Hybrid Optical Devices: The Case of the Unification of the Electrochromic Device and the Organic Solar Cell

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ABSTRACT

The development of Hybrid Optical Devices, using some flexible optically transparent substrate material and organic semiconductor materials, has been widely utilized by the organic electronic industry, when manufacturing new technological products. The Hybrid Optical Device is constituted by the union of the electrochromic device and the organic solar cell. The flexible organic photovoltaic solar cells, in this hybrid optical device, have been the Poly base (3-hexyl thiophene), P3HT, Phenyl-C61-butyric acid methyl ester, PCBM and Polyaniline, PANI, all being deposited in Indium Tin Oxide, ITO. In addition, the thin film, obtained by the deposition of PANI, and prepared in perchloric acid solution, has been identified through PANI-X1. In the flexible electrochromic device, the Poly base (3,4-ethylenedioxythiophene), PEDOT, has been prepared in Propylene Carbonate, PC, being deposited in Indium Tin Oxide, ITO. Also, both devices have been united by an electrolyte solution prepared with Vanadium Pentoxide, V_2O_5, Lithium Perchlorate, $LiClO_4$, and Polymethylmethacrylate, PMMA. This device has been characterized through Electrical Measurements, such as UV-Vis Spectroscopy and Scanning Electron Microscopy (SEM). Thus, the result obtained through electrical measurements has demonstrated that the flexible organic photovoltaic solar cell presented the characteristic curve of standard solar cell after spin-coating and electrodeposition. Accordingly, the results obtained with optical and electrical characterization have revealed that the electrochromic device demonstrated some change in optical absorption, when subjected to some voltage difference. Moreover, the inclusion of the V_2O_5/PANI-X1 layer reduced the effects of degradation that this hybrid organic device caused, that is, solar irradiation. Studies on Scanning Electron Microscopy (SEM) have found out that the surface of V_2O_5/PANI-X1 layers can be strongly conditioned by the surface morphology of the dielectric.

Keywords: Polyaniline, PANI, P3HT/PCBM Blend, electrochromic device, Flexible Organic Photovoltaic.

1. INTRODUCTION

The synthesis and application of new nanostructured organic materials, for the development of technology based on organic devices, have taken great interest from the scientific community [1]. In recent years, the first polymeric electronic products have got on the market (organic semiconductor materials), including electrochromic devices, named as smart windows, by considering that they control the passage of light or heat through a closed environment, like an ordinary window. Similarly, the main functional aspects of electrochromic devices, utilized in the architectural and automotive industry, have been related to controlling the passage of light and temperature in order to provide thermal and visual comfort[2].

Furthermore**,** these devices can be flexible and very thin, containing no heavy metals, and being formed by layers of organic material deposited in several architectures. The greatest interest in studying organic semiconductor materials has been connected to its already known potential applications, such as: batteries,

organic solar cells, flexible organic solar cells, organic light emitting diodes and others [3].
Therefore, this research has aimed to develop thin films with some semiconductor organic material for the Hybrid Optical Device, constituted by the union of the electrochromic device and the flexible organic solar cell, when utilizing the Electrodeposition technique, characterizing layers and devices, as well as by utilizing electrical Measurements and Scanning Electron Microscopy (SEM) techniques.

2. EXPERIMENTAL DETAILS

The Hybrid Optical Device, developed in this research, has utilized some optically transparent material, covered with Indium Tin Oxide (ITO) on the surface, as its substrate. ITO has presented high conductivity and transmission in the visible region of the electromagnetic spectrum, which has enabled its utilization, for instance, in organic solar cells and electrochromic devices [4].
The poly(ethylene terephthalate) substrate, based on polymeric material, being utilized for the spin-coating of P3HT/PCBM Blend, has been, then, prepared with chlorobenzene, using 150 to 150 µL at 500 rpm, for five seconds, in each deposition. The PANI-X1 layer was deposited through the Electrodeposition system in solution prepared with perchloric acid ($HClO_4$), applying voltage of 10.0 volts, for 5 minutes, and resulting on an active layer of PANI-X1, with thickness between 180 nm and 220 nm. The other layer has utilized poly(ethylene terephthalate) substrate, based on polymeric material; PEDOT has been utilized for the spin-coating of Poly (3,4-ethylenedioxy thiophene), prepared in Propylene Carbonate solution, PC, with thickness of 100 nm, and being covered by a layer of ITO, with a thickness of 200 nm. Beyond that, the PEDOT layer has been deposited through the spin-coating technique, adding from 100 to 100 µL at 750 rpm, for ten seconds, in each deposition. Both devices have been united by an electrolyte solution, prepared with Vanadium Pentoxide, V_2O_5, Lithium Perchlorate, $LiClO_4$, and Polymethylmethacrylate, PMMA.
The developed Hybrid Optical Device has presented a layered configuration with PET/ITO/P3HT:PCBM Blend/PANI-X1/V_2O_5/ $LiClO_4$/PC/PMMA/PEDOT/PC/ITO/PET, as represented schematically in figure 1.

