Supplementary information

**Suppressed Recombination for Monolithic Inorganic Perovskite/Silicon Tandem Solar Cells with an Approximate Efficiency of 23%**

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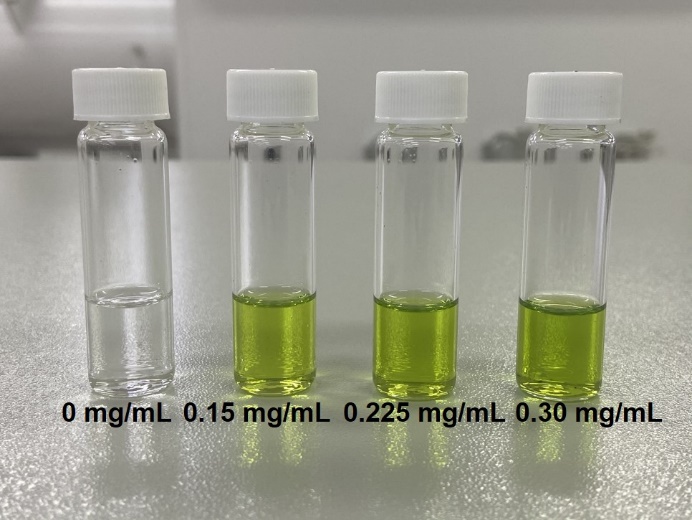
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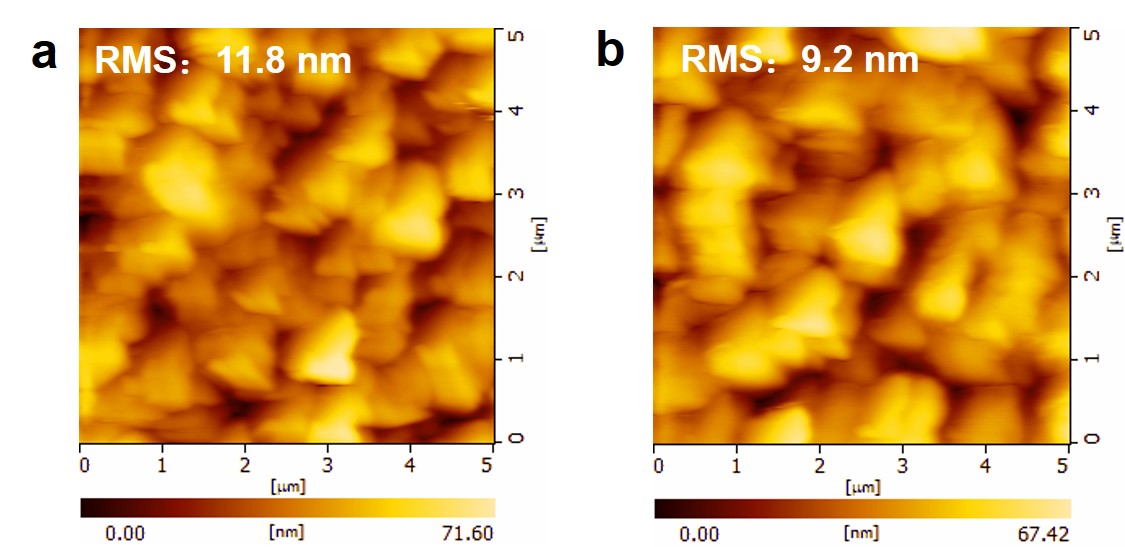
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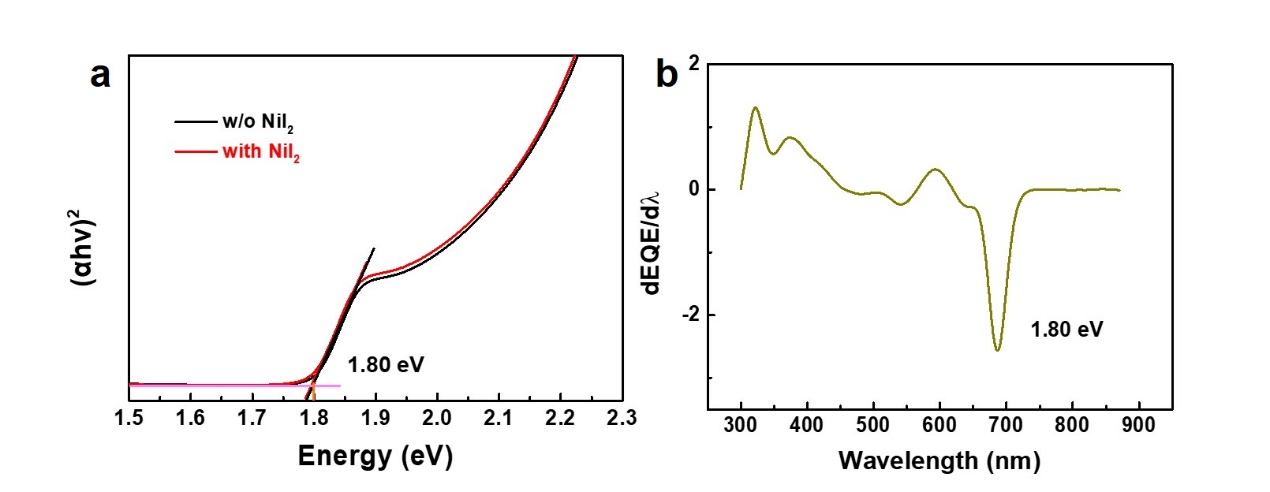
1 S.L. Wang and P.Y. Wang contributed equally to this work.



