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Impact of Thickness Variation on Reflection and Quantum Efficiency of Monocristallin for Photovoltaic Applications

Awa Dieye, Alassane Diaw, El Hadji Abdoulaye Niass, Modou Pilor, Oumar A. Niasse, Nacire Mbengue, Moulaye Diagne and Bassirou Ba

University Cheikh Anta Diop of Dakar, Bp: 5005, Avenue Cheikh Anta Diop.

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ABSTRACT

This paper focuses on anti-reflective coatings on monocrystalline silicon solar cells and the impact of thickness and refractive index on reflectivity. The reference wavelength of silicon is nm, with its optimal refractive index (n = 3.7838) and a surface reflectivity of 33%. The calculations were made on the basis of values of layer thicknesses and refractive indices that allow to respect the phase and amplitude conditions chosen, namely (HfO_2), (MgF_2); (SiOxNy), (SiOx), (Si_3N_4) and (SiNx:H). Numerical simulations have shown that low reflectivities at the surface of the planar cell coated with a single layer, can be obtained (3% with Si_3N_4) and (2% with HfO_2). Multilayers such as MgF_2/SiNx:H/Si, give a very low reflectivity around 1%.

Introduction

In view of the rising price of fossil fuels, the development leads to an increased competitiveness of solar electricity, if the prices fall by about 5% per year.

The main disadvantage of photovoltaic energy is the production cost. Research must intervene in order to develop less expensive manufacturing processes while guaranteeing stable or even better conversion yield. The option of using anti-reflective coatings to reduce photon losses on the surface of the silicon has certain conditions. It requires the development of calculation models, allowing to take into account the components of the different environments (air/antireflection/silicon). The matrix approach is more general and allows treating several layers, including interfaces.

However, it is necessary to find a good compromise between the thickness of the AR layer to be deposited on the substrate and the adequate material to obtain the minimum of reflection in the active area of the silicon. Our study will focus on varying the thickness of the AR layer by increasing and decreasing 10nm from its optimal thickness.

The influence of the thickness of the anti-reflection materials is well shown for the two materials of refractive index more or less close to that of the silicon substrate (n = 3.78), namely HfO_2 (n = 2.10; e=83.37) and SiOx (n = 1.5; e=116.67)

Study on the simulation of anti-reflective multilayers

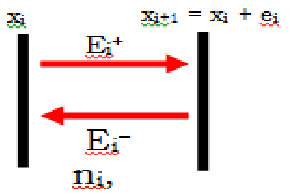

Figure 1. Multilayer's coatings.

$$E^{+;i}(x_{i+1}) = E^{+;i}(x_i)\exp(-jj_i) \quad (1)$$

$$E^{-;i}(x_{i+1}) = E^{-;i}(x_i)\exp(jj_i)) \quad (2)$$

with Error! ,

the phase shift between the beams at xi and xi+1 and introduced by the layer.

Table 1. Materials used as anti-reflection layers with their refractive indices and optimum thicknesses for a reference wavelength λ_0 = 700 nm.

λ_0 = 700 nm		
materials	refractive index	Thickness (nm)
MgF_2	1,38	127 ,17
SiOx	1,50	116,67
SiOxNy	1,80	97,22
Si_3N_4	2,03	86,11
HfO_2	2,10	83,37
SiNx : H	2,30	58,33
Si (substrat)	3,78	46,20

Figure 1 shows a variation of the reflectivity from 400 nm to 1000 nm for the various coatings of the solar cell, the minimum value being observed for the reference wavelength 0 = 700 nm. It is observed that the structures Si_3N_4/Si, SiOxNy/Si and HfO2/Si, present a null reflectivity at the reference wavelength, knowing that for the monocrystalline silicon the reflectivity turns around 33 % at this same reference wavelength [1,2,3].

This shows the importance of the coatings which makes the reflectivity pass to a value almost null thus generating a rather important transmission within the cells with anti-reflection layer.

