Studies of the Effect of a Photons Converter (LDS) on the Characteristic Parameters of the Solar Cells

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Abstract- The aim of this paper is the improvement of the quantum efficiency of single crystalline silicon solar cells by applying the down-shift conversion of the solar spectrum. We have used this phenomenon of solar spectra shift in order to transfer incident photons of UV-Blue region to lower energy photons in visible spectra to be adapted to spectral sensitivity of the solar cells. Consequently, the reflection losses are reduced. For this object, we replace the PV encapsulation glass by polymethyl methacrylate (PMMA) doped with optically actives components. The effects of some optical transitions on the incident solar spectrum are modeled and simulated by taking into account the spectra of absorption and emission of each type of dopants used. We have shown an increase of about 9% in short circuit photo-current density (Jsc) and then in the photovoltaic conversion efficiency.

Keywords- Spectral Converter, Solar cells, PMMA, Solar spectrum, Encapsulation.

1. Introduction

The converter of photons (Luminescent Dawn Shift LDS) is a thin plate of PMMA doped with organic and inorganic dyes; the solar photons entering the LDS laminate are absorbed by the luminescent species and reemitted in random directions to where they will be converted by appropriate photovoltaic cells [1]. The primary motivation in developing LDS is the lower cost of converting to solar energy and also reduces the total weight of the PV modules, especially with there use in BIPV and space application, replacing the glass by PMMA doped at the PV encapsulation processes. It is a polymer which exhibits high physical and optical properties [2].

In our work we present the effect of LDS on electrical characteristics of the two structures formed by crystalline silicon solar cells, both provided with an antireflection coating of silica SiO2 and TiO2 titanium dioxide respectively. The reflection losses at the surface PMMA-ARC for both structures are modelled and simulated by taking into account the changes in incident solar spectrum mainly due to the absorption and emission of optically active substances in the layer of PMMA.

2. Understanding the Structure

The fig.1 presents the two structures of single junction type crystalline silicon coated with an antireflection coating of silica and titanium dioxide respectively, encapsulated by poly-methyl methacrylate (PMMA) doped with optically active molecules, whose optical properties of dopants are listed in Table 01 [2].

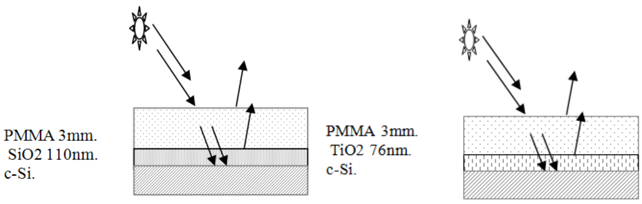

Fig. 1. Presentation of the two structures studied

3. Encapsulation Materials

The PMMA is a photovoltaic encapsulation material that has a high transmission (see Fig. 2), particularly in the region where the spectral response of solar cells is higher and the diffusion coefficient is low. At the same time, it presents an optimal environment for the dissolution of the luminescent species. It also supports the heat treatment that solar cells are subjected during their manufacturing and have a photo-stability extended over long periods of 20-25 years that PV manufacturers guarantee a minimum of 80% of the initial performance of their modules [3].

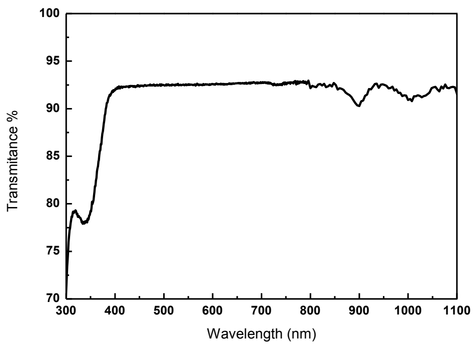

Fig. 2. UDES Experimental data of PMMA transmission Spectrum

4. Dopants

The fluorescent materials employed in LDS systems are wavelength converters, emitting photons of energy less than absorbed. We employed the interesting optical properties of these systems to form a luminous cascade, to obtain a shift of ultraviolet photons and blue to red and relative's red in the solar spectrum incident, which generally has a high conversion efficiency PV.

Many types of fluorescent materials have been studied for use in LDS including organic dyes, inorganic phosphors materials, and more recently quantum dots [3, 4, 5]. The good choice of the fluorescent materials is based on the emission band of the first substance that corresponds with the absorption band of the second and so on until have the wavelength shift.

The luminescent species used for LDS ideally characterized by:

- The unit of Luminescent Quantum Efficiency (LQE).
- Wide absorption band in the region where the External Quantum Efficiency (EQE) of the solar cells is lower.
- High absorption coefficient.
- Narrow emission band, which coincides with the top of the EQE solar cells,
- Good separation between absorption and emission of sin the order of the band to minimize losses due to resorption.
- Low cost.

