Supplementary Information for

Multiple-engineering controlled growth of full-bandgap perovskite nanowires for high performance photodetectors

Kuankuan Ren,[ab] Jian Wang,[c] Kong Liu,[ab] Yanbin Huang,[ab] Yang Sun,[ab] Muhammad Azam,[ab] Peng Jin,[c] Zhijie Wang,*[ab] Shengchun Qu*[ab] and Zhanguo Wang[ab]

[a]Key Laboratory of Semiconductor Materials Science, Beijing Key Laboratory of Low Dimensional Semiconductor Materials and Devices, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, 100083, China.

[b]Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049, China

[c]Research Center of Ultra-Precision Optoelectronic Instrument, Harbin Institute of Technology, Harbin 150080, China.

*E-mail: Z.W. (wangzj@semi.ac.cn); S.Q. (qsc@semi.ac.cn).

Experimental section

Electrodeposition of PbO_2 Film. The precursor solution was prepared by dissolving lead acetate ($PbAc_2$) and potassium nitrate (KNO_3) in the deionized water with extra volumes of nitric acid (HNO_3). The final solution was prepared with concentrations of 0.1 M $PbAc_2$, 0.2 M KNO_3 and 0.1 M HNO_3. The PbO_2 film was electrochemically deposited on the ITO substrate in the as-prepared solution with a working voltage of 1.7 V for 10 s. The platinum foil and $Ag/AgCl/KCl_{sat}$ were used as the counter electrode and reference electrode respectively in the deposition processes. The deposited PbO_2 film was dipped into the pure deionized water with several seconds for removing residual solutes and then dried under the flow of nitrogen.

Synthesization of Perovskite Nanowires. The perovskite $CH_3NH_3PbBr_3$ nanowires were synthesized by immersing the PbO_2 film in the CH_3NH_3Br isopropanol solution with reaction time of several hours. After that, the product was dipped into the isopropanol for removing residual solute. For controlling the growth processes of the perovskite, the PbO_2 film was also put into the mixture solution of isopropanol with DMF or DMSO. For the growth of perovskite $CH_3NH_3PbI_3$ (or $CH_3NH_3PbCl_3$) nanowires, the PbO_2 film was just placed in the CH_3NH_3I (or CH_3NH_3Cl) solution. For the growth of mixed halides $CH_3NH_3PbCl_{3-x}I_x$, $CH_3NH_3PbCl_{3-y}Br_y$ or $CH_3NH_3PbBr_{3-z}I_z$ nanowires, the PbO_2 film was just placed in the different halide ratios of CH_3NH_3Cl: CH_3NH_3I, CH_3NH_3Cl: CH_3NH_3I or CH_3NH_3Cl: CH_3NH_3I isopropanol solution, respectively. All these reactions were conducted at room temperature except additional instructions. The detail growth conditions are shown in Table 1.

Fabrication of Photodetectors. According to the length of perovskite $CH_3NH_3PbBr_3$ nanowires, the shadow mask was designed with a suitable spacing (~40 μm). And then the 60 nm thick gold interdigital electrodes were evaporated on the Quartz glass through the shadow mask under the vacuum of 2×10^{-4} Pa. At last, we used PDMS to transfer the perovskite nanowires from the ITO substrate to the interdigital electrodes. Under good contact between the nanowire and the electrode, the photodetector was fabricated.

Characterization of Perovskites and Photodetectors. The PXRD data were tested by a Rigaku SmartLab diffractometer with Cu Kα as the X-ray source. The scanning electron microscope (SEM) images of the as-grown perovskite samples were collected on FEI NanoSEM 650. The Photoluminescence emission spectra were measured at a micro fluorescence test platform. All the spectra were excited with a pumping wavelength of 400 nm except the emission wavelengths around 400 nm, which were excited with a wavelength of 800 nm based on the two-photon pumping effect. The dry-transferred perovskite nanowires on the interdigital electrodes were measured by optical

microscope (Olympus BX51M). The performances of the photodetectors were characterized by a Keithley 2450 source meter under the dark and light illumination. The light source was a 450 nm laser with adjustable optical power.

