Thermal Degradation of Poly Methy Methacrylate (PMMA) Doped with Optically Active Molecules/Applications in Photovoltaic Conversion

M. Ayad and M. Fathi
EPST Centre de Développement des énergies Renouvelables, Unité de Développement des Equipements Solaires, RN11 Bou-Ismail BP. 386, 42415 Tipaza, Algeria
Email: ayad_h20@yahoo.fr

***Abstract*—In this work we develop the idea of using a Poly Methyl Methacrylate (PMMA) polymer doped with optically active molecules such as photovoltaic encapsulation materials wholes ensuring concentration of photons in the region where there is a high spectral response of solar cells by the Luminescent Down Shift (LDS) system. The results showed that the short-circuit current increased by 9%. These solar energy conversion systems are subject to a set of constraints upon exposure to environmental conditions, these processes have adverse effects on the long-term performance. The resistance of the doped PMMA an increase temperature was tested by Raman spectroscopy in the presence of a temperature rise of controlled system (DSC), the effect of some cycles of increasing in temperature on the optical properties of PMMA (Absorption, transmission and fluorescence) were presented. Moreover, the effect of this treatment in the LDS/c-Si solar cell performance was studied.**

***Index Terms*—conversion efficiency, down-shift system, polymethyl-methacrylate, organic dyes, spectrophotometry, solar spectrum, solar cell**

I. Introduction

The major problem in the technology of solar energy is to reduce the cost of collecting this energy or how to improve the efficiency of a solar cell [1]. To reduce the cost of photovoltaic energy conversion, many theoretical and experimental studies have been conducted to study the various parameters that affect the optical efficiency of photovoltaic conversion [2]-[4].

Downshift phenomena, is among the most efficient system, given its positive contribution in improving the performance of photovoltaic conversion. Moreover, due to the nature of the operation systems of solar energy conversion are subjected to a set of constraints on exposure to environmental conditions, and these processes have detrimental effects on long-term performance and life cycle costs of the system. These constraints include UV radiation, temperature, atmospheric gases and other pollutants. In addition, rain, dust, wind, etc..., may impose additional losses in the performance of a solar system.

In this work, we studied the effect of an increasing number of cycles temperature on the optical properties of PMMA_LDS samples (Absorption, transmission and fluorescence), in the second part, we study this effect on the performance of LDS/c-Si solar cells structures.

II. Luminescent Down Shift Systems

Luminescent Down Shift Systems (LDS) layers typically consist on a host material polymer PMMA doped with suitable luminescent species, the advantage of Luminescent Down-Shifting (LDS) system is that it does not require extensive fabrication procedures to improve the electronic properties of the semiconductor and could be implemented on existing solar cell technology’s [5].

The LDS process involves the modification of the incoming spectrum by absorbing light in the short wavelength region and shifting it to longer wavelengths where the spectral response of the solar cell is more efficient. As a result, the short circuit current (I_{sc}) is increased, increasing the power conversion efficiency [6].

The Poly Methyl Methacrylate (PMMA) has proven to be a very good candidate to be used as polymeric carrier matrix as it is highly transparent over a wide wavelength range, it possesses a high refractive index and it is easily processable [7]. However, this polymer still presents some limitations related to its environmental stability upon exposure to temperature and light [8].

In addition to carrier degradation, another major contribution to the performance decline of the illuminated LDS device is given by the relatively limited environmental satiability of the organic luminescent dyes, particularly when exposed to temperature. In this work, the thermal-degradation mechanism of a film LDS was investigated to identify the molecular modifications occurring to the organic dye when exposed to some cycles numbers of increasing temperature.

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III. Experimental Setup

The PMMA samples doped with optically actives molecules as a fluorescent solar collector have been prepared by a thermal transformation of PMMA process [6]. The emission spectrum of the fluorescent plate was measured by a spectrofluorophotometer (Perkin-Elmer). The spectra of absorption coefficient and of transmittance of the fluorescent plate were obtained by means of a spectrophotometer (Perkin-Elmer, Lambda 19).

