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Simulation Study of Optical Reflection and Transmission Properties of the Anti-Reflection Coatings on the Silicon Solar Cells

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Abstract : Solar cells thin layers are increasingly used in the last decades the performance of these cells were clearly improved. In the present work, we simulated a silicon solar cell to analyse certain parameters. Particularly the antireflective properties of the layer (thickness, refractive index) play a crucial role in the performance of the cell, and to optimize them, we studied their effect on the quantities of photovoltaic solar cell. In order to highlight the importance of the testimony of an antireflection coating (SARC) on silicon solar cells a comparison between two cells, one without anti-reflective layer (bare silicon), the other with a layer antireflection was made. The deposition of an antireflection coating shows a significant improvement is in addition to the benefits of the change or not the latter.

The reflection, transmission intensity and amplitude recorded by a simple matrix method are consistent with the literature.

Keywords:* *Solar-Cell, SARC, Reflection, Silicon, transmission

I. INTRODUCTION

The photovoltaic industry is concentrated to more than 90% [2] on the use of silicon as a base material this semiconductor has in effect, various advantages:

It is not toxic as certain III-V semiconductors; it has a native oxide (SiO_2) having excellent electronic properties and it can be easily doped (with phosphorus or boron). His only real downside is its indirect gap of 1.1 eV. This leads to a lower absorption of radiation with a direct bandgap material: to absorb 90% of the solar spectrum, you have to use a thickness of 100 microns for silicon [1, 2, and 3].

The surface of the semiconductor contains a high density of defects (dangling bonds, impurities, etc.) resulting in significant losses due to surface recombination. The passivation is to improve the electronic quality of the surface and volume of the material by neutralizing the effects of its electrically active defects. Various passivation layers are used in photovoltaic but the main ones are the thermal silicon oxide (SiO_2) and the hydrogenated silicon nitride (SiNx: H). We discuss the passivation of the silicon surface more accurately and considering a more general framework [4].

II. THEORY

(A) Silicon vacuum

It is desirable to achieve a zero reflection of the surface of the active silicon layer, so that the cell performance is limited by the absorption in this layer.

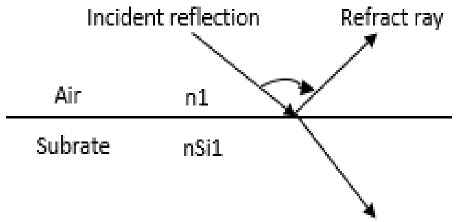

Figure 1: Interface Bare silicon

This zero reflection can be considered with the ant reflector consisting of antireflection layer of nanoparticles on the silicon but with a different geometry of the particles [5].

(B) Single anti-reflective coatings

-Simple Method

(Refractive index and index substrate constant)

To minimize the reflection of light, an antireflection layer (ARC) is used.

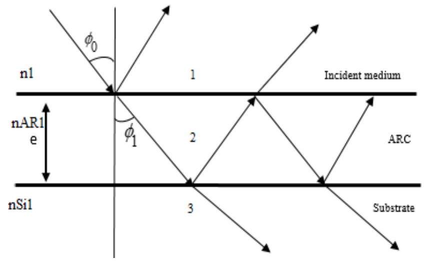

Figure 2 : Interface Air/ARC/Substrate.

The principle of action of antireflection layers is based on the interference of light beams in the layers, the thickness of the layer is equal to a quarter of the wavelength, as well as the phase differences are given by:

$$\Delta\varphi = \frac{4\pi n_{AR} e}{\lambda} \qquad (1)$$

The thickness of the layer used for this destructive interference depends on the refractive index of the materials [6, 7].

$$e = \frac{\lambda}{4n_{AR}} \qquad (2)$$

And repairs and transmission of the different interfaces Air / Substrate are given by:

$$r_{12} = \frac{n_1 - n_{AR}}{n_1 + n_{AR}} \qquad (3)$$

$$r_{23} = \frac{n_{AR} - n_{Si1}}{n_{AR} + n_{Si1}} \qquad (4)$$

$$t_{12} = \frac{2n_1}{n_1 + n_{AR}} \qquad (5)$$

$$t_{21} = \frac{2n_{AR}}{n_1 + n_{AR}} \qquad (6)$$

$$r = r_{12} + \frac{t_{12}t_{21}r_{23}e^{i\Delta\varphi}}{1 - r_{21}r_{23}e^{i\Delta\varphi}} \qquad (7)$$

$$R = |r|^2 \qquad (8)$$

The calculation factors of reflection and transmission by the conventional method of the simple method can lead to narrow oscillations (called Fabry-Perot resonances) in the calculated values. [8] These oscillations occur when at least one of the layers of the multilayer structure is sufficiently thick (compared with the wavelength of incident light) and transparent enough to produce multiple coherent reflection, Figure 3 illustrates this:

