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INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/15345
DOI URL: http://dx.doi.org/10.21474/IJAR01/15345

RESEARCH ARTICLE

IMPACT OF TEXTURING SILICON COATED WITH A SINGLE ANTIREFLECTIVE LAYER

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Manuscript Info

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Manuscript History
Received: 05 July 2022
Final Accepted: 09 August 2022
Published: September 2022

Key words:-
Anti-Reflective Coating, Single Layer, Texturization, Reflection, Thickness, Refractive Index

Abstract

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This paper focuses on anti-reflective coatings on monocrystalline silicon solar cells and the impact of front surface texturing. The reference wavelength of silicon is λ_0 =700 nm, with its optimum refractive index (n = 3.7838) and a surface reflectivity of 33%. The calculations were made on the basis of layer thickness values and refractive indices that allow the phase and amplitude conditions chosen to be respected, namely (MgF_2); (SiO_xNy), (SiOx), and (SiNx:H). Numerical simulations have shown low reflectivity's at the surface of the planar cell coated with a single layer, but texturing on this same alloy allows a significant reduction in reflectivity. However, the comparison of the results of silicon coated with a simple anti-reflection layer on a plane surface and the textured one gives us important differences such as: 7,05% for MgF2 /Si, 4,6% SiOx/Si, 0,6% for SiOxNy/Si and 0,4% for SiNx:H/Si.

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Introduction:-

Any surface roughness reduces reflectivity by increasing the chances of light reflecting off the to reflect on the material. The texturization operation aims to develop a micrometric surface a micrometric relief (typically 5-10 µm), allowing multiple reflections[1]. The wavelength of the incident light being lower than the dimensions of the structures, the incident rays follow the laws of geometrical optics. Forexample, a ray arriving in normal incidence with respect to the plane of the cell is reflected on the face of an adjacent "pyramid", thus reducing the reflection coefficient from R-to-R². Moreover, the ray transmitted in the cell is with an angle of refraction different from 0°, increasing its path within the silicon compared to the case of a flat surface. The probability of absorption of photons is therefore improved[2]. Finally, the texturization of the back face leads to a more important trapping of the light within the cell.

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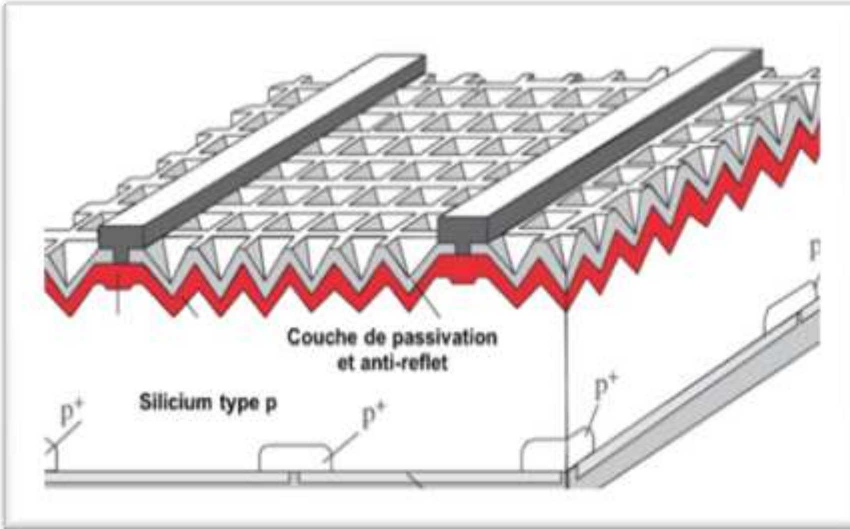

Figure 1:-Texturized surface of a silicon cell [3].

The **Figure 1**show a silicon cell with a textured front surface for better trapping of the incident light flux. In some situations, texturing can provide passivation of the semiconductor surface by removing some dangling bonds at the silicon surface. In addition, the path of the transmitted beam in the cell increases within the silicon compared to the case of a flat surface; the probability of absorption of photons is improved[4].