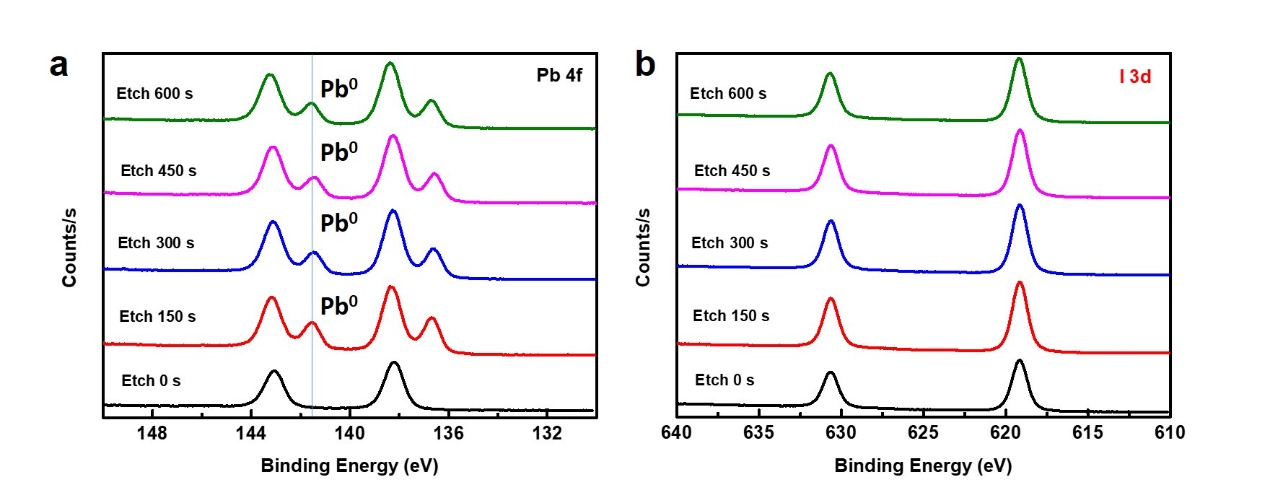
**Fig. S1**. Image of various concentrations of NiI2 solution.



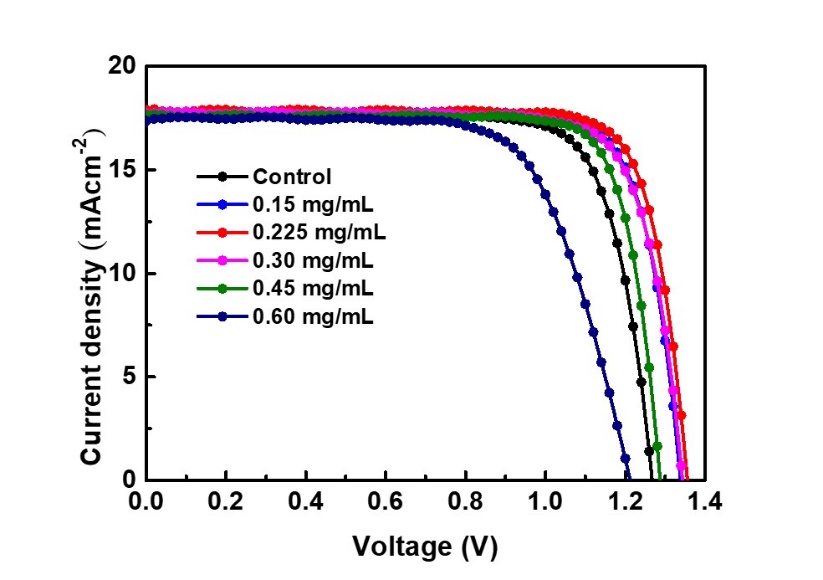
**Fig. S2**. Atomic force microscopy (AFM) images of CsPbIxBr3-x perovskite films without (a) and with NiI2 (b) treatment. The root means square (RMS) is 11.8 nm and 9.2 nm, respectively.



