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Supporting Information

Non-preheating fabricated semitransparent Quasi-2D perovskite solar cells

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Experimental Section

Materials

Methylammonium iodide (MAI, 99.9%), Butylamine Hydroiodide (BAI, 97%), lead iodide (PbI_2, 99.99%), [6,6]-phenyl-C_{61}-butyric acid methylester (PCBM, 99% HPLC), and bathocuproine (BCP, 99% HPLC) were purchased from Xi'an Polymer Light Technology Corp. (DMF, 99.9%), dimethylsulfoxide (DMSO, 99.9%), Ethanol (ET), chlorobenzene (CB, 99.8%), ethanolamine (ETA), and isopropanol (IPA, 99.7%) were from Sigma-Aldrich. Nickel(II) acetate tetrahydrate ($Ni(CH_3COOH)_2{\cdot}4H_2O$) was obtained from Acros Organics. All reagents were used as received.

Device fabrication

The FTO glass substrates were cleaned using detergent, acetone, isopropanol, deionized water, and ethanol. Dry the cleaned FTO substrate and treated with UV-ozone for 15 min. The NiO_X precursor solution was prepared by mixing

$Ni(CH_3COOH)_2 \cdot 4H_2O$ (100 mg), ETA (24 μL) in ET (4 mL) and stirred at 60 ºC for 8 h. The prepared NiO_X precursor solution was spin-coated on the FTO at 1500 rpm for 40 s and then annealed at 310 ℃ for 60 min. The perovskite precursor solutions were prepared by dissolving BAI, MAI, and PbI_2 in DMF and DMSO (volume ratio is 97:3) with a molar ratio of 2: 3: 4. The molar concentrations of PbI_2 were 0.25 and 0.65 mmol/mL. PCBM was dissolved in chlorobenzene (20 mg/mL) and BCP was dissolved in isopropanol (0.5 mg/mL). The BCP solution was stirred at 60 ℃ until complete dissolution. All the solutions were filtered with 0.22 um polytetrafluoroethylene filters. The substrates were transferred into the nitrogen glovebox. The FTO substrates that need to be preheated were preheated for two minutes at 45 °C and 65 °C, respectively, and the substrate without preheating is directly spin-coating, the perovskite solution was spin-coated on the substrate at 6000 rpm for 20 s at 25 °C in N_2 ambient and annealed at 95 ℃ for 10 min. The PCBM and BCP solutions were both spin-coated at 3000 rpm for 30 s. For opaque cells, a 70 nm Ag electrode was deposited by thermal evaporation under a vacuum of 6×10^{-4} Pa. The substrate we use was 1.6×2 cm^2 in size, the device's effective area was 0.105 cm^2. For semitransparent cells, the BCP solution was spin-coated at 2000 rpm for 30s and annealed at 70 ℃ for 3 min, Ag (1 nm) was deposited via thermal evaporation under a vacuum of 6×10^{-4} Pa, and then, the IZO films were prepared by RF magnetron sputtering, and the background vacuum of the sputtering chamber was less than $5.0*10^{-4}$ pa, with a sputtering pressure of 0.5 pa, an argon flow rate of 40 Sccm, a sputtering power of 90 W, and a sputtering time of 25 min, IZO targets are made of $Zn:In_2O_3$ (10%:90%) ceramic targets, and annealed at 100 ℃ for 30 min. finally, a 70 nm Ag electrode was deposited by thermal evaporation under a vacuum of 6×10^{-4} Pa. The substrate we use was 2×2 cm^2 in size, the device's effective area was 0.16 cm^2.

Characterizations

The J-V measurement was recorded in glove-box using a Keithley B2901A SourceMeter. The Simulated solar illumination was provided by a AAA Class Solar Simulator (SS-F5-3A, Enli Technology Co., Ltd.) with AM1.5G spectrum and light

intensity of 100 mW/cm^2. The AFM morphology of the 2D perovskite films were conducted using atomic force microscopy (AFM, KEYSIGHT Technologies 7500). The top-view morphology of the 2D perovskite films were carried out by scanning electron microscope (FEI INSPECT F50, USA). The X-ray diffraction were conducted by X-ray diffractometer (PANalytical B.V., X'Pert Pro MPD). UV-visible absorption spectra were performed using a Shimadzu UV 2600 spectrophotometer. Steady-state photoluminescence (PL) were carried out by an Edinburgh FLS 980 spectrophotometer. The external quantum efficiency (EQE) spectrum and integral current density were measured by EQE system (BENTHAM TMC300, USK) in the range of the 300–850 nm wavelength at ambient temperature. The film thickness was measured by a step profiler (Brucker DektakXT).

