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Design of Building Integrated Photovoltaic (BIPV) and integration of photons converters

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Abstract

By the growth of global energy consumption and the increasing integration of renewable energies to the building, it becomes urgent to find innovative materials while increasing efficiency from energy conversions and lowering manufacturing costs. For this research, we began the study of replacement of glass used in solar panels by polymers having the function of converters of photons. Indeed, our led characterization tests have shown innovative polymers properties in the conversion of photons of UV to the visible range. This both, reduces the degradation of polymers exposed to UV and improves the power generation of PV cells. In fact, it is well known that conventional solar PV cells of terrestrial usage are more receptive to the range of visible than UV. By this method, we hope to reduce the cost of PV modules and increase conversion efficiency (up to 2-5%). Also, with these lighter materials the integration to roofs of buildings and agricultural greenhouses becomes very affordable.

Keywords: Photovoltaic, Building Integrated Photovoltaic (BIPV), Photons converter

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1. Introduction

The integration of photovoltaic modules to the building allows the efficient use of space and the production of energy needs. This approach contributes as an innovative element in modern architecture to the economy of energy and space. The photovoltaic modules are components whose life exceeds 25 years guaranteed and can be considered as an investment opportunity for building.

The application of photovoltaic technology has positive effects on the surfaces exploitation of the building. The photovoltaic modules can be used in different parts of the construction such as roof level

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(solar tiles) and absorb more incident solar radiation and then reduce heating of building. Photovoltaic modules are also used commonly in external facades to replace traditional glass and allow a decoration active in the energy saving. The Day lighting of building can be developed and specific design of the PV modules (BIPV) adapted to lighting needs of the day can be obtained by adjusting the spacing between solar cell assemblies in the case of silicon technology.

In the present study, we will focus on the replacement of conventional glass used in PV modules with a polymer material type PMMA doped. The role of this new material is the improvement of the optoelectronic performances and the reduction of total weight and cost. On this last point concerning weight and cost, the advantages of polymers comparatively to glass are well recognized. However, improvement of optoelectronic performance with the polymer material is based on an innovative concept for the conversion of photon energy in the UV and blue range to the wavelengths near of red and infrared area. It is so called "Downshift photons converter" and permits conversion of high energies photons to lower energies where silicon cells has better spectral response as explained here below.

2. Principal of Photons Down shift conversion

The solar spectrum contains photons with an energy range from 300 nm to 3000 nm. For example, in the multicrystalline (mc-Si) silicon solar cells the spectral responses are important to the near infrared and low in the violet and blue region of the spectrum (see Fig 1). Wavelengths ranging from UV to Violet and Blue for multicrystalline silicon solar cells have low response due to the fact the junction depth of these cells is very shallow, generally about 0.3µm (300 nm) then the photons of the solar spectrum near the junction depth will be almost completely absorbed in this area (emitter) and generate positive charges (holes) with a minimal contribution to the spectral response of photocell.

Typically, a solar cell absorbs a very specific energy range and the remaining energy is either reflected or transmitted. This range of photon energy for which the cell is most sensitive will depend on the technology used. For example, in the case of silicon cells (mono and multi crystalline) which is in particular interest for the present study, the range of high-energy photons (UV, Violet and Blue) give a low answer to cell, which in this case is more sensitive to the wavelengths located in the visible red.

The improvement of the photovoltaic cell performances by Downshift conversion (see Fig 2) is obtained with the transformation of photons having low conversion contribution (UV, Blue and Violet) by photons which can be absorbed beyond the zone of space charge (junction). This conversion may allow a greater contribution in the energy conversion and increase the performance (efficiency, and photo current). In particular, by using PC1D solar cells simulation software, we will predict the “down shifting” effect on solar cells characteristics. In addition, we will present our experimental analysis by spectrophotometry and photoluminescence techniques to quantify wavelength shifts that we have to use in PC1D simulation to study the effect of tested polymer material type doped PMMA. Several types of fluorescent dopants could be applied as like organic days, inorganic phosphors or quantum dots [1-5].