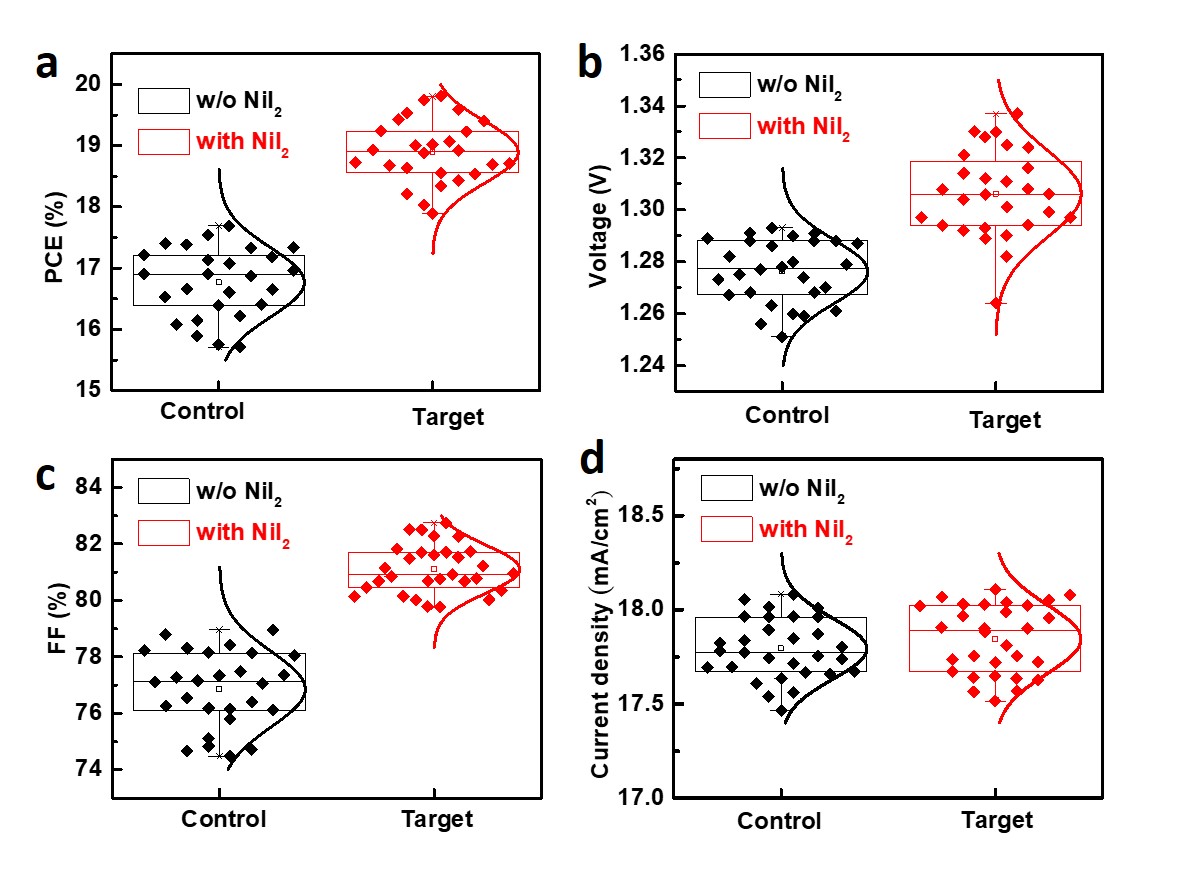
**Fig. S3**. The optical band gap of CsPbIxBr3-x perovskite. (a) The relationship of (αhv)2 vs. energy derived from UV-Vis, the bandgap of CsPbIxBr3-x perovskite film without and with NiI2 treatment shows a bandgap of 1.80 eV. (b) The EQE differential of the NiI2 treated PSCs.



