

Supporting information for
Passivation of oxygen and light induced degradation by the PCBM electron transport layer in
planar perovskite solar cells

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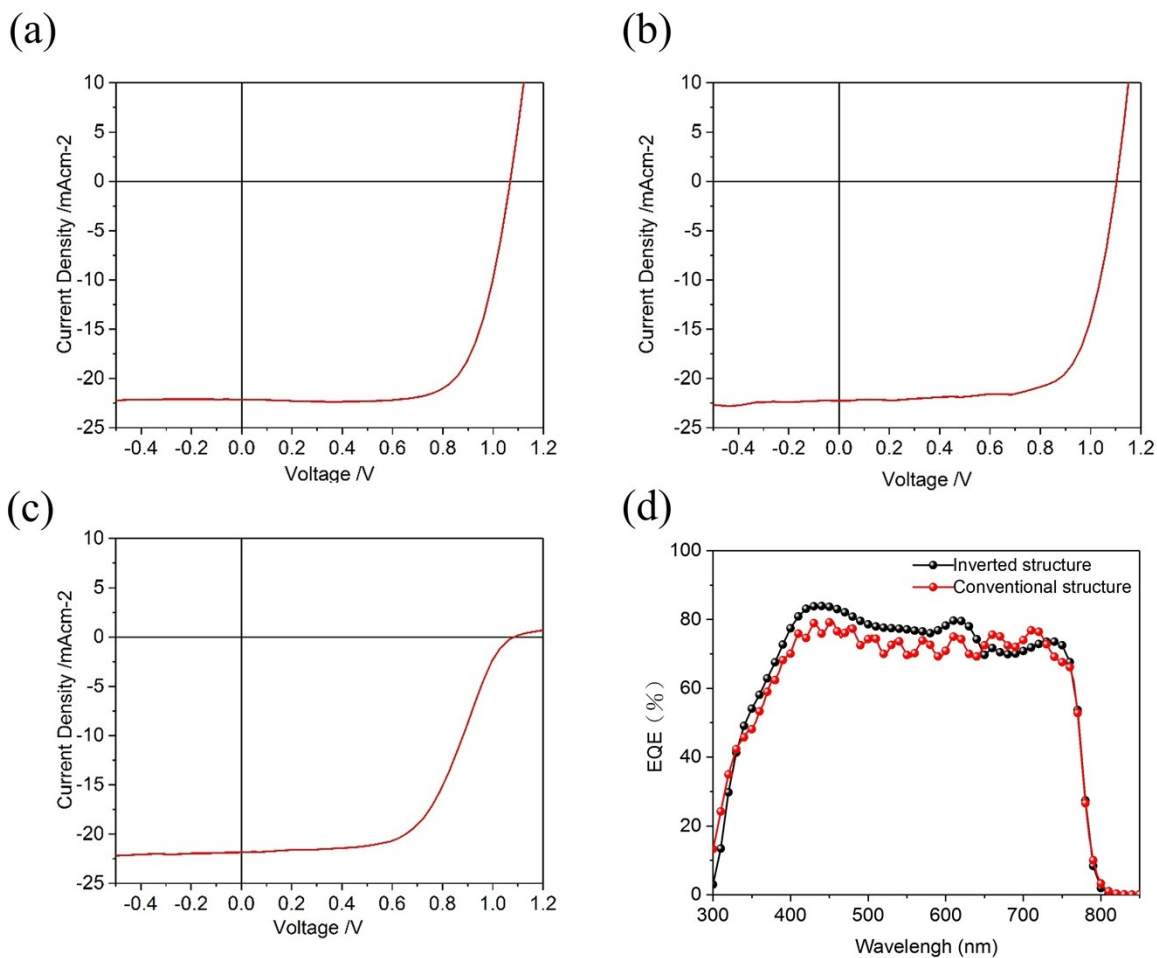


Figure S1. Current voltage characteristic of (a) conventional structure device (FTO/compact-TiO₂/meso-TiO₂/CH₃NH₃PbI₃/spiro-OMeTAD/Au) (b) Inverted structure device with BCP/Cu contact (ITO/PTAA/CH₃NH₃PbI₃/PCBM/BCP/Cu) (c) Inverted structure device with Au contact (ITO/PTAA/CH₃NH₃PbI₃/PCBM/Au) (d) External quantum efficiency (EQE) of inverted structure and conventional structure devices. The integrated current shown 18.8 mA/cm² for inverted structure device and 18.0 mA/cm² for conventional structure. The difference between EQE and JV measurement may attributed to larger barrier for photocurrent while the EQE is measured under low light intensity.

Table S1. The device performance of conventional and inverted structure solar cell shown in Figure S1.