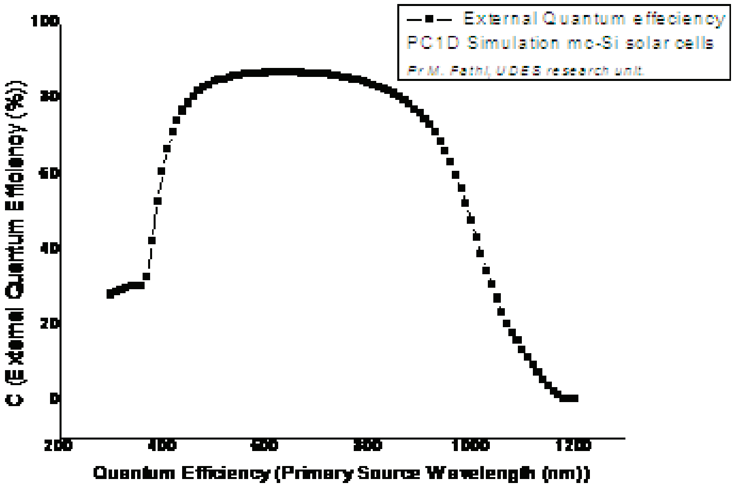
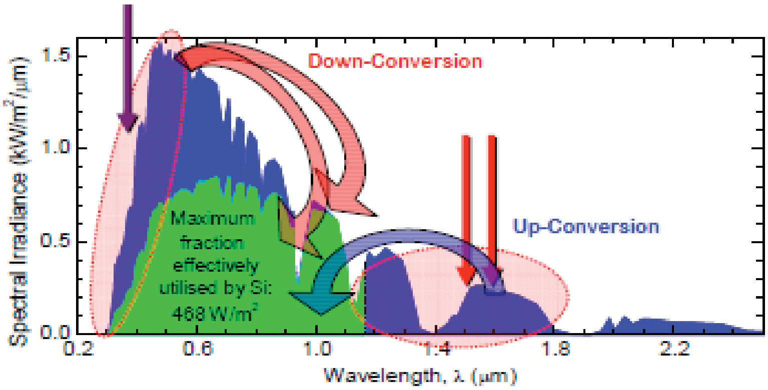


Fig. 1: Representation of the spectral response of wafer based solar cells



[adapted from Richards, Sol. En. Mat. & Sol. Cells 90 (2006) 2329–2337]

Fig. 2: Solar spectrum AM 1.5 and the principle of down shift conversion

3. Experimental and Spectrophotometry analysis data

As represented on Fig 3, 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 [1].

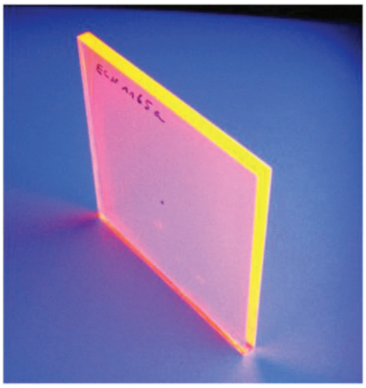


Fig. 3: Picture of the PMMA doped material applied to PV modules encapsulation

PMMA doped sample were analyzed by Spectrophotometric technique to determine the absorption, reflection and transmission coefficients in the spectral range (300-1100 nm).These measures have been done by using a Varian Cary 500 UV-VIS-NIR spectrophotometer equipped with an integrating sphere.Then, we get the absorption spectra of Absorption (A), Reflection (R) and Transmission (T) as it is reported on Fig 4.

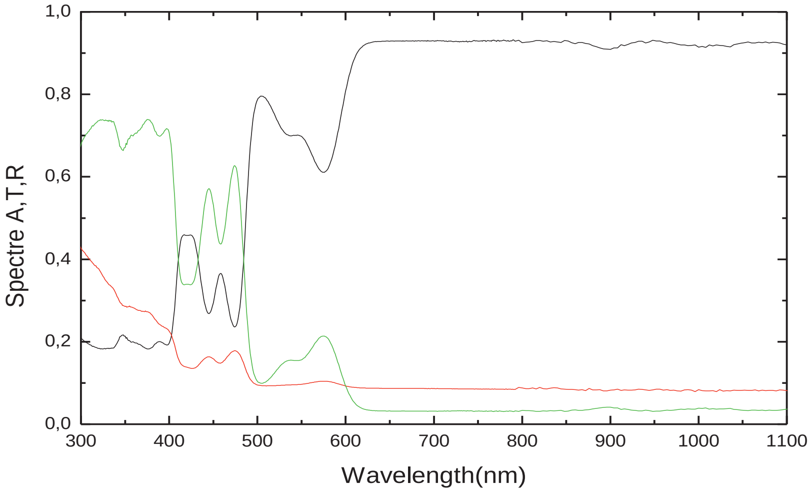


Fig. 4: Spectrophotometry analysis of PMMA doped sample, Absorbance A -, Transmission T-, Reflectance R-

On Fig 5, we observe that from the wavelength (457nm), an increase of the transmission coefficient, which gives a remarkably natural lighting inside the building in the visible spectral range. Meanwhile, the reflectance coefficient is less than 42% throughout the spectral range shown on Figure 05 and is about 8% for wavelengths above 600 nm. The sun light is absorbed in the 300 – 575 nm wavelength range and reissued with a shift towards the visible. Our led analysis by photoluminescence technique has shown that each absorption peak in the range of 300-574 nm has a corresponding peak to the fluorescence shifted to the visible wavelengths.