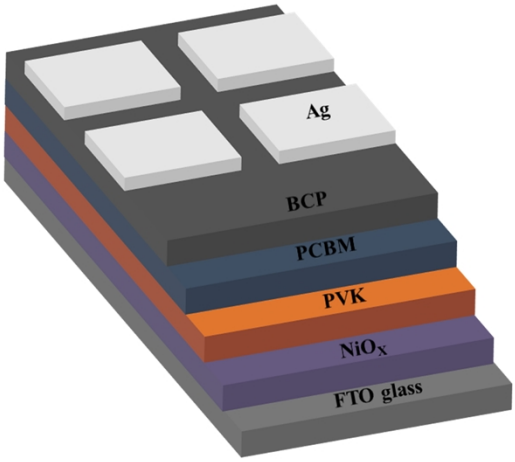

Figure S1. The structure of the opaque solar cells, simplifying the structure is beneficial to study the properties of perovskite thin films.

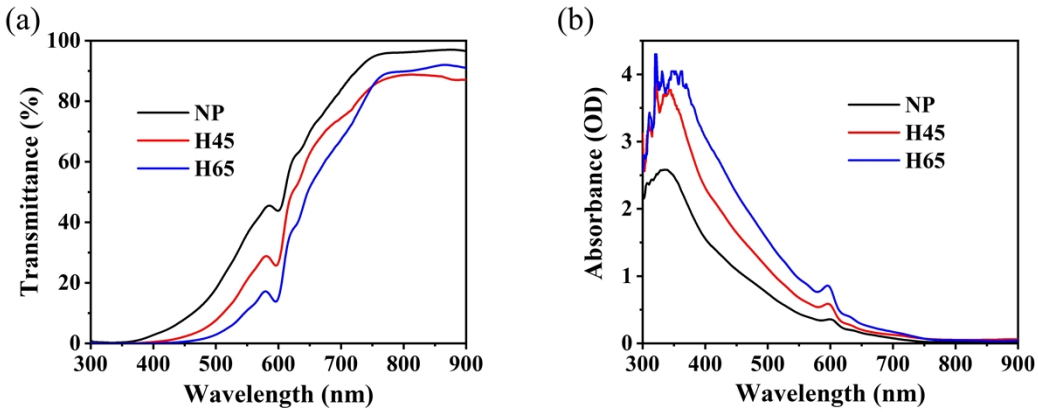

Figure S2. The (a) transmission spectrum and (b) UV–vis absorption spectra of the perovskite films.

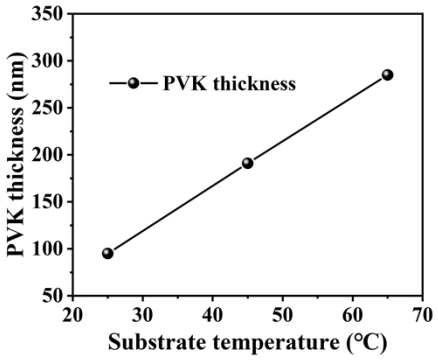

Figure S3. Perovskite film thickness with different substrate preheating temperature.

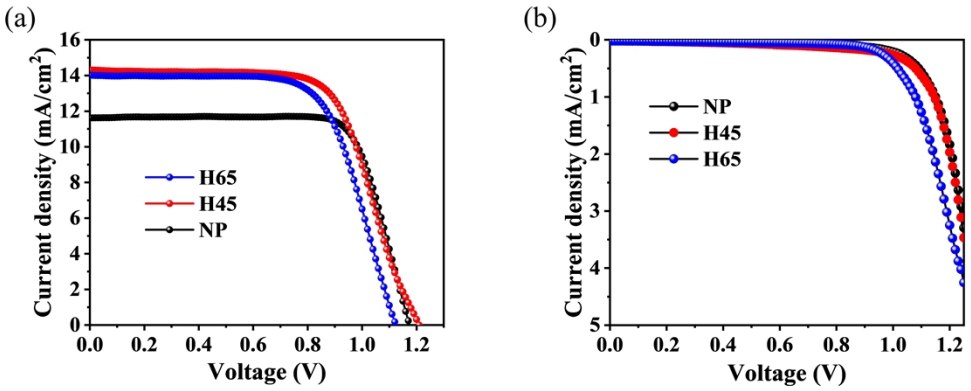

Figure S4. *J-V* curves of the opaque solar cells, (a) light, (b) dark.

