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Reflection optimization of a multicrystalline solar cell embedded in a photovoltaic module

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Abstract - *In this paper we study the surface reflection of a photovoltaic module. The antireflection layer based on silicon nitride SiN_x, is deposited by PECVD technique and optimized to a solar cell surface. However, encapsulating the cell in a module (Glass/EVA/SiN_x/Silicon) modifies the total reflection of the whole structure. Therefore an optimization of reflection is required to get a good electrical output of the module. In this purpose, we have proceeded by characterizing step by step the optical constants of each layer constituting the module structure: SiN_x antireflective layer, EVA layer and glass. We elaborated a specific structure to get those parameters. We measured the total reflection in the UV-VIS-NIR spectra. Reflection curves of EVA and Glass show the same flat shape between 350 and 1100 nm. The mean reflection value of 8.2 % and 7.8 % respectively indicate that the two mediums EVA and glass are quasi similar. Meanwhile the whole structure presents a spectral reflection with a shape similar to that of silicon nitride layer, with a minimum around 600 nm (5.1 % and 2.3 % respectively). After simulating the optical parameters of the layers, we optimized again the reflection of the structure to be minimal. This indicates us that the optimal values of the SiN_x layer to be used in the structure are: n = 2.4 and d = 69.18 nm. These values give a minimum reflection of the structure around 0.16 % at 614 nm.*

Résumé - *Dans cet article, il est étudié la réflexion de la surface d'un module photovoltaïque. Une couche antireflet à base de nitrure de silicium SiN_x est déposée par la technique PECVD et est optimisée pour la surface de la cellule solaire. Cependant, l'encapsulation de la cellule solaire dans un module modifie la réflexion totale de l'ensemble de la structure Verre/EVA/SiN_x/Silicium. Par conséquent, une optimisation de la réflexion est nécessaire pour obtenir une bonne réponse électrique du module. A cet effet, nous avons procédé à la caractérisation étape par étape des constantes optiques de chaque élément constituant la structure: la couche antireflet SiN_x, la couche d'EVA et le verre. Nous avons élaboré une structure spécifique pour obtenir les paramètres n et d de chaque élément. Nous avons mesuré la réflexion totale dans le spectre UV-VIS-PIR. Les courbes de réflexion de l'EVA et du verre présentent une forme plane entre 350 et 1100nm. Les réflexions moyennes respectives de 8.2 % et 7.8 % indiquent que que les deux milieux EVA et Verre sont quasi-similaires. Alors que l'ensemble de la structure Verre/EVA/SiN_x/Silicium présente une allure de la courbe de réflexion similaire à celle de la couche de SiN_x et indique un minimum de réflexion autour de 600 nm (5.1 % et 2.3 % respectivement). Après simulation des paramètres optiques des couches, nous avons optimisé à nouveau la réflexion de la structure pour qu'elle soit minimale. Ce calcul nous indique que les valeurs optimales de la couche de SiN_x sont: n = 2.4 et d = 69.18. Ces valeurs donnent un minimum de la réflexion autour de 0.16 % à la longueur d'onde 614 nm.*

Keywords: Reflection - Simulation – SiN_x - Solar cell encapsulation.

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1. INTRODUCTION

Solar cell fabrication based on crystalline silicon dominate the world PV market with more than 90 % these recent years [1, 2]. For multicrystalline silicon, a layer of silicon nitride (SiN_x) is used as antireflective coating and a passivating layer [3 - 5]. The antireflective function ameliorates the quantity of photons penetrating the cell while the surface and bulk passivating function neutralizes grain boundaries and permits the collection of photo-generated charge carriers. So the SiN_x layer contributes to ameliorate the cell efficiency.

The cells connected in serial and parallel are encapsulated in glass and EVA (ethylene-vinyl acetate) structure to get the photovoltaic module [6]. The optical parameters (thickness and refractive index) of SiN_x layer are generally optimized to minimize the reflection of the Air/SiN_x/Silicon structure. However, after the encapsulation of the cells in the module, the structure becomes Air/Glass/EVA/SiN_x/Silicon. Optical adaptation must take into account those two additive layers which are EVA and glass. Hence optical constant optimization of silicon nitride has to be done integrating EVA and Glass contribution to the total reflection.

2. EXPERIMENTS

The transparent and plastic EVA material is a key element in cell encapsulation in quasi totality module elaboration for which the assembly [2] is illustrated in figure 1.