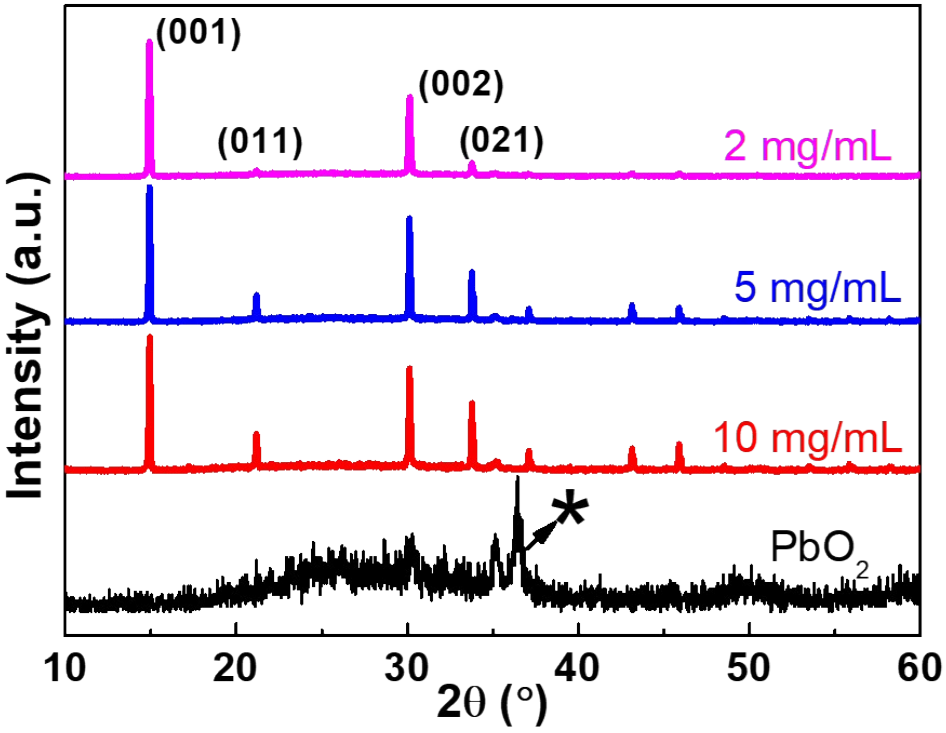

Fig. S1. The PXRD patterns of the initial electrochemically deposited PbO_2 film and the as grown perovskite $CH_3NH_3PbBr_3$ nanostructures at different concentrations of CH_3NH_3Br in isopropanol solution.

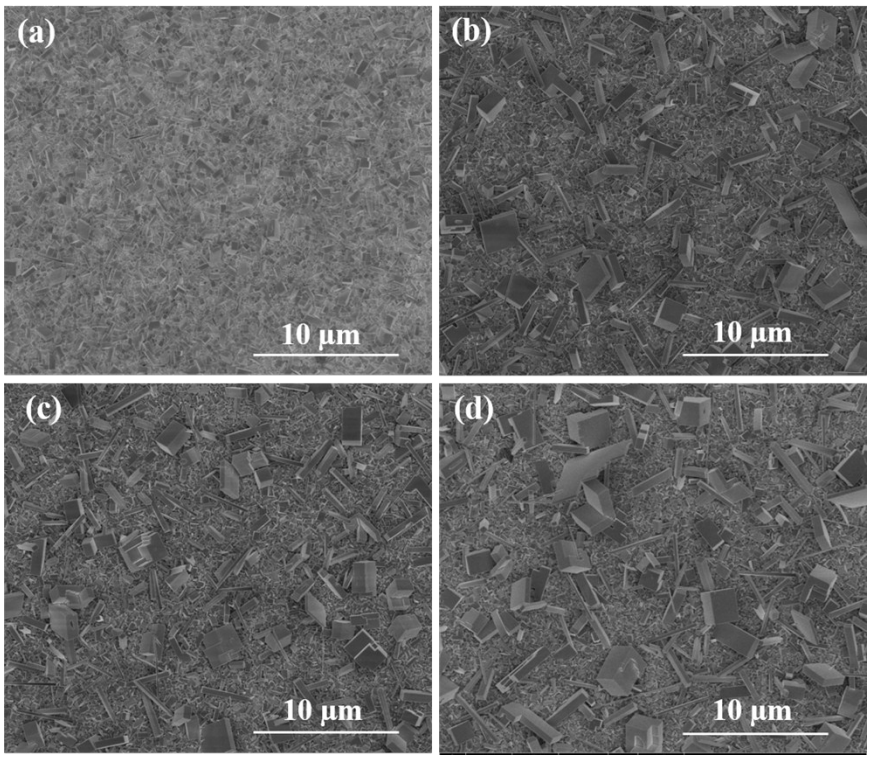

Fig. S2. The perovskite $CH_3NH_3PbBr_3$ nanostructures grown at different reaction time. (a) 20 min, (b) 1 h, (c) 2 h (d) 4 h.