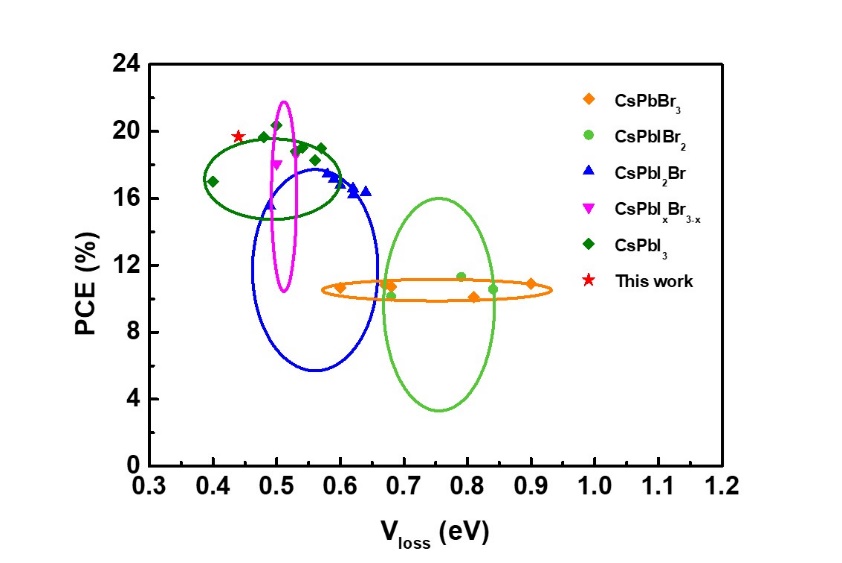
**Fig. S4** (a) The Pb 4f and (b) I 3d core level spectra of perovskite films etched with different times (0 s, 150 s, 300 s, 450 s and 600 s).



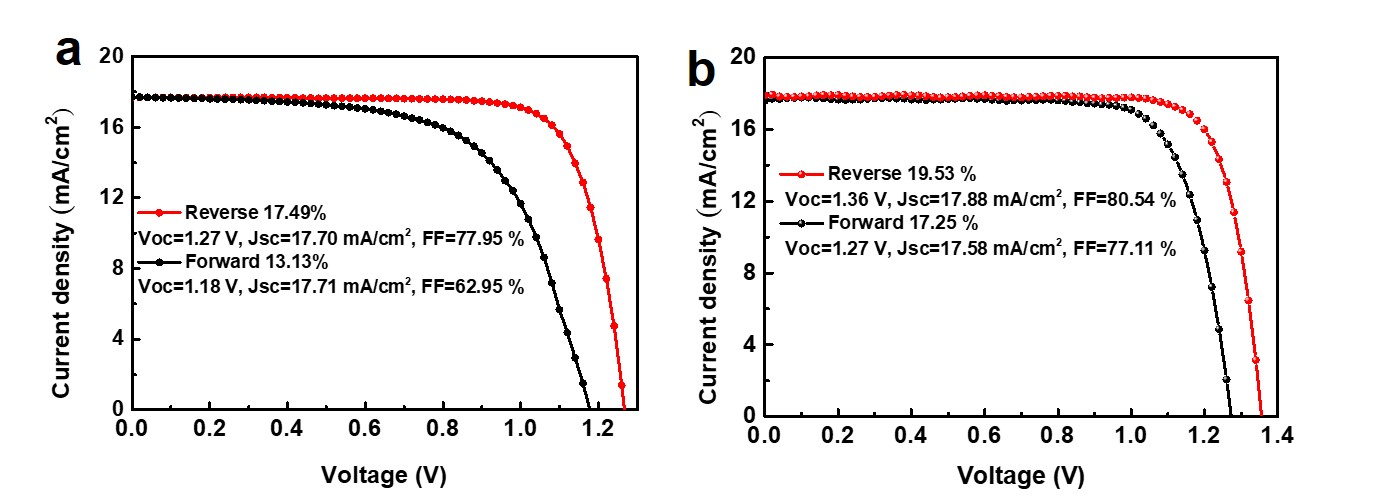
**Fig. S5**. J-V characteristics of CsPbIxBr3-x PSCs treated with various concentrations of NiI2, the PCE of corresponding PSCs are 17.49%, 19.06%, 