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A novel fabrication of MEH-PPV/Al:ZnO nanorod arrays based ordered bulk heterojunction hybrid solar cells

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ABSTRACT

Vertically aligned Al:ZnO nanorod arrays has been used as window layer in the fabrication of ordered bulk heterojuction hybrid solar cells. The utilization of the nanorod arrays will enhance the electron transport in vertical direction and also for light harvesting applications for high performance devices. The performance of this hybrid polymer/metal oxide photovoltaic devices based on MEH-PPV [poly(2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene)] and oriented Al:ZnO nanorod arrays is studied. The Al:ZnO nanorod arrays with a diameter of about 70–80 nm and thickness of approximately 500 nm were successfully grown on Al:ZnO-coated ITO substrate by sonicated sol–gel immersion technique. The photovoltaic performance of a short-circuit current density of 5.320 mA/cm^2, an open-circuit voltage of 195 mV and a fill factor of 27.71%, with a power conversion efficiency of about 0.287% under AM 1.5 illumination (100 mW/cm^2). To the best of our knowledge, the preparation of aligned Al:ZnO nanorod arrays on Al:ZnO seeded catalyst layer for this type of solar cell fabrication has not been reported by any research group. The configuration of the solar cell device is considered as the novelty of this research.

1. Introduction

Hybrid solar cells have been the subject of intensive research during the last decade. Hybrid solar cells based on conjugated polymer donor (D) and inorganic semiconductor nanocrystal acceptor (A) composites have drawn increasing attention due to the combined merits of both materials. Besides, it possesses tremendous advantages over the conventional silicon based cells, such as less expensive, easy processability and reproduction and also capability to make more flexible devices. Inorganic semiconductors are easily accessible and in the last decade a great number of inorganic semiconductors have been manufactured with various types of nanostuctured.

On the other hand, easy processibility and tailorable functionality of organic materials make this organic-inorganic hybrid concept more interesting and attractive [1]. By far, various hybrid polymer solar cells with promising power conversion efficiency (η) up to 5% has been reported based on regioregular *poly (3-hexylthiophene)* (P3HT) and *(6,6)-phenyl C61 butyric acid methyl ester* (PCBM) as the electron donor and the electron acceptor, respectively [2,3]. Inorganic nanostructures, such as TiO_2 [4,5], ZnO [6–8], and SnO_2 [9] have been applied as an alternatives to the polymer based solar cells. This is due to the intrinsic properties of inorganic material such as high conductivity and good stability which may contribute to better performance of solar cell device.

There are two types of hybrid solar cell fabrication structure that are commonly developed. The first is the bilayer structure which was proposed by Tang in 1985 [10]. This type of solar cell contains two different layers of conjugated polymer and inorganic material in between the conductive electrodes as has been illustrated in Fig. 1(a). This polymer/metal oxide hybrid devices can be prepared by depositing conjugated polymer on the top of an inorganic semiconductor layer, but very low power conversion efficiency is often a result from the limited D/A interface area [11]. In addition, the conjugated polymers have short exciton diffusion lengths (4–20 nm) [12–16]. In order for most excitons to diffuse to the interface of layers and break up into carriers, the layer thickness should also be in the same range with the diffusion length. However, typically a polymer layer needs a thickness of at least 100 nm to absorb most of the light at their peak absorption wavelength [17]. At such a large thickness, only a small fraction of the excitons can reach the heterojunction interface. Thus, the performance of a bilayer device made with a conjugated polymer and another semiconductor material is ultimately limited.

The second type is the bulk heterojunction hybrid solar cell. In this type of solar cell configuration, the electron donor and acceptor are mixed together, forming a polymer blend as shown in Fig. 1(b). This concept was usually used to overcome the very

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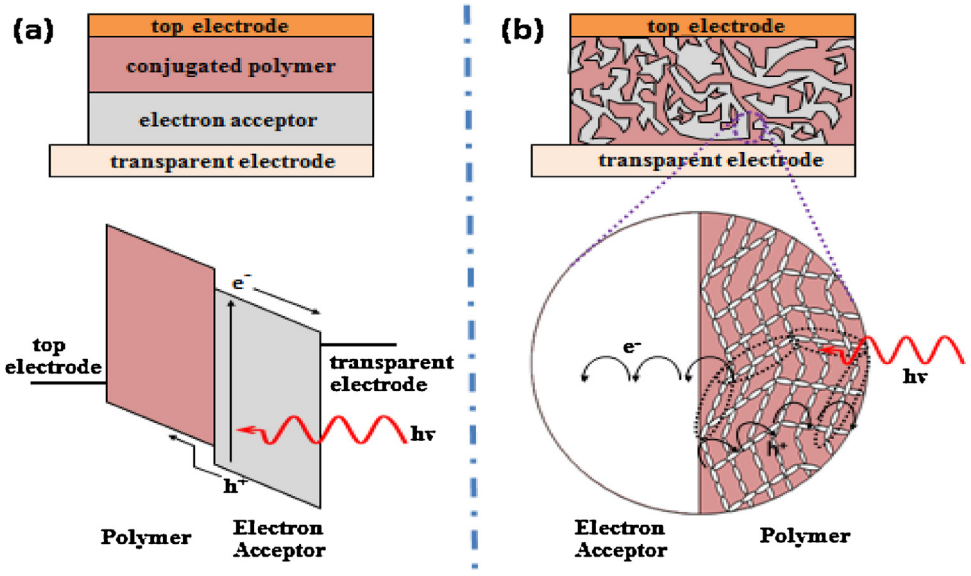