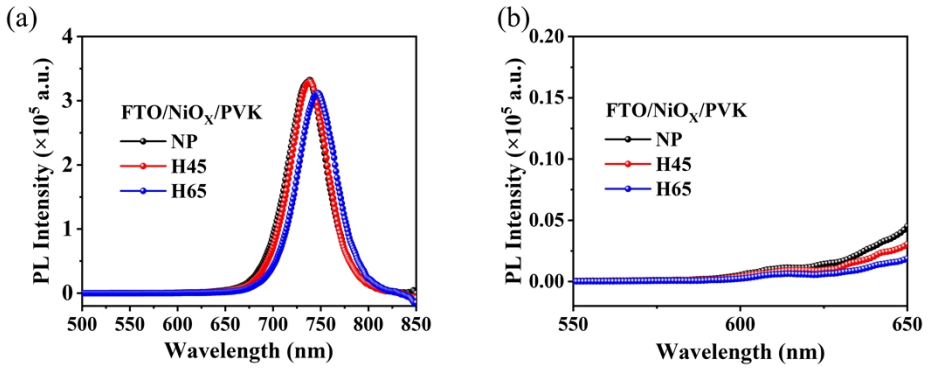

Figure S5. (a) And (b) Steady-state PL spectra of $(BA)_2(MA)_3Pb_4I_{13}$ perovskite films deposited on glass/FTO/NiO_X with different substrate temperatures, illuminated from the front side.

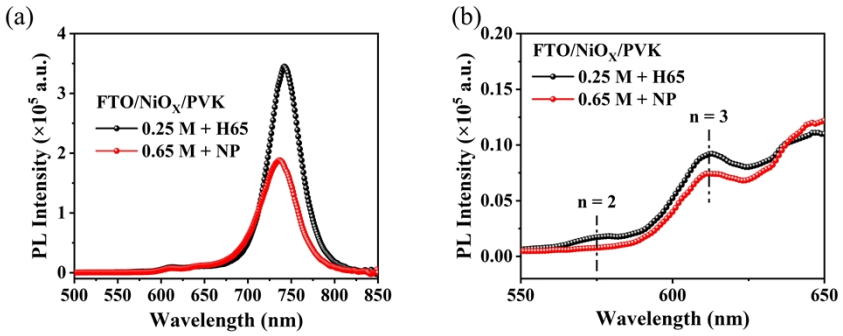

Figure S6. (a) And (b) Steady-state PL spectra of $(BA)_2(MA)_3Pb_4I_{13}$ perovskite films deposited on glass/FTO/NiO_X , illuminated from the back side.

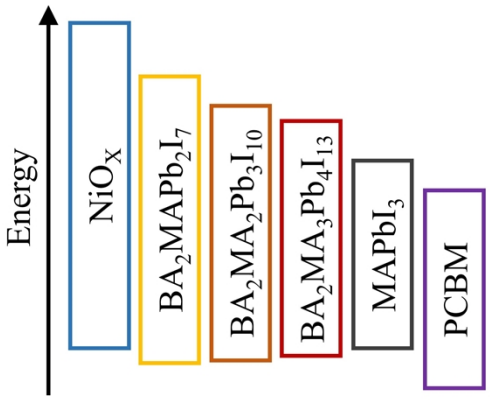

Figure S7. Energy levels of the quasi-2D perovskites film.

