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Efficient planar heterojunction perovskite solar cells with weak hysteresis fabricated via bar coating

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ABSTRACT

We report efficient, planar heterojunction perovskite solar cells prepared via bar coating that are compatible with large-scale fabrication on flexible substrates. Our $MAPbI_3$ perovskite devices by bar coating method achieved a maximum power conversion efficiency (PCE) of 13.0% using a ITO/PEDOT: PSS/ $CH_3NH_3PbI_3$($MAPbI_3$)/PCBM/Ag structure, and there is very weak hysteresis in these devices. After formulation of the precursor solution and optimization of the coating process, planar perovskite thin films containing large-size grains with low surface roughness were obtained. We found that anti-solvent plays an important role in determining the uniformity, size of grains and width of grain boundaries in perovskite films. The addition of 5 vol% isopropanol into the precursor solution leads to the formation of large aspect ratio grains with a length ca. 200 µm and width of a few hundred nanometers, together with narrow grain boundaries. However, the absence or excessive of isopropanol result in perovskite films with high surface roughness and broad grain boundaries due to inefficient crystal growth or the formation of ridges between crystal grains. These grain boundaries have high PL intensity due to charge recombination and consequently deteriorate device efficiency. When bar-coating the perovskite films in air, best devices with PCE over 11% can be achieved with a relatively high humidity around 50%, eliminating the low humidity requirement during air processing.

1. Introduction

Organic-inorganic lead halide perovskite solar cells have attracted tremendous attention in recent years due to their ability to obtain high PCE [1–5]. The highest PCE has been reported to be as high as 20.8% in published work [6] and 22.1% in certificated report [7]. The low material cost, tunable band gap [8], long carrier diffusion length [9] and facial solution processing properties [10] bring great potential for commercialization. The major efforts on solution processed perovskite solar cells are focused on spin coating, a method that could produce high quality perovskite films with less pin-holes and better coverage [11]. However, spin coating has disadvantages in terms of losing and wasting raw materials as well as limiting the large-scale production. The formulation and optimization protocols to achieve the best champion cell from a spin coating process always fail to obtain devices with similar efficiency when using a scalable production methods, such as spray coating [12], blade coating [13,14] and inject printing [15]. Comparing with a typical spin coating process, the solvent evaporation rates in these scalable printing processes are slow and usually result in poor film coverage and crystal growth. The crystallization during the film formation process shows significant influence, and a balance between the nucleation and crystallization stages is therefore key to receive uniform and high quality perovskite films for efficient and stable perovskite solar cells.

A lot of work have been dedicated to morphology control during the solution casting process of perovskite [16,17]. Fast nucleation and crystallization during spin coating were found to be beneficial to prepare high quality perovskite films [16,17]. A few approaches have been demonstrated to be able to accelerate the crystallization process, including gas blowing [18], hot-casting [19] and anti-solvent treatment [20]. For example, when applying hot blade casting or gas blowing after film casting to increase solvent evaporation, nucleation and crystallization of perovskite were accelerated [21]. The grain size within the perovskite films has also been found to be important, large and uniform grains effectively reduce the grain boundaries to reduce charge recombination and facilitate charge transport, consequently improve device efficiency [3].

Here we report the fabrication of efficiency perovskite solar cells using a bar-coating method. Bar-coating deposition is recognized as one of methods that is facial to large-scale fabrication on either hard or

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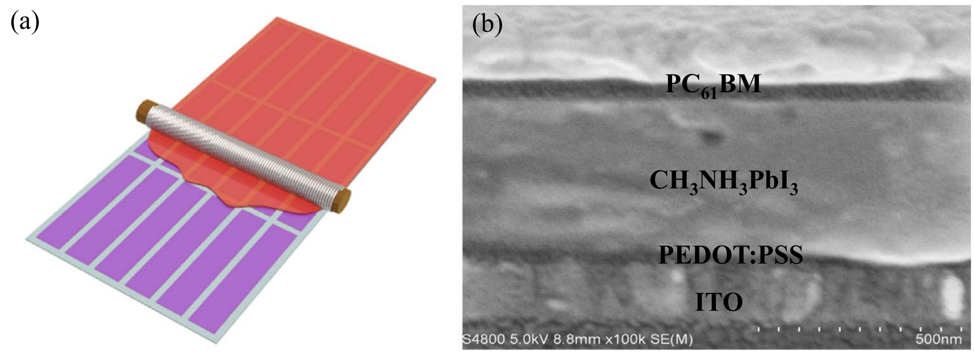

Fig. 1. (a) Scheme of perovskite film casting via bar coating; (b) Cross-sectional scanning electron microscopy image of the perovskite solar cell.

Table 1
The photovoltaic parameters of devices processed with different amounts of IPA, with a structure of ITO/PEDOT: PSS/Perovskite/PCBM/Ag. The data was obtained based on 15 individual devices.

