Supporting Information

Temperature-dependent performance metrics of tin-doped perovskite photodetectors

Ruiming Li[1,2], Jiannan Song[1], Jiali Peng[1,2], Xiaoyu Tian[1], Yalun Xu[1,2], Huihuang Huang[1], Songxue Bai[1], Yanyan Li[1,2], Fang Yao[1] and Qianqian Lin[1, 2] *

[1] Key Lab of Artificial Micro- and Nano-Structures of Ministry of Education of China, School of Physics and Technology, Wuhan University, Wuhan 430072, P. R. China

[2] Suzhou Institute of Wuhan University, Suzhou 255123, P. R. China

Corresponding Author：

*E-mail: q.lin@whu.edu.cn

1. Experimental details
2. Supporting figures

1. Experimental Section

***Materials and chemicals*:**

Formamidinium iodide (FAI) was purchased from Greatcell Solar. Formamidinium bromide (FABr) was purchased from Xi'an Polymer Light Technology Corp. Cesium iodide (CsI), dimethyl sulfoxide (DMSO), and *N,N*-Dimethylformamide (DMF) were purchased from Sigma-Aldrich. Lead iodide (PbI_2) was purchased from TCI Chemicals. Tin (II) iodide (SnI_2) was purchased from Energy Chemical. Isopropanol (C_3H_8O) was purchased from Macklin. Ethanol (C_2H_6O) and toluene were purchased from Sinopharm Chemical Reagent Co., Ltd. Ethyl acetate (EA) was purchased from Aladdin.

***Device Fabrication*:**

All pre-patterned indium tin oxide (ITO)-coated glass substrates (1 μm channel) and glass substrates (100 μm channel) were ultrasonically cleaned sequentially in deionized water, isopropanol, and ethanol for 10 min respectively. The substrates were dried by air gun and treated with UV-ozone for 15 min. $FA_{0.83}Cs_{0.17}Pb_{1-x}Sn_xI_{2.7}Br_{0.3}$ (x=0%, 0.001%, 0.002%, 0.01%, 1.2 M) was spin-coated on substrates at 6000 rpm for 120 s in the nitrogen glove box. After 25~30 s, 200 μL of EA was dispensed on the film as the antisolvent. Then, these samples were immediately annealed at 140℃ for 60 min in air. $MAPb_{1-x}Sn_xI_3$ (x=0%, 0.0001%, 0.001%, 0.01%, 0.1%, 1%, 1.2 M) was deposited on substrates at 3000 rpm for 80 s. After 30 s, 200 μL of toluene was dropped as the antisolvent. After the spin-coating, the perovskite films were transferred on the hot stage to anneal at 100℃ for 10 min in the nitrogen glove box. 60 nm Au was evaporated on the top of glass/perovskite samples as top electrodes with a shadow mask.

***Characterization*:**

The absorption spectra were tested with a spectrometer (ThetaMetrisis, FR-Basic-UV/NIR-HR). The photoluminescence (PL) spectra were recorded using a Morpho Nova spectrometer with the excitation of a 405 nm CW laser. The time-resolved photoluminescence (TRPL) spectra were measured by using the time-correlated single-photon counting technique (TimeHarp 260 PICO Single, PicoQuant GmbH) and a picosecond diode laser (405 nm, PiL040X, NKT photonics). The X-ray diffraction (XRD) investigations were characterized using a D8 Advance X-ray diffractometer (Cu Kα=1.5418 Å) with a scanning range from 10° to 50°. The morphology of perovskite films was acquired using a Zeiss SIGMA 500 field-emission scanning electron microscope operated at 5 keV. Current-voltage characteristics (both in dark and under illumination 15 mW cm^{-2}) of the devices were carried out at room temperature or within a cryostat (HCS621G, Instec) by using a B1500A semiconductor analyzer (Keysight). The conductivity measurements of perovskite films with various Sn concentrations were repeated for several times, and at least 10 devices were fabricated for each concentration of Sn-doping. Frequency response were obtained using 528 nm LED (Thorlabs) modulated with an arbitrary wave function generator (Agilent, 33612A), and the photocurrent responses of these devices were recorded with a digital storage oscilloscope (LeCroy Waverunner 8254).