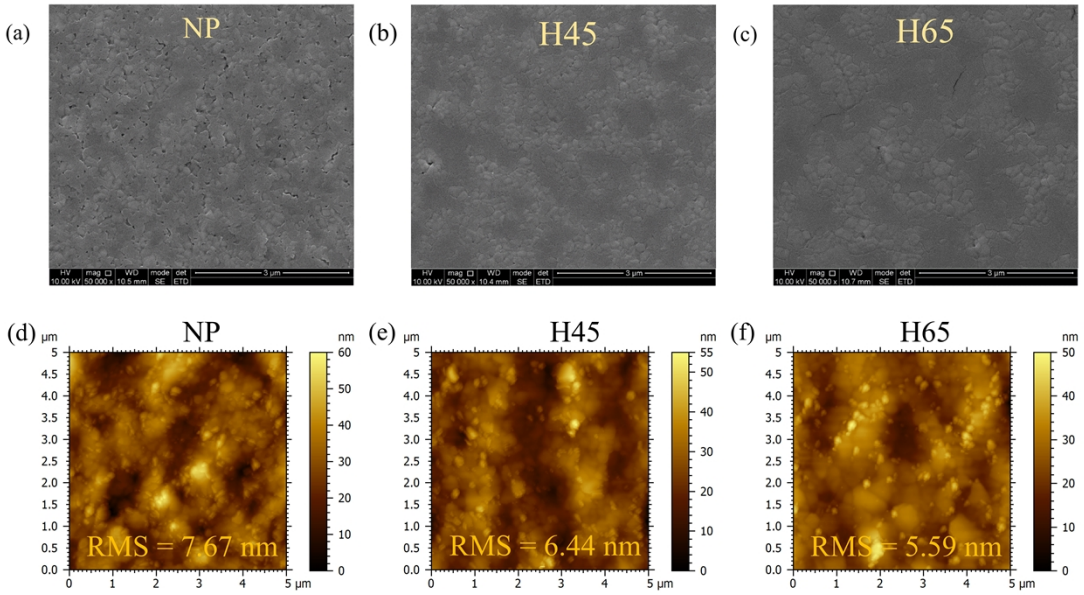

Figure S8. (a) NP, (b) H45 and (c) H65 Top-view SEM images of PVK films. AFM images of precursor solutions with different preheating temperatures, (d) NP, (e) H45 and (f) H65.

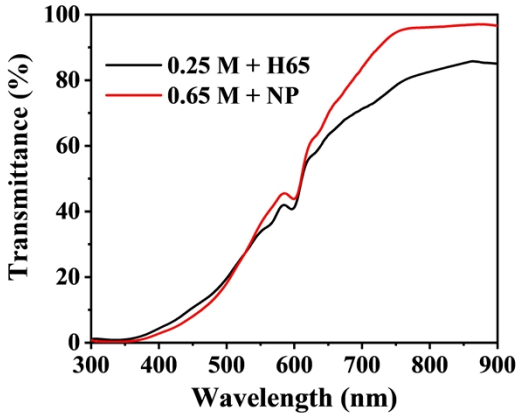

Figure S9. The transmission spectrum of perovskite films prepared at 0.25 M + H65 and 0.65 M + NP.

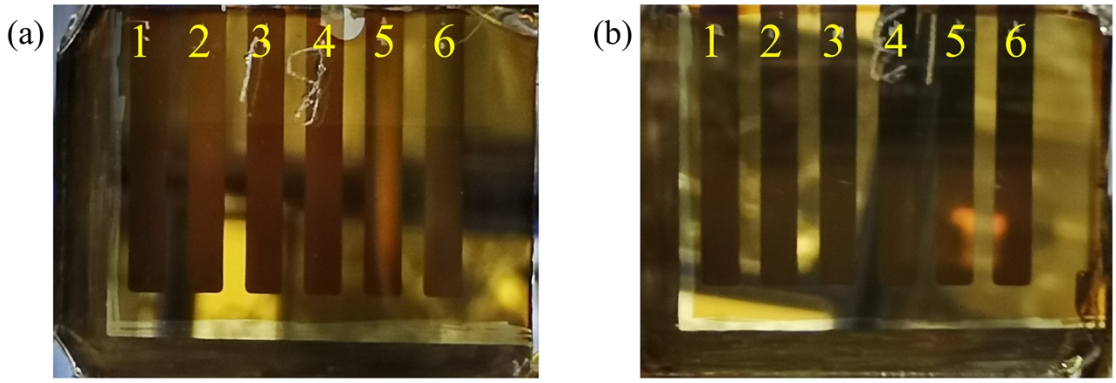

Figure S10. The position of the six different points on the substrate, (a) 0.65 M + NP, (b) 0.25 M + H65.