The thermal-degradation of the LDS system was monitored by means of RAMAN spectroscopy (RXN-785nm) see Fig. 1, at exposed in some cycles of increasing in temperature via a DSC system Fig. 2-Fig. 3, a degradation mechanism for the dye molecule was proposed.

Figure 1. RAMAN spectroscopy system RXN-785nm

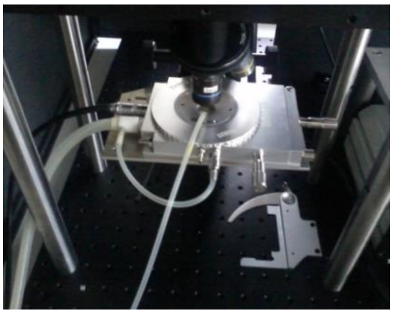

Figure 2. Differential ccanning calorimetric system

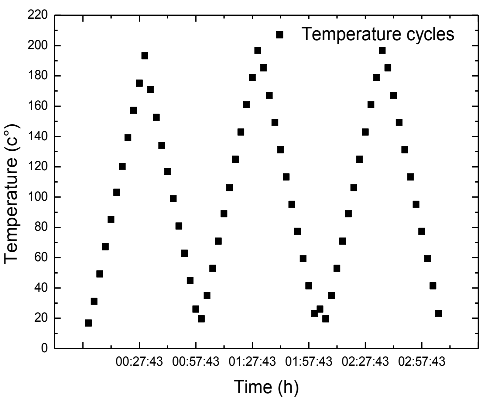

Figure 3. Represent a three cycles of increasing temperature

IV. Results and Discussions

A. Optical Characterization

The Absorption coefficient progressively decreases according to the increase of the number of heat treatment cycles. It is clearly observed in the range of [300 to 400 nm] (see Fig. 4).

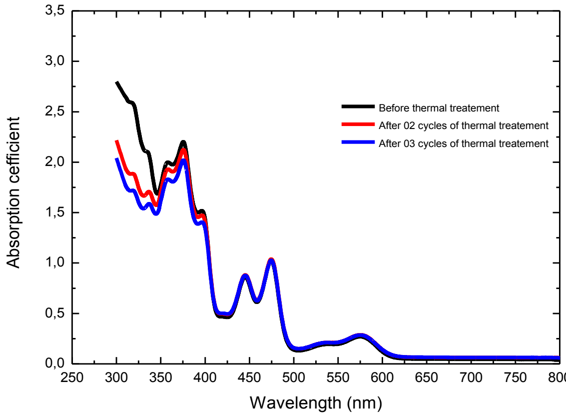

Figure 4. Experimental data absorption spectrum for PMMA sample doped fluorescents dyes.

Fig. 5 shows the emission spectrum of fluorescence LDS unexposed film to a heat treatment which is characterized by the emission peaks in the Region go from [400-600 nm]. Emission spectra were taken after the finish of each cycles of the thermal treatment (Fig. 5). A progressive decrease in the emission intensity is observed when increasing the period treatment.

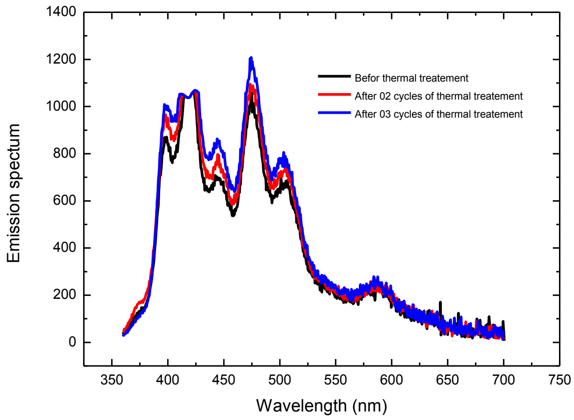

Figure 5. Experimental data emission spectrum for PMMA sample doped fluorescents dyes.