2. Supporting figures

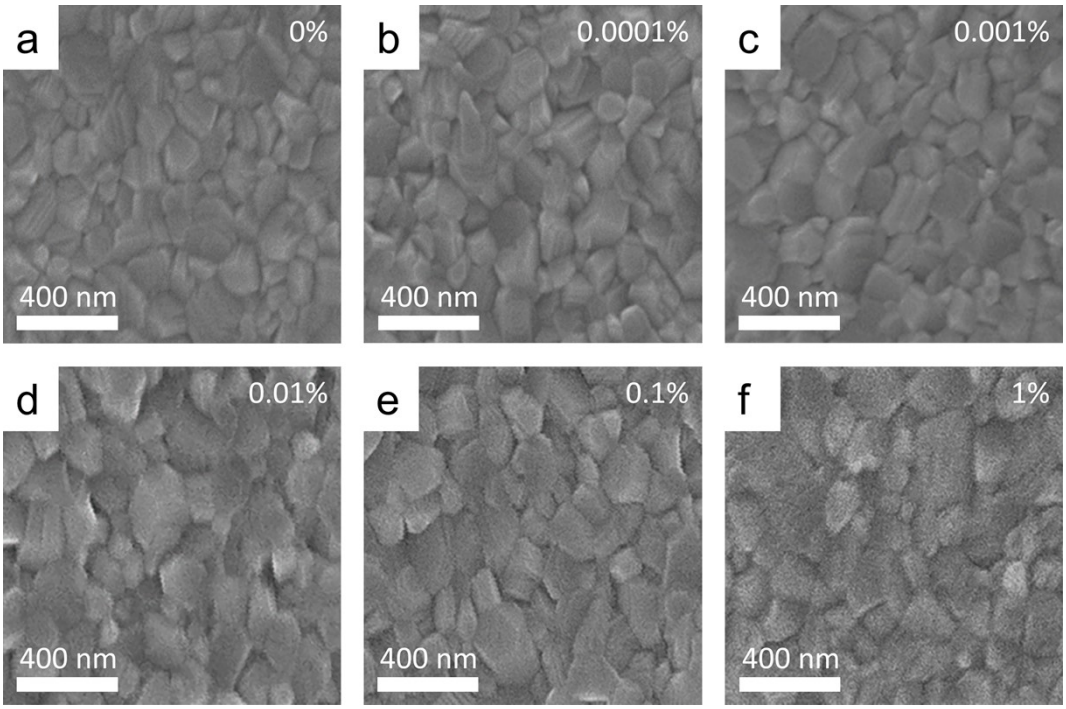

Fig. S1. The surface morphology of $MAPb_{1-x}Sn_xI_3$ film with various tin doping concentration, (**a**) x= 0%, (**b**) 0.0001%, (**c**) 0.001%, (**d**) 0.01%, (**e**) 0.1%, (**f**) 1%.

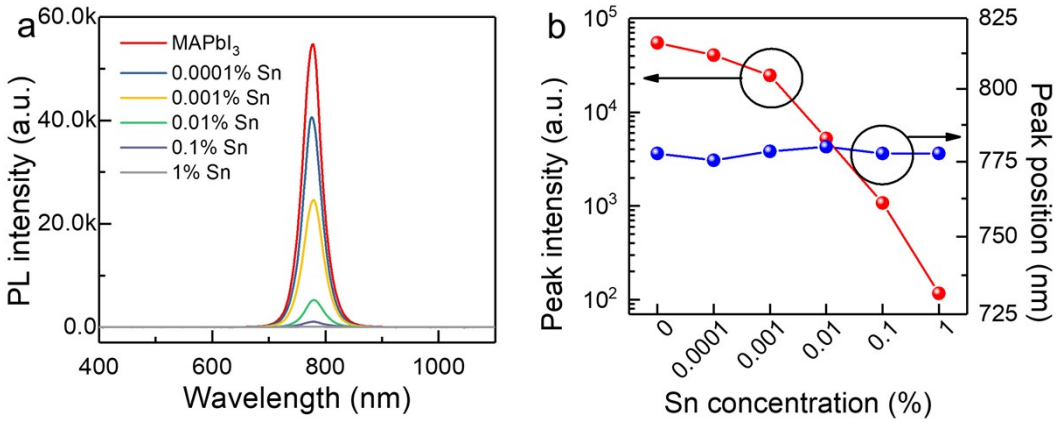

Fig. S2. The PL spectra of $MAPb_{1-x}Sn_xI_3$ (x=0%, 0.0001%, 0.001%, 0.01%, 0.1%, 1%).