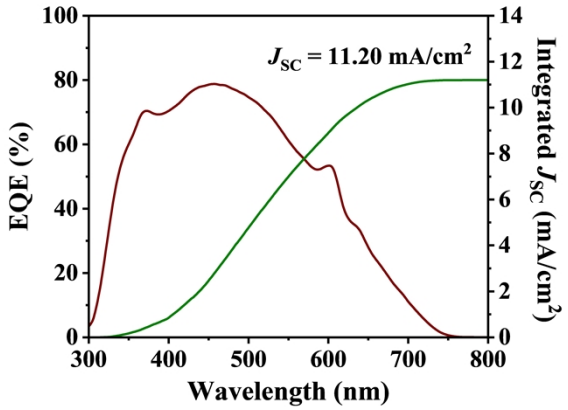

Figure S11. External quantum efficiency (EQE) and the integrated J_{SC} of fresh ST-Quasi-2D-PSCs.

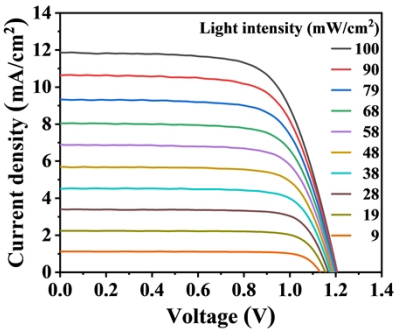

Figure S12. The *J-V* curves with different light intensity illumination of the ST-Quasi-2D-PSC which stored at 60 °C in a nitrogen glovebox for 600 h.

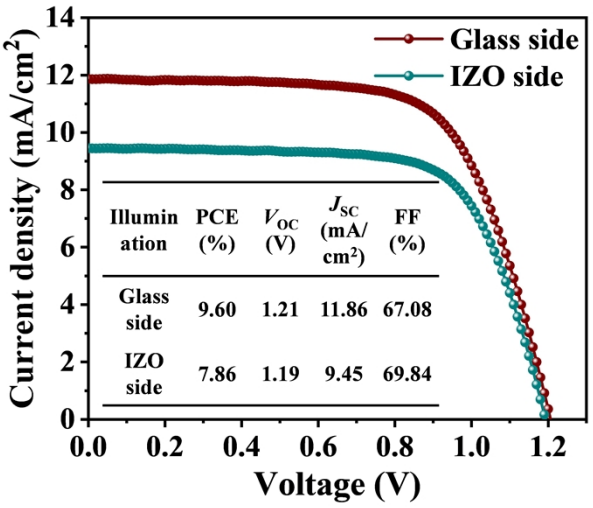

Figure S13. *J-V* curve of the ST-Quasi-2D-PSC kept in nitrogen glovebox at 60 °C for 600 h, illuminated from the glass side and IZO side.

Table S1. The PCE* of opaque cells, the AVT* of perovskite cells, and the LUE*.

	NP	H45	H65
The best PCE*% of opacity cells	10.37	11.45	10.63
Perovskite film AVT*% （400-800 nm）	50.99	41.28	34.45
Film LUE*%	5.29	4.73	3.77

Table S2. The (202)/(111) peak intensity ratio of the perovskite film.

	NP	H45	H65
(202)/(111)	1.14	1.50	1.70

Table S3. The *R*s and *R*ct of perovskite solar cells.

Device	R_s (ohm)	R_{ct} (ohm)
NP	15.82	997.6
H45	21.08	5448
H65	49.69	19127

Table S4. Optimal parameter for fresh semitransparent quasi-2D perovskite solar cell.

Illumination	PCE (%)	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)
Glass side	8.71	1.19	11.76	62.05
IZO side	7.33	1.17	9.69	64.41

Table S5. Optimal parameter for semitransparent quasi-2D perovskite solar cell after aging in a nitrogen glovebox at 60 °C for 600 h.

	PCE (%)	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)
Fresh	7.98	1.16	11.89	57.75
Aged	9.60	1.21	11.86	67.08