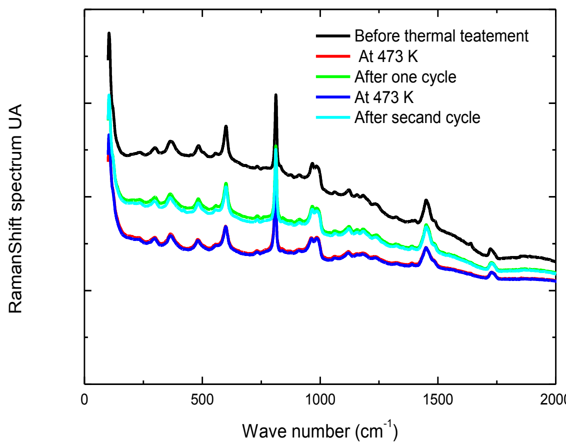

Figure 6. Shows the RAMAN spectra of LDS of different temperature degrees.

The normalized RAMAN fluorescent shifting is plotted against the temperature in Fig. 6. When the temperature increases the fluorescence intensity in the Raman spectrum decreases above 70% of its initial value. This phenomenon can be attributed to the creation phonon relaxation process; the energy of electron excitation can be dissipated by vibrations of the surrounding matrix, and the level of fluorescent species energy.

B. Electrical Characterization and Results

The effect of luminescent down shifting systems (LDS) on electrical characteristics of the (LDS/c-Si) solar cell structure are obtained in indoor testing, taking into account the changes in incident solar spectrum mainly due to the absorption and emission of optically active substances in the PMMA layer.

To evaluate the performance of LDS in different number thermal treatment cycles, a photovoltaic device was used for assessing the down shifting effect of the LDS, is fabricated by depositing the LDS layer above the surface of the c-Si cell. To minimize the losses walls, aluminum mirrors of a higher reflectance 90% for visible light were fixed on the four edges of the LDS layer.

By illuminating the LDS using a solar simulator under AM 1.5 conditions (100mW/cm^2, 25 ℃) as shown schematically in Fig. 7, the density current-voltage (J-V) curve of the attached solar cell was measured via a Keithley source measurement unit 236 [9].

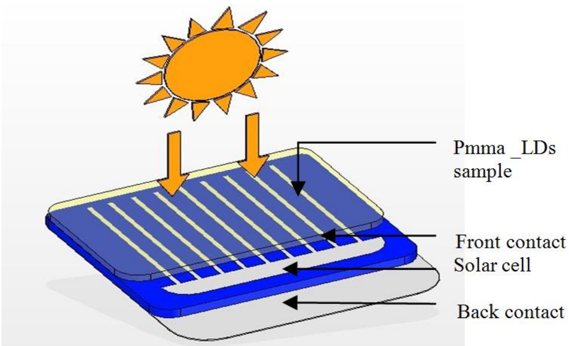

Figure 7. Presentation of the structure studied

A Labview interface was used to control the settings and display the J-V and P-V curves for each cell. From these curves the fill factor (*FF*), open circuit voltage (Voc) and the short circuit current (J_{sc}) was determined. The efficiency of the cell was calculated using equation 1 [9].

$$\eta = \frac{P_{max}}{AI_r} \quad (1)$$

where, P_{max} is the maximum power calculated in W, I is the global solar radiation measured in W/m^2 and A is the cell area given in m^2.

The current-voltage characteristics of the photovoltaic cell with PMMA_LDS layer under direct sun light radiation (100 W/cm^2) are shown in Fig. 8. The open circuit voltage (V_{oc}), short circuit current density (J_{sc}), the fill factor (FF), (P_{max}) and energy efficiency (η) were calculated and given in Table I.

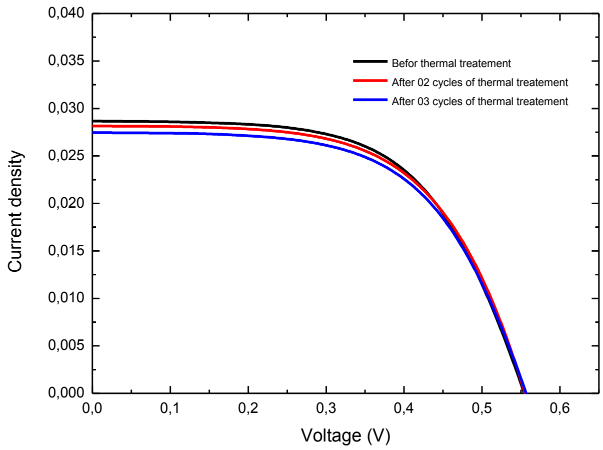

Figure 8. J–V curves of LDS/c-Si solar cell structure in various time of thermal treatment.