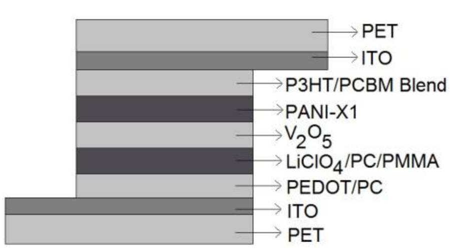

Figure 1. Configuration of the Hybrid Optical Device.

3. DISCUSSION

The electrical characterization of the Hybrid Optical Device has been carried out at room temperature, by utilizing an Electrometer Keithley 6517A semiconductor parameter analyzer. All measurements were realized without vacuum and no precautions were taken to prevent the degradation of multilayer polymeric films [5][6].
Figures 2 and 3 have demonstrated the results obtained in the electrical measurements for electrodes PET/ITO/P3HT:PCBMBlend/PANI-X1/V_2O_5 and PEDOT/PC/ITO/PET. It is interesting to note that there has been not only an increasing in the electrical resistance, R_s, but also in the electrical resistivity, ρ, after the deposition of thin film layers. The electrical resistivity has been calculated through equation 1, where V is the voltage in volts, I is the electric current, ρ is the electrical resistivity and Δx is the thickness of the deposited material [7]. See equation 1.

$$R_s = \frac{\rho}{\Delta x} = \left(\frac{\pi}{\ell n2}\right) . \frac{V}{I} \qquad (1)$$

These graphs have indicated that the electrical resistivity has been completely related to sheet resistance and thickness, Δx, of the deposited thin film. In addition, counting on the linear fit of the experimental results through equation 2, it is possible to obtain the conductive layer of the deposited thin film, α, and the lowest resistivity, B_{res}, being associated with the gap between the valence band and the conduction band [8][9]. See equation 2.

$$\rho = \alpha . R_s + B_{res} \qquad (2)$$

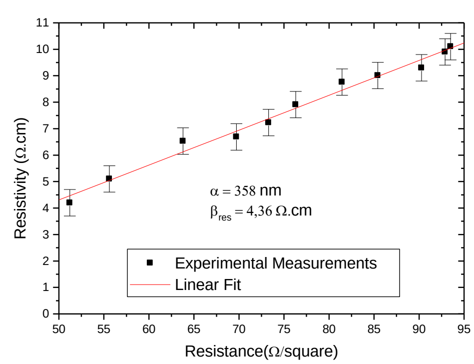

Figure 2. Electrical resistivity of the PET/ITO/P3HT:PCBMBlend/PANI-X1/V_2O_5 in function of sheet resistance.

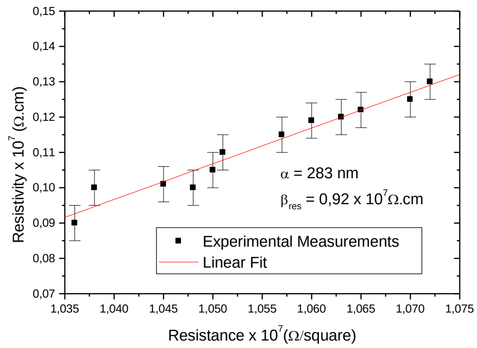

Figure 3. Electrical resistivity of the PEDOT/PC/ITO/PET in function of sheet resistance.

The absorption spectroscopy ultraviolet-visible characterization of the Hybrid Optical Device, utilized a Cary 50 UV-Vis Spectrophotometer.

Figure 4 has demonstrated the spectrum absorption in the spectral region of 200-1100 nm of the Hybrid Optical Device. This result has indicated that the gradual increase of ddp of 0.0 volt to 5.0 volt generated a greater deviation in the optical spectral region between 400-700 nm. Consequently, this result has characterized the device as a good attenuator to the radiation occurring in the visible region. In the spectrum of the Hybrid Optical Device, it can be also observed that there has been an increase in the optical absorption in the infrared region, which may prescribe the utilization of this device as a film attenuating infrared radiation in buildings and automobiles.