Furthermore, as in the case of host materials (PMMA), the luminescent species must also present photo-stability for prolonged periods of 20-25 years. [1].

We obtained the samples of Poly Methyl Methacrylate (PMMA), after thermal treatment of the monomer methyl methacrylate (MMA) by adding fluorescent dopants with well studied concentration and thickness uniformity of the solution. In order to homogenize the solution, we put the MMA and fluorescent dopants in a centrifuge at a controlled speed. To complete polymerization of the monomer we make curing in an oven at 50 ° C for 3 h. Then, PMMA doped sample is removed carefully and cut it in the desired format and size [7].

Table 1. Shift in wavelength between the peaks from absorbance and florescence for each kinds of dopants used

Dyes	Max abs (nm)	Max emis (nm)	LQE(%)
Violet570	378	413	94
Yellow083	473	490	99
Orange240	525	539	100
Red300	578	613	98

5. Simulations Results and Discussions.

When exposed our sample of PMMA (LDS), to solar spectrum, which contains photons with an energy range from 300nm to 2000nm, much of this spectrum is absorbed for reissued with a shift to the visible range. The incident solar spectrum $\phi_S(\lambda)$, is modified by absorption of photons in the PMMA layer.

The quantity of photons absorbed in this layer $\phi_a(\lambda)$, is determined from the absorption spectrum, which depends on the size QD (quantum dyes), their concentration in the layer, and the thickness of this layer. This quantity of photons absorbed is subtracted from the spectrum incident. The Quantum dyes remit light at the red-shifted wavelength, the quantity of photons emitted $\phi_e(\lambda)$ is calculated from the emission spectrum QD, furthermore three quarters of the emitted photons are directed towards the solar cell, this is due to internal reflection in the converter layer [6].

All quantity of photons emitted is added to the modified solar spectrum incident.

$$\phi_{sa}(\lambda) = \phi_S(\lambda) - \phi_a(\lambda) + \phi_e(\lambda) \quad (1)$$

The result spectrum serves as an input for the solar cells simulation models [6]. Change in the (AM1.5G) solar spectrum caused by PMMA doped layer is reported in Fig.3.

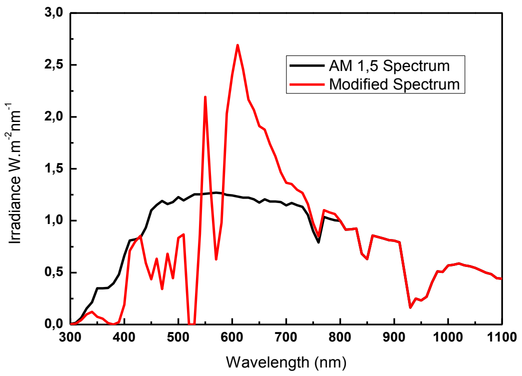

Fig. 3. The effect of the LDS system down- shifting on the AM 1.5 G solar spectrums.

The effect of LDS on the photocurrent generated by the c-Si solar cell is modelled, taking into account the reflection effect at the LDS-ARC interface.

The expression of the photo-current density with spectral sensitivity of silicon solar cells is given by the relation. [8]

$$J_{ph} = \phi(\lambda).(1-R(\lambda)).S(\lambda) \tag{2}$$

$\phi(\lambda)$:Irradiance expressed by W/m^2.

$R(\lambda)$:Reflection losses at the surface of the antireflection coating.

$S(\lambda)$:Spectral response of c-Si in (mA/W.m^2) is presented in Fig.4.

We calculated by simulation model of PN junction solar cell based on mono-crystalline silicon semiconductor, taking in account the technological parameters listed in Table 2 [7], with PC1D software (Version 5.8).

Table 2. Values of technological parameters input

Input technological parameters in PC1D software	Values
$N_d(cm^{-3})$	$2.8.10^{20}$
$N_a(cm^{-3})$	$1.5.10^{16}$
$S_p(cm/s)$	10^5
$S_n(cm/s)$	10^6
$\tau_p(s)$	10^{-6}
$\tau_n(s)$	10^{-6}
$L_p(\mu m)$	50
$L_n(\mu m)$	150
X_j (μm)	0.3
W(μm)	0.1
H(μm)	300

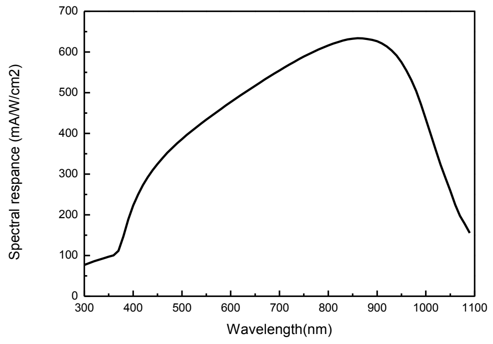

Fig. 4. Spectral response of a mono-crystalline silicon solar cell.