	Voc [V]	Jsc [mAcm ⁻²]	FF	PCE [%]
a. Conventional	1.07 ± 0.01 (1.07)	22.00 ± 0.1 (22.13)	0.71 ± 0.01 (0.72)	16.73 ± 0.25 (17.03)
b. Inverted (BCP/Cu)	1.10 ± 0.01 (1.10)	22.33 ± 0.62 (22.26)	0.69 ± 0.04 (0.72)	17.05 ± 0.46 (17.7)
c. Inverted (Au)	1.07 ± 0.03 (1.03)	21.57 ± 0.21 (21.4)	0.57 ± 0.03 (0.61)	13.28 ± 0.19 (13.4)

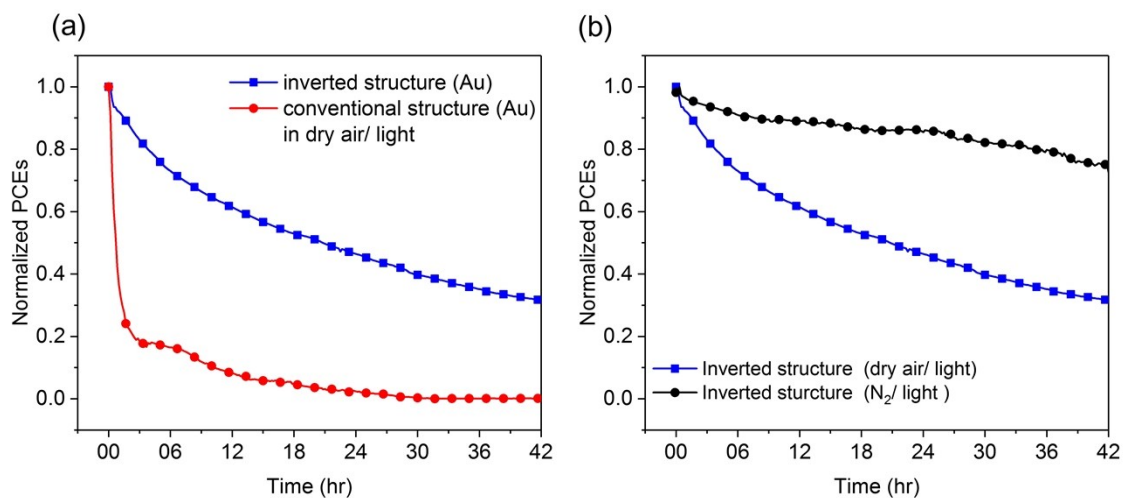


Figure S2. (a) Normalized PCE stability curve of inverted structure (ITO/PTAA/CH₃NH₃PbI₃/PCBM/Au) and conventional structure (FTO/compact-TiO₂/meso-TiO₂/CH₃NH₃PbI₃/spiro-OMeTAD/Au). Devices were measured in dry air and continuous illumination as Fig 1. (b) Normalized PCE stability curve of inverted structure device measured in dry air/light condition and N₂/light condition.

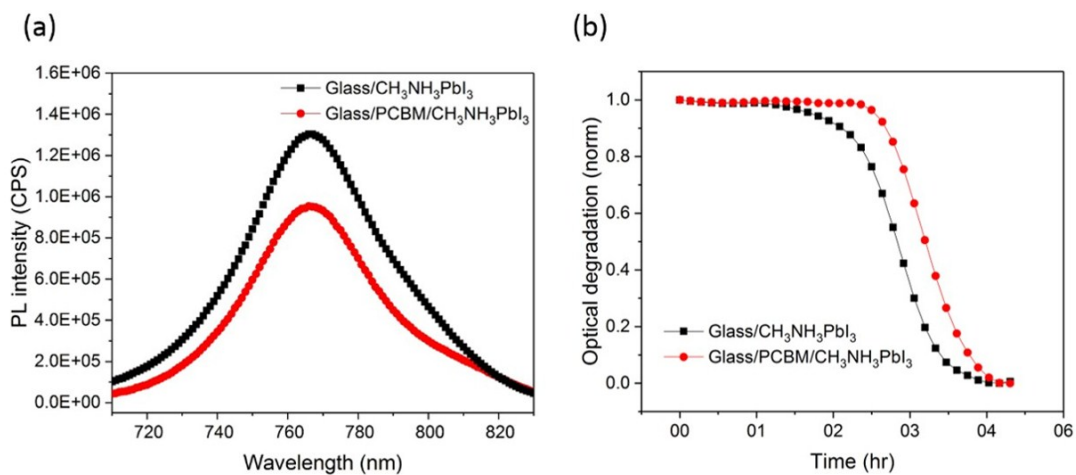


Figure S3. (a) Photoluminescence of glass/CH₃NH₃PbI₃ and glass/PCBM/CH₃NH₃PbI₃ under 1 sun in N₂. (b) Normalized optical degradation of glass/CH₃NH₃PbI₃ and glass/PCBM/CH₃NH₃PbI₃ film in oxygen and light. Light was provided by LED with 1 sun calibrated by equal J_{sc} of sealed CH₃NH₃PbI₃ device under 1 sun measured by solar simulator.