Multitude of Reflections: -

The reflection on a textured surface is three times greater than on a flat surface. In this case, the final equation for the total reflectivity of a textured surface of a cell is equal to the sum of one-third of the reflectivity on a flat surface plus the double reflection on two flat faces as shown in **figure 2.**

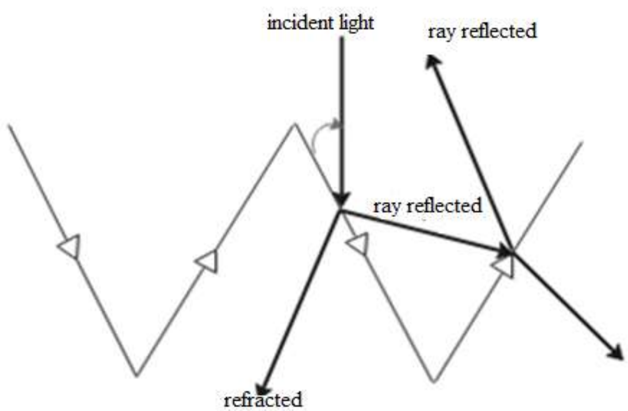

Figure 2:-Structure of silicon texturing in pyramidal form and under vertical illumination at the interface (under normal incidence).

Therefore, the total reflection estimation formula for the pyramid-shaped textured surface is given by the following equation:

$$R_{st} = \frac{1}{3} R_{sp}(\lambda) + \frac{2}{3} R^2{}_{sp}(\lambda) \quad (1)$$

The **Figure 3**shows the evolution of the reflectivity of silicon without an antireflective layer on a flat surface and on a textured surface as a function of the visible wavelength.

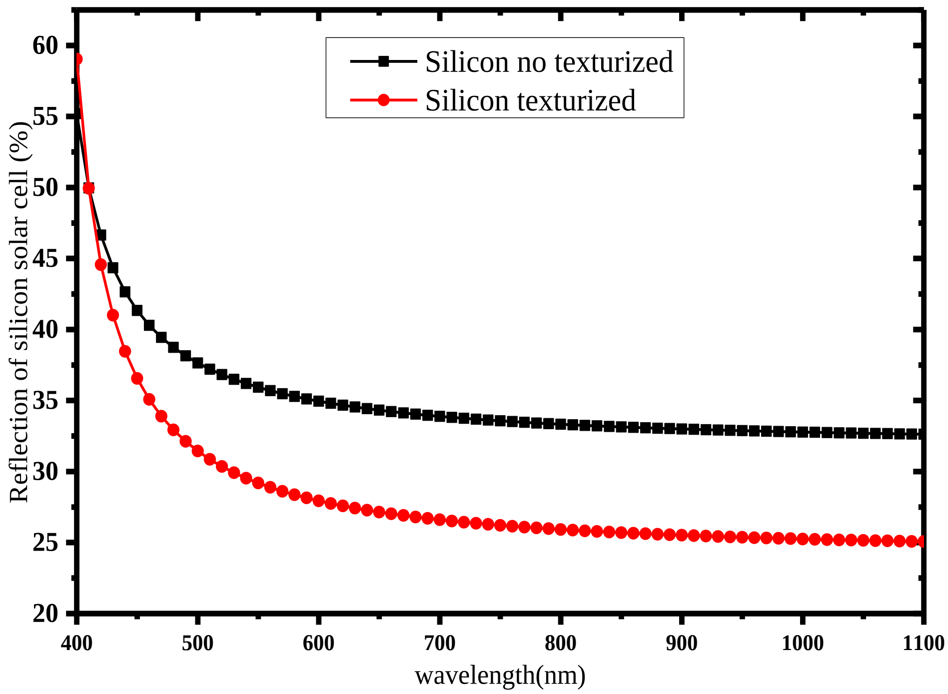

Figure 3:- Monocrystalline silicon solar cell with flat front surface (black) and textured front surface.

