Electronic Supplementary Information

Room-Temperature Film Formation of Metal Halide Perovskites on n-type Metal Oxides: The Catalysis of ZnO on Perovskite Crystallization

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EXPERIMENTAL SECTION

Materials and Synthesis:

ITO substrates were all purchased from Shenzhen Huayu Union Technology Co. Ltd. Methylammonium iodide (CH_3NH_3I) powder was purchased from Dyesol Limited. Poly[(9,9-dioctylfluorenyl-2,7-diyl)-*co*-(4,4'-(N-(4-sec-butylphenyl)diphenylamine)] (TFB) was supplied by Lumtec. Ltd. 2-isopropanol (HPLC, 99.9%) , ethanol (anhydrous, 99.8%), lead iodide (PbI_2, 99.99%), Toluene (99.9%), Polyethylenimine (PEIE) 80% ethoxylated solution, Zinc acetate dihydrate (99.999%), N, N-Dimethylformamide (DMF, 99.9%) were all purchased from Sigma Aldrich. Tin(IV) oxide (SnO_2) 15% in H_2O colloidal dispersion was purchased from Alfa Aesar. PEIE was dispersed in IPA solution with a concentration of 0.05 wt %. All the materials were used as received without any further purification. ZnO nanocrystals, SnO_2 and TiO_x solution were prepared as previous reported.[1-3] The precursor solution of perovskite halide with a concentration of 1.0 M of PbI_2, were prepared by mixing CH_3NH_3I with PbI_2 powder with 2:1 molar ration in DMF. The solution was stirred at 60 ℃ over 2 h and filtered with a 0.45 μm filter before use.

***Film and device fabrication process*:**

All the ITO coated glass substrates were treated with detergent overnight and then by TL1 (NH_3: H_2O_2: H_2O = 1:1:5) procedure for 20 min prior to dry them at high-speed nitrogen flow. TiO_x, SnO_2 and ZnO films were all deposited in ambient condition and annealed at 150 °C for 15 mins. Perovskite films were spin-coated on the substrates in glovebox (under room light) at 5000 r.p.m for 45 s. 120 µL toluene was quickly dropped on the substrate 5 s after starting the spin coating process. For the vacuum dried perovskite devices, the film was placed into the vacuum chamber for 12 h at -1 Bar under dark. TFB (8 mg/ml in CB) were prepared by spic-coating corresponding solution onto perovskite film. The device fabrication processes were finished by depositing 8 nm MoO_3 film and 100 nm Ag film as electrode inside of the thermal evaporator. The device working area is 0.0725 cm^2. For the ZnO/PEIE based films, the PEIE was coated and annealed at 100 °C for 10 min in the glovebox.

Film and device characterizations:

The SEM images were obtained by FEI (Quanta 200 FEG) scanning electron microscopy. For the absorption measurements and XRD, all the samples are covered with a ~100 nm layer of polymethyl methacrylate (PMMA). UV-Vis absorption spectra are obtained with PerkinElmer Lambda 900. Steady state PL spectra were obtained with a 485 nm laser and an Andor spectrometer. The XRD spectrum of perovskite film was performed using a PANAlytical Empyrean system. Perovskite LED devices were all measured in a nitrogen-filled glovebox at room temperature. A Keithley 2400 was used to collect current density and driving voltage data and an integrating sphere together with the Go pro spectrometer (Ocean Optics) were used to collect emission data.

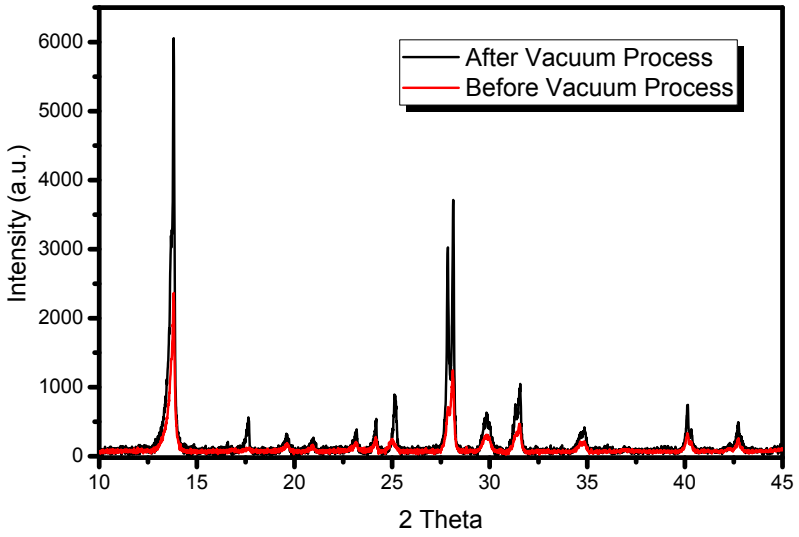

Fig. s1. The XRD pattern of perovskite films deposited on ZnO films before and after the vacuum-processing.

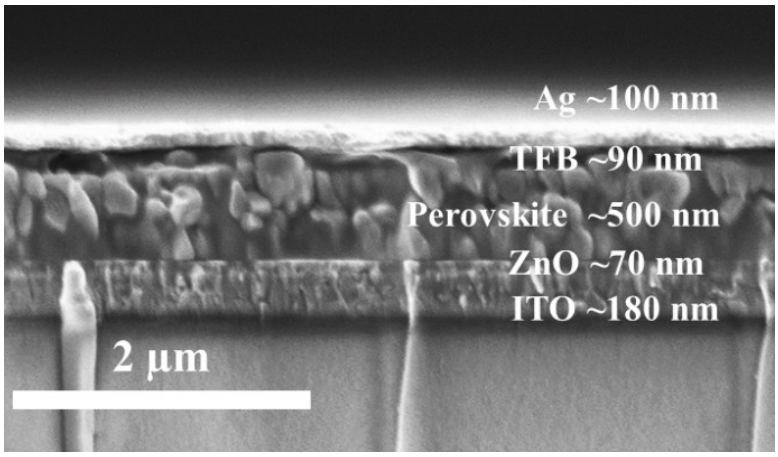

Fig. s2. The cross-sectional SEM images of the perovskite device on ZnO substrates.

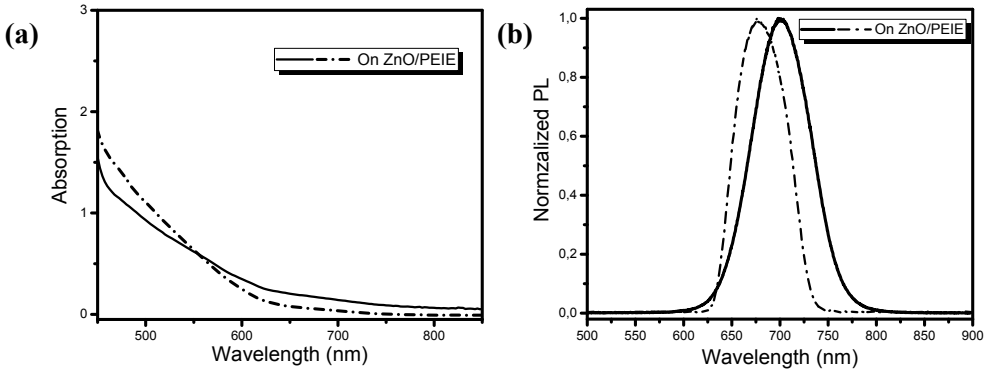

Fig. s3. a) the UV-Vis absorption spectra and b) PL spectra of perovskite films deposited on ZnO/PEIE substrates before (dotted line) and after (solid line) vacuum-processing.

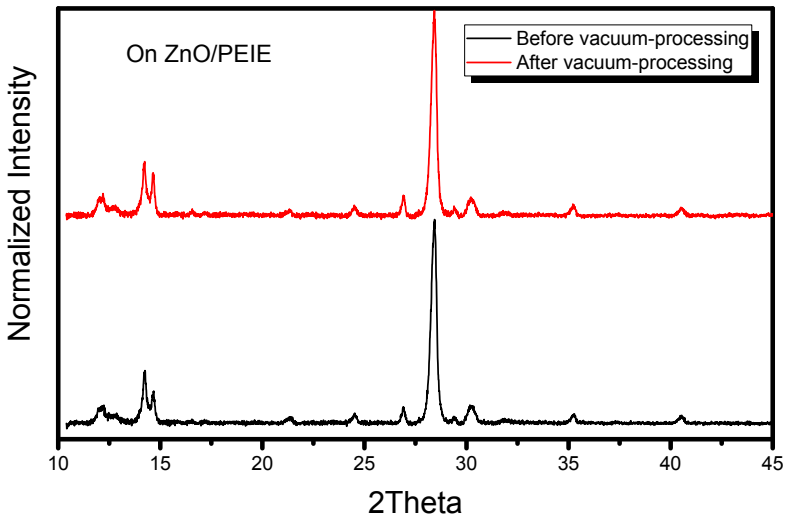

Fig. s4. The XRD patterns of perovskite films deposited on ZnO/PEIE substrates before and after vacuum-processing.

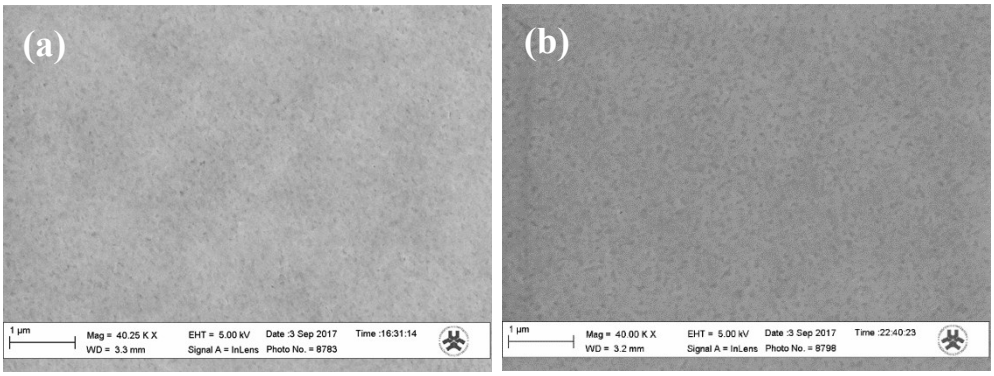

Fig. s5. The SEM images of perovskite films deposited on ZnO/PEIE substrates before (a) and after (b) vacuum-processing.

Reference

[1] Q. Jiang, L. Zhang, H. Wang, X. Yang, J. Meng, H. Liu, Z. Yin, J. Wu, X. Zhang, J. You, *Nat. Energy* **2017,** *2*, 16177.

[2] S. Bai, Z. Wu, X. Wu, Y. Jin, N. Zhao, Z. Chen, Q. Mei, X. Wang, Z. Ye, T. Song, *Nano Res.* **2014,** *7*, 1749.

[3] P. Docampo, J. M. Ball, M. Darwich, G. E. Eperon, H. J. Snaith, *Nat. commun.,* **2013,** *4*, 2761.