Solar Energy 180 (2019) 594–600

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

# Study of inverted planar $CH_3NH_3PbI_3$ perovskite solar cells fabricated under environmental conditions

Marco Polo Montoya[a,b], Siraj Sidhik[b], Diego Esparza[a,*], Tzarara López-Luke[b], Isaac Zarazua[c], Jesús Manuel Rivas[a], Elder De la Rosa[d,*]

[a] Unidad Académica de Ingeniería Eléctrica, Universidad Autónoma de Zacatecas, Av. Ramón López Velarde 801, Zacatecas C.P. 98060, Mexico
[b] Nanophotonics and Advanced Materials Group, Centro de Investigaciones en Óptica, A.P. 1-948, León, Gunajuato C.P. 37150, Mexico
[c] Departamento de Ciencias Exactas y Tecnología, Universidad de Guadalajara, Centro Universitario de Los Lagos, Lagos de Moreno, Jalisco 47460, Mexico
[d] Universidad De La Salle Bajio Campus Campestre, León Gto 37150, Mexico

ARTICLE INFO

*Keywords:*
Inverted structure
Perovskite
Solar cells

ABSTRACT

Organic-inorganic inverted perovskite solar cells have been analyzed. This structure uses organic semiconductors as electron and hole selective electrodes and the perovskite as light harvesting layer. The anti-solvent deposition method is a frequently used techniques in the elaboration of conventional perovskite solar cells (FTO/$TiO_2$/$CH_3NH_3PbI_3$/Spiro-OMetad/Au). However, the anti-solvent method is seldom used in the inverted structure. In this work, we use the anti-solvent method to fabricate the perovskite film for solar cells in the ITO/PEDOT:PSS/$CH_3NH_3PbI_3$/$PC_{61}BM$/Ag configuration, systematically studying the effect of the anti-solvent dripping time and the relative humidity in cell fabrication and performance. The morphological, optical and photovoltaic analyses indicate that the right combination of these two parameters will result in a preferential crystal growth in the (1 1 0) orientation. This allows the formation of homogeneous pinhole-free films that enhance light harvesting and reduce charge-carrier leakage, hence increasing short circuit current and fill factor to obtain a photo-conversion efficiency of about ~10%.

## 1. Introduction

Perovskite solar cells (PSC) have attracted much attention due to their strong light absorption coefficient, high electron-hole diffusion length, ambipolar charge transport, low temperature solution processing, tunable band gap and simple fabrication processes (Christian et al., 2014; Huang et al., 2015; Jeon et al., 2014; Michael et al., 2018; Xiao et al., 2016). The normal mesoscopic configuration (n-i-p) has the highest power conversion efficiency (PCE) for perovskite devices > 20% (Correa-Baena et al., 2017; Il et al., 2018; Lu et al., 2018; Saliba et al., 2016a; Saliba et al., 2016b). This architecture (FTO/$TiO_2$/$CH_3NH_3PbI_3$/Spiro-OMetad/Au) employs a mesoscopic $TiO_2$ as the electron transport layer. However, this configuration has several disadvantages, for example the mesoporous $TiO_2$ layer requires a high temperature (> 450 °C) sintering which makes it incompatible with flexible devices, the most frequently used hole transport material, Spiro-OMetad, has problems of oxidation, degradation with UV light (Christians et al., 2018; Jena et al., 2018; Sanchez and Mas-Marza, 2016; Tsai et al., 2018) and morphological deformation at high temperature (Jena et al., 2017). The inverted planar structure (p-i-n) was derived from organic solar cells. This architecture (ITO/PEDOT:PSS/Perovskite/PCBM/Ag) employs a p-type and n-type organic semiconductors as bottom and top charge transport layers, respectively. Inverted perovskite solar cells (PSC) have several advantages like low temperature processing and the possibility of scaling up to large production levels. Additionally, the low temperature processing allows the fabrication of flexible PSCs (Heo et al., 2015; Roldan-Carmona et al., 2014).

The performance of the perovskite device is mostly determined by the quality of perovskite film. Usually, high quality films were made under controlled conditions, inside the glovebox with a precise control over the temperature, humidity, and the oxygen content resulting in the formation of a smooth and uniform perovskite film. The exposure to high humidity conditions during the crystallization process enhances the degradation of perovskite film leading to the disintegration to $H_3NH_2I$ and $PbI_2$ (Contreras-Bernal et al., 2018; Huang et al., 2016; Niu et al., 2014). The fabrication of perovskite films without the use of a glovebox is made possible by considering the humidity while adjusting

* Corresponding authors at: Unidad Académica de Ingeniería Eléctrica, Universidad Autónoma de Zacatecas, Av. Ramón López Velarde 801, Zacatecas C.P. 98060, Mexico (D. Esparza). Universidad De La Salle Bajio Campus Campestre, León Gto 37150 Mexico (E. De la Rosa).
*E-mail address:* desparza@uaz.edu.mx (D. Esparza).

https://doi.org/10.1016/j.solener.2019.01.061
Received 22 October 2018; Received in revised form 17 January 2019; Accepted 21 January 2019