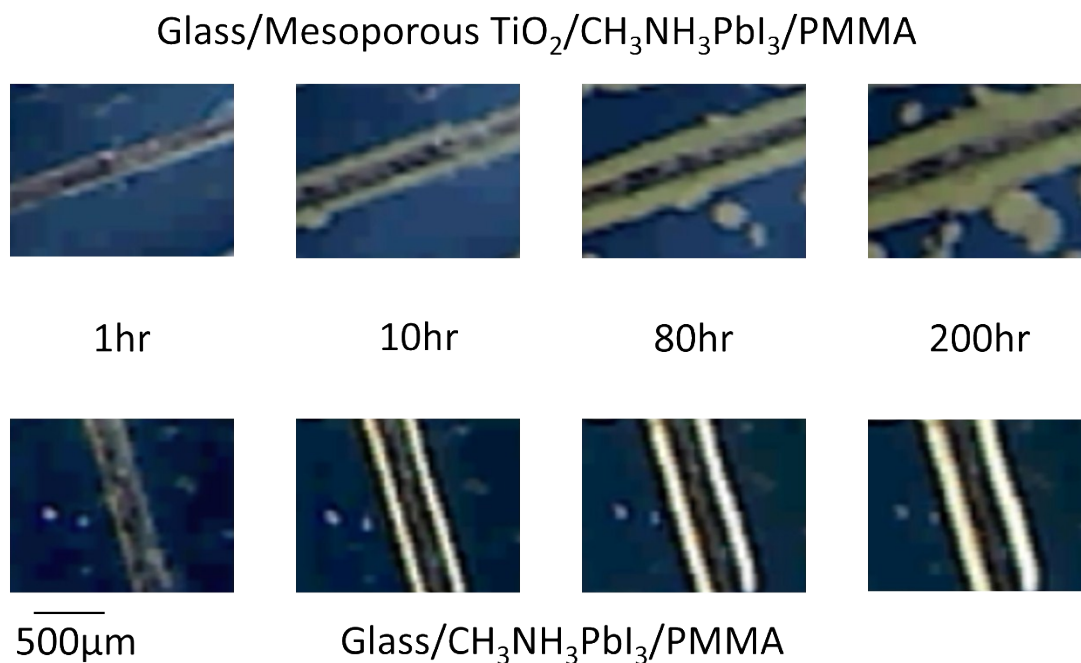


Figure S4. CCD images of films consisted of glass/mesoporous-TiO₂/CH₃NH₃PbI₃/PMMA and glass/CH₃NH₃PbI₃/PMMA degraded in dry air/ light condition over time.

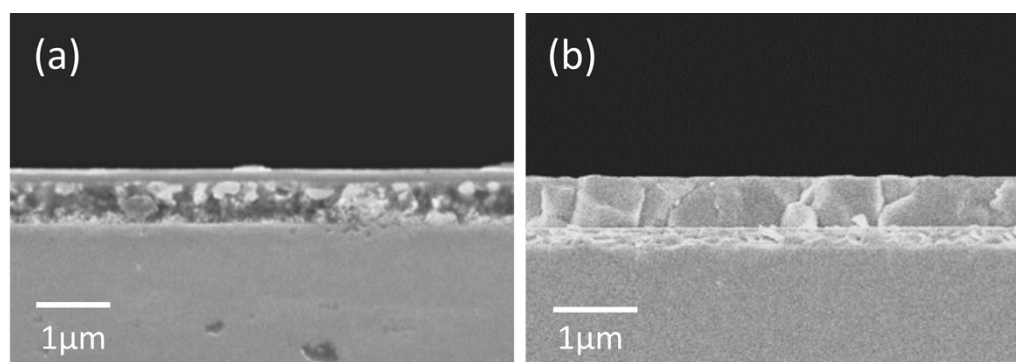


Figure S5. Cross-section SEM of (a) glass/ mesoporous-TiO₂/CH₃NH₃PbI₃/PMAA (b) glass/CH₃NH₃PbI₃/PMMA

Experimental Section

Perovskite films preparation

The methylammonium lead iodide ($\text{CH}_3\text{NH}_3\text{PbI}_3$) precursor solutions were prepared by dissolving PbI_2 (Alfa Aesar) and $\text{CH}_3\text{NH}_3\text{I}$ (Dyesol) into solvent (GBL: DMSO=7:3) at 1.25M and stirred for 6 hours at 25°C. The solutions were filtrated by 0.45 μm filter before deposition. Glass were sonicated in soap, water, acetone and 2-propanol in sequence, dried with nitrogen, followed by oxygen plasma treatment. The perovskite precursor solutions were spin-coated at 4000rpm for 40 seconds and dripped toluene at 20 second before the end of program. At last, the films were dried at 100°C for 10min.

