

Improved planar perovskite solar cells using the modified hole transporting layer and solvent annealing

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Abstract

Organometal trihalide perovskites have been demonstrated as excellent light absorbers for high efficiency solar cell [1]. In this work, Glass/ITO/PEDOT:PSS/Perovskite/PCBM/Ag planar heterojunction structure was designed and investigated. For the reference cell, the efficiency of 12.5 % was achieved. An relative low J_{sc} was exhibited at the result, mainly owing to the low conductivity of the electric transport layer – PEDOT:PSS. By controlling the amount of DMSO doped in PEDOT:PSS, a superior device was obtained with the efficiency of 13.6% although the roughness of the PEDOT:PSS layer was also increasing with doping DMSO. Furthermore, another key factor for a perovskite solar cell is the high crystallization of the perovskite layer[2]. Solvent annealing was adopted to improve the crystallization in this work. With dropping IPA around the solar cell and annealing for 20 minute, a surprising characteristics of the device with the efficiency of 15%, V_{OC} of 0.99 V, Fill Factor of 67.9%, J_{SC} of 22.3mA/cm² was obtained.

1. Introduction

Due to the energy shortage, solar energy has acquired enormous attentions[3]. The growth of the perovskite solar cell as one new novel solar energy device is quite amazing. Only developed for a few years, the efficiency has exceeded 20%[4]. There are some possibilities that this type of device could replace the silicon solar cell for its low cost and simple in preparation[5].

In order to achieve high power conversation efficiency (PCE), the proper hole transport layer (HTL) with a high electrical conductivity and a high perovskite quality are required[6]. In this work, by controlling the amount of DMSO doped in PEDOT:PSS, the electric conductivity of PEDOT:PSS is improved and a superior device was obtained with the efficiency of 13.6%. Furthermore, solvent annealing was adopted to improve the crystallization in this work[7]. With dropping IPA around the fabricated solar cell and annealing for 20 minute, a surprising characteristic of the device with the efficiency of 15%, V_{OC} of 0.99 V, Fill Factor of 67.9%, J_{SC} of 22.3mA/cm² was obtained.

2. Experimental

Material and methods

ITO glass substrates are obtained from Zhuhai Kaivo Optoelectronic Technology Co.. Poly (3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS Clevios P VP Al 4083) solution was acquired from Heraeus. Phenyl-C61-butyric acid methyl ester (PCBM) was acquired from American Dye Source. MAI (99.8%, Dyesol), PbI₂ (99.999%, ultra dry, Alfa), Dimethyl Sulphoxide



(99.8%, anhydrous, Sigma), Chlorobenzene (99.8%, anhydrous, Sigma), Toluene (99.8%, anhydrous, Sigma), γ -Butyrolactone (99.8%, anhydrous, Aladdin) were used as received.

Device Fabrication and characterization

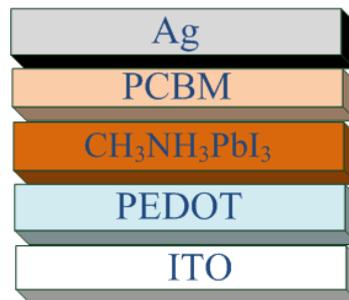


Fig. 1. Schematic of perovskite solar cell.

The fabricated device structure is shown in Fig. 1 and the corresponding energy diagram is shown in Fig. 2. The perovskite solar cell is based on a planar heterojunction structure, with HTL of PEDOT:PSS deposited on the transparent conductor ITO layer. The fabrication procedures are briefly stated as the following. First, the ITO glass substrates were cleaned with detergent, DI water, acetone, alcohol for 15 mins, respectively. And then they were treated by O_2 plasma for 15 minutes before the device fabrication. A layer of PEDOT:PSS was spin coated on ITO substrate at 7000 rpm for 40 seconds. Then, they were annealed at 150°C for 20 minutes. The substrates were transferred into a glove box filled with nitrogen. $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite films were prepared by spin coating a solution containing 1.4M PbI_2 and 1.35M $\text{CH}_3\text{NH}_3\text{I}$ in co-solvent of DMSO:GBL (3:7 vol. ratio). The spin-coater was started at a rotation speed of 1000 rpm for 15 seconds and 5000 rpm for another 25 seconds. 350 μl toluene was added quickly at 40 seconds after the start of spin coating process. The perovskite films were then annealed at 100°C for 20 minutes. 20 mg/ml chlorobenzene solution of PCBM was spin-coated at 2000 rpm for 40 seconds. Finally, the films were transferred to a metal evaporation chamber, 100 nm thick Ag contacts were deposited under high vacuum ($< 4 \times 10^{-4}$ Pa).