I noticed a significant sensitivity of these values to the near infrared and poor in the violet and blue.

We can extend the calculation of the photo-current on the solar spectrum range between 300-1100nm bands.

In fact:

$$J_{Ph} = \int_{\lambda 1}^{\lambda 2} J_{Ph}(\lambda).d\lambda \tag{3}$$

$$J_{Ph} = \int_{\lambda 1}^{\lambda 2} S(\lambda).\phi(\lambda).(1-R(\lambda)).d\lambda \tag{4}$$

The reflection coefficient as a function of the wavelength is modeled for the two polarizations by the following expression:

$$R(\lambda) = \frac{R_S(\lambda)+R_P(\lambda)}{2} \tag{5}$$

$$R_P = \left|\frac{E_r}{E_i}\right|_p^2 , \quad R_S = \left|\frac{E_r}{E_i}\right|_s^2 \tag{6}$$

Fig. 5, presented the variation of the reflection coefficient of the two structures study (TiO2/Si and SiO2/Si) with wavelength.

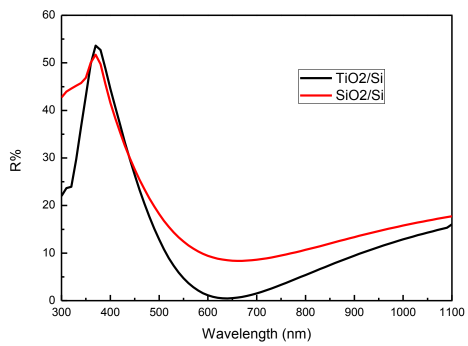

Fig. 5. Variation of reflection coefficient with the wavelength for the two structures studied.

The following table presented the output photo-current density values of the two structures studied (with and without

PMMA doped). The numerical simulation of the two structures demonstrate, an increasing in the photo-current density output values of the two structures doped with PMMA, good result obtained with TiO2 compared with SiO2 antireflection coatings, this explain by the remarkable differences between the reflection spectral coefficient of the two structure in the range 550-800nm see Figure 5.

Table. 3. Simulation results of Photo-current density values.

The structure	J_{Ph} (mA/cm2) without PMMA doped (LDS)	J_{Ph} (mA/cm2) with PMMA doped (LDS)	GJ_{Ph}(%)
SiO2/c-Si	26.356	28.70	8.90
TiO2/c-Si	28.04	30.66	9.36
GJ_{Ph}(%)	6.38	6.84	---

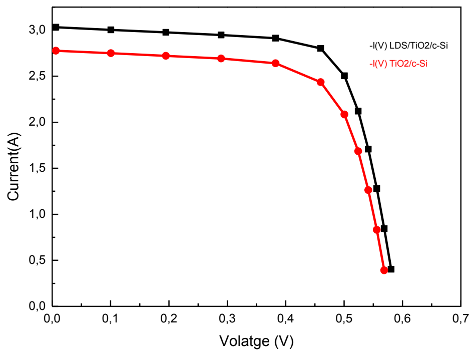

Fig. 6. I(V) Characteristics for the two structures studied (LDS/TiO2/c-SI and TiO2/c-SI) .

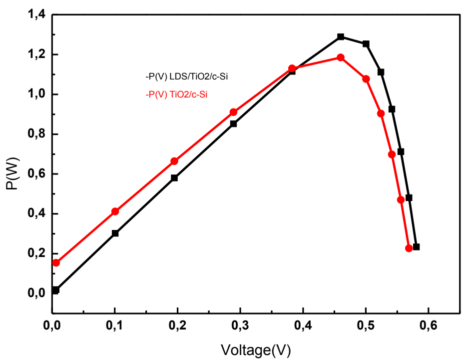

Fig. 7. P(V) Characteristics for the structures studied LDS/TiO2/c-Si and TiO2/c-Si .

Figures 6,7 , presents I(V) and P(V) characteristics of the two structures, demonstrat the good adaptation between LDS and TiO2 Anti-reflection coatings system compared to the other structures.

6. Conclusion

The numerical simulations indicate that the use of PMMA cascade luminescent encapsulation materials improves the performance of the solar cell structure and also gives an increase of the photo-current density (9.36%) in the case of the TiO2 antireflection layer deposited on silicon.

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