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Enhanced efficiency of organic solar cells based on (MEH-PPV) with graphene and quantum dots

Nazir Mustapha*, Zakia Fekkai, Ahmed Alkaoud

Department of Physics, College of Sciences, Al Imam Mohammad Ibn Saud Islamic University, P.O. Box 90950, Riyadh 11623, Saudi Arabia

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ABSTRACT

In this work, organic photovoltaic cells are fabricated using a spin coated composite active layer of organic electronic materials conjugated polymer poly[2-methyl-5-(2′-ethyl-hexyloxy)-1,4-phenylene vinylene] (MEH-PPV) mixed with cadmium selenide (CdSe) quantum dots and graphene. The active layer is sandwiched between two metallic conductors, typically a layer of silicon and indium tin oxides (SiO_2:ITO) with high work function of (4.3 eV) and a layer of low work function aluminum metal (3.7 eV) as anode and cathode respectively.

Spectral properties were explored for thin films of pure MEH-PPV, CdSe, MEH-PPV:CdSe, and MEH-PPV:CdSe:graphene blends coated onto glass at a spin speed of 6000 rpm using a spectrophotometer for optical absorption in the visible region with various concentration and benzene as a solvent. The photoluminescence (PL) spectra of the pure quantum dots and blended MEH-PPV:CdSe with graphene from various concentrations were recorded. The current–voltage characteristics (I–V) of the solar cells showed that incorporation of the quantum dots and graphene in the copolymer resulted into further increase in the power conversion efficiency compared to that in their absence.

1. Introduction

Polymer solar cells that only consist of a conducting polymer alone have a low minority carrier mobility, for example, poly[2-methyl-5-(2′-ethyl-hexyloxy)-1,4-phenylene vinylene] MEH-PPV has a high hole mobility, but a low electron mobility [1]. The intrinsic carrier mobility imbalance in MEH-PPV severely limits the performance of pure-polymer-based solar cells. To overcome this imbalance, a second material is often incorporated to act as an electron acceptor and as a pathway for electron transport. For polymer-nanoparticle bulk heterojunction solar cells, a power conversion efficiency of 5% (under AM 1.5 simulated solar radiation at one sun intensity) has been reported [2].

Solar cells based on solution-processable organic semiconductors have shown a considerable performance increase in recent years, and a lot of progress has been made in the understanding of the elementary processes of photo generation [3]. Recently, organic bulk heterojunction solar cells with almost 100% internal quantum yield were presented, resulting in up to almost 8% power conversion efficiency [4,5]. This device concept has been shown to be compatible with solution-processing at room temperature.

Recently, organic conjugated polymers have attracted much attention for applications in electronics and optoelectronics, including light emitting diodes [6–10], thin film transistors [11–13], and photovoltaic cells [14–17]. The organic polymers have the advantages that they can be easily processed by spin coating so that the manufacturing cost of organic solar cells can be significantly reduced [18]. However, these solar cells have low efficiency which limits their uses in practical applications. Among the factors affecting polymeric solar cell efficiency, the morphology of the active layer and its composition related to blend preparation. Fundamental studies of the morphology and physical properties of conjugated polymers, such as photo physics, charge transport, electrical conductivity, photoconductivity, optical nonlinearity, are also commonly done on spin coated thin (0.2–1.0 μm) and ultrathin (<0.2 nm) films [19–24].

According to Cai et al., by using solar cells fabricated from low bandgap polymers, it is possible to capture more of the solar radiation and thereby increase their efficiency [25]. The performance of organic photovoltaics is severely limited by low efficiencies, short lifetimes and low charge mobilities in polymers. This challenge can be met through the use of blended and layered heterojunctions as such morphologies can offer thicker and more absorbing polymer films [26]. Jung et al. noted that UV light protection method

* Corresponding author. Tel.: +96 65 01844817.
E-mail addresses: nazirmustapha@yahoo.co.uk (N. Mustapha), zakia_fekkai@yahoo.co.uk (Z. Fekkai).

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should be included in the processing of MEH-PPV films for the optical device applications to prevent the significant change of optical property of the film and to maintain its efficient absorption of sunlight for solar cell devices. The UV–Vis absorption and photoluminescence (PL) characteristics of poly[2-methoxy-5-(2′-ethyl hexy loxy)-1,4-phenylene vinylene (MEH-PPV) films were studied for optoelectronic devices such as light emitting diodes and solar cells [27]. Kumar et al. reported on the first solar cells based on CdTe nanoparticles/MEH-PPV composites. It was found that CdTe nanocrystal/MEH-PPV composites are well suited for an organic solar cell, even though the technological realization needs to be improved [28].

Nozik discussed the impact on solar cells, when QDs dispersed in a blend of electron- and hole-conducting polymers and the effects of size quantization on the carrier dynamics. The most important process for the QD solar cells to reach very high conversion efficiency is the multiple electron–hole pair production in the photoexcited QDs; the various cell configurations simply represent different modes of collecting and transporting the photo-generated carriers produced in the QDs [29].

