

Enhancement of photovoltaic performance using hybrid CdS nanorods and MEH-PPV active layer in ITO/TiO₂/MEH-PPV:CdS/Au devices

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ABSTRACT

Polymer-based solar cells offer many advantages for cell fabrication such as low-cost roll-to-roll production, large area and flexibility. In this study, the effect of blending cadmium sulfide (CdS) nanorods in poly(2-methoxy-5-(2'-ethylhexyloxy)-*p*-phenylene vinylene) (MEH-PPV) active layer of ITO/TiO₂/MEH-PPV/Au heterojunction devices on the photovoltaic performance was investigated. The ITO/TiO₂/MEH-PPV:CdS blend/Au solar cells were fabricated using nano-porous titanium dioxide (TiO₂) layer infiltrated with a blend of the MEH-PPV and CdS nanorods to form an active layer for the solar cells. The MEH-PPV layer is known to be an electron donor and a hole transport material. Schottky diode ITO/MEH-PPV/Al devices have a limited power conversion efficiency so the modified ITO/TiO₂/MEH-PPV:CdS blend/Au ohmic heterojunction devices were fabricated. Improvement of photocurrent density, fill factor and power conversion efficiency were demonstrated. These improvements were expected to be a result of a more stable depletion region at the TiO₂/MEH-PPV interface. Moreover the mixing of the CdS nanorods in the MEH-PPV layer improved electron transport in the conjugated polymer MEH-PPV film areas that were disconnected between the conjugated polymer and the TiO₂ film.

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1. Introduction

Electronic devices based on organic materials have attracted much interest and competed with inorganic based devices with potential applications such as organic light emitting diodes [1], organic field effect transistors [2], solar cells [3], etc. Among these applications, dye-sensitized solar cells (DSCs) based on nanoporous titanium dioxide (TiO₂) particles and photo-sensitizing dyes have demonstrated energy conversion efficiencies of around 10%, comparable to amorphous silicon based solar cells [4]. Although the TiO₂ nanocrystalline DSCs show excellent power conversion performance, they require a liquid electrolyte which results in difficulties in outdoor applications due to problems related to sealing, evaporation of the electrolyte, and the degradation of the electrolyte or the dye. For the DSCs to overcome disadvantages of having the liquid electrolyte system, several solid state DSCs have been investigated using solid polymer electrolytes [5] or conducting polymers [6].

The current investigation demonstrates our attempt to optimize benefits of layered and bulk heterojunction hybrid inorganic–organic solar cell (HSC) structures consisting of titanium dioxide (TiO₂) thin film prepared by sol–gel dip-coating technique and poly(2-methoxy-5-(2'-ethylhexyloxy)-*p*-phenylene vinylene) (MEH-PPV) conjugated polymers [7] as well as bulk heterojunction solar cells consisting inorganic cadmium sulfide (CdS) semiconducting nanorods blended with MEH-PPV conjugated polymers [8].

2. Material and methods

MEH-PPV was synthesized in-house following Gilch's method [9]. Its molecular weight (M_w) as determined by GPC was 31,139. To obtain a stable TiO₂ sol, a precursor solution was prepared following Legrand-Buscema et al. [10]. Firstly, 1.6 M titanium(IV) isopropoxide (Fluka) was dissolved in isopropanol (Fluka) and stirred at room temperature for 30 min. Then, acetylacetone (Merck) was added to make 10:1 molar ratio of titanium(IV) isopropoxide to acetylacetone. The mixture was used as chelating agent to stabilize the solution. The mixture was then stirred for 10 min more. Acetic acid (Lab-scan) was added afterward to help initializing hydrolysis by creating esterification reaction with

