, t_{21} and $\Delta\varphi$:

$$E_r = E_0\left[r_{12} + \frac{t_{12}.r_{23}.t_{21}.e^{j\Delta\varphi}}{1 - r_{23}.r_{21}.e^{j\Delta\varphi}}\right] \qquad (3)$$

The reflection coefficients r_{ij} and the transmitted ones t_{ij} (i, j = 1, 2, 3) are given by Fresnel formulas, in the case where the electric field E_0 is perpendicular to the incidence plane. For destructive interferences, the amplitude condition is $E_r = 0$ and the phase condition is ⍰ ⍰ =⍰ , thus giving e^j⍰ = –1. Under these conditions, equation (3) gives:

$$r_{12} - \frac{t_{12}.r_{23}.t_{21}}{1 + r_{23}.r_{21}} = 0 \qquad (4)$$

The phase condition for the optimum thickness and the refractive index of the antireflection layer is:

$$e = \frac{\lambda}{4n_2} \qquad (5)$$

Losses caused by the reflection on solar cells without antireflection layer are important and have a significant impact on cell photocurrent. It is interesting to minimize these losses by growing simple or multiple anti-reflective coatings on solar cells. The improvement provided by a high refractive index of the ARC for high photons energy may be attenuated by the increase of absorption of light in the anti-reflective coating. It is appropriate from these

Corresponding Author: Awa Dieye, Tel: (7) 771370401
Email: naciire@gmail.com

elements to not considering only the reflection, but also the absorption coefficient of the thin layer coating. Accordingly, it is convenient to use, in the case of an ARC, a SiN layer with a refractive index slightly lower than 2 so to obtain a maximum of radiation transmitted [4].

Study of Multi antireflective Coating

Multilayer antireflections coating (MARC) are simulated using a «Matrix method» [5]. This method allows to deal with multiple anti-reflective layers of different materials as shown in Fig. 2.

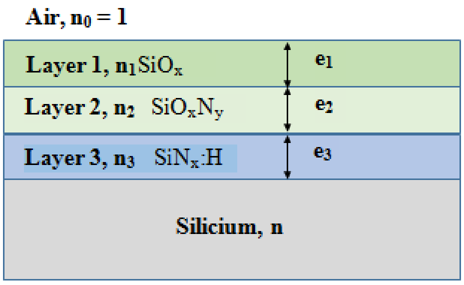

Figure 2: Example of multiple anti-reflective coatings

As indicated in figure 3, the method is based on a stack of p thin layers with different refractive indexes n_1, n_2, ...n_p with respective thicknesses e_1, e_2, ...e_p placed on a substrate of refractive index n_s. The incident ray propagates with an amplitude E_0 and incident angle which is between 0 and 65°.

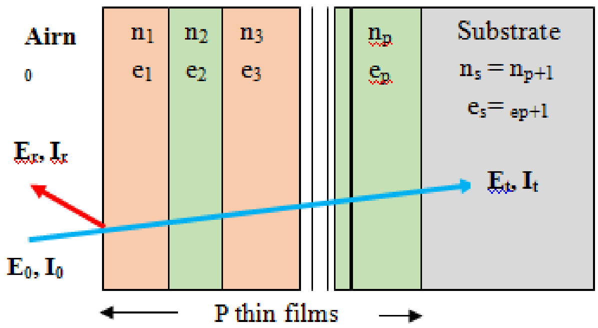

Figure 3: A stack of thin films coating an active substrate for solar cell

The total amplitude E_r of the reflected radiations and the total ones $E_t$transmitted by the several layers are obtained using the following relation. 6 is the product of all amplitudesof radiations crossing through the layers and the diopters separating two layers.

$$\begin{pmatrix} E_r \\ E_0 \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} 0 \\ E_t \end{pmatrix} = M \begin{pmatrix} 0 \\ E_t \end{pmatrix} \quad (6)$$