Conventional structured devices fabrication

Conventional devices are consisted of FTO/compact- TiO_2 /meso- TiO_2 / $\text{CH}_3\text{NH}_3\text{PbI}_3$ /spiro-OMeTAD/Au. The compact TiO_2 layer was deposited by spray pyrolysis of titanium diisopropoxide bis(acetylacetonate) solution (Aldrich) on FTO at 400°C. After cooling to room temperature, diluted commercial mesoporous TiO_2 paste (Dyesol) was spin-coated on substrate and heated at 450°C to form mp- TiO_2 layer. The 0.1M Li-TFSI in acetonitrile were deposited on mp- TiO_2 layer and heated at 450°C for 30 minutes. Next, the $\text{CH}_3\text{NH}_3\text{PbI}_3$ precursor solution was spin-coated on substrates and treated with toluene during the spin-coating program, which is same as film preparation condition. The substrate was dried at 100°C to form the glassy perovskite film. The spiro-OmeTAD (Borun material) in chlorobenzene was doped by bis(trifluoromethane) sulfonimide lithium salt and 4-tert-butylpyridine. After the spiro-OmeTAD layer was spin-coated, the substrate was oxidized in dry box for 24 hours. At last, the Au (70nm) were evaporated on the substrates.

Inverted structured device fabrication

Inverted devices are consisted of ITO/PTAA/ $\text{CH}_3\text{NH}_3\text{PbI}_3$ /PCBM/BCP/Cu. ITO were rinsed with acetone to remove the photoresist and cleaned with soap, DI water, acetone and 2-propanol, and then blow dry with N_2 immediately. Oxygen plasma were treated before deposited PTAA layer. 0.25% PTAA solution were deposited on ITO by spin-coating at 5000 rpm for 20second. Perovskite solution was deposit on substrates by spin-coating with antisolvent treatment and dried at 100°C for 10min. Varies concentration of PCBM solutions (4.5 mg/ml to 27 mg/ml, Ossila) were spin-coated on perovskite at 1300 rpm. BCP solution in ethanol (0.5 mg/ml) was spin-coated at 4000 rpm on substrate. Finally, the 80nm Cu was evaporated on the substrates.

Environmental stability examination of films

The stability examination of films was observed in glovebox by monitored the change of average RGB output value.

$$\text{Optical degradation} = \frac{|RGB_t - RGB_{deg}|}{|RGB_0 - RGB_{deg}|}$$

RGB_t refer to average value of red-green-blue value at time. RGB₀ refer to RGB value of fresh sample. RGB_{deg} refer to RGB value of degraded sample. The environment of glovebox was controlled by Bridgelux 4000 K LED, humidity control and the atmosphere between dry air and nitrogen. The light intensity of LED was calibrated by matching current of an encapsulated device

under AM1.5 solar spectrum. Dry air was obtained from ambient air dehumidified by dehumidifier with desiccant column.

Environmental stability examination of devices

Initial device performances were determined by JV characteristics which measured in N₂ atmosphere under Xenon lamp. The intensity of Xenon lamp is AM1.5 which is calibrated by silicon reference cell. To investigate the oxygen/light stability of devices, all cells were unencapsulated and placed in chamber with dry air (RH<10%). The temperature is controlled under 35° C. The light intensity is calibrated by matching the current of initial device performances. JV characteristics were scanned every 10 min from 1.2V to -0.5V with the PCE averaged over 60 min periods. Between the measurements the devices were held at open circuit voltage.

Photoluminescence Spectroscopy

Photoluminescence spectroscopy (Horiba Jobin Yvon Fluorolog system) and electronic absorption spectra (Shimadzu UV-2600) were used to check the optical material properties. For varying the power density and wavelength of the excitation light for photoluminescence spectroscopy, an external white LED light source with 650 and 700nm short wavelength pass filter was used. Global analyses of the data were carried out by using origin.

Scanning electron microscopy:

Scanning electron microscopy (SEM) images were obtained using Gemini LEO 1525, with accelerating voltage of 3-5kv and working distance of 2-5mm.