Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A. This journal is © The Royal Society of Chemistry 2015

# **Electronic supplementary information**

### Effects of Annealing Temperature of Tin Oxide Electron Selective Layers on the

## **Performance of Perovskite Solar Cells**

Weijun Ke,<sup>ab</sup> Dewei Zhao,<sup>b</sup> Alexander J. Cimaroli,<sup>b</sup> Corey R. Grice,<sup>b</sup> Pingli Qin,<sup>a</sup> Qin Liu,<sup>a</sup> Liangbin Xiong,<sup>a</sup> Yanfa Yan\*<sup>b</sup> and Guojia Fang\*<sup>a</sup>

<sup>a</sup>Key Laboratory of Artificial Micro- and Nano-structures of Ministry of Education of China, School of Physics and Technology, Wuhan University, Wuhan 430072, China. E-mail: gjfang@whu.edu.cn <sup>b</sup>Department of Physics and Astronomy and Wright Center for Photovoltaics Innovation and Commercialization, The University of Toledo, Toledo, OH 43606, USA. E-mail: yanfa.yan@utoledo.edu

### **Experimental Section**

Device fabrication:

LT-SnO<sub>2</sub> and HT-SnO<sub>2</sub> ESLs were prepared by spin-coating precursor solutions of SnCl<sub>2</sub> (Alfa, 99.9985%) in ethanol on clean FTO substrates. The thicknesses of the SnO<sub>2</sub> films were controlled by the concentrations of SnCl<sub>2</sub> solutions 40 and 100 nm SnO<sub>2</sub> films were prepared by 0.1 and 0.25 mol/L SnCl<sub>2</sub> solution, respectively. The spin rate is 500 rpm for 1s and then 2000 rpm for 30s. The LT-SnO<sub>2</sub> and the HT-SnO<sub>2</sub> ESLs were heated on a hotplate in air at 185 °C and 500 °C for 1 hour, respectively. 320 nm thick CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> perovskite films were evaporated by heating CH<sub>3</sub>NH<sub>3</sub>I and PbI<sub>2</sub> (Sigma, 99.999%) powder in two individual crucibles and then the films were annealed on a hotplate at 100 °C for 10 min in glove box. The solution of HSL consisted of 26 mM Li-bis-(trifluoromethanesulfonyl) imide (LiTFSI) (Sigma, 99.95%), 55 mM 4-tert-butylpyridine (TBP) (Sigma, 96%), and 68 mM spiro-OMeTAD (Shenzhen Feiming Science and Technology Co., Ltd., 99.0%), which were dissolved in a mixed solvent of chlorobenzene (Sigma, 99.8%) and acetonitrile (Sigma, 99.8%) with a volume ratio of 10:1. The solution of HSL was coated on the perovskite films at 500 rpm for 1s and then 2000 rpm for 60 s. The devices were completed by thermally evaporating 60 nm thick Au electrodes. The active area of the cells defined by the Au electrodes were 0.08 cm<sup>2</sup>.

### Characterization

Transmission spectra and ultraviolet-visible absorbance spectra were measured by an ultraviolet-visible spectrophotometer (CARY5000, Varian, Australia). Morphologies

of LT-SnO<sub>2</sub> and HT-SnO<sub>2</sub> films deposited on FTO substrates, and perovskite films deposited on ESLs were characterized by a high-resolution field emission SEM (Hitachi S-4800). Atomic-force microscopy (AFM) images of the SnO<sub>2</sub> films deposited on FTO substrates were measured by a Veeco Nanoscope IIIA instrument. The crystal structure of SnO<sub>2</sub> films was examined by XRD (Rigaku Ultima III) with Cu K $\alpha$  radiation under operation conditions of 40 kV and 44 mA. *J-V* curves and steady-state efficiencies were measured by a Keithley Model 2400 under AM1.5G simulated irradiation with a standard solar simulator (PV Measurements Inc.). QE spectra performed on a QE system (PV Measurements Inc.). Impedance spectra were performed on an electrochemical workstation (Voltalab PGZ-301) at 0 mV bias in dark.  $V_{oc}$  decay measurements were performed on an electrochemical workstation (Voltalab PGZ-301). Electrical resistivity, electron mobility, and carrier densities of LT-SnO<sub>2</sub> and HT-SnO<sub>2</sub> films were characterized by a Hall Effect system (MMR Technologies, INC., H-50).



**Fig. S1** Top view SEM images of 320 nm thick vacuum-processed perovskite films on (a) LT-SnO<sub>2</sub> and (b) HT-SnO<sub>2</sub> ESLs deposited on FTO substrates.



Fig. S2 Top view SEM image of bare FTO substrate.



Fig. S3 AFM images of (a) LT- and (b)  $HT-SnO_2$  thin films (40 nm) deposited on FTO substrates.



**Fig. S4** X-ray diffraction patterns taken from LT- and HT-SnO<sub>2</sub> thin films deposited on silicon substrates.



**Fig. S5**  $V_{oc}$  decay curves of the perovskite solar cells using LT-SnO<sub>2</sub> and HT-SnO<sub>2</sub> ESLs.