The matrix M can be written as:

$$M = D_0.C_1.D_1.C_2.....C_p.D_p \quad (7)$$

The quantity $D_i$is the matrix associated to the two layers i and i + 1:

$$D_i = \begin{pmatrix} \frac{n_i + n_{i+1}}{2n_i} & \frac{n_i - n_{i+1}}{2n_I} \\ \frac{n_i - n_{i+1}}{2n_i} & \frac{n_i + n_{i+1}}{2n_i} \end{pmatrix} \quad (8)$$

The path difference for radiation crossing the layer i is given by:

$$C_i = \begin{pmatrix} e^{-j\varphi_i} & 0 \\ 0 & e^{+j\varphi_i} \end{pmatrix} \quad (9)$$

The phase angle is:

$$\varphi_j = \frac{2\pi n_i e_i}{\lambda}$$

The reflection and transmission coefficients in amplitude are given by:

$$r = \frac{M_{12}}{M_{22}} ; t = \frac{1}{M_{22}} \quad (10)$$

The ones in intensity are:

$$R = r.r^* \; T = t.t^* \quad (11)$$

Results and Discussion

The first approach is to use a double anti reflective coating (DARC) with two materials with different refractive indexes. Table 1 shows the materials used to make computer simulations.

Table 1: Materials used in the simulations as ARC and their refractive indexes [6]

Materials	Refractive index
SiO_x	n_1 : 1,45 ~ 1,50
SiO_xN_y	n_2 : 1,50~1,80
SiN_x:H	n_3 : 1,80 ~3,00
Si	3,75

The appropriate materials in physical and technological point of view are SiN_x:H, SiO_xN_y and SiO_x. Double anti-reflection layers are realized in many works with different materials like SiO_2/Si_3N_4, SiO_2/TiO_2 and ZnS/MgF_2[7]. However, some of these works are focused on the way to optimize these multilayers anti-reflective coating.

In the following, are presented the results obtained from the simulations of double and multi-layer reflective coatings on silicon substrate. The silicon oxide SiO_x is appropriate to minimize optical losses in PV silicon cells because the minimum reflectivity was found for small optical index [8].

The hydrogenated silicon nitride (SiN_x:H), combined with proper texturing [9], has interesting optical properties with refractive index varying between 1.8 and 3.0 with a low absorption coefficient [10]. It is first deposited on silicon substrate and provides good passivation.

Figure 4 shows the reflection coefficient as a function of incident light wavelength for a silicon substrate coated at different configurations: SiO_x/Si, SiN_x:H/Si and SiO_x/SiN_x:H/Si.

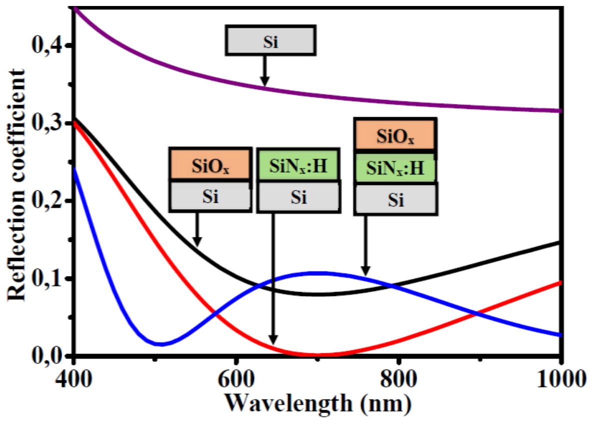

Figure 4: Reflection coefficient of silicon substrate with different anti-reflective coatings. The ARC thicknesses are calibrated for a wavelength λ = 700 nm. The refractive indexes are n(SiO_x) = 1.45; n(SiN_x:H) = 2; n(Si) = 3.75

It is noted the high reflection coefficient of silicon varying from 45% to 30 % from 400 to 1000 nm. The reflectivity is lowered from 30% to 12 % in this wavelength range when silicon substrate is coated with a SiO_x thin film. A minimum of 8 % is obtained at 700 nm corresponding to a better transmission of photons flux. For a SiN_x:H/Si configuration, the reflectivity lies between 30 to 8 % with a zero reflectivity at 700 nm.The blue curve shows the reflectance of SiO_x/SiN_x:H/Si which is a DARC on silicon substrate. Two minima nearly zero reflectance appear at 500 nm and 1000 nm with a maximum of 10 % at 700 nm, showing that the single antireflecting layer SiN_x:H/Si has a better performance than the ones for SiO_x/Si and for DARC SiO_x/SiN_x:H/Si especially at the calibrated wavelength.