It shows two configurations, one in the range between 400 nm to 650 nm, the reflection coefficient is stronglydependent on the wavelength passing from 60% to 36% for the cell not textured. For a cell with a textured coating, the reflection coefficient varies from 60% to 26%. This reflection remains almost constant above 700 nm for boththe planar and texturized representations, 33% and 24% respectively. The lower reflectivity of the textured surface could be due to the trapping of light photons within the solar cell. This favors a strong absorption, hence the increase of the transmission and a decrease of the reflectivity. Moreover, the ray transmitted in the cell is with an angle of refraction different from 0°, increasing its path within the silicon compared to the case of a flat surface. Theprobability of photon absorption is therefore improved. Finally, the texturization of the back surface leads to a more important trapping of the light inside the cell.

Impact of texturizing simple anti-reflection layers: -

Texturing of the silicon surface can be done either in combination with an anti-reflective coating by itself. It is used to minimize reflection from the cell surface. A single crystal substrate can be textured by etching along the faces of the crystal planes. If this texturing is followed by the deposition of an anti-reflection layer (CAR), the reflectivity coefficient of the surface can be reduced to 3 or 4% for all wavelengths considered.

Table 1:- Materials used as anti-reflection layers with their refractive indices and optimumthicknesses for a reference wavelength □□= 700 nm.

Materials	Refractive index	Thickness (nm)
MgF_2	1,38	127,17
SiO_x	1,50	116,67
SiO_xN_y	1,80	97,22
SiN_x:H	2,30	58,33
Si (substrat)	3,78	46,20

In this section, the simulation is done on the reflectivity of silicon in the case where the front surface is textured and then in the case where this face is covered with an anti-reflective coating with materials such as MgF_2, SiO_2 and SiOxNy and SiNx:HThe attenuation of the incident luminous flux, before its transmission in the cell is due to the flux of photons reflected by the front surface of the cell. The reflection coefficient is then close to 35% for monocrystalline silicon[7, 8, 9 and 10].

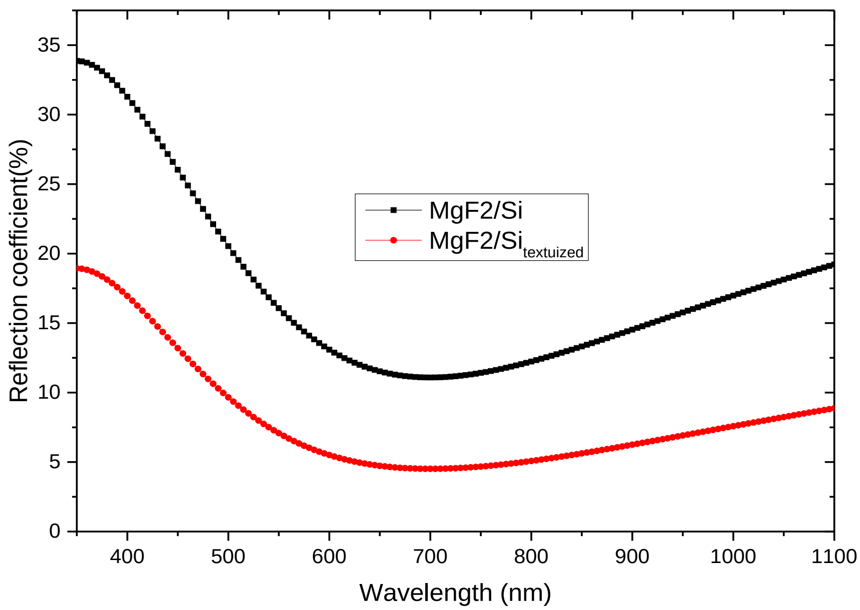

Figure 4:- Reflectivity of silicon with flat and textured anti-reflection layer

The **Figure 4** shows the combination of the textured silicon surface with various antireflective coatings. It shows that texturing the cell surface with an anti-reflective coating, reduces the reflectivity by 35 to 18% for all configurations at the 700 nm wavelength. This is justified by the trapping of a maximum amount of light which thus reduces the reflectivity losses and consequently improves the cell efficiency. It has been shown that the deposition of a single, double or triple anti-reflective layer decreases the reflectivity over the entire spectrum and can be zero for given wavelengths. The effective reflectivity of a cell without texturing covered with a single layer anti-reflection is about 12%.