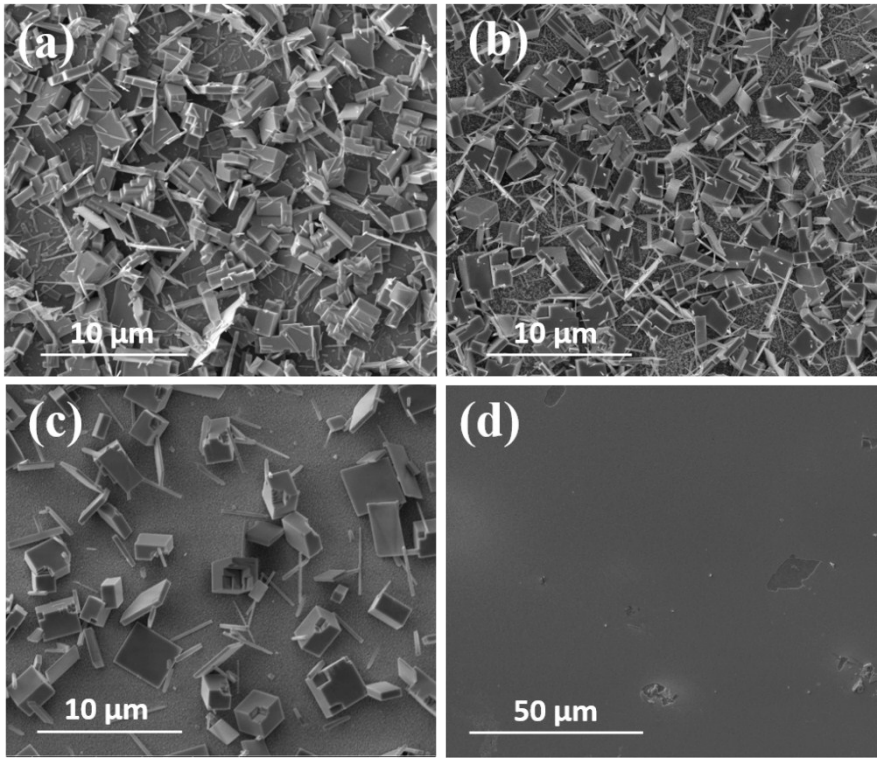

Fig. S3. The perovskite $CH_3NH_3PbBr_3$ nanostructures grown with different additive volumes of H_2O in the 1 mL MABr/ISP solution. (a) 10 μL, (b) 20 μL, (c) 50 μL, (d) 80 μL.

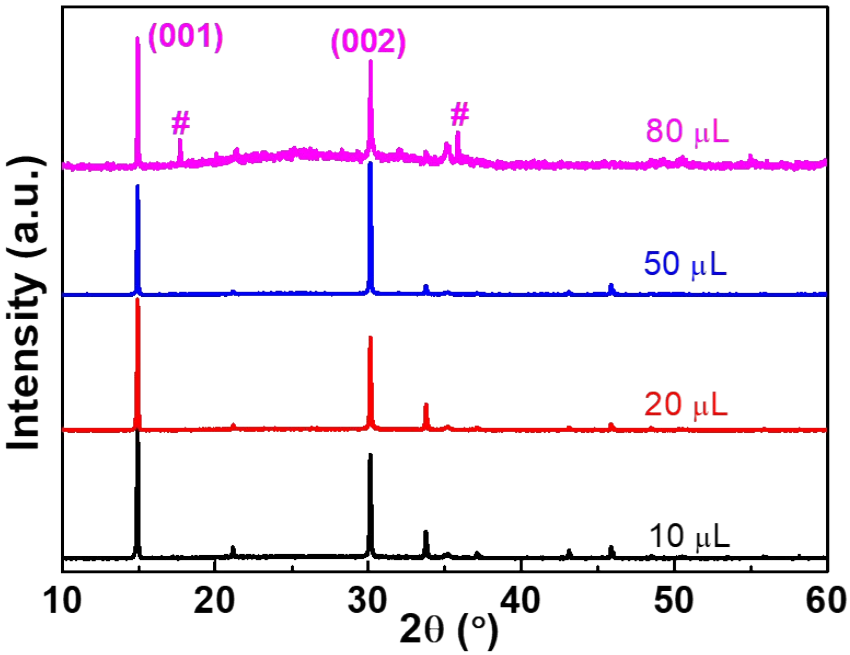

Fig. S4. The PXRD patterns of perovskite $CH_3NH_3PbBr_3$ grown at different additive volumes of H_2O in the isopropanol solution.