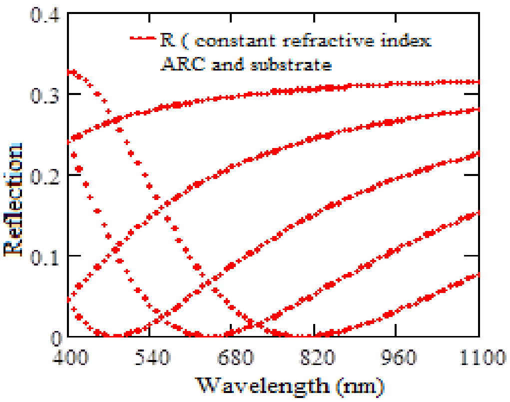

Figure 3: Reflection of an antireflection coating on the silicon as a function of the wavelength (λ = 800 nm, n_{Si1} = 3.665, = 1.914 n_{AR1}).

shows a reflection oscillation zero over the range of wavelength [400-820 nm] thereby significantly improving the efficiency of the cell. This is explained by the fact that the light photons are absorbed more on the low visible wavelengths.

-Matrix method (refractive index and index substrate constant)

The method of transfer matrix (or interference matrix) is an analytical tool for studying the optical properties of a multilayer system with a matrix description of the electromagnetic field to

assess the reflection and the transmission.

And the phase difference between the interfaces as well as the crossed layers and diopters and given by the following expressions:

$$\Delta\varphi = \frac{2\pi n_{AR} e}{\lambda} \qquad (9)$$

The matrix thus obtained, called transfer matrix or interference, is generally represented as:

$$D_0 = \begin{pmatrix} \frac{n_1 + n_{AR}}{2n_1} & \frac{n_1 - n_{AR}}{2n_1} \\ \frac{n_1 - n_{AR}}{2n_1} & \frac{n_1 + n_{AR}}{2n_1} \end{pmatrix} \qquad (10)$$

$$C1 = \begin{pmatrix} e^{-i\Delta\varphi} & 0 \\ 0 & e^{i\Delta\varphi} \end{pmatrix} \qquad (11)$$

$$D_1 = \begin{pmatrix} \frac{n_{AR} + n_{Si1}}{2n_{AR}} & \frac{n_{AR} - n_{Si1}}{2n_{AR}} \\ \frac{n_{AR} - n_{Si1}}{2n_{AR}} & \frac{n_{AR} + n_{Si1}}{2n_{AR}} \end{pmatrix} \qquad (12)$$

The resolution of matrices formed by X and Y allows you to find the coefficients of reflection and transmission.

$$r = \frac{M_{12}}{M_{22}} \qquad (13)$$

$$t = \frac{1}{M_{22}} \qquad (14)$$

$$T = \frac{n_{Si1}}{n_1}|t|^2 \qquad (15)$$

These last two expressions can be used for any number of layers determine the reflection and transmission coefficients, which, in turn, used to determine the reflection factors thereof by applying the latter relationship is the matrix product of different layers and interfaces diopter inside the material.

$$M = D_0 C_1 D_1 \qquad (16)$$

The figure 4 going to the sense of inducing reflection zero compared to previous expressions.

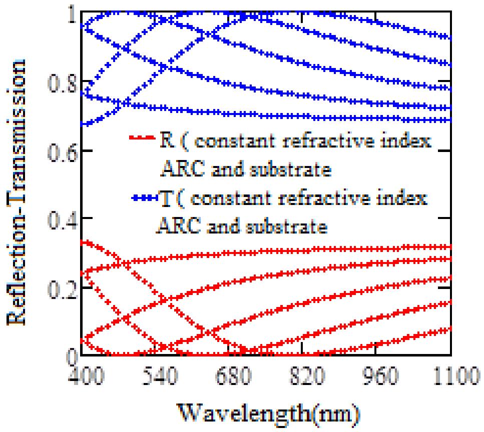

Figure 4: Reflection and Transmission of a coating as a function of the wavelength (λ = 800 was calibrated nm n_{Si1} = 3.665, n_{AR1} = 1.914).

The figure 4 shows a plot of reflectivity and transmission of a single antireflection layer of index of refraction equal to 1.914.