Tele:
E-mail address: evalinadieye@hotmail.com

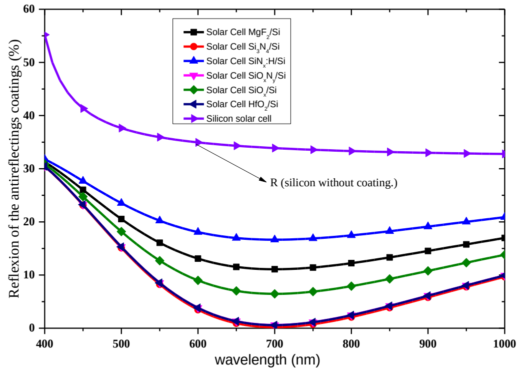

Figure 1. Reflection of a simple coating of anti-reflective materials on silicon (reference wavelength: 700 nm).

Beyond the reference wavelength, the reflectivity varies between 1 and 33% for all the different types of antireflective coatings. The decrease in reflectivity for the three coatings mentioned above, is due to the fact that these materials have refractive indices very close to the optimal index n = 1.96 (nSiOxNy = 1.80, nSi3N4 = 2.03, nHFO2 = 2.10) and which correspond to the condition of obtaining destructive interference between the rays reflected by the coating. The transmission of the photon flow within the cell is thus improved.

However, the other coatings whose refractive indices present a deviation from the optimal index, the conditions of destructive interference are not achieved. The optical path is much weaker, which leads to a decrease in reflectivity within the cells with anti-reflective coatings. The influence of the refractive indices shows the importance of the choice of the material as antireflection layer.

Impact of the thickness of the antireflective layer on the reflectivity of antireflective materials

If we vary the thicknesses of the materials around their optimal values, for example HfO2 (n =2.10) and SiOx, we note on figures 2 and 3, the impact of this geometric parameter on the reflectivity of the coating.

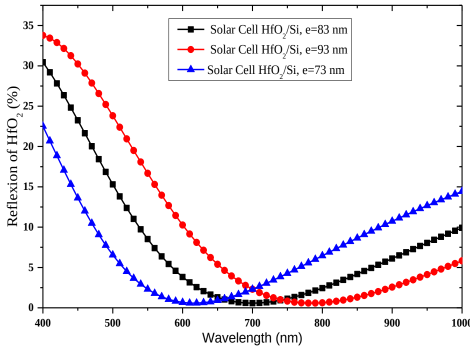

Figure 2. Impact of the thickness on the reflectivity of silicon coated with a layer of HfO_2

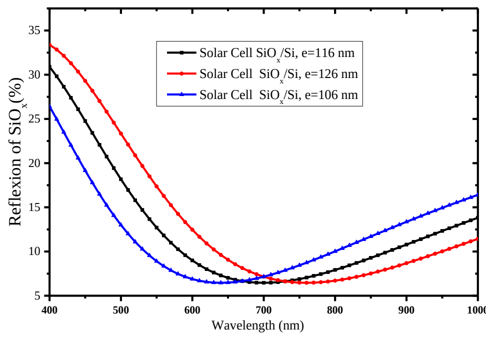

Figure 3. Impact of the thickness on the reflectivity of silicon coated with a layer of SiOx.

The influence of the thickness of anti-reflective materials is well shown for the two materials of refractive index more or less close to that of the silicon substrate (n = 3.78) namely HfO_2 (n = 2.10) and SiOx (n = 1.5). We note that the reflection is not zero at the reference wavelength, the minimum value observed is 7% for the SiOx / Si coating and 2% for the HfO2/Si, for all the chosen thicknesses.

We also note the shift of the reflection minima towards the longer wavelengths when the thickness of the coating increases. Moreover, the curves reveal that the reflection coefficient decreases if the thickness of the HfO_2 and SiOx layer increases for wavelengths higher than the reference wavelength (700 nm).

For short wavelengths, the reflection increases to more than 34% at 400 nm wavelength, when the thickness of the AR layer increases. We note two opposite behaviors due to the thickness of the layer on both sides of the critical thickness. On the other hand, the improvement of the transmission at long wavelengths for the greater thicknesses allows a greater absorption of the photons of low energies because of the increase of the optical path of the luminous flux [4].

