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Hybrid solar cells using PbS nanoparticles

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Abstract

Solution-processed bilayer heterojunction hybrid solar cells have been fabricated using size-quantized PbS nanoparticles and poly (3-hexylthiophene) (P3HT). PbS was used as an electron-transporting layer whereas P3HT was used for hole transport. A photovoltaic device consisting of PbS and P3HT exhibited 3% incident photon to current efficiencies (IPCE) under 550-nm monochromatic irradiation.

Keywords: Hybrid solar cells; PbS nanocrystals; Inorganic semiconductor nanocrystals

1. Introduction

Hybrid solar cells have been the subject of intensive research during the last decade. A hybrid solar cell, consisting of both organic and inorganic materials, combines the unique properties of inorganic semiconductors with the film forming properties of conjugated polymers [1,2]. Inorganic semiconductors are easily accessible and in the last decade a great number of inorganic semiconductors have been manufactured as nanoparticles. Nanocrystals of inorganic semiconductors are well suited for the development of novel opto-electronic devices, due to their flexibility and simple processability combined with their optical properties. As a result of the strong quantum confinement in nanocrystals, they exhibit photoluminescence with high quantum efficiencies and the emission peak as well as the absorption onset is strongly size-tunable [3]. Therefore, nanocrystals have been used to improve the performance of plastic light-emitting diodes [4,5], to obtain single-photon sources operating at room temperature [6], and the development of optically pumped laser devices [7,8]. In addition to applications as light emitters, semiconductor nanocrystals have also been used to improve polymer photovoltaic solar cells [9–11], based on the bulk or bilayer heterojunction concepts. On the other hand, easy processibility and tailorable functionality of organic materials make this organic/inorganic hybrid concept more interesting and attractive [12].

In this study, we report solution-processed bilayer heterojunction hybrid solar cells using size-quantized PbS nanoparticles and P3HT. We investigated the effect of temperature annealing on the morphology of PbS films and photovoltaic performance of the hybrid devices.

2. Experimental

As substrates, glass sheets of $1.5 \times 1.5\,cm^2$ covered with ITO, from Merck KG Darmstadt, were used with an ITO thickness of about 120 nm and sheet resistance $<15\,\Omega\,cm^{-2}$. The ITO was patterned by etching with an acid mixture of HCl_{conc}:HNO_{3conc}:H_2O (4.6:0.4:5) for ~30 min. The part of the substrate, which forms the contact is covered with a Scotch tape preventing the etching. The Scotch tape was removed after etching and the substrate was then cleaned by using acetone in an ultrasonic bath and finally with iso-propanol.

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PbS nanocrystals were synthesized as previously reported in Ref. [13]. PbS films were prepared in two ways: (i) spincasting PbS nanoparticle solution from chloroform at 700 rpm and (ii) spincoating mixture of PbS nanoparticles and ethyl acetate solutions with 1:1 volume ratio at 700 rpm. The films were annealed at 200 °C for 1 h in both cases. A 1 wt% of P3HT in chlorobenzene was dropcasted onto the PbS films. Then 160 nm of gold was thermally evaporated onto the film.

3. Results

The morphology of PbS films was characterized by atomic force microscopy (AFM). Fig. 1(a) and (b) show the AFM images of PbS films before and after annealing, respectively. The PbS nanoparticles seem to form agglomerates before annealing. After annealing the surface of PbS films is smoothened. However, the resulting films were soluble upon deposition of P3HT.

We added ethyl acetate into the PbS solution before spincasting. The effect on the morphology of the obtained films is shown in Fig. 2(a) and (b) before and after annealing, respectively. In both cases, the PbS films have smooth surfaces. We observed that after annealing at 200 °C the PbS films become insoluble upon addition of ethyl acetate into the PbS solution.

