ELSEVIER

Synthetic Metals 121 (2001) 1549–1550

SYNTHETIC METALS

www.elsevier.com/locate/synmet

Solid state dye-sensitized TiO_2 solar cells with poly(3-octylthiophene) as hole transport layer

D. Gebeyehu[1*], C. J. Brabec[1], F. Padinger[2], T. Fromherz[2],

S. Spiekermann[3], N. Vlachopoulos[3], F. Kienberger[4], H. Schindler[4] and N.S. Sariciftci[1]

[1] *Linz Institute for Organic Solar Cells (LIOS), Physical Chemistry, Johannes Kepler University Linz, Altenbergerstraße 69, A-4040 Linz (Austria)*

[2] *Quantum Solar Energy Linz, Austria*

[3] *Inst. Phys. Chem. Ecole Polytechnique, Lausanne, Switzerland*

[4] *Institute for Biophysics, Johannes Kepler University of Linz*

Abstract

Hole conducting polymers are of practical interest as a possible replacement for the liquid electrolyte in dye-sensitized TiO_2 photoelectrochemical solar cells. We have studied the photovoltaic properties of P3OT/dye coated porous nanocrystalline TiO_2 and P3OT/porous nanocrystalline TiO_2 devices and compared them with P3OT/dye coated flat TiO_2 and P3OT/flat TiO_2 devices. The surface network morphology of these film layers is investigated by atomic force microscope, AFM.

Keywords: Solar cells; Polythiophene and derivatives; TiO_2; Organic/inorganic interface; Metal/semiconductor interfaces.

1. Introduction

Dye-sensitized nanoporous TiO_2 photoelectrochemical solar cells emerged recently as legitimate alternative to conventional photovoltaic cells for the conversion of sunlight to electrical power [1-3]. The highest efficiency reported for this device is around 10% under AM 1.5 (1000 W/m^2) irradiation [2].

Although the dye-sensitized nanocrystalline TiO_2 solar cells (nc-DSCs) show such a good performance, it has not yet found significant commercial application because of problems like evaporation of the electrolyte, stability or degradation of the electrolyte or dye. Replacing the liquid electrolyte by a polymer gel electrolyte that conduct ions [4] or an amorphous conducting material that transports holes [5] already allowed the assembly of all-solid-state devices. Polymer materials that behave as hole-conductors and sensitizers are of practical interest as replacements for the liquid electrolyte since they are inexpensive and can be tailored chemically to fit a wide range of purposes. In this work, we present the photovoltaic properties of three- and bilayered devices, combining the electron transporting properties of TiO_2, light absorbing properties of Ru-dye complex and the hole accepting and transporting properties of poly(3-octylthiophene), P3OT.

2. Experimental

Films of nanocrystalline TiO_2 on ITO or SnO_2:F coated glass substrates (sheet resistance of 13 ohm/square) were prepared by doctor blading a paste from Solaronix Co.(Ti-Nanoxide T, colloidal anatase particle size about 13 nm). The above layers of the paste were then sintered for 30 minutes at 450 °C in the oven and soaked with cis-bis(isothiocyanato)bis(2,2′-bipyridyl-4,4′-dicarboxylato)-ruthenium(II)bis-tetrabutylammonium, RuL2(NCS)2 : 2 TBA dye from Solaronix Co. used as sensitizer for 2 μm layer thickness. Subsequently, a hole transport layer was applied by spin-coating films of P3OT from toluene solution (10 mg in 1ml toluene). After an additional drying step the top electrode gold (Au) was deposited by vacuum deposition. The current-voltage (I/V) characteristics were measured with a Keithley SMU 2400 Source Meter

* Correponding author:Desta.Gebeyehu@jk.uni-linz.ac.at

PII: S0379-6779(00)01239-X

measurement unit in argon atmosphere under illumination through ITO or SnO_2:F side by a white light source solar simulator. The surface network morphology of these film layers was examined with an atomic force microscope in contact mode (Nanocsope IIIa from digital instruments).

3. Results and Discussion

Figure 1 shows the I/V characteristics comparison of ITO/nc-TiO_2/Ru-dye/P3OT/Au with ITO/nc-TiO_2/P3OT /Au photovoltaic devices under illumination using a linear scale.

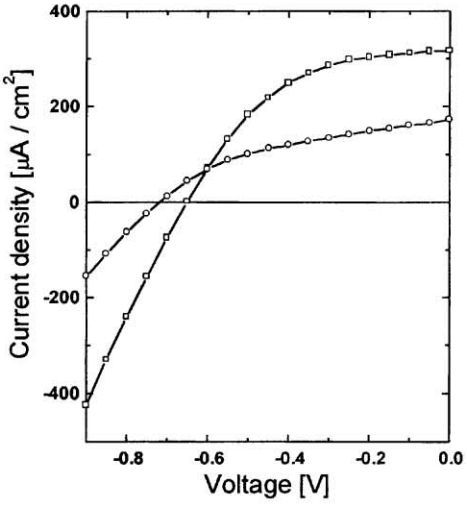

Figure 1: I/V characteristics of P3OT/Ru-dye/nc-TiO_2 (open squares: illuminated with 60 mW/cm^2) and P3OT/nc-TiO_2 (open circles: illuminated with 60 mW/cm^2).