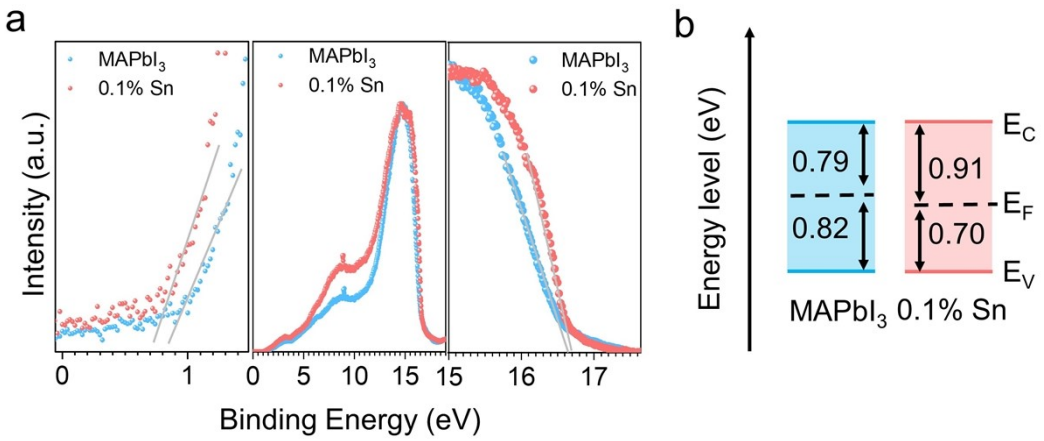

Fig. S3. Comparison of (**a**) ultraviolet photoelectron spectra and (**b**) schematic energy level diagram of the pristine and 0.1% Sn-doped $MAPbI_3$ thin films.

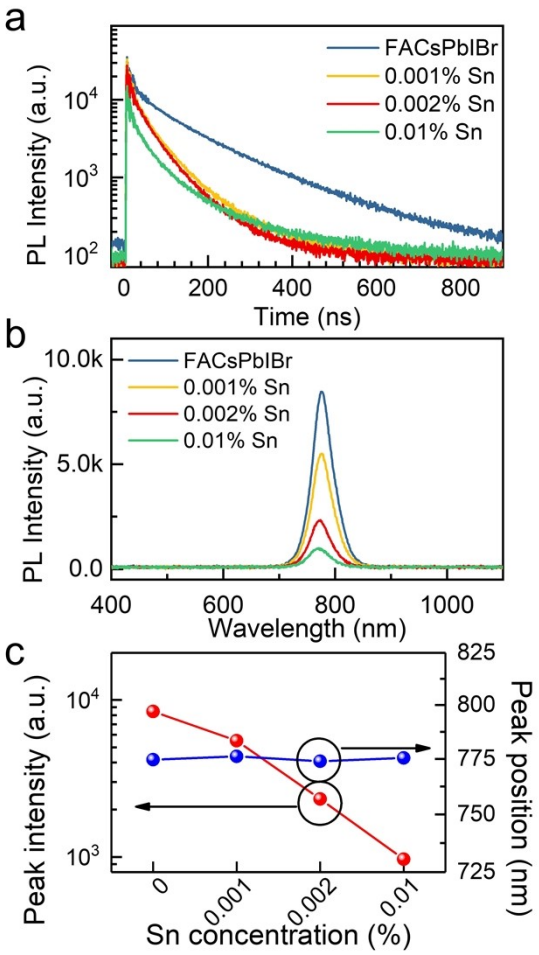

Fig. S4. (**a**) TRPL and (**b**) PL spectra of $FA_{0.83}Cs_{0.17}Pb_{1-x}Sn_xI_{2.7}Br_{0.3}$ (x=0%, 0.001%, 0.002%, 0.01%), (**c**) the peak intensity and position of the obtained PL spectra.