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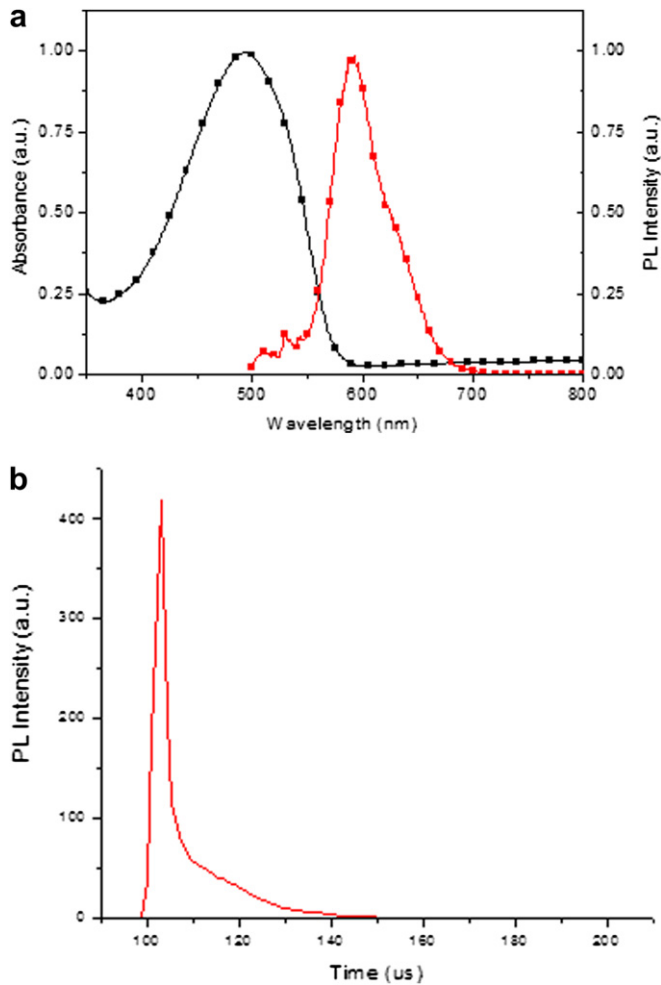


Fig. 1. (a) Optical absorption, photoluminescence spectra of MEH-PPV. (b) Excited electron lifetime of MEH-PPV.

isopropanol. Finally, 0.3 g of poly(ethylene glycol) (PEG) having M_w of 3000 g mol⁻¹ was added to 180 ml of titanium dioxide-containing sol. The sol was then dip-coated on to commercial indium tin oxide (ITO) coated glass substrates. The films were dried at 60 °C overnight before calcination at 450 °C for 4 h in air.

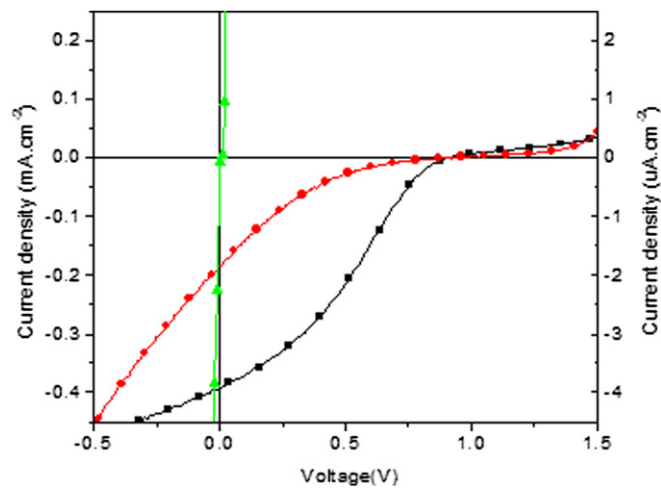


Fig. 2. I – V characteristics of ITO/TiO₂/MEH-PPV/Au (—■— and use left vertical axis), ITO/MEH-PPV/AI (—●— and use right vertical axis), and ITO/MEH-PPV/Au (—▲— and use right vertical axis) solar cells.