Fig. 1. Device configurations: (a) bilayer hybrid solar cell and (b) bulk heterojunction hybrid solar cell.

low power conversion efficiency which is often a result from the limited D/A interface area [11]. The D/A interface area can be greatly enhanced by dispersing nanoparticles into the polymer matrix, offering photovoltaic devices in a bulk heterojunction structure [7,8,18]. Besides, if the length scale of the blend is similar with the exciton diffusion length, most of the excitons generated in either material may reach the interface layer, where excitons break efficiently. Operation of such solar cells, caused by photocurrent generation at the interface of inorganic/polymer composite materials, has been demonstrated in various blends containing CdSe [19], $CuInS_2$ [20], CdS [21], and PbS [22] nanocrystals. However, these disordered structures generally lead to a serious recombination and instability of the morphological structure in the active layer [11,18].

Recent research and theoretical studies have proposed that the ideal heterojunction would have a nanostructured network of the *n*-type and *p*-type materials preserving the physical continuity of each material both within the active layer. The combination of polymer with oriented one-dimensional (1-D) nanostructures has been regarded as an ideal device architecture for highly efficient solar cells. Nanostructures of inorganic semiconductors such as nanorods are well suited to the development of novel optoelectronic devices because of their feasible synthesis by solution routine at low temperatures with a controllable morphology combined with their optical properties. As a result of strong quantum confinement, they exhibit photoluminescence with high quantum efficiencies, and their emission peaks, as well as the onset of absorption, are strongly size-tunable [23].

Furthermore, the vertically aligned electron acceptor channels normally improve the device performance by facilitating the transport of charge carriers to electrodes and minimizing the charge recombination. In addition, the morphology structure which was fixed by the oriented nanostructures can provide the device with a good stability [24]. Hence, the structures that meet these criteria are called ordered bulk heterojunctions as has been illustrated in Fig. 2. This structure has the form high work function electrode (HWFE)/*p*-type/*n*-type/low work function electrode (LWFE). The structure has a cross-section with an interdigitated arrangement of *n*-type and *p*-type phases compared to bilayer structure.

Ying Guo and Hongwei Geng have reported the performance of MEH-PPV/ZnO photovoltaic devices by manipulating the reaction time of the ZnO nanorod [25]. They found that the length of their ZnO nanorod increases from 170 to 550 nm. The optimized length of ZnO nanorods is 400 nm, offering a peak power conversion efficiency of $\eta = 0.337\%$ under 1.5 AM illumination. On the other hand, Olson et al. stated that increasing the ZnO nanofiber length from 250 to 500 nm results in a significant increase in the short circuit current of the device, but the open circuit voltage remains almost unchanged [26]. This might be due to the oriented ZnO nanorods which introduce a direct pathway for charge carrier transport for the improved device performance. The optimized ZnO nanorod length for high efficiency due to the intrinsic nanorod properties is still unclear. Hence, in this paper, we are reporting on the performance of solar cells based on fixed length of intrinsic and Al doped a ZnO nanorod which is 500 nm.

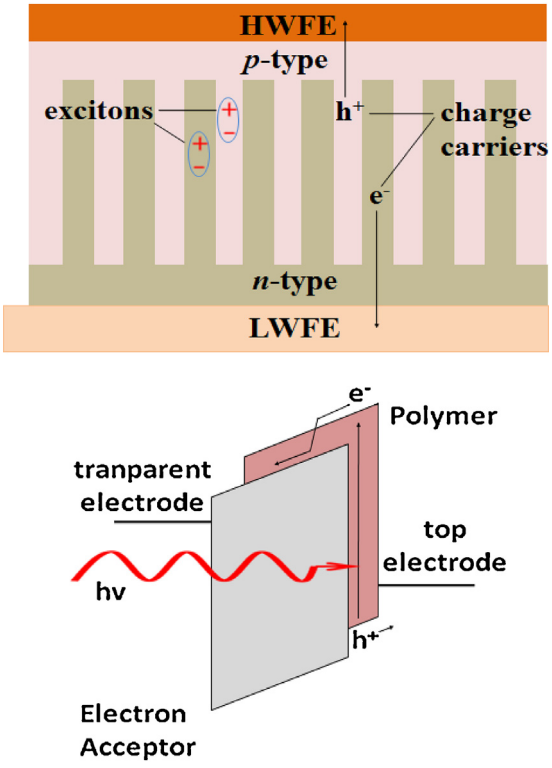

Fig. 2. Schematic diagram of an ordered bulk heterojunction solar cell.