The photovoltaic properties of the solar cells were characterized by measuring current–voltage (*I*–*V*) curves in the dark and under white light illumination (simulated AM 1.5, 100 mW/cm^2) through the ITO side (see Fig. 3). The characteristic parameters of the solar cells are deduced from the *I*–*V* curves on linear scales. This device exhibited

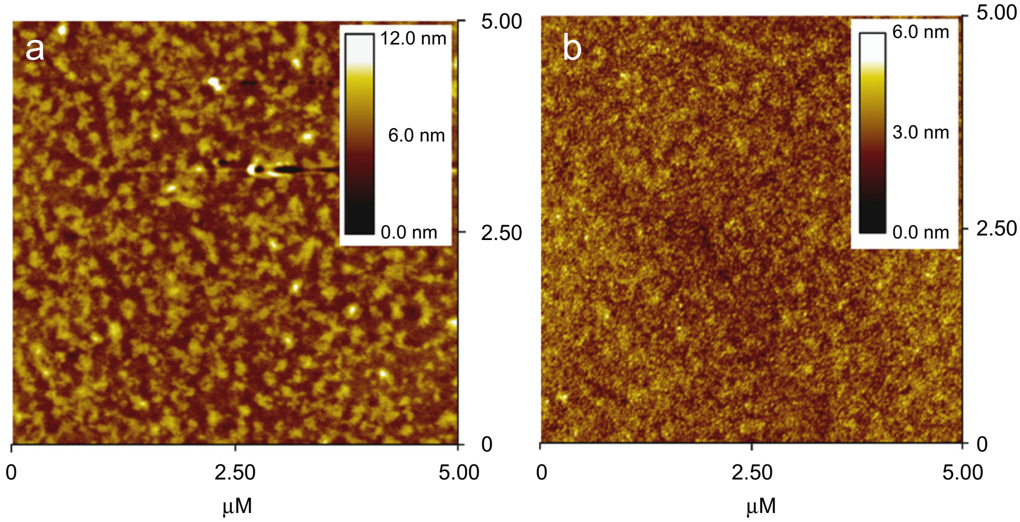

Fig. 1. AFM images of PbS films as deposited (a) before and (b) after annealing.

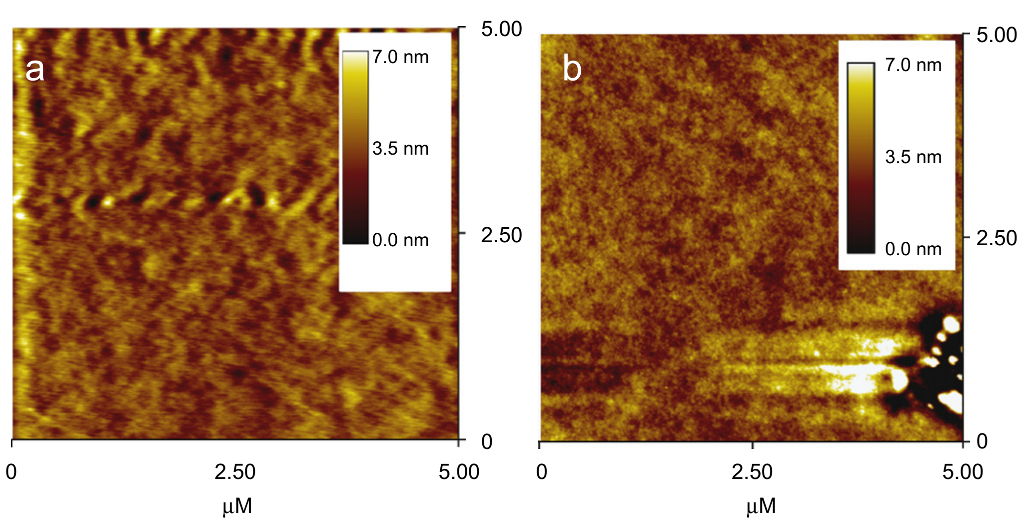

Fig. 2. AFM images of PbS films after addition of ethylacetate into the PbS solution (a) before and (b) after annealing.