19.53%, 18.82%, 18.40% and 14.78% for control, treated with NiI2 of 0.15 mg/mL, 0.225 mg/mL, 0.30 mg/mL, 0.45 mg/mL and 0.6 mg/mL, respectively.



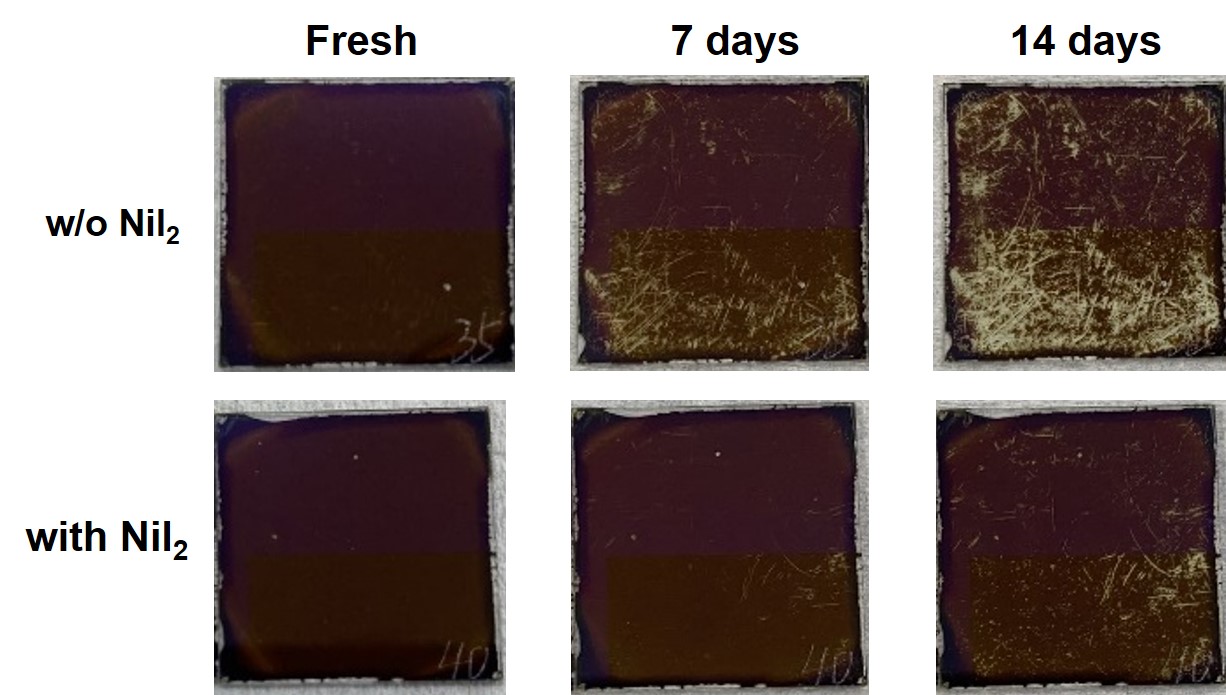
**Fig. S6**. Photovoltaic parameters of PCE, *VOC*, FF and *JSC* distributions of PSCs obtained from control CsPbIxBr3-x PSCs and NiI2 (0.225 mg/mL) treated CsPbIxBr3-x PSCs, respectively.