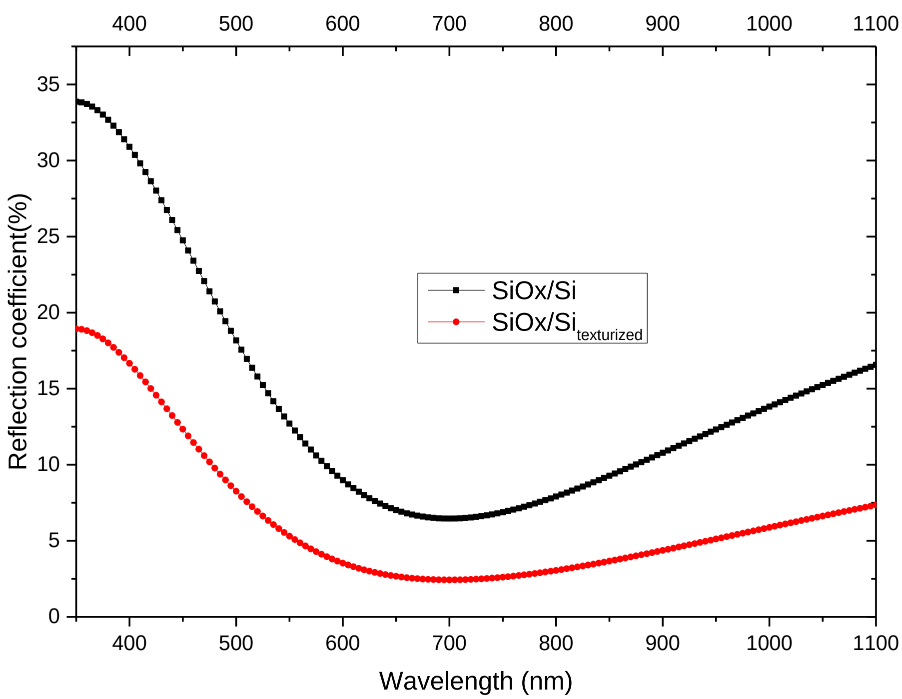

Figure 5:-Silicon reflectivity with flat and textured anti-reflection layer;

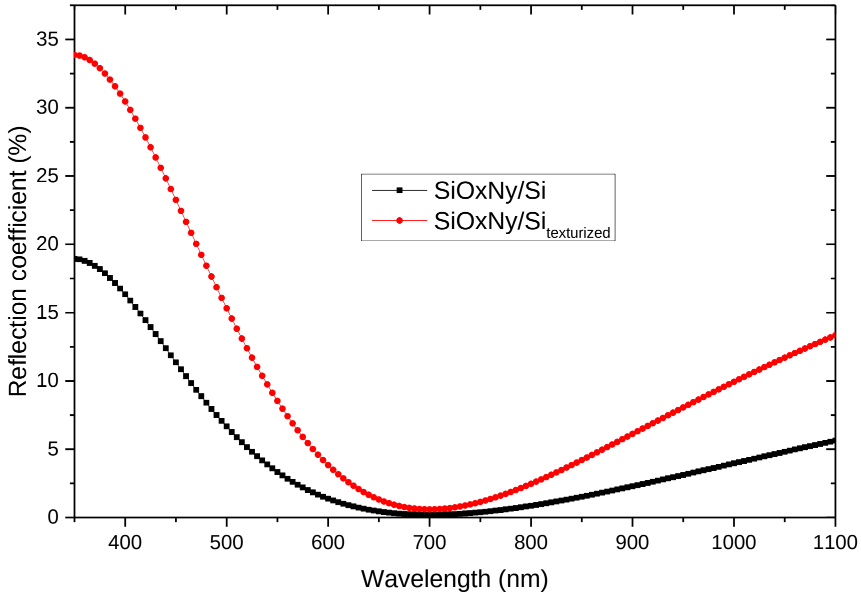

Figure 6:-Silicon reflectivity with flat and textured anti-reflection layer

The same phenomenon is reproduced with the two other anti-reflection layers such as SiOx and SiOxNy with areduction in reflectivity from 7.1 to 2.5% and from 1.1 to 0.5% respectively at the reference wavelength of 700nm.

