Physical Science International Journal

Volume 26, Issue 8, Page 41-45, 2022; Article no.PSIJ.95553
ISSN: 2348-0130

Spectral Response of a Monocrystalline Silicon Solar Cell: Under the Influence of the Variation of the Refractive Indices of the Antireflection Materials

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/PSIJ/2022/v26i8759

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/95553

Original Research Article

Received: 27/10/2022
Accepted: 30/12/2022
Published: 31/12/2022

ABSTRACT

Numerical simulations have shown that low reflectivity's at the surface of the planar cell coated with a single layer can be obtained. For example, for single coatings of Si_3N_4 and HfO2 materials, reflectivity values of around 3% and 2% respectively are obtained. Structures with multilayer coatings such as MgF_2 /SiNx: H/Si, give a very low reflectivity of around 1%. Thus, the refractive index of the coating is an important parameter that plays a major role in the optical properties of the

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materials. The closer the refractive index is to the index of the substrate or the layer above the substrate, the higher the reflectivity. The low reflectivity's of silicon coated with anti-reflective materials increase the external quantum efficiency of the solar cell; for example, the efficiency is 95% for HfO2 /Si and Si_3N_4 /Si, as there is a maximum incident photon flux within the solar cell.

Keywords: Materials coating; spectral response; solar cell; reflectivity; refractive index.

1. INTRODUCTION

"The external quantum yield or spectral response is the ratio of the photo current density delivered by the cell to the photon flux incident on the front of the cell" [1,2]. "Optical parameters such as refractive index and thickness contribute to a significant improvement in reflectivity thereby increasing transmission. A good compromise must be found between these two parameters and the AR material in order to improve the quantum efficiency of the solar cells" [3,4]. This paper was devoted to the simulation of anti-reflection layers involving the best anti-reflection materials and the optimization of their performance. Anti-reflective coatings play an important role in reducing optical losses in silicon solar cells, which is a highly reflective material (60% loss of the incident light flux). The variety of materials that can be used as anti-reflective coatings provides several solutions.

2. STUDY OF THE SPECTRAL RESPONSE

The solar cell, used to simulate the spectral response, is an ideal p-n junction with the following parameters:

Emitter thickness of the silicon cell: 0.5 m;

Total thickness of the silicon cell: 200 m;

Transmitter doping (area p): Nd = 1019 cm^{-3};

Doping of the base (area n): Na = 1016 cm-3

Recombination speed on the front face Sp = 0 $cm.s^{-1}$

Recombination velocity at the rear surface Sn = 0 $cm.s^{-1}$ (BSF).

Table 1. Materials used as anti-reflective coatings with their optimum refractive indices and thicknesses for a reference wavelength (λ_{ref}) = 700 nm

	λ_{ref} = 700 nm	
Materials	**Refractive index**	**Thickness, e(nm)**
MgF_2	1,38	127 ,17
SiOx	1,50	116,67
SiOxNy	1,80	97,22
If3 N4	2,03	86,11
HfO2	2,10	83,37
SiNx: H	2,30	58,33
Si (substrat)	3,78	46,20

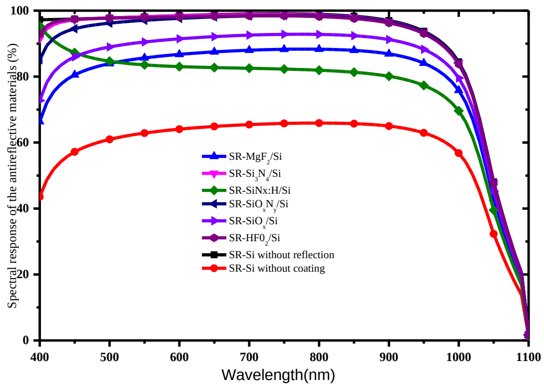

Fig. 1. Spectral response of silicon solar cell with different anti-reflection coatings

Give adequate information to allow the experiment to be reproduced. Already published methods should be mentioned with references. The curves below show the spectral responses of silicon solar cells coated with various anti-reflection layers. The calculations are made using the optimal parameters for these materials at the reference wavelength (λ_{ref}) = 700 nm. The optimal values of the material parameters are listed in Table 1, in order to better understand their influence on the spectral response [5,6,7]. The spectral response of the solar cell is strongly dependent on the nature of the material used as an anti-reflective coating. The uncoated solar cell has a lower efficiency at all wavelengths, with silicon reflecting more than 30% of the incident light flux. Coatings contribute significantly to increasing this response as shown in Fig. 1 for the structures of MgF_2/Si, Si_3 N_4/Si, SiNx:H /Si, SiOxNy /Si, SiOx/Si, HfO_2/Si.

The HFO_2/Si, Si3N4 /Si, and SixNy/Si show better spectral responses due to the refractive index of the coatings being close to the optimum value n = $\sqrt{;nair \times nSi}$.

3. INFLUENCE OF CAR THICKNESS ON SPECTRAL RESPONSE

To study the impact of layer thickness on the spectral response, two anti-reflective materials were chosen with their thicknesses varying by ± 10 nm from the optimum value. Fig. 2 shows the SiOx/Si structure with the optimum thickness(e) [8,9,10].