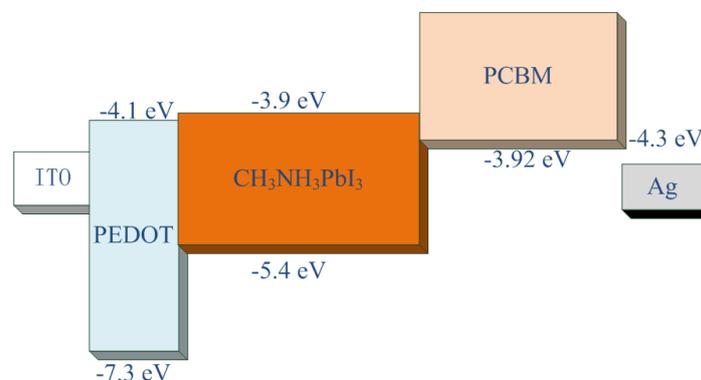


Fig. 2. Band alignment of Glass/ITO/PEDOT/Perovskite/PCBM/Ag.

3. Results and discussion

The I-V characteristics of the devices are shown in Fig. 3. As is shown, the reference device

without any HTL treatment and solvent annealing, the device had a low PCE of 12.5%. Considering the weak electric conductivity of the HTL, it's necessary to dope the PEDOT:PSS. Dimethyl Sulphoxide (DMSO) was one ideal doping material for PEDOT:PSS[8]. By controlling the doping ratio of DMSO in PEDOT:PSS (1%, 2%, 5%, and 10%), we could find that PCE of the perovskite solar cells is continuously increased until the doping dose reaches 5%. Beyond this doping ratio, PCE of the perovskite solar cells began to decrease. Thus the optimal doping ratio of DMSO in PEDOT:PSS is 5% and at this time, the highest device PCE was 13.6%. Doping the DMSO in the PEDOT:PSS could improve the electric conductivity, so that at the beginning PCE was improved[9]. When the doping dose reached one critical point, the electric conductivity reached the best. When increasing the DMSO further would dilute the concentration of PEDOT:PSS, therefore the PCE dropped[10].

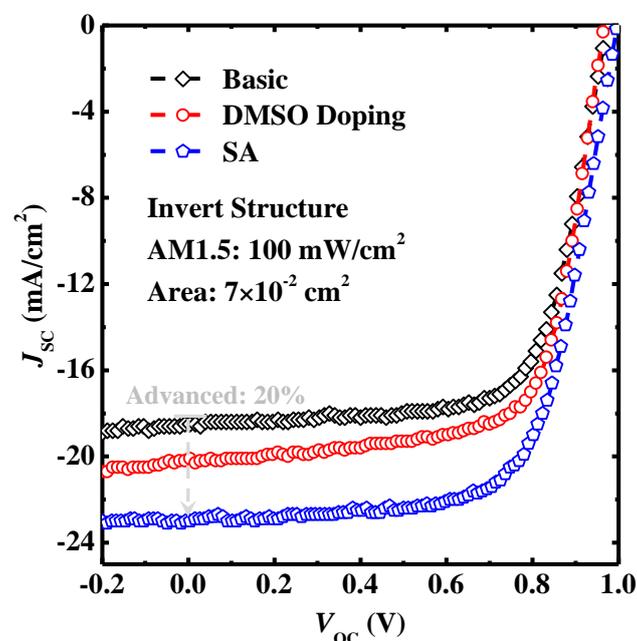


Fig. 3. Current density versus voltage (J_{sc} – V_{oc}) characteristics of devices with undoped, DMSO doping PEDOT and annealed DMSO doping PEDOT. basic structure in black line the efficient of 12.5% was achieved. By controlling the amount of DMSO doped in PEDOT, (red line) a superior device was obtained with Efficiency of 13.6%, With dropping IPA around the DMSO doping solar cell and annealing for 20 minute, a surprising characteristics of the device with the efficient of 15% (blue line), V_{oc} : 0.99 V, Fill Factor: 67.9%, J_{sc} : 22.3 mA/cm²

By using solvent annealing further, PCE acquired obvious enhancement. From the Fig. 3, we could find that PCE rise from 13.6% to 15%. When solvent annealing was used to treat on the perovskite, the PCE enhancement originates from the improved perovskite layer quality. The solvent was mixed by DMF and IPA (with ratio as 5:95). In the annealing process, DMF would evaporate and reach the perovskite layer surface. The DMF vapor could dissolve the perovskite, so the perovskite was in the dynamic equilibrium between crystallization and dissolution. At the start, perovskite crystallization wasn't perfect, crystalline grain were in different size, and the perovskite layer was not

flat enough. When the device was not treated by solvent annealing, its PCE is low. After solvent annealing, the layer becomes more flat[11], and has an excellent contact with HTL layer PEDOT:PSS and ETL PCBM. All of these produce the highest PCE of 15%.

4. Conclusion

In conclusion, by controlling the amount of DMSO doped in PEDOT:PSS, a superior device was obtained with the efficiency of 13.6%. Furthermore, another key factor for a perovskite solar cell is the high crystallization of the perovskite layer. Solvent annealing was adopted to improve the crystallization in this work. With dropping IPA around the solar cell and annealing for 20 minute, a surprising characteristic of the device with the efficiency of 15%, V_{OC} of 0.99 V, Fill Factor of 67.9%, J_{SC} of 22.3mA/cm² was obtained.

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