When our PMMA doped sample is exposed to sunlight, the light spectrum contains photons with energy range from 300 nm to 3000 nm, we find that much of this spectrum is taken to be reissued with a shift towards the visible. The solar spectrum at the entrance and exit of the sample doped PMMA is shown in Fig 5. An estimated downshift of 243 nm was applied to spectral range of 300-574 nm which is converted to 574-817 nm.

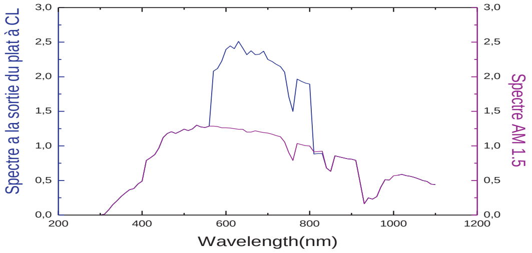


Fig. 5: Representation of the effect of the Downshift conversion system light on the solar spectrum AM 1.5

4. Simulation Results and Discussion

Solar cells based on silicon have significant spectral responses to the near infrared and poor sensitivity in the violet and blue (see Fig 1).To get the most from the conversion of the solar spectrum into electrical energy, photons with energies in the ultraviolet-blue band could be transformed into visible energy [6]. To study this purpose, we have stimulated by PC1D software the effect of photons downshifting on the photo-current generated by the solar cell. The parameters of the silicon solar cell used in the simulation PC1D are summarized in Table 1.

Table 1: Values of PV cell parameters applied in PC1D simulation

Applied parameters in PC1D simulation	Parameters values
Front doping (N)	2.8 10^{20} cm^{-3}
Background doping (P type Bulk)	1.5 10^{16} cm^{-3}
Bulk thickness	300 µm
(N) Junction depth	0.3 µm
Front surface texture depth	3 µm
Exterior front reflectance	10%
Bulk recombination	$\tau_n = \tau_p = 7$ µs
Front surface recombination	$S_n = S_p = 10^6$ cm/s
Back surface recombination	$S_n = S_p = 10^5$ cm/s
Device Area	100 cm^2

The Fig 6 shows our simulation results by PC1D software applied to a structure of silicon solar cell with our specific Downshift conversion layer (PMMA doped). We have used the experimentally obtained spectrum at the output of the PMMA doped layer and represented on Fig 5. Our PC1D simulation results establish that there is an important increase in PV cell photo-current output and efficiency encapsulated in

PMMA doped coating comparatively to cells without Downshift polymer; the Table 2 summarizes our simulation outcome.

Table 2: PC1D calculation of photo-current and efficiency for PV cell with Downshift conversion

J_{sc} (mA/cm^2) PV cell allone	J_{sc} (mA/cm^2) PV cell with Down Converter	η (%) PV cell alone	η (%) PV cell with Down Converter	Jsc Current improve (%)	Efficiency η improve (%)
31.8	44.0	13.62	18.62	38.36	5

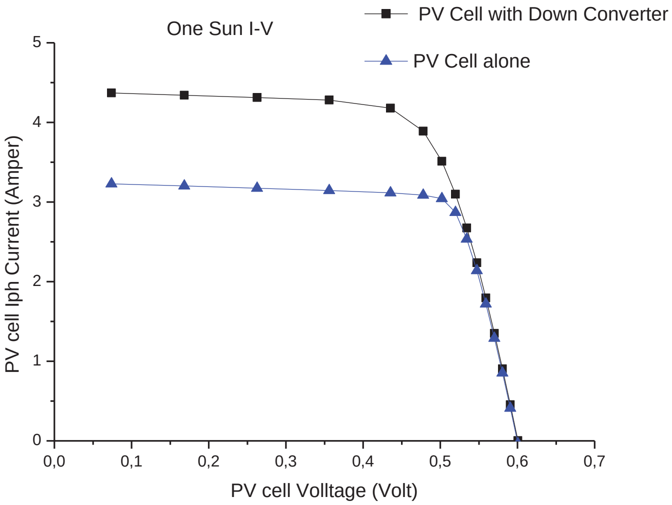


Fig. 6: PC1D Simulation of Downshift PMMA doped layer on PV cell characteristics

5. Conclusion

In order to match the spectral response of the solar cells applied to BIPV technology, we have introduced polymers of PMMA doped type. By using our synthesized polymers of doped PMMA, we have experimentally shown by spectrophotometry measurements a down shift of 243 nm in the spectral range from UV-Green [300-574 nm] to Visible-Red [574-817 nm] range. Then, we have demonstrated by PC1D simulation that the conversion efficiency of silicon solar cells will increase from 13.6% to 18.62% this corresponds to 5% improvement. We can consider that photon converter of PMMA type applied in the BIPV would ensure both the Daylighting and satisfaction to improved solar electricity power generation. The application of PMMA encapsulation material to silicon solar cells is a promising technology that contributes to decrease of cost and gives remarkable increases in the photoelectric energy production.

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