The characteristic values of the P3OT/Ru-dye/nc-TiO_2 device are open circuit voltage, V_{oc} ~ -0.65 V, short circuit current, I_{sc} ~ 325 μA/cm^2 and a fill factor, FF ~ 0.44, whereas for the P3OT/nc-TiO_2 device an V_{oc} ~ -0.70 V, I_{sc} ~ 170 μA/cm^2 and a fill factor, FF ~ 0.4 under white light illumination with 60 mW/cm^2 are observed. The overall energy conversion fficiency, η_e, for the P3OT/Ru-dye/nc-TiO_2 solid-state solar cells was calculated to be approximately 0.15 % under white light solar simulator 60 mW/cm^2 for an active area of 5 mm^2.

Figure 2 below illustrates the surface morphology of P3OT/nc-TiO_2 and P3OT/Ru-dye/nc-TiO_2 AFM images.

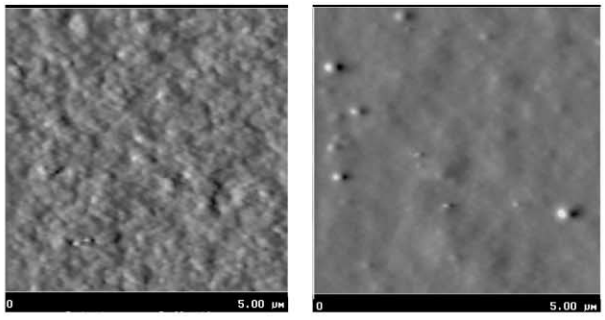

Figure 2: AFM of P3OT/nc-TiO_2 (left picture) and P3OT/Ru-dye/nc-TiO_2 (right picture).

The nc-TiO_2/Ru-dye/P3OT film shows a dense and very homogeneous flat surface (with a root mean square value, RMS of about 4.4 nm ± 0.8 nm) without pinholes, in contrast to P3OT/nc-TiO_2 (left picture) which indicates less smooth films with RMS value of about 6 ± 0.85 nm and an average depth of about 20 nm.

To verify possible problems with shunting, devices were rebuilt on flat TiO_2. In figure 3 the comparative characteristic data of P3OT/Ru-dye/ flat TiO_2 and P3OT/flat TiO_2 devices are in a linear scale plotted.

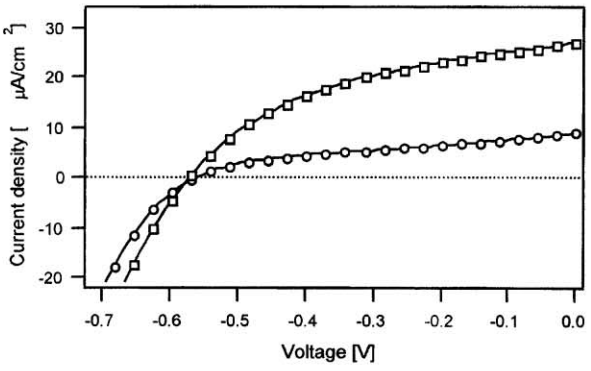

Figure 3: I/V characteristics of P3OT/Ru-dye/flat TiO_2 (open squares illuminated with 64 mW/cm^2) and P3OT/flat TiO_2 (open circles: illuminated with 64 mW/cm^2).

The characteristic values of the P3OT/Ru-dye/flat TiO_2 and P3OT/flat TiO_2 device are V_{oc} ~ -0.57 V, I_{sc} ~ 27 μA/cm^2 and a fill factor FF ~ 0.43 and V_{oc} ~ -0.56 V, I_{sc} ~ 9 μA/cm^2 and a fill factor FF ~ 0.36 under white light illumination with 64 mW/cm^2, respectively. Compared to nc-TiO_2 devices, both I_{sc} and V_{oc} are found to be smaller, while the FF stays the same.

4. Conclusion

We have realized a novel device concept for hybrid solid-state solar cells. These devices showed the usefulness of conducting polymers as a hole transport material as well as sensitizer materials for the possible replacement of the liquid electrolyte in nanoporous TiO_2 type solar cells. Our results showed, the polythiophene seemed to go quite well into the pores of TiO_2. Even for nc-TiO_2 devices, no problems with shunting are observed.

References

[1] B. O'Regan, M. Grätzel, Nature 353 (1991) 737.
[2] M. K. Nazeeruddin, A. Kay, I. Rodicio, R. Humphry-Baker, E. Müller, P. Liska, N. Vlachopoulos, M. Grätzel, J. Am. Chem. Soc. 115 (1993) 6382.
[3] C. J. Barbe, F. Arendse, P. Comte, M. Jirousek, F. Lenzmann, V. Shklover, M. Grätzel, J. Am. Ceram. Soc. 80 (1997) 3157.
[4] F. Cao, G. Oskam, P. C. Searson, J. Phys. Chem. 99 (1995) 17071.
[5] U. Bach, D. Lupo, P. Comte, J. E. Moser, F. Weissörtel, J. Salbeck, H. Spreitzer, M. Grätzel, Nature 395 (1998) 583.