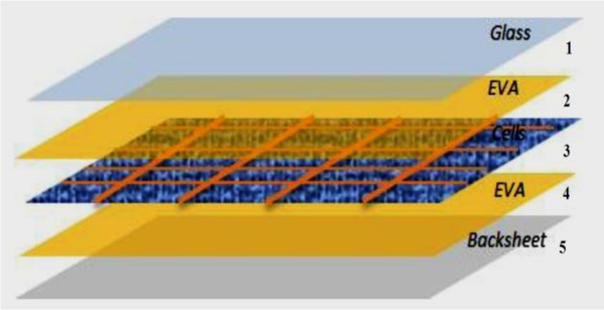

Fig. 1: Photovoltaic module Structure

(1) Glass protection screen, (2) 1st transparent layer ‘EVA’, (3) Interconnected solar cells
(4) 2nd transparent encapsulating layer ‘EVA’ (5) Rear Module isolation

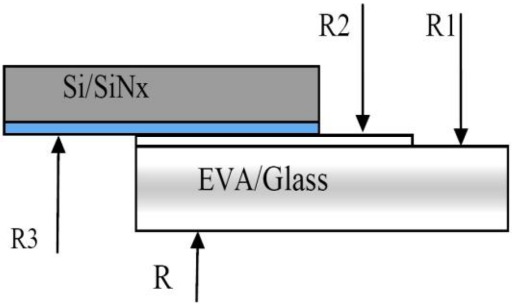

Fig. 2: Elaborated structure for reflection measurement

In our approach, for optical constant determination of SiN_x ARC layer, EVA layer and glass, we have proceeded by measuring the spectra reflection of the hole structure and individual layers (Glass, EVA, SiN). Silicon solar cell surface is polished. Measurement is made in the 350-1100 nm range on the specific elaborated structure as shown in figure 2.

The EVA layer was intercalated between the glass and SiN/Si by lamination at 200°C. The R1, R2, R3 and R rays correspond to the measurement of reflection of the light on the glass, EVA/glass, SiN_x/Si and all the structure Glass/EVA/SiN_x/Si respectively. The reflection spectra measured using a UV-VIS-NIR spectrophotometer (Varian CARY 500 model) are shown in figure 3.

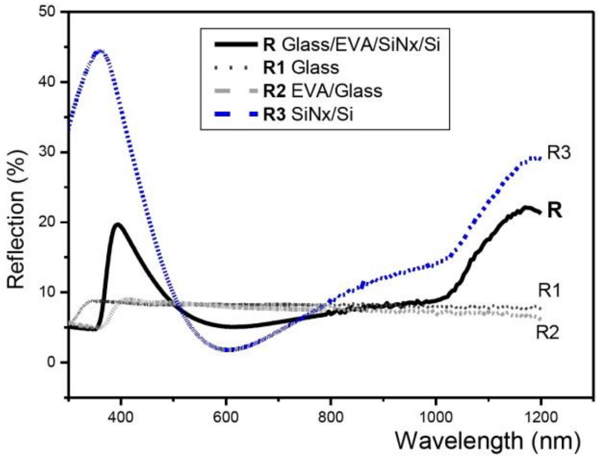

Fig. 3: Reflection of the structure Glass/EVA/SiN_x/Si and individual layers

3. RESULT ANALYSIS AND SIMULATION

The reflectance curves of glass and EVA have the same form and have a flat shape between 350 and 1100 nm with an average reflectance of 8.2 and 7.8 % respectively. In return, the reflection of the structure follows the shape of silicon nitride notably with a minimum around 600 nm (5.1 and 2.3 % respectively).

The assembly has a flatter shape due to the presence of glass and EVA. The value of 2.3 % can be improved by showing that SiN_x thickness and refractive index are not optimized for the entire system.

To optimize the optical constants n and d of SiN_x and EVA, the system Glass-EVA-SiNx-Si was dissected to simulate their individual reflection spectra. For this we used a software simulation FilmStar Design FTG Software Princeton, NJ Filmstar FTG Software Design (Princeton, N.J.).

3.1 Simulation of the EVA layer

We measured the reflection spectrum of EVA deposited on glass after lamination. The experimental curve is represented by vertical green dashes, and the simulated curve by continuous line. Figure 4 shows a good correlation between the two curves.

The simulated optimal values of the EVA are:

n = 1.48 ; d = 44.75 nm

It is these values that we use in the simulation of the whole structure.

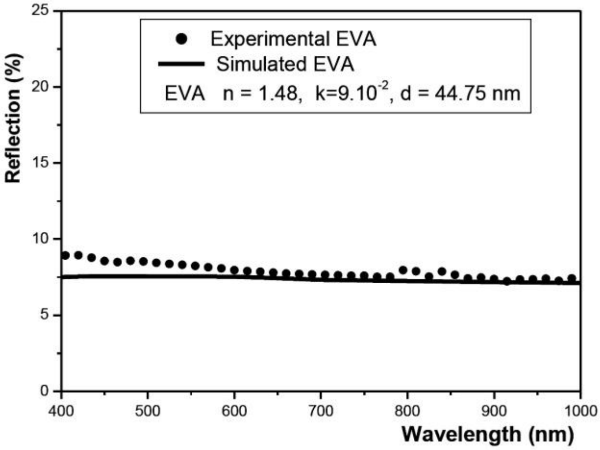

Fig. 4: Reflection Simulation of EVA layer

3.2 Simulation of the silicon nitride layer

The simulated values of the layer of silicon nitride are:

n = 2.39 ; k = 5×10^{-5} and d = 59.18 nm

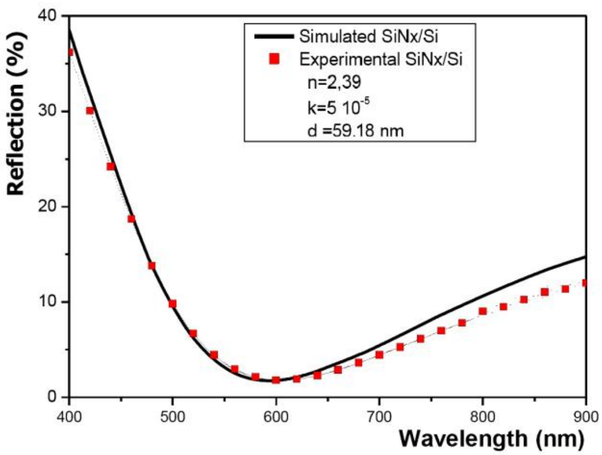

Fig. 5: SiN_x layer reflection simulation

3.3 Simulation of the whole structure Glass/EVA/SiNx/Si

From the simulated curve of figure 6, we have the following characteristics for the system Glass/EVA/SiN_x/Si: EVA: n = 1.48; d = 44.75 nm; SiN_x: n = 2.4; d = 25.74 nm. The curve has a minimum reflection of 5.05 % at 615 nm.

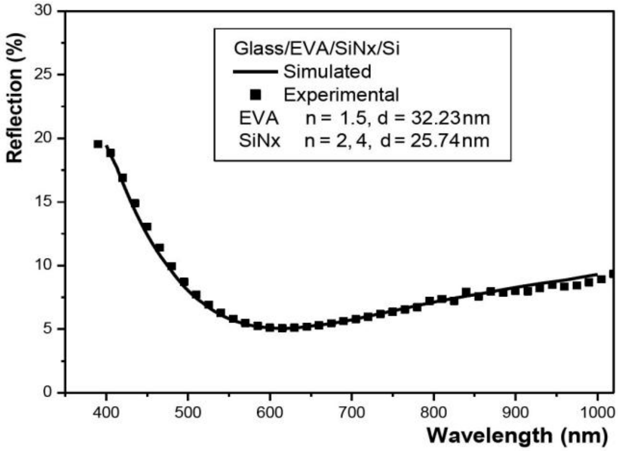

Fig. 6: Reflection simulation of Glass/EVA/SiNx/Si structure

Note that the values obtained for SiNx and EVA in the individual simulation and across the structure are different particularly the thickness.

3.4 Reflection optimization of the whole structure Glass/EVA/SiNx/Si

We made the optimization of theoretical parameters of the Glass/EVA/SiNx/Si structure. The simulation of the reflection spectrum allowed us to obtain a minimum reflection of the structure of 0.16 % at wavelength 614 nm (Fig. 7).

The SiNx and EVA n, k and d optimized parameters are:

SiNx: n = 2.4, k = 5 × 10^{-5}, d = 69.18 nm

EVA: n = 1.46, d = 32 nm.

We used a Seellmeier dispersion ($n(\lambda)$ = 1.5591; 0.2842; 0.9688; 0.0121; 0,0535; 112.17) for the glass parameters.

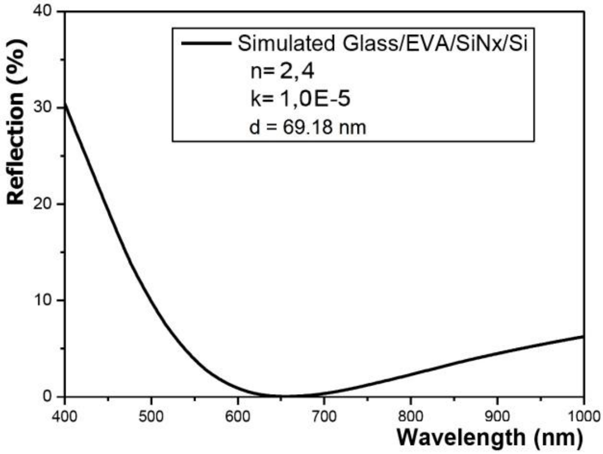

Fig. 7: SiN_x layer reflection optimization for the whole structure

4. CONCLUSION

We realized a specific schema editing Glass / EVA / SiNx / Si in order to measure the reflection spectrum of each element within that system.

Analysis of these spectra allowed us to accurately identify the most suitable values, including the thickness and the refractive index of the layer of silicon nitride, which allow us to minimize the reflection of the whole structure to a value of 0.16 % around 614 nm.

These values are respectively 2.4 and 69.18 nm.

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