Recently, Dabbousi et al. reported on electroluminescence obtained from nearly mono-disperse CdSe nanocrystallites (quantum dots (QDs)) incorporated into thin films (1000 Å) of polyvinylcarbazole (PVK) and an oxadiazole derivative (*t*-Bu-PBD) and sandwiched between ITO and Al electrodes. The electroluminescence and photoluminescence spectra (bandwidths ≤40 nm) are nearly identical at room temperature and are tunable from ~530 to ~650 nm by varying the size of the dots. Variable temperature studies indicate that the electroluminescence efficiency increases substantially as the films are cooled down to cryogenic temperatures [30].

Jin et al. reported in their work on tandem solar cells with different absorption characteristics that power–conversion efficiencies of more than 6% were achieved at illuminations of 200 mW/cm^2 when comprising semiconducting polymers and fullerene derivatives to the bulk heterojunction materials of the solar cells [31].

In this work, we prepared and characterized MEH-PPV conjugated polymer doped with quantum dots CdSe and graphene onto SiO_2:ITO coated glass substrates. Then, we used them in a polymeric solar cell, since less work has been carried on this blended conjugated polymer in such research field. The composite films made of these materials have not yet been investigated thoroughly for organic solar cell applications.

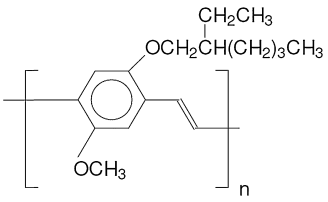

Fig. 1. Chemical structure of MEH-PPV.

2. Experimental

Prior to spin coating of conjugated polymer based on poly[2-methoxy-5-(2′-ethyl hexyloxy)-1,4-phenylene vinylene (MEH-PPV), solution with various concentrations of the polymer dissolved in benzene were prepared. The glass substrates were cleaned using ultrasonic bath with detergent (acetone) then rinsed with de-ionized water and dried by air blow. The solution of (MEH-PPV) in benzene of concentration ranging from 0.1 μM to 100 μM were mixed, stirred on magnetic stirrer and filtered thoroughly prior to casting onto glass substrates with a spin speed of (6000 rpm). The film thickness was between 100 and 120 nm measured by a Deck Tack 150. The films were dried at room temperature, and protected from light to avoid photo degradation process.

Fig. 1 shows the chemical structure of MEH-PPV supplied by Sigma Aldrich. The optical properties such as absorption of the pure MEH-PPV and various blended films were measured in visible range wavelength (340–700 nm) using a Perkin Elmer lambda 40 UV–VIS spectrophotometer.

The photoluminescence (PL) spectra for the MEH-PPV films were recorded at room temperature using Perkin Elmer LS 45 luminescence.

CdSe quantum dots (used as received from the supplier) were prepared by dissolving them in benzene and then spin coated onto glass substrate at 6000 rpm for the various concentrations of CdSe weighing from 10 mg to 200 mg in 5 ml of benzene.

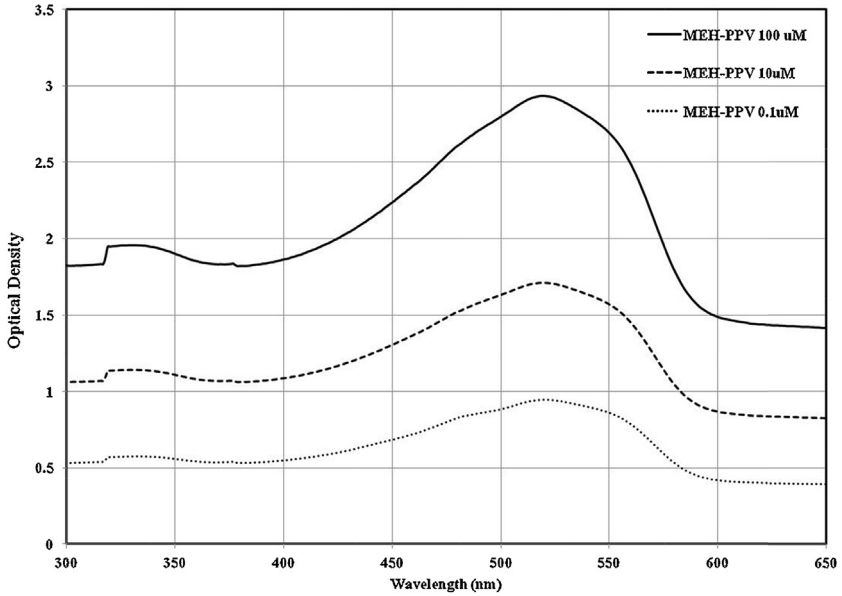

Fig. 2. Absorption spectra of MEH-PPV in benzene to form a concentration ranging from 0.1 μM to 100 μM.