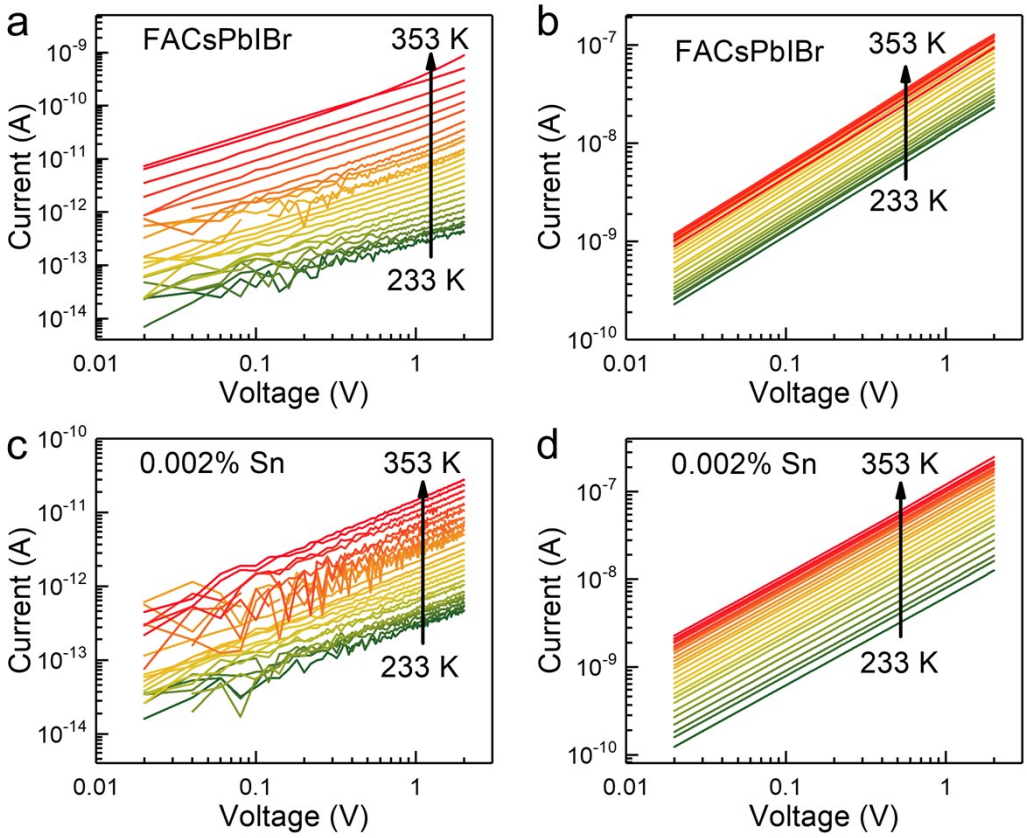

Fig. S5. Current- voltage (*I-V*) curves of $FA_{0.83}Cs_{0.17}PbI_{2.7}Br_{0.3}$ device (**a**) in dark and (**b**) under 15 mW cm^{-2} white LED, *I-V* curves of x=0.002% device (**c**) in dark and (**d**) under 15 mW cm^{-2} white LED.