The smaller the thickness, the more the cancellation of the reflectivity occurs towards the short wavelengths

Study of the spectral response of a silicon solar cell to various antireflection coatings

Influence of the anti-reflective material index

The optical parameters such as the refractive index and thickness contribute to a clear improvement of the reflectivity thus increasing the transmission. This allows to have a good compromise on the spectral rest of a monocrystalline silicon solar cell in order to increase the quantum yield of the different anti-reflection coatings. The solar cell, used to simulate the spectral response, is an ideal p - n junction whose parameters have the following values

- Thickness of the emitter of the silicon cell: 0.5 m;
- Total thickness of the silicon cell: 200 nm;
- Doping of the emitter (p zone): Nd = 1019 cm^{-3};
- Base doping (n zone): Na = 1016 cm^{-3}
- Recombination speed on the front face Sp = 0 $cm.s^{-1}$
- Recombination speed at the back surface (BSF), Sn = 0 $cm.s^{-1}$ (BSF).

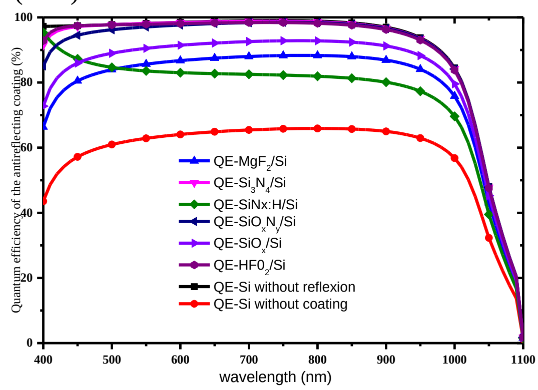

Figure 4. Spectral response of silicon solar cell with different antireflection coatings.

The curves below show a study of the spectral response of a silicon solar cell coated with various anti-reflection layers. The calculations are done using the optimal parameters for these materials at the reference wavelength ref = 700 nm. The studies show significant variation in the spectral response of MgF2/Si, Si3N4/Si, SiNx:H /Si, SiOxNy/Si, SiOx/Si, HfO_2/Si.

The optimal values of the materials are listed in Table 1, allowing a better understanding of the variations of the spectral response [5,6].

Influence of the thickness of the CAR on the spectral response

To study the impact of thickness on the spectral response, two anti-reflective materials are chosen and the thickness is varied by increasing and decreasing by 10 nm from the optimal value.

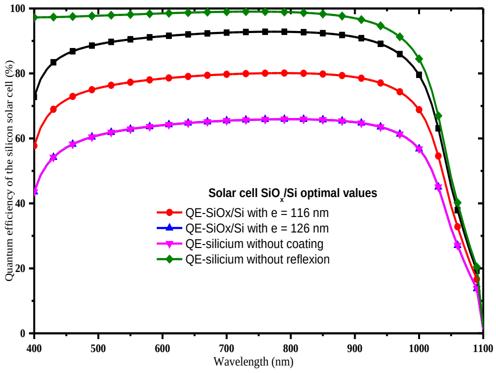

Figure 5. Quantum efficiency of SiO2/Si as a function of wavelength at different thicknesses.

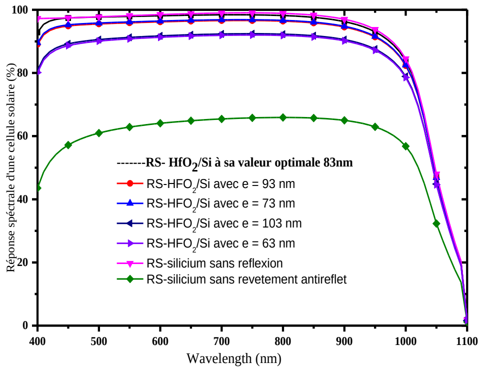

Figure 6. Quantum efficiency of HfO2/Si as a function of wavelength following different thicknesses.

These two figures show us that the increase and decrease of 10 nm on the optimal value does not give us a better quantum efficiency. We also see that HFO_2/Si gives a better performance than other anti-reflective materials [7,8,9].

Conclusion

The influence of their thickness on these optical constants have been highlighted, by the fact that it can participate in the improvement of the transmission of light flow in the substrate on which this layer is deposited.

We note two opposite behaviors due to the thickness of the layer on both sides of the critical thickness.

On the other hand, the improvement of the transmission at long wavelengths for the greater thicknesses allows a greater absorption of the photons of low energies because of the increase of the optical path of the luminous flux.

The smaller the thickness, the more the cancellation of the reflectivity occurs towards the short wavelengths.

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