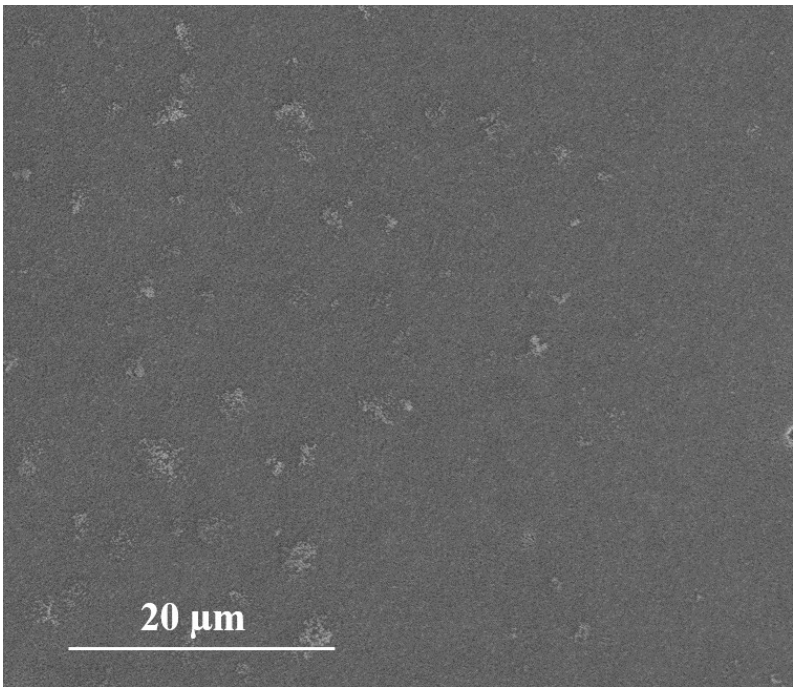

Fig. S5. The perovskite $CH_3NH_3PbBr_3$ film formed with 200 µL DMF in 1 mL of isopropanol solution.

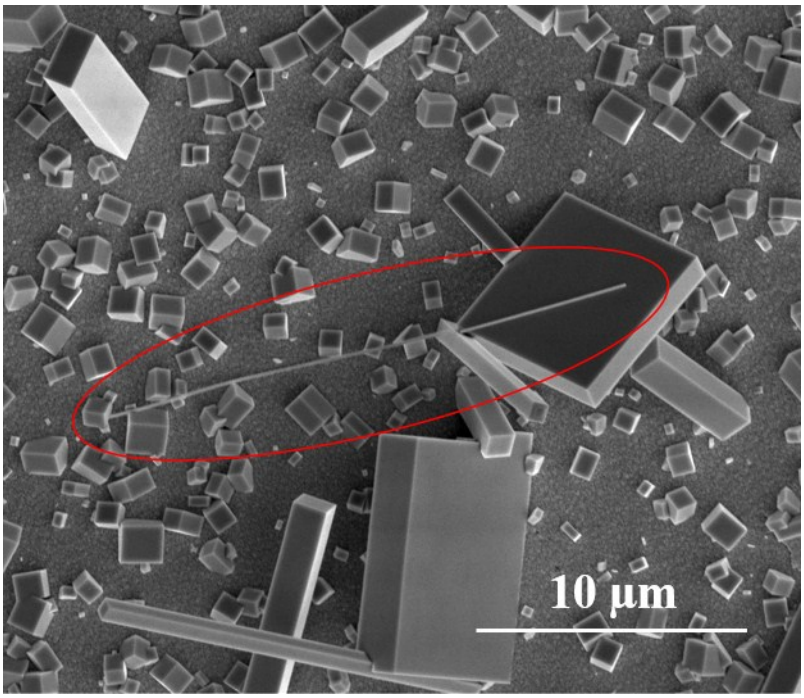

Fig. S6. The SEM image of a selected area in Fig. 4d. The new formed thinner perovskite $CH_3NH_3PbBr_3$ nanowire circled in the red line.