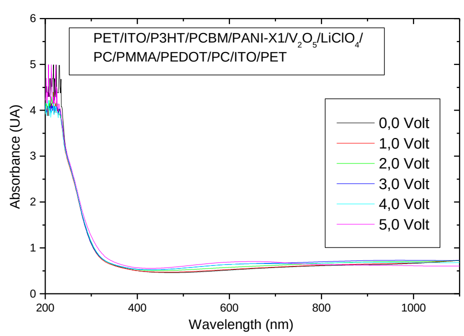

Figure 4. UV-Vis spectroscopy of the Hybrid Optical Device

The microscopic analysis performed in the Hybrid Optical Device, through Scanning Electron Microscopy, has allowed us to observe the induction on the surface of the samples before and after the application of illumination with 100mW/cm^2. Figure 5 has shown the micrograph of the Hybrid Optical Device, before applying illumination, and the surface of the sample may be observed as demonstrating some homogeneous aspect, being plane and presenting no changes.

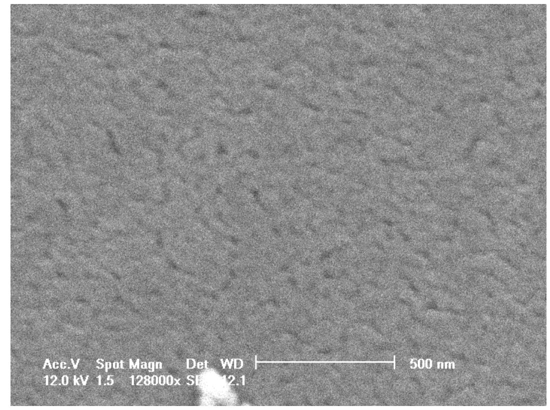

Figure 5. SEM of the Hybrid Optical Device before applying illumination.

4. CONCLUSIONS

The production of the Hybrid Optical Device, utilizing electrodes PEDOT/PC/ITO/PET, has provided some change in the observed UV-Vis spectral behavior, while PEDOT has not had benzene rings, which may present absorption in the region of 300-500 nm. The PC has not caused the displacement of bands, inferring that the optical absorption, in the infrared region, has occurred due to the proposed innovative architecture. On the other hand, the electrodes PET/ITO/P3HT:PCBMBlend/PANI-X1/V_2O_5 have not provided any change in the observed UV-Vis spectral; this electrode has been utilized as an active layer of the organic solar cell. Thus, the inclusion of the V_2O_5/PANI-X1 layer reduced the effects of degradation that this hybrid organic device caused, that is, solar irradiation.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] A. G. MacDiarmid, *Current applied physics* 1, p.269-279 (2001).

[2] H. Varela et alii, *Química Nova*. n. 2, v. 25, p.287-299 (2002).

[3] A. F. S. Guedes, E. M. Costa, V. P. Guedes, Formation of Nanoparticles in Organic Materials used in Semiconductors Optoelectronic Devices. *ECS Trans.* **31**, 231-236 (2010).

[4] S. Yun et alli. Noncontact characterization of sheet resistance of indium–tin-oxide thin films by using a near-field microwave microprobe. *Thin Solid Films* **515**, 1354-1357 (2006).

[5] A. F. S Guedes, V.P. Guedes, S. Tartari, M. L. Souza. I.J. Cunha. New Electronic Technology

Applied in Flexible Organic Optical System. *Journal of Systemics, Cybernetics and Informatics*, v. **12**, p. 1-4, 2014.

[6] A. F. S Guedes, V.P. Guedes, S. Tartari, M. L. Souza. I.J. Cunha. New optoelectronic technology simplified for organic light emitting diode (oled). *Journal of Systemics, Cybernetics and Informatics*, v. **12**, p. 72-74, 2014.

[7] R. C. Jaeger, Introduction to microelectronic fabrication. Addison-Wesley Publishing Co., Massachusetts, **5**, (1989) 230p.

[8] A. F. S Guedes, V.P. Guedes, S. Tartari, M. L. Souza. I.J. Cunha. New organic semiconductor materials applied in organic photovoltaic and optical devices. *Journal of Systemics, Cybernetics and Informatics*, v. **13**, 2015.

[9] A. F. S Guedes, V.P. Guedes, S. Tartari, M. L. Souza. I.J. Cunha. The Electrodeposition of Multilayers on a Polymeric Substrate in Flexible Organic Photovoltaic Solar Cells. *Proc. SPIE* 9561, *Thin Films for Solar and Energy Technology* VII, 95610N. 2015.