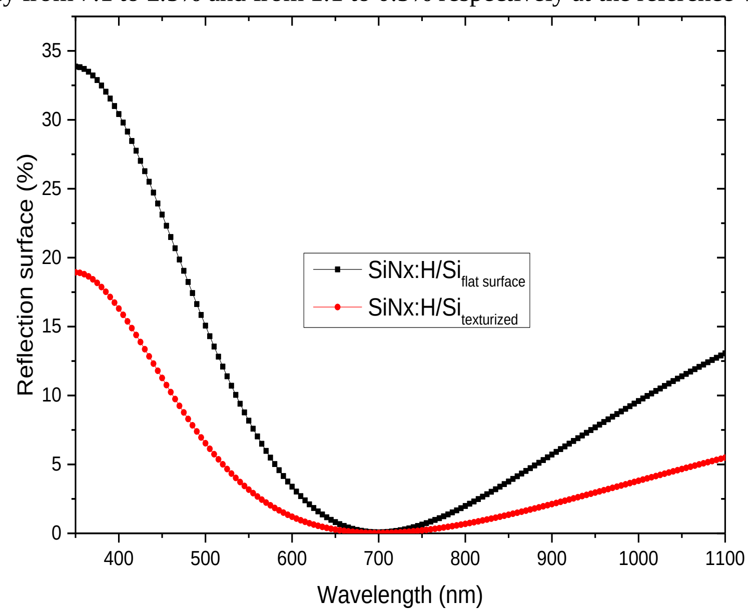

Figure 7:-Silicon reflectivity with flat and textured anti-reflection layer.

Concerning the SiNx:H the texturization reinforces the cancellation of the reflectivity at the reference wavelength ranging from 0.5 to 0.1% and being on a wider range of wavelength. This cancellation of reflectivity gives us an almost total absorption of the light flow by the cellThe absorption of all the radiation entering the solar cell is essential to obtain the best possible performance. The amount of light absorbed is a function of the length of the optical path and the absorption coefficient. Thus, the thinner the cell, the more it is necessary to increase the optical path within the silicon. The texturing of the back side (done at the same time as the front side) goes in this direction.Moreover, the desirable reduction of the cell thickness, for cost and efficiency reasons, generates too high mechanical stresses on this metal layer. The use of a BSF would reduce these constraints. Nevertheless, it would be necessary to add an additional layer between the contacts in order to passivate the back surface. A well-chosen refractive index would increase the probability of total internal reflection, maintaining a long optical path even for very thin cells. The possibility of using such a layer will be discussed in the following.

Table 2:- Different values of antireflective materials deposited on the flat and textured silicon interface taken at the reference wavelength 0 = 700 nm

Materials/substrate(silicon)	MgF2/Si	SiOx/Si	SiOxNy/Si	SiNx:H/Si
Reflectivity at the plane interface	11,8	7,1	1,1	0,5
Reflectivity at the textured interface	4,75	2,5	0,5	0,1
% of Gain in reflectivity	7,05	4,6	0,6	0,4

Conclusion:-

The grain texturing and the resulting change in thickness of the deposited layers change the reflectivity values. The antireflection layer and a well optimized back reflector combined with a good texturing on the front and back surfaces of the cell respectively, allow to reduce the reflection losses and to increase the reflection coefficient on the back side of the cell by creating constructive interferences, as shown in Table II which summarizes the reflection coefficient values of some textured coatings at the reference wavelength. The comparison of the results for the textured and untextured silicon surface leads us to a significant reduction of the reflectivity in percentage giving the following values: 7.05% for MgF2 /Si, 4.6% SiOx/Si, 0.6% for SiOxNy/Si and 0.4% for SiNx:H/Si. The texturing of the cell surface can reduce the reflectivity by up to 1/3 compared to the flat surface. These results lead us to say that the texturization of silicon covered with an anti-reflection layer strongly decreases the reflectivity thus favoring the absorption of almost all the luminous flux which will be converted into electrical energy.

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