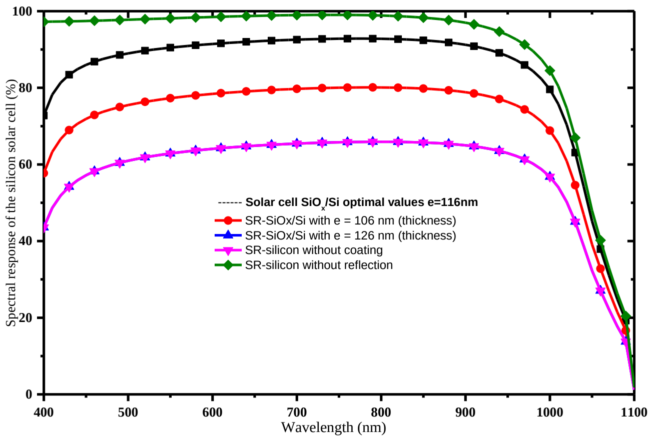

Fig. 2. Quantum efficiency of SiO_2/Si and HfO_2/Si as a function of wavelength for different thicknesses

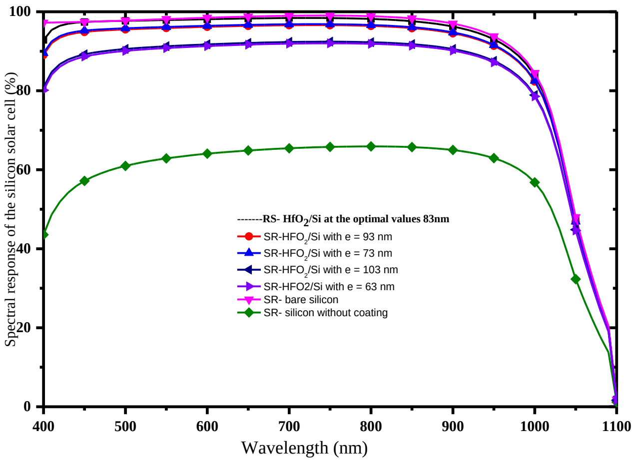

Fig. 3. Quantum efficiency of SiO_2/Si and HfO_2/Si as a function of wavelength for different thicknesses

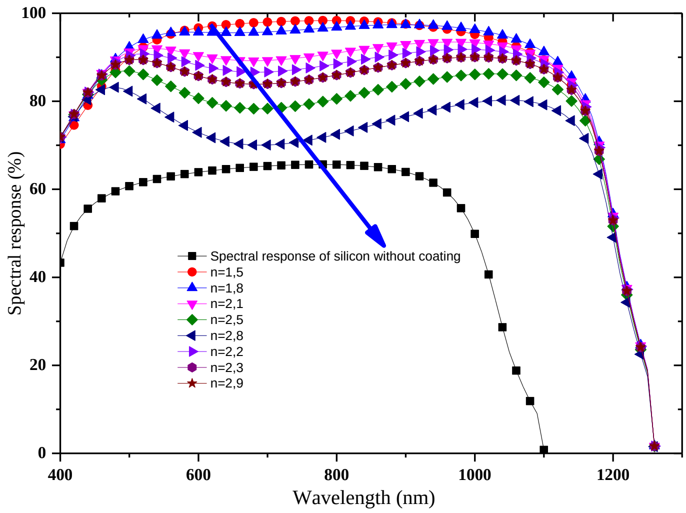

Fig. 4. Spectral response of the variation of the refractive index of one of the layers

These two figures show us that increasing and decreasing by 10 nm from the optimum value does not give a better quantum yield. It can also be seen that HFO_2 /Si gives a better performance than the other anti-reflective materials.

4. REFRACTIVE INDEX VARIATION OF ONE OF THE AR LAYERS FOR A DOUBLE LAYER COATING

In this section, the spectral response is studied on the silicon cell coated with two anti-reflection layers, with the indices of the materials varying from the largest to the smallest from the silicon substrate to the top outer layer. The Fig. 3. shows the importance of double-layer anti-reflection coatings on the external quantum efficiency of the monocrystalline silicon solar cell [11,12].

In the wavelength band between 650 and 1000 nm, there is a progressive decrease in the spectral response, which is explained by a very low absorption of the incident light with photon energies close to the silicon gap. Beyond 1100 nm, corresponding to photon energies below the silicon gap, the spectral response is cancelled out. Among the materials used, the SiO_x /Si combination presents the best response compared to other coatings. The refractive index of SiO_x , which is n =1.5, is close to the optimum index $\sqrt{;n_{air} \times n_{silicium}}$ related to the amplitude condition. This explains the fact that the cell with an anti-reflective SiOx coating has a spectral response close to 99% at the reference wavelength. On the other hand, it is observed that the response of the cell is lower in the range of the reference wavelength at an index of n = 2.8 which is quite close to the index of silicon and therefore different from the optimal index mentioned above. The optimal thickness of the anti-reflection layer also plays an important role as it must be large for low index materials which give a relatively lower efficiency than the other materials mentioned above. The main challenge related to the performance of solar cells with anti-reflective coating is to find a judicious compromise in the choice of thickness and the targeted material in order to reduce the manufacturing costs [13,14,15]. However, a clearer increase in spectral response implies an improvement in the minority carrier generation rate in the single crystal silicon solar cell.

5. CONCLUSION

Among these materials, magnesium fluoride (MgF_2), silicon nitride (Si_3N_4), hydrogenated silicon nitride (SiNx:H), silicon oxide (SiO_2), halfinium (HFO_2), silicon nitride oxide (SiOxNy) have shown interesting properties by reducing the reflectivity of silicon to less than 35%. The closer the index of the layer is to the optimum index $\sqrt{;n_{air} \times n_{silicium}}$ (n_{opt} =1.9451), the more the reflectivity becomes practically zero in the spectrum centred around the reference length which was chosen in this work equal to 700 nm.

Simulation studies of the spectral response of a conventional silicon p-n junction have shown the influence of thickness, which shifts the reflection coefficient minima towards short wavelengths for small thicknesses and towards long wavelengths for large thicknesses on either side of the reference wavelength of the anti-reflection layers, and the impact of the stacks on the cell performance with an increase from 60% to 90% or even 98%.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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