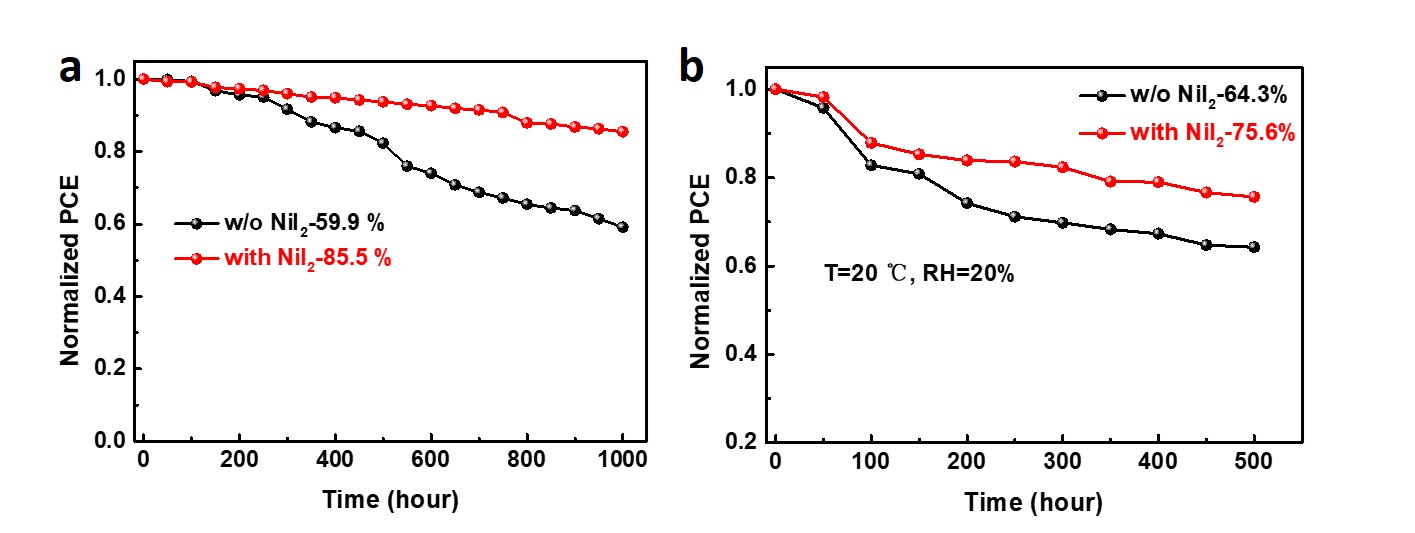
**Fig. S7**. Plots of PCE against voltage loss of inorganic PSCs are reported in this work and previous research from Table S4.