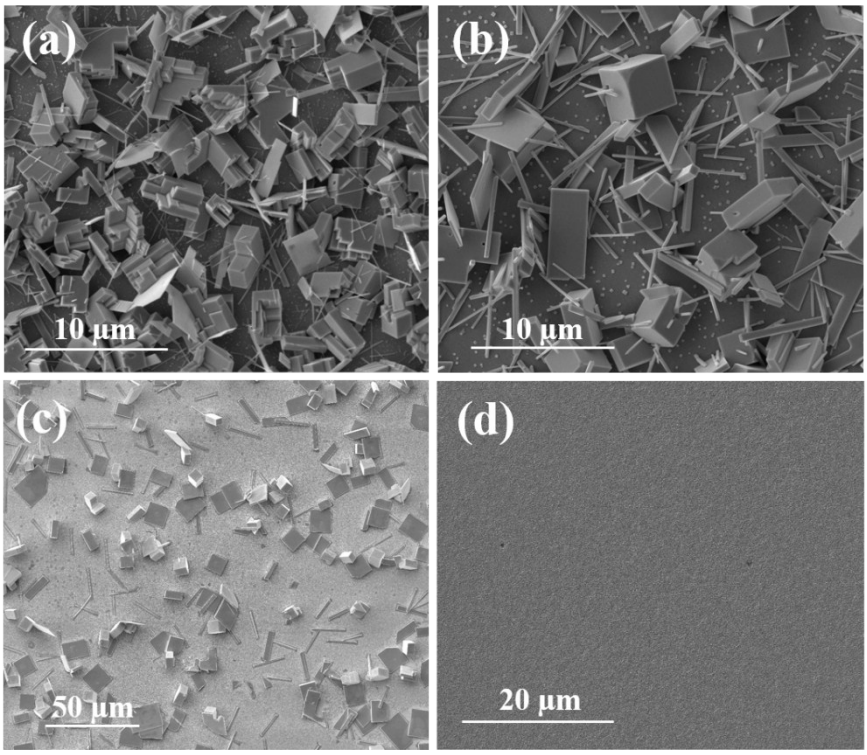

Fig. S7. The perovskite $CH_3NH_3PbBr_3$ nanostructures grown with different additive volumes of DMSO in the 1 mL of isopropanol solution. (a) 10 μL, (b) 50 μL, (c) 100 μL, (d) 200 μL.

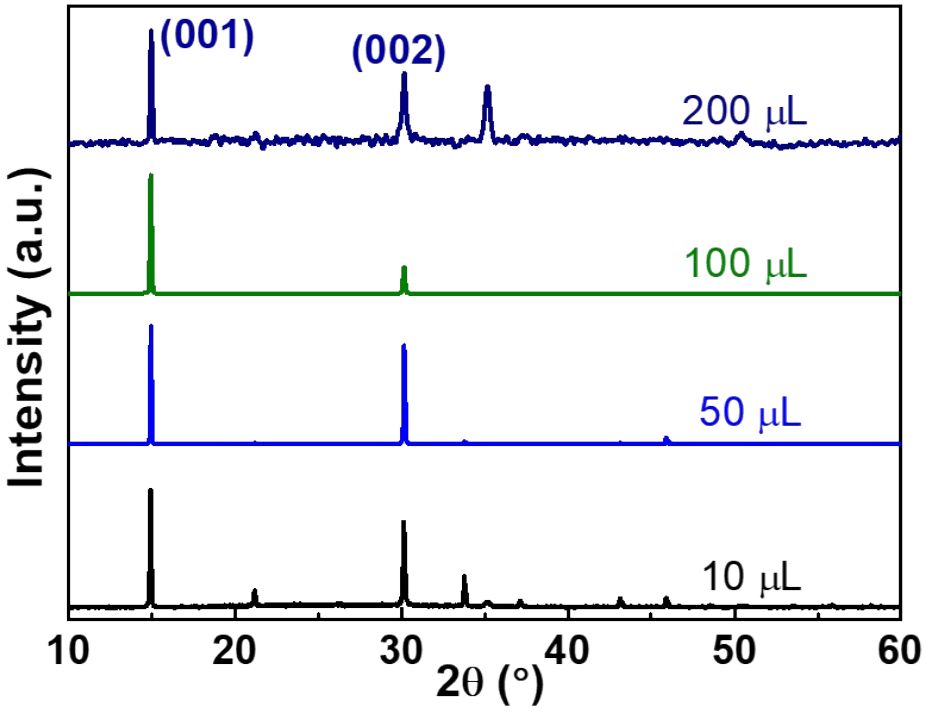

Fig. S8. The PXRD patterns of $CH_3NH_3PbBr_3$ grown at different additive volumes of DMSO in the isopropanol solution.

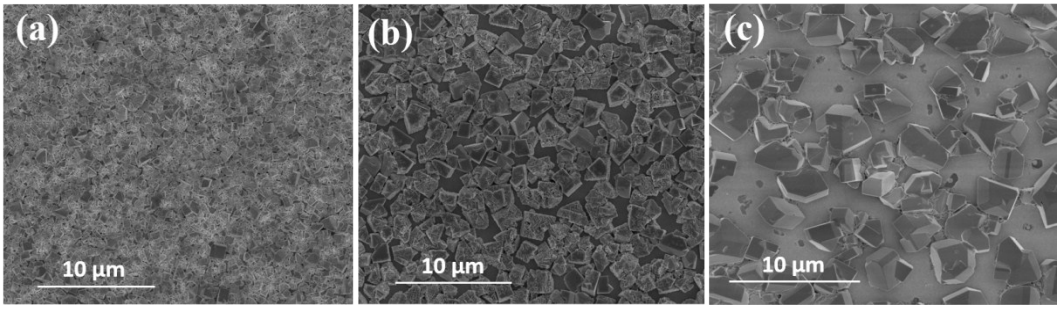

Fig. S9. The SEM images of the perovskite $CH_3NH_3PbI_3$ nanostructures grown with different cocentrations of CH_3NH_3I in the isopropanol solution. (a) 20 mg/mL, (b) 10 mg/mL, (c) 5 mg/mL.