DMSO: GBL:IPA 3:7: X (v/v/v)	PCE_{ave} ± error bar (PCE_{max}) (%)	FF ± error bar (%)	J_{sc} ± error bar (mA/ cm^2)	V_{oc} ± error bar (V)
0	7.23 ± 0.98 (8.30)	58.31 ± 4.48	15.19 ± 0.89	0.82 ± 0.10
0.5	11.82 ± 0.57 (13.03)	70.71 ± 7.34	20.14 ± 1.48	0.83 ± 0.01
1	10.03 ± 0.13 (10.44)	63.68 ± 4.39	19.95 ± 0.39	0.79 ± 0.01
3	8.63 ± 1.41 (10.76)	54.90 ± 7.58	19.17 ± 0.68	0.82 ± 0.03

flexible substrates [22]. It has already been used to prepare thin films during the fabrication of various optoelectronic devices [23]. We firstly optimized the bar-coating conditions, i.e. levelling time and substrate temperature, to prepare perovskite films with better uniformity and film coverage. We found that the surface roughness, coverage and crystal growth were greatly improved by adding 5 vol% anti-solvent isopropanol (IPA) into the precursor solution. Morphology study shows that large aspect ratio grains (with a length over 200 µm and width less than 500 nm) with narrow ground boundaries are formed within these perovskite films. The presence of more IPA, however, broadens the grain boundaries and deteriorates device efficiency. Our bar-coated perovskite film incorporated in PEDOT: PSS- and PCBM- based planer heterojunction perovskite solar cells achieved a maximum PCE of 13%. Furthermore, we demonstrate that perovskite solar cells with the maximum PCE over 11% can be achieved by bar-coating in air with a relatively high humidity of 50%. Our best perovskite devices by bar-coating either in glovebox or in air show very weak hysteresis.

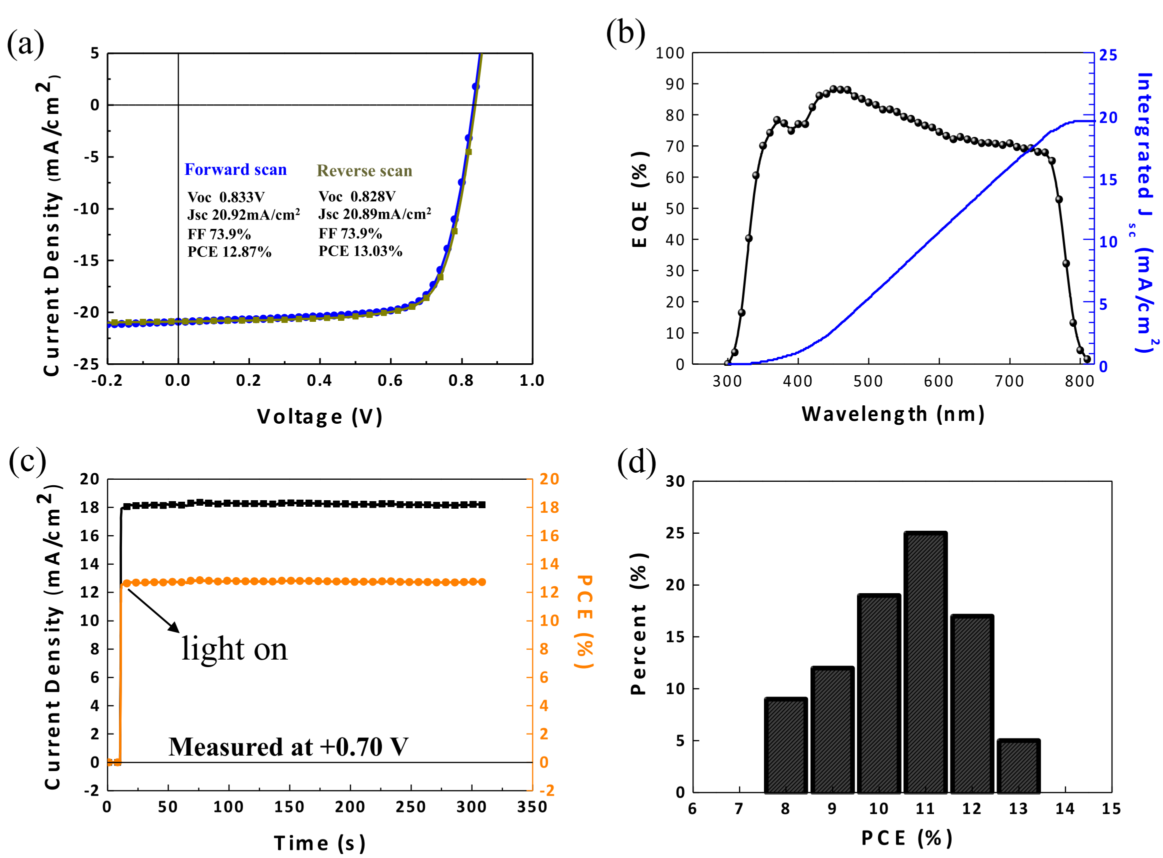

Fig. 2. (a) J-V curves and (b) EQE spectrum of bar-coated perovskite solar cells with the presence of 5 vol% IPA. (c) Stabilized photocurrent density at the maximum power point (voltage=0.7 V). (d) Histogram of PCE.