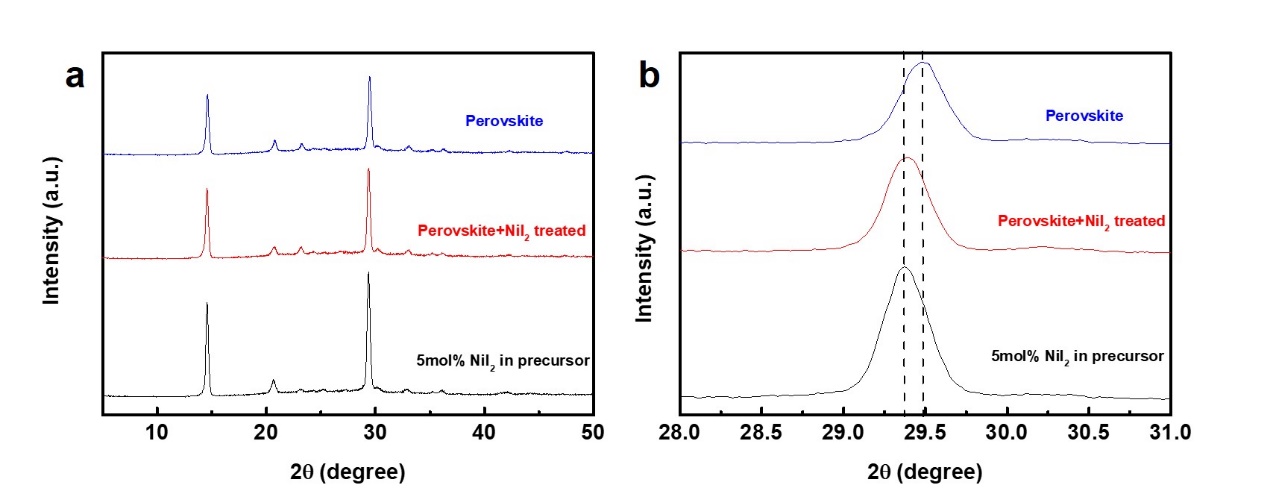
**Fig. S8**. J-V hysteresis characteristics of CsPbIxBr3-x PSCs without (a) and with (b) NiI2 treatment.

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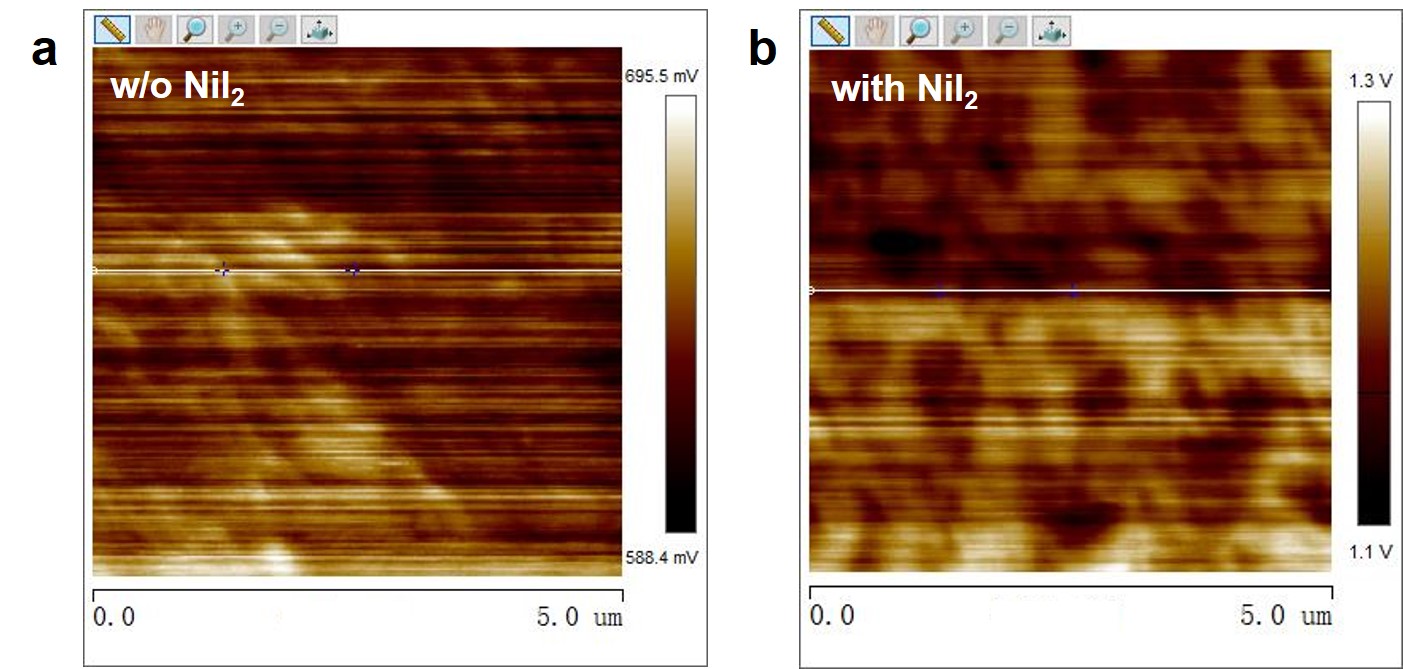
**Fig. S9**. Images of CsPbIxBr3-x film and NiI2 treated CsPbIxBr3-x film placed in ambient air (Temperature: 25 oC, RH about 20%) for various time.