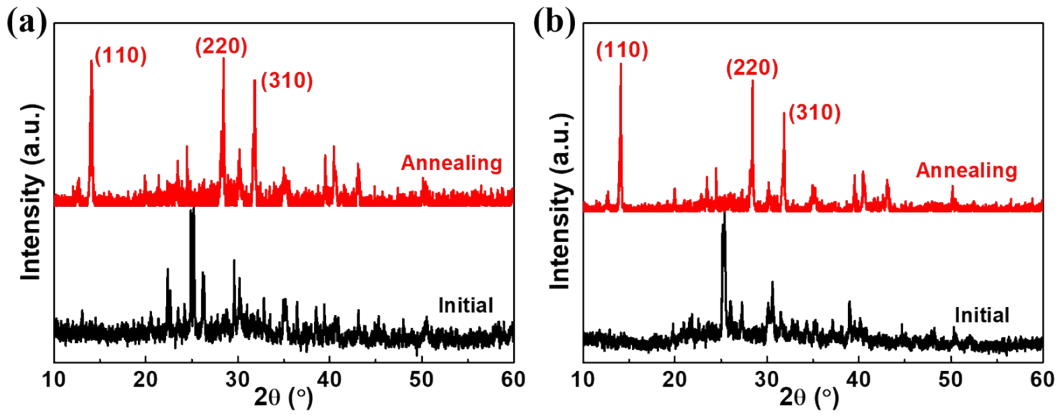

Fig. S10. The PXRD patterns of the perovskite $CH_3NH_3PbI_3$ grown with 50 μL (a) DMF and (b) DMSO in the CH_3NH_3I/ISP solution. The black lines show the white color adduct of MAI-PbI_2-DMF and MAI-PbI_2-DMSO were synthesized, the three characteristic peaks belonging to $CH_3NH_3PbI_3$ appear at 14.1º, 28.5º and 31.9º after annealing at 100 ℃ with 15 mins.

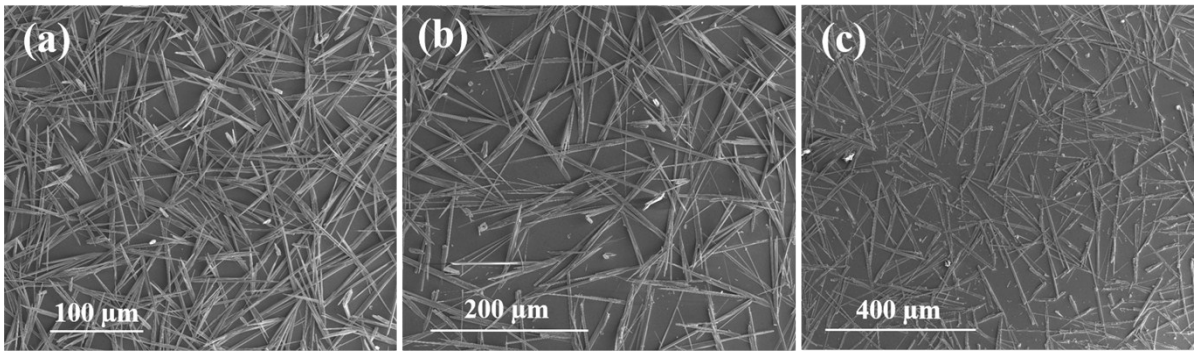

Fig. S11. The SEM images of the intermediate phase $CH_3NH_3PbI_3$ grown with different volumes of DMF in the isopropanol solution. (a) 30 μL, (b) 50 μL, (c) 80 μL.

