

# Solid state dye-sensitized TiO<sub>2</sub> solar cells with poly(3-octylthiophene) as hole transport layer

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## Abstract

Hole conducting polymers are of practical interest as a possible replacement for the liquid electrolyte in dye-sensitized TiO<sub>2</sub> photoelectrochemical solar cells. We have studied the photovoltaic properties of P3OT/dye coated porous nanocrystalline TiO<sub>2</sub> and P3OT/porous nanocrystalline TiO<sub>2</sub> devices and compared them with P3OT/dye coated flat TiO<sub>2</sub> and P3OT/flat TiO<sub>2</sub> devices. The surface network morphology of these film layers is investigated by atomic force microscope, AFM.

*Keywords:* Solar cells; Polythiophene and derivatives; TiO<sub>2</sub>; Organic/inorganic interface; Metal/semiconductor interfaces.

## 1. Introduction

Dye-sensitized nanoporous TiO<sub>2</sub> 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<sup>2</sup>) irradiation [2].

Although the dye-sensitized nanocrystalline TiO<sub>2</sub> 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<sub>2</sub>, light absorbing properties of Ru-dye

complex and the hole accepting and transporting properties of poly(3-octylthiophene), P3OT.

## 2. Experimental

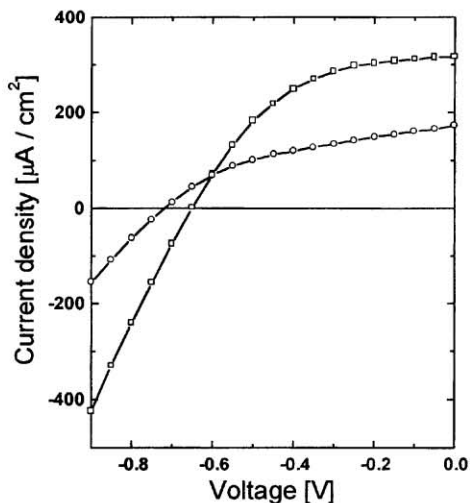
Films of nanocrystalline TiO<sub>2</sub> on ITO or SnO<sub>2</sub>:F coated glass substrates (sheet resistance of 13 ohm/square) were prepared by doctor blading a paste from Solaronix Co. (Ti-Nanoxide T, colloidal anatase particle size about 13 nm). The above layers of the paste were then sintered for 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)<sub>2</sub> : 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

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measurement unit in argon atmosphere under illumination through ITO or  $\text{SnO}_2\text{:F}$  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 (Nanoscope IIIa from digital instruments).

### 3. Results and Discussion

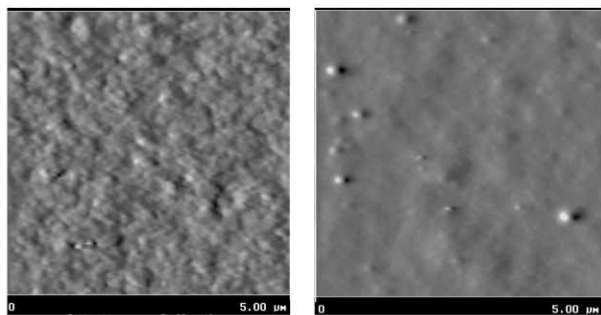
Figure 1 shows the I/V characteristics comparison of ITO/ $\text{nc-TiO}_2$ /Ru-dye/P3OT/Au with ITO/ $\text{nc-TiO}_2$ /P3OT/Au photovoltaic devices under illumination using a linear scale.



**Figure 1:** I/V characteristics of P3OT/Ru-dye/ $\text{nc-TiO}_2$  (open squares: illuminated with  $60 \text{ mW/cm}^2$ ) and P3OT/ $\text{nc-TiO}_2$  (open circles: illuminated with  $60 \text{ mW/cm}^2$ ).