Choosing doc seems a good compromise between minimizing optical losses and a relatively low total thickness.

We have shown that theoretically the application of a graded antireflection coating 800 nm on an unencapsulated cell therefore a reflection which rotates to 32.3% and an average transmission of 75.17%.

(C) Single anti-reflective coatings

-Simple Method

(Refractive index and index substrate various according to the wavelength)

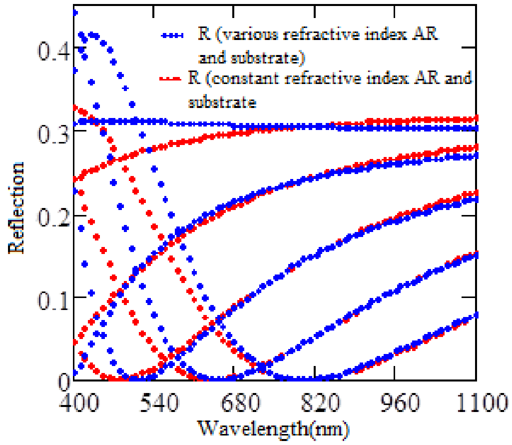

Figure 5: Reflection of the coating in different wavelength values.

In order to obtain refractive indices between 1.465 and 1.914, we have methods to variations in the wavelength of the antireflection layer and the substrate.

This deposit has helped us comparing the reflectivity on various parameters and constants in a wavelength range between 400 and 800 nm and in the range of refractive indices 1.46 <n (800 nm) <1.91 sought. The corresponding average reflection coefficients are 21.4% for low amplitudes and absorption in these layers can be neglected.

However, the thicknesses necessary to achieve these coatings are relatively large, which may cause problems during the realization of the contacts there through.

It is therefore interesting to also minimize the total thickness of SCAR.

The solutions of these curves in this direction. These lead has low and significant reflectivity's on the quantum efficiency and influencing the short-circuit current.

The improvement of this last parameter that is the reflectivity is mainly due to a better transmission of photons of high energy which will be discussed at Figure 6.

-Matrix method (Refractive index and index substrate various according of the wavelength values)

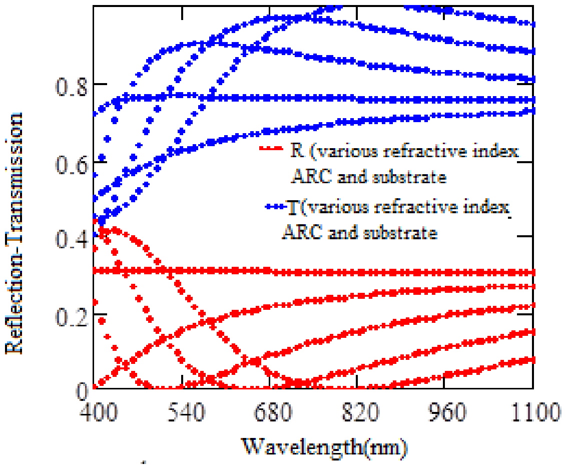

Figure 6: Reflection of the antireflection coating in different wavelength values.

In this Figure 6 we have just been the coating of a single crystal silicon solar cell whose parameters vary as a function of wavelength.

For non-encapsulated cells allows us to test the reflectivity and transmission.

If the effective reflectivity is extremely small (R = 2.6%, T = 98%, 0.8µm), the layers involved are highly absorbent and induce a large reduction in the transmission coefficient for photons of high energies.

Thus, we did not find satisfactory combinations with several layers.

These stacks are indeed appeal to large refractive indices and such layers, even low thicknesses are too great absorbency.

III. CONCLUSION

Optical losses corresponding to the reflected photons on the front and those transmitted through the cell without being absorbed, so they could generate peers / electron holes.

This work allowed us to better understand the properties of different reflective materials.

The different techniques used characterizations showed us that its complex structure and numerous studies are still needed in order to understand and thus control the properties arising in respect of optoelectronics materials.

On the one hand the optical indices of the materials can be adjusted to act as anti-reflective layer encapsulated or not, so as to significantly reduce the optical losses in our case here of around 10.13% on average at 0.8 microns and thus increased current photogenerated.

These simulations also allowed us by comparison of the different variations of attachments and indices subrats and antireflection layers reflectivity measurements, to determine the thickness deposited on a textured surface .We have thus demonstrated that the deposition rate is more slow on such a surface mainly because of an area to be covered far more important.

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