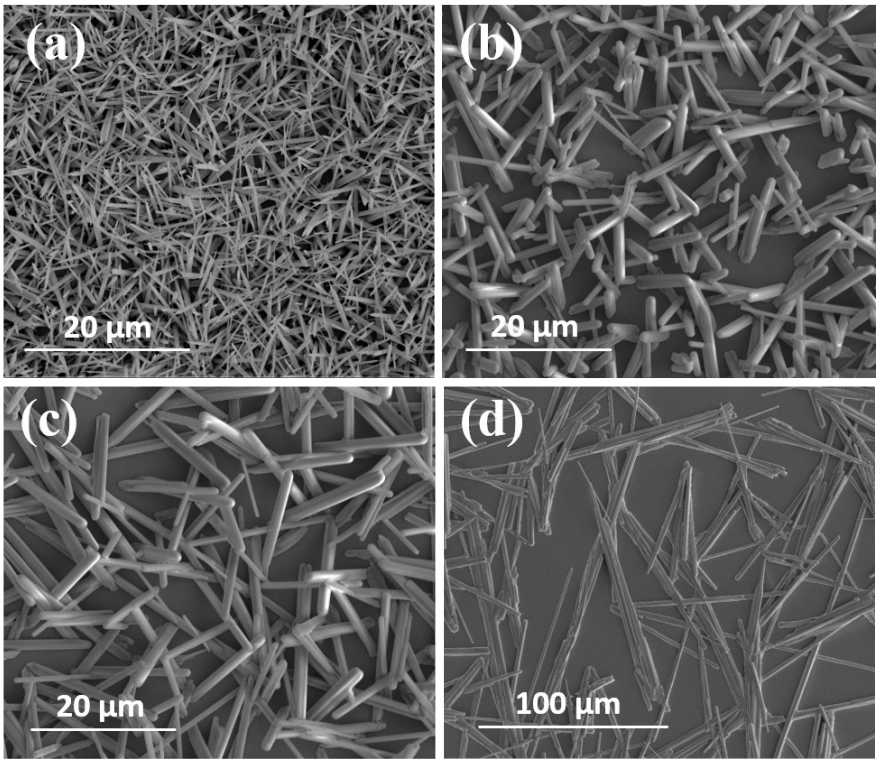

Fig. S12. The SEM images of the intermediate phase $CH_3NH_3PbI_3$ grown with different additive volumes of DMSO in the isopropanol solution. (a) 10 µL, (b) 30 µL, (c) 50 µL, (d) 80 µL.

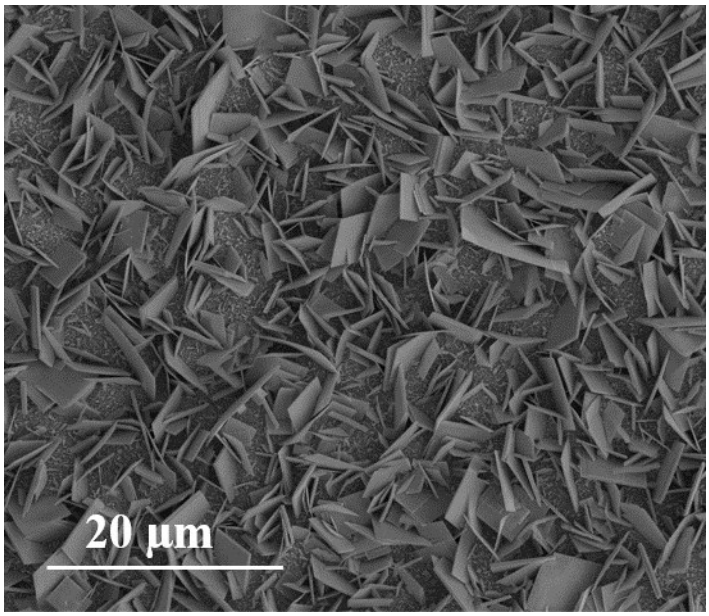

Fig. S13. The SEM images of the mixed halides $CH_3NH_3PbCl_{3-x}I_x$ grown at the same concentration ratios of CH_3NH_3Cl: CH_3NH_3I in the isopropanol solution.

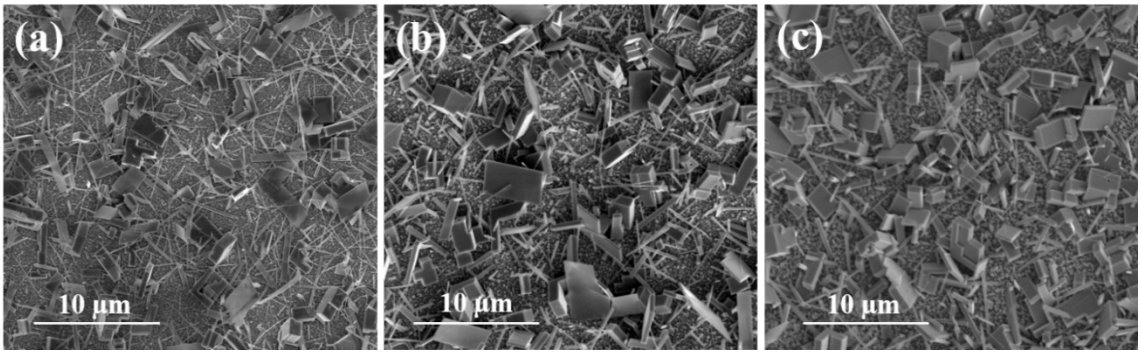

Fig. S14. The SEM images of the $CH_3NH_3PbCl_{3-y}Br_y$ nanowires grown at different solute concentration ratios of CH_3NH_3Br: CH_3NH_3Cl in the isopropanol solution. (a) 5:7, (b) 5:3, (c) 4:1.