TABLE I. REPRESENT THE EVOLUTION OF CHARACTERISTICS PARAMETERS OF SOLAR CELL STRUCTURE STUDIED

Characteristics parameters	Treatment stats		
	c-Si with PMMA LDS before thermal treatment	c-Si with PMMA LDS after 2 Cycles of thermal treatment	c-Si with PMMA LDS after 3 Cycles of thermal treatment
Jsc (A/cm^2)	0.02867	0.02816	0.02745
Voc (V)	0.580	0.578	0.583
Pmax (W)	0.00954	0.0094	0.00915
FF	57.36	57.75	57.17
Ƞ (%)	9.54	9.4	9.15

The relationship between output power Pout and the number of thermal treatment cycles are plotted in Fig. 9 inset. As a number of thermal treatment cycles as increases, the power output (P_{out}) decreases.

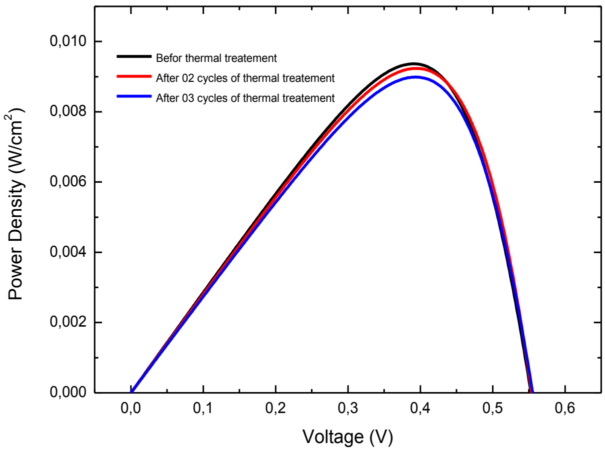

Figure 9. P–V curves of LDS/c-Si solar cell structure in various time of thermal treatment.

Fig. 10 shows the change in the current density and conversion efficiency of the LDS/c-Si solar cell structure according to the cycles number of increasing temperature, after 3 cycles, the conversion efficiency reached about 95% of its initial value.

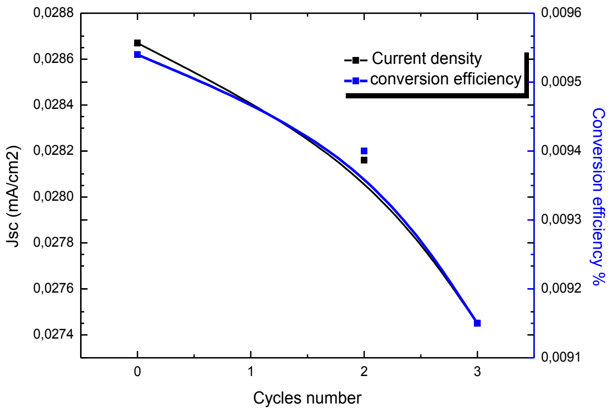

Figure 10. Represent the evolution of short-current density and conversion efficiency of the solar cell structure according to the number of thermal treatment cycles.

V. Conclusion

Our study indicates that the use of Luminescent Down Shifting (LDS) system such as converter photons in the encapsulation of made of mono-crystalline silicon solar cells is a technology capable of introducing remarkable improvements in the electrical characteristics of photovoltaic's components. It also gives an increase of the conversion efficiency. In addition, the thermal degradation of the LDS layer has an important role in the design of photovoltaic systems for photon conversion, electrical characterization of the component study shows small decrease noticed on the essential characteristics of the solar cell structure, current density and shorts conversion efficiency.

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References

[1] E. Klampaftis, D. Ross, K. R. Mcintosh, and B. S. Richards, "Enhancing the performance of solar cells via luminescent down-shifting of incident spectrum: A review," *Solar Energy Materials & Solar Cells*, vol. 91, pp. 1182–1194, 2009.