The characteristic values of the P3OT/Ru-dye/ $\text{nc-TiO}_2$  device are open circuit voltage,  $V_{oc} \sim -0.65 \text{ V}$ , short circuit current,  $I_{sc} \sim 325 \text{ } \mu\text{A/cm}^2$  and a fill factor,  $FF \sim 0.44$ , whereas for the P3OT/ $\text{nc-TiO}_2$  device an  $V_{oc} \sim -0.70 \text{ V}$ ,  $I_{sc} \sim 170 \text{ } \mu\text{A/cm}^2$  and a fill factor,  $FF \sim 0.4$  under white light illumination with  $60 \text{ mW/cm}^2$  are observed. The overall energy conversion efficiency,  $\eta_e$ , for the P3OT/Ru-dye/ $\text{nc-TiO}_2$  solid-state solar cells was calculated to be approximately 0.15 % under white light solar simulator  $60 \text{ mW/cm}^2$  for an active area of  $5 \text{ mm}^2$ .

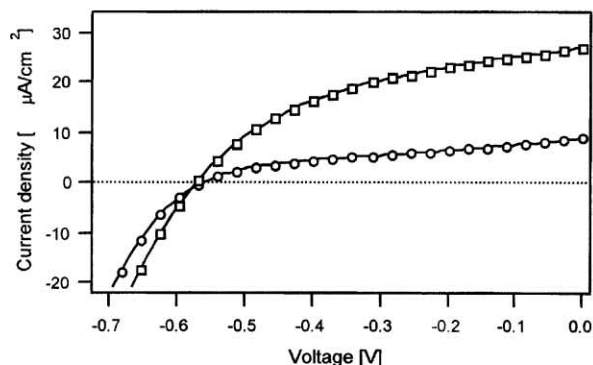
Figure 2 below illustrates the surface morphology of P3OT/ $\text{nc-TiO}_2$  and P3OT/Ru-dye/ $\text{nc-TiO}_2$  AFM images.



**Figure 2:** AFM of P3OT/ $\text{nc-TiO}_2$  (left picture) and P3OT/Ru-dye/ $\text{nc-TiO}_2$  (right picture).

The  $\text{nc-TiO}_2$ /Ru-dye/P3OT film shows a dense and very homogeneous flat surface (with a root mean square value, RMS of about  $4.4 \text{ nm} \pm 0.8 \text{ nm}$ ) without pinholes, in contrast to P3OT/ $\text{nc-TiO}_2$  (left picture) which indicates less smooth films with RMS value of about  $6 \pm 0.85 \text{ nm}$  and an average depth of about 20 nm.

To verify possible problems with shunting, devices were rebuilt on flat  $\text{TiO}_2$ . In figure 3 the comparative characteristic data of P3OT/Ru-dye/flat  $\text{TiO}_2$  and P3OT/flat  $\text{TiO}_2$  devices are in a linear scale plotted.



**Figure 3:** I/V characteristics of P3OT/Ru-dye/flat  $\text{TiO}_2$  (open squares illuminated with  $64 \text{ mW/cm}^2$ ) and P3OT/flat  $\text{TiO}_2$  (open circles: illuminated with  $64 \text{ mW/cm}^2$ ).

The characteristic values of the P3OT/Ru-dye/flat  $\text{TiO}_2$  and P3OT/flat  $\text{TiO}_2$  device are  $V_{oc} \sim -0.57 \text{ V}$ ,  $I_{sc} \sim 27 \text{ } \mu\text{A/cm}^2$  and a fill factor  $FF \sim 0.43$  and  $V_{oc} \sim -0.56 \text{ V}$ ,  $I_{sc} \sim 9 \text{ } \mu\text{A/cm}^2$  and a fill factor  $FF \sim 0.36$  under white light illumination with  $64 \text{ mW/cm}^2$ , respectively. Compared to  $\text{nc-TiO}_2$  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  $\text{TiO}_2$  type solar cells. Our results showed, the polythiophene seemed to go quite well into the pores of  $\text{TiO}_2$ . Even for  $\text{nc-TiO}_2$  devices, no problems with shunting are observed.

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