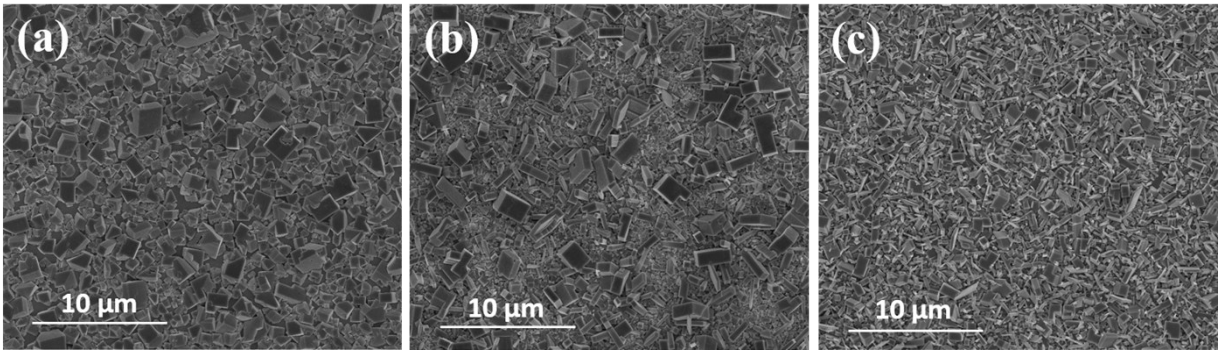

Fig. S15. The SEM images of the $CH_3NH_3PbBr_{3-z}I_z$ grown at different solute concentration ratios of CH_3NH_3Br: CH_3NH_3I in the isopropanol solution. (a) 1:3, (b) 1:1, (c) 3:1.

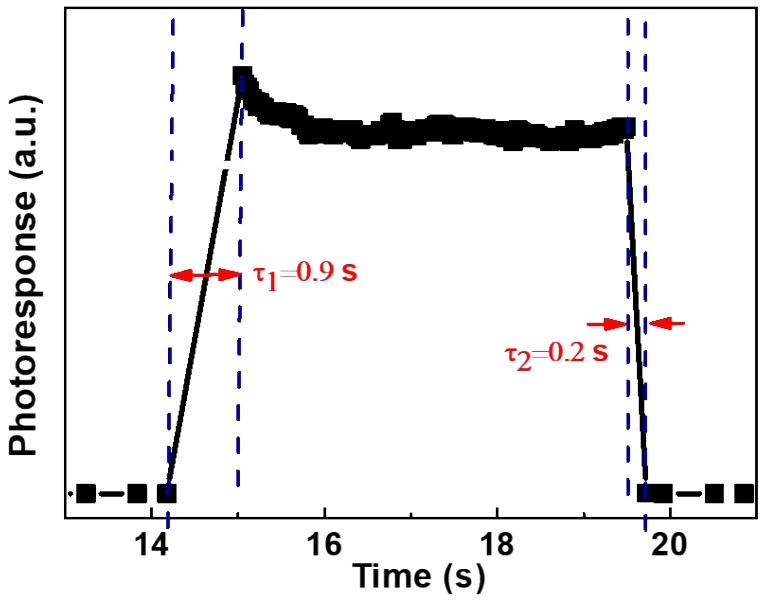

Fig. S16. A single normalized photocurrent rises and decays with and without the light illumination.

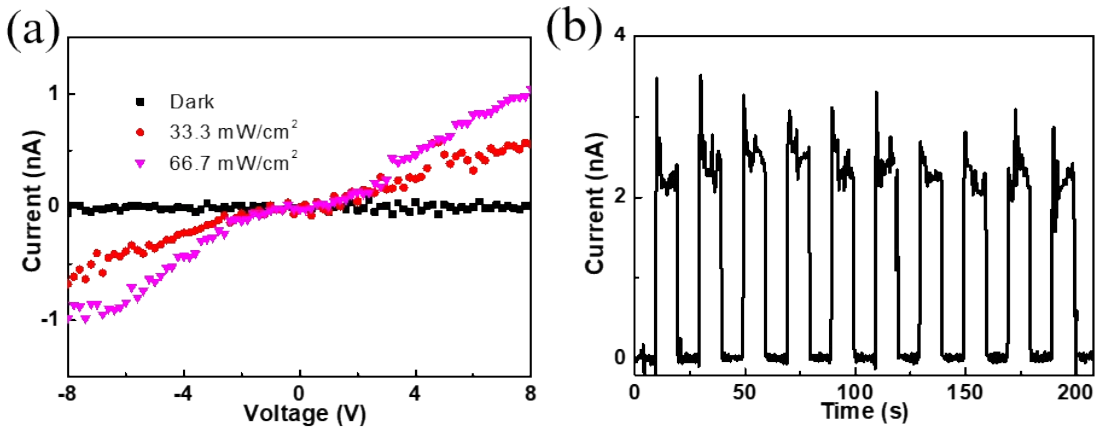

Fig. S17. (a) Dark current and photocurrents of the perovskite $CH_3NH_3PbI_3$ nanowire photodetector at various power densities. (b) Time-dependent photocurrent curves of the perovskite $CH_3NH_3PbI_3$ nanowire photodetector at a voltage of 10 V. Both the rise time and decay time are shown to less than 0.45 s.