[2] L. Danos, *et al.*, "Increased efficiencies on CdTe solar cells via luminescence down-shifting with excitation energy transfer between dyes," *Solar Energy Materials & Solar Cells*, vol. 98, pp. 486-490, 2012.

[3] B. S. Richards and K. R. Mclntosh, "Enhancing the efficiency of production CdS/ CdTe PV modules by overcoming poor spectral response at short wavelengths via luminescence down-shifting," in *Proc. IEEE 4th World Conference on Photovoltaic Energy Conversion*, Hawaii, USA, May 2006, vol. 1, pp. 213-216.

[4] T. Maruyam and R. Kitamura, "Transformations of the wavelength of the light incident upon CdS/CdTe solar cells," *Solar Energy Materials & Solar Cells*, vol. 69, pp. 61-68, 2001.

[5] H. Ahmed, J. Doran, and S. J. McCormack, "Increased short-circuit current density and external quantum efficiency of silicon and dye sensitised solar cells through plasmonic luminescent down-shifting layers," *Solar Energy*, vol. 126, pp. 146–155, 2016.

[6] M. Ayad and A. Aisssat, "Photo-stability of the photons converter applied in the photovoltaic conversion systems," *Solar Energy*, vol. 133, pp. 221-225, 2016.

[7] Y. Zhang, *et al.*, "Polymethylmethacrylate-based luminescent solar concentrators with bottom-mounted solar cells," *Energy Conversion and Management*, vol. 95, pp. 187–192, 2015.

[8] H. A. Ahmed, J. Walshe, M. Kennedy, T. Confrey, J. Doran, and S. Cormack, "Enhancement in solar cell efficiency by luminescent down-shifting layers," *Advances in Energy Research*, vol. 1, no. 2, pp. 117-126, 2013.

[9] J. Merigeon, O. Maalej, B. Boulard, A. Stanculescu, L. Leontie, D. Mardare, and M. Girtan, "Studies on Pr3+–Yb3+ codoped ZBLA as rare earth down convertor glasses for solar cells encapsulation," *Optical Materials*, vol. 48, pp. 243–246, 2015.

Mohammed Ayad was born in Jijel, Algeria, in 1977. He received his undergraduate in physics from Jijel University in 2001 & Magister in Physics of Optoelectronics Materials from Oum Bouaghi University Algeria in 2003. To date, he is PhD student of electronics at technology faculte from Saad Dahlab Blida 01 University Algeria. From 2005 to 2016, he is a researcher in the Renewable Energy Equipment Division at Solar Equipments Development Unit EPST CDER. He has experience in the fields of electronic engineering, and solar photovoltaic energy.

Dr. Mohamed Fathi received the B.S., M.S. and PhD degree in Electrical Engineering and Electronics from Bordeaux I University, France, in 1988, 1990 and 1996 respectively. He obtained the title of Professor Habilitated in Electronics from Saad Dahlab Blida University, Algeria, February 2012. He joined the UDES in 2009 (Unit é de D éveloppements des Equipements Solaires, Bou-Ismail, Algeria) where he was promoted at the scientific level position of Research Director since June 2011 after several academia valorisations. He was a former General Director of CRTSE Research Center in Semiconductor Technology for the Energetic (CRTSE-UDTS) (Algiers). Previously, he was Head of Renewables Energy Equipment Division at UDES and Head of Photovoltaic Cells Laboratory (LCP) at UDTS (Silicon Development Unit), Algiers, Algeria. He obtained over 80 International publications and conference papers, two patents. He leaded several expertise and consultancies for industry in developing high scale photovoltaic manufacturing projects on the whole PV value chain: stating from the poly-silicon raw material to PV cells and modules. Lastly, Dr. Mohamed Fathi focused his scientific research projects on implementation of Thin Films and Nanotechnology for improving the performance of solar energy systems and adaptation to desert climates. Since 2012 he is Professor at Specialized Telecom Engineers School of Transmission, El-Mouradia, Ministry of the Interior and Local Government Algeria.