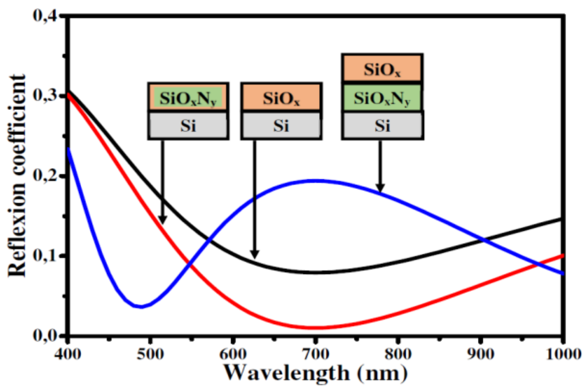

Figure 5: Reflection coefficient of silicon substrate with different anti-reflective coatings. The ARC thicknesses are calibrated for a wavelength λ= 700 nm. The refractive indexes are n(SiO_x) = 1.45; n(SiO_xN_y) = 1.75; n(Si) = 3.75

The reflection coefficient, as a function of the wavelength, is plotted for the following configurations: SiO_x/Si, SiO_xN_y/Si, SiO_x/SiO_xN_y/Si.The plots show an increase of reflection coefficient of SiO_x/SiO_xN_y/Si in wavelengths ranging around 700 nm. Lower values of reflection coefficient are obtained for 500 nm. From the analysis of these results, it is noted that the two single antireflecting layers show near zero reflectivity at the calibrated wavelength, at the contrary of the DARC configuration.

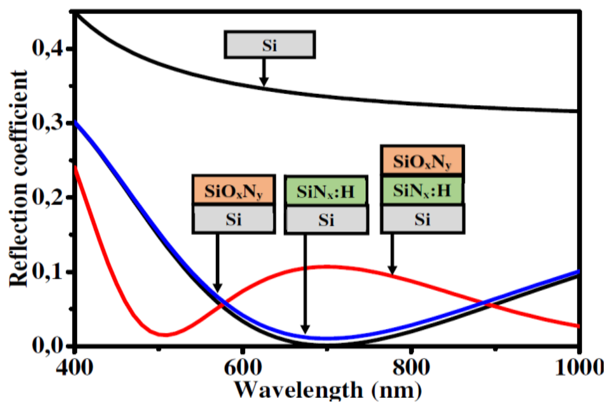

Figure 6: Reflection coefficient of silicon substrate with different anti-reflective coatings. The ARC thicknesses are calibrated for a wavelength λ= 700 nm

The refractive indexes are n(SiN_x:H) = 2; n(SiO_xN_y) = 1.75; n(Si) = 3.75.

The same analysis is obtained in Figure 6 showing the variation of the reflection coefficient of SiO_xN_y/Si, SiN_x:H/Si, SiO_xN_y/SiN_x:H/Si.Accordingly, the reflection coefficients are smaller at the calibrated wavelength for single layers than that of DCAR ones. The single antireflecting layers SiNx:H/Si and SiO_xN_y/Si allow a better photons flux transmission in the substrate and thus give higher cell efficiency than DCAR configuration.