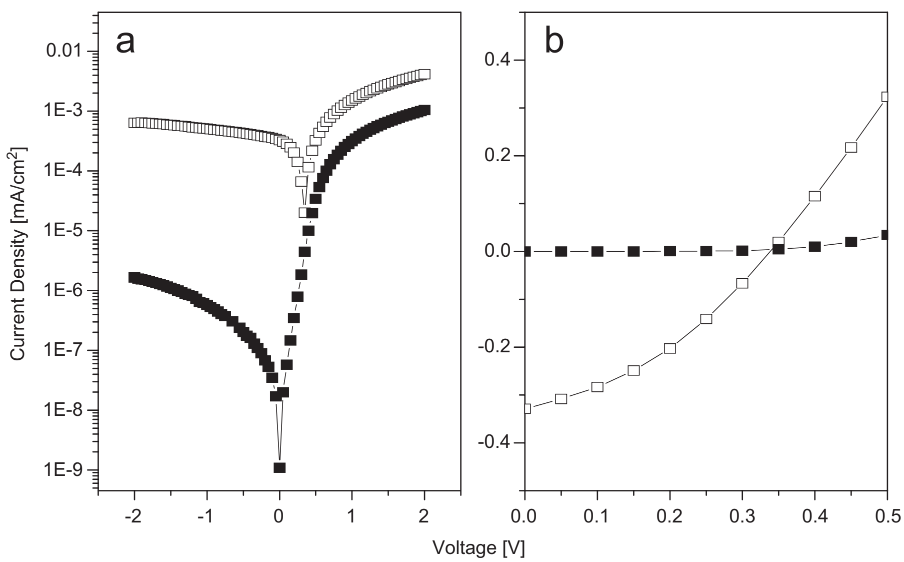

Fig. 3. I–V characteristics of ITO/PbS/P3HT/Au in (a) semilogarithmic and (b) linear scale.

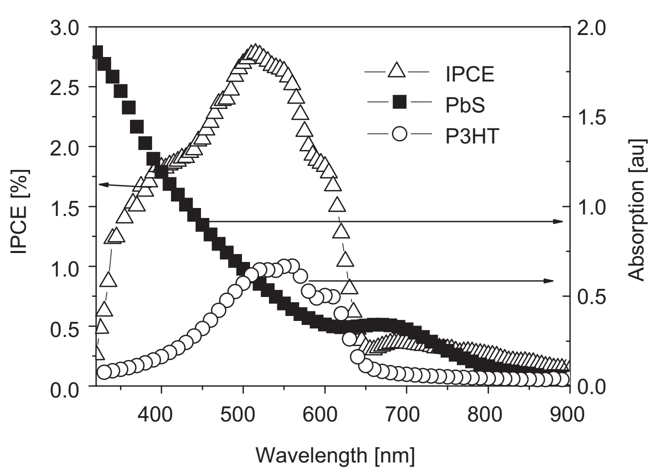

Fig. 4. Comparison of the IPCE spectra with the absorption spectra of the individual components of the investigated hybrid solar cell.

an I_{sc} of 0.3 mA/cm^2 and a V_{oc} of 350 mV with a fill factor of 0.35 corresponding to 0.04% power conversion efficiency.

Fig. 4 shows a comparison of the incident photon to current efficiency (IPCE) of the hybrid device with PbS and P3HT with the absorption spectra. The % IPCE is the percentage of electrons, measured under short circuit current conditions, related to the number of incident photons and is used to obtain information on the number of photons of different energy that contribute to the charge generation in the solar cell [14]. The comparison of the IPCE and the optical absorption spectra gives information on the charge carrier generation mechanism. The absorption edge around 850 nm shows that PbS nanoparticles are size quantized since bulk PbS has an absorption edge at 3100 nm [15,16]. P3HT has a broad absorption with an absorption maximum at 550 nm. As can be seen from this figure both PbS and P3HT contribute to the charge carrier generation. The response at wavelengths longer than 650 nm is attributed to the PbS absorption.

4. Conclusion

We have demonstrated solution-processed bilayer heterojunction hybrid solar cells using size-quantized PbS nanoparticles and P3HT. A bilayer heterojunction between PbS and P3HT is achieved without losing the size-quantization effect. We also achieved an extended spectral response following the PbS absorption. For the further improvement of device performance PbS nanoparticles with different surface properties (surfactant) or different sizes will be considered.

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