**Fig. S10**. Normalized PCE of control and NiI2 treated PSCs stored in N2 atmosphere (a) and ambient air (RH about 20%) (b) for 1000 h and 500 h, respectively.



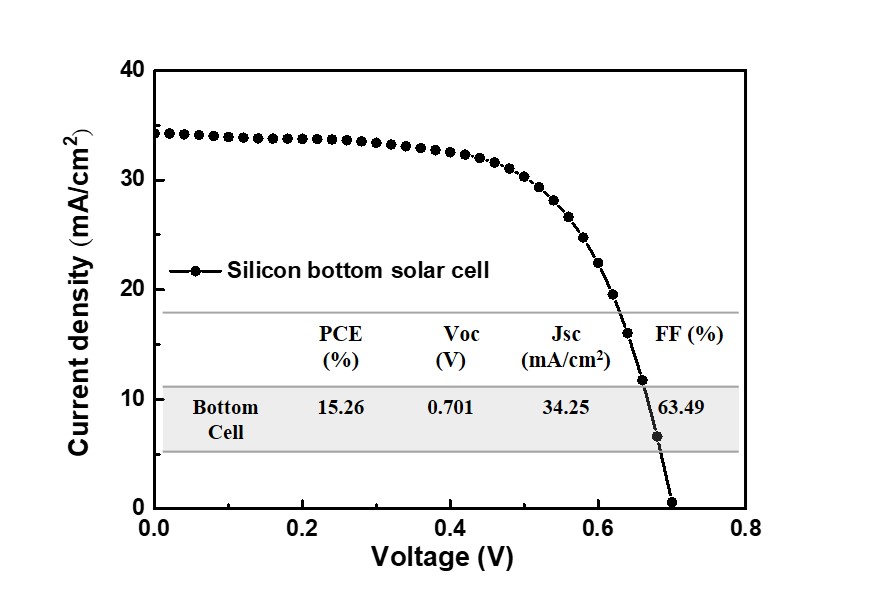
**Fig. S11** The XRD patterns of perovskite film without and with NiI2 surface treatment, incorporated with 5% NiI2 in precursor, respectively.



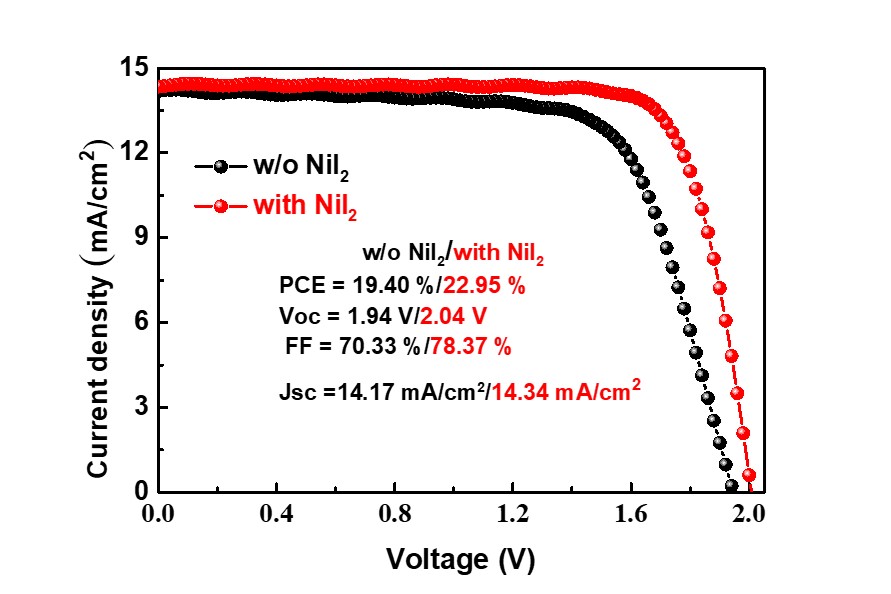
**