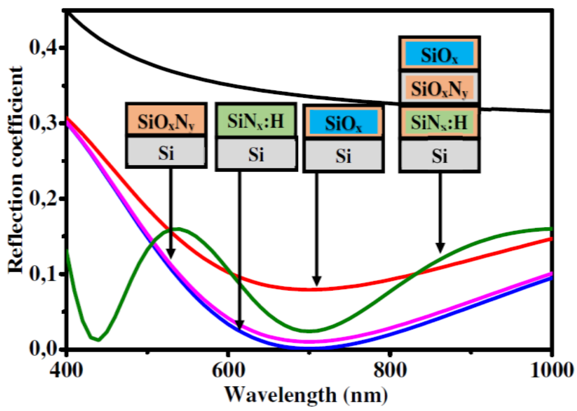

Figure 7: Reflection coefficient of a multi antireflecting layer (SiO_x/ SiO_xN_y/SiN_x:H/Si) as a function of incident light wavelength

Figure 7 shows a comparative study of the three single antireflecting layers with a multi antireflecting coating (MARC) composed with SiO_x/SiO_xN_y/SiN_x:H/Si.As already analyzed in preceding paragraph, the variation of the reflectivity of three single antireflecting layers shows zero reflectivity at the calibrated wavelength. In addition, the MARC provides more zero reflectivities at 450 nm and 700 nm and thus gives a better transmission in a larger wavelength range.

Conclusions

The work is focused on the influence of antireflecting coatings on silicon substrate optimization. It is shown that the SiNx:H/Si configuration gives lower reflectivity than those forSiO_x/Si and SiO_xN_y/Si and thus improve the short-circuit current. Therefore, the performance is altered for

DARC at the calibrated wavelength, the zero reflectivity being shifted to a lower value of wavelength (450 nm), proving that the photons flux transmission is increased in the ultraviolet range. A MARC, composed of three ARC, allows to enlarge the zero reflectivity wavelength range.

References

1. Y. Lee and D. Gong,Stability of SiNx/SiNxdouble stack antireflective coating for single crystalline silicon solar cells, Nanoscale Research Letters,2012, 7:50, 1 – 6.
2. W. Lijuan, Z. Feng, Y. Ying, Z. Yan, L. Shaoqing, H. Shesong, N. Haiqiao and N. Zhichuan,Influence of window layer thickness on double layer antireflection coating for triple junction solar cells, Journal Semiconductor, 2011, 32, N°6.
3. L. Remache, A. Mahdjoud, E. Fourmond, J. Dupuis and M. Lemiti,Design of porous silicon/PECVD SiOx antireflection coatings for silicon solar cells, Proceeding of international conference on renewable energies and power quality (ICREPQ), Mars23 – 25, 2010, Granada, Spain,
4. S. A. Boden, D. M. Bagnall,Sunrise to sunset optimization of thin film antireflective coatings for encapsulated planar silicon solar cells, Progress in Photovoltaics: Research and Applications, 2009, Vol 17, 4, 241 – 252.
5. N. Mbengue, M. Diagne, M. Niane, A. Dieye, O. A. Niasse, B. Ba,Optimization of Double Anti-Reflective Coating SiOx/SiNx on the Solar Cells with Silicon Conventional, IJETT, 2015, Vol 20, 2, 101 – 104.
6. M. Beye, M. E. Faye, A. Ndiaye, F. Ndiaye and A. SeidouMaiga, Optimization of SiN_xSingle and Double Layer ARC for Silicon Thin Film Solar Cells on Glass, Research Journal of Applied Sciences, Engineering and Technology, 2013,6, 3: 412 – 416.
7. S. Bensmaïne and B. Benyoucef, Analyse des Paramètres Optimaux sur les Microtechnologies Utilisées dans la Fabrication des Cellules Photovoltaïques à Base de SiliciumMonocristallin Rev. Energ. Ren.: Valorisation, 1999, 55 – 64.
8. D. Bouhafs, A. Moussi, A. Chikouche and J. M. Ruiz, Design and simulation of antireflection coating systems for optoelectronic devices: Application to silicon solar cells, Solar Energy Materials Solar Cells, 1998, 52, 1-2, 79 – 93.
9. M. Lipinski, Silicon nitride for photovoltaic application, Archives of Materials Science and Engineering, 2010, 46, 2, 69 – 87.
10. Mahdjoub,Graded refraction index antireflection coatings based on silicon and titanium oxides, Semiconductor Physical Quantum Electronic and Optoelectronic, 2007, 60, 1,60 – 66.