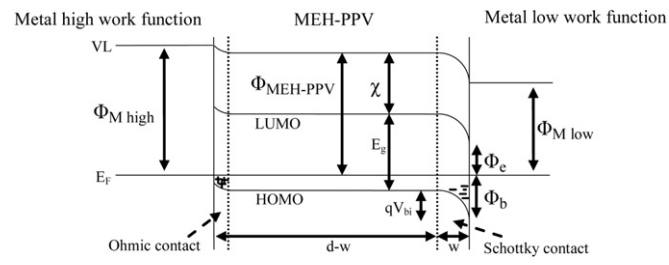


Fig. 3. ITO/MEH-PPV/metal (Al, Au) Schottky diode in the band picture. For simplicity the polaron levels are not shown. Φ_b : Schottky barrier: $\Phi_b = E_g - \Phi_e$, E_g : band gap of the polymeric semiconductor, Φ_e : barrier for electron injection: $\Phi_e = \Phi_m - \chi$, χ : electron affinity of the polymeric semiconductor [16].

Table 1

Short-circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and power conversion efficiency (η) of the ITO/MEH-PPV/Al (0) and the ITO/TiO₂/MEH-PPV/Au (1).

Device	J_{sc} (mA cm ⁻²)	V_{oc} (V)	FF	η (%)
0	1.83×10^{-3}	0.88	0.13	2.2×10^{-4}
1	0.39	0.9	0.3	0.1

The CdS nanorods were prepared via precipitation from homogenous solution technique, similar to reported elsewhere [11]. 0.28 g CdCl₂·2.5H₂O and 0.4 g 1-pyrrolidine dithiocarboxylic acid ammonium salt were added into 25 ml ethylenediamine. The mixture solution was placed in the typical microwave (850 W) with a close reflux system and the reaction was performed under ambient air for 5 min. After cooling to room temperature, the yellow precipitates were centrifuged, washed with distilled water and absolute ethanol, and dried in the air.

The front transparent conducting oxide (TCO) electrode used was commercial glass substrate coated by indium tin oxide (ITO) thin film. The TiO₂ thin film was prepared following steps described above. Then, blends of 0.0, 1.0, 2.0, 3.0 and 5.0 mg/ml of CdS nanorods and 10 mg/ml of MEH-PPV in 1,2 dichlorobenzene were prepared and spin cast onto the TiO₂ films using a P-6000 spin coater (Specialty Coating Systems, INC). A spin speed used to cast a blend MEH-PPV:CdS layers (having w/w ratios of 1:0, 1:0.1, 1:0.2,

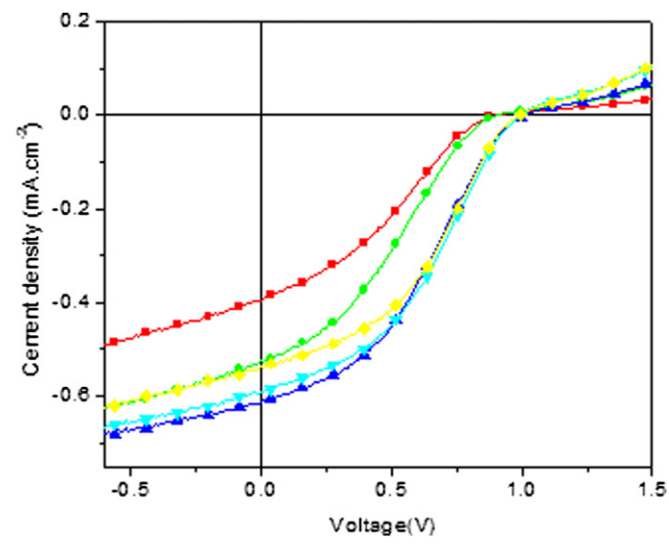


Fig. 4. I – V characteristics of ITO/TiO₂/MEH-PPV/Au (—■—), ITO/TiO₂/MEH-PPV:CdS (1:0.1)/Au (—●—), ITO/TiO₂/MEH-PPV:CdS (1:0.2)/Au (—▲—), ITO/TiO₂/MEH-PPV:CdS (1:0.3)/Au (—▼—), and ITO/TiO₂/MEH-PPV:CdS (1:0.5)/Au (—◆—) solar cells.

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