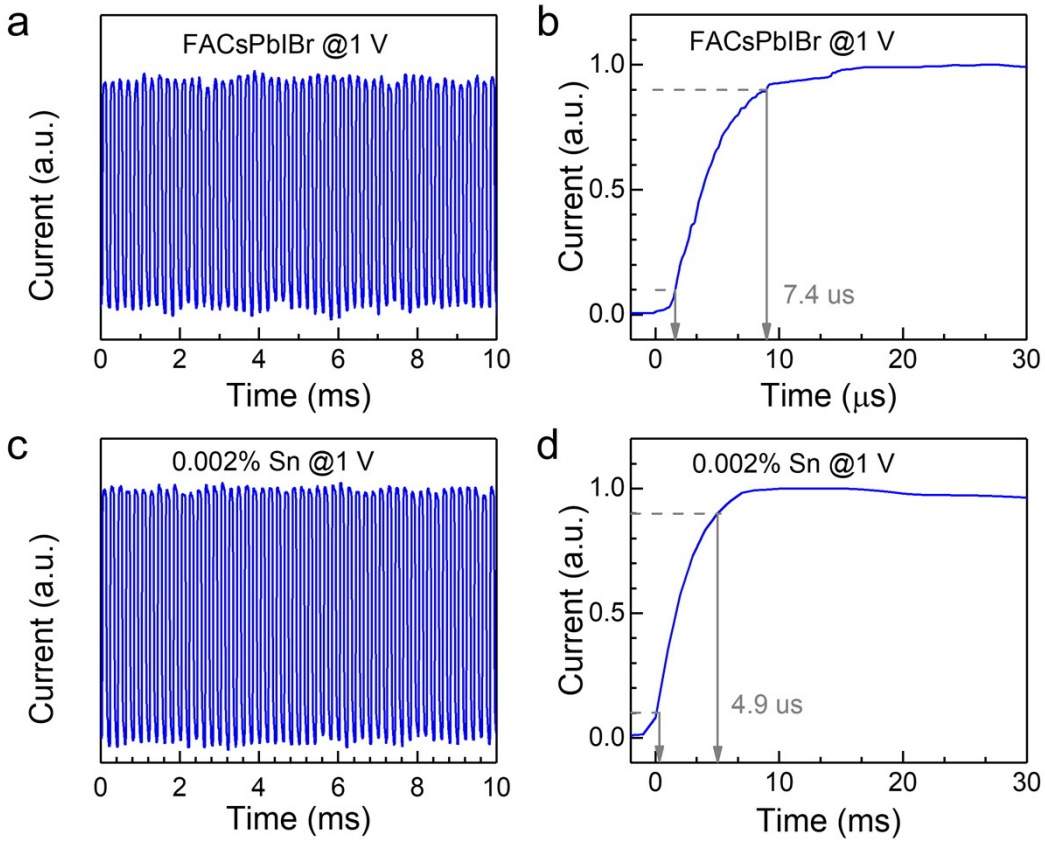

Fig. S6. Temporal responses to 528 nm LED of (**a**-**b**) $FA_{0.83}Cs_{0.17}PbI_{2.7}Br_{0.3}$ control and (**c**-**d**) x=0.002% Sn-doped devices at 1 V.

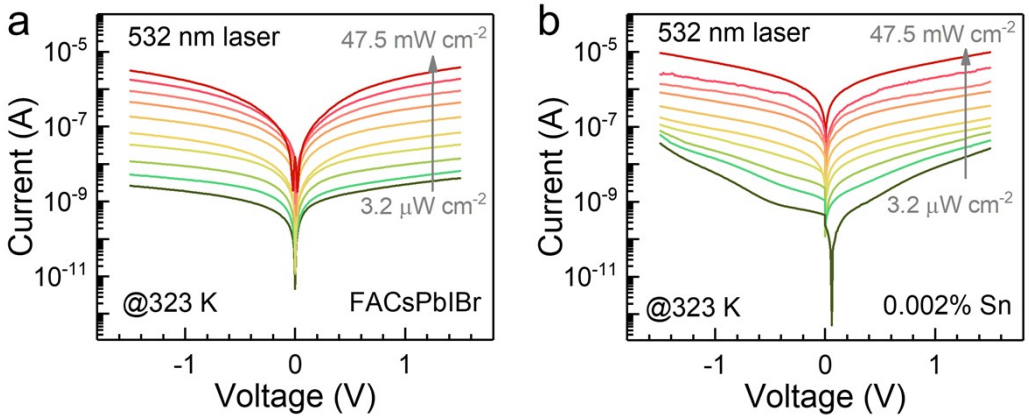

Fig. S7 *I-V* curves of (**a**) $FA_{0.83}Cs_{0.17}PbI_{2.7}Br_{0.3}$ control and (**b**) x=0.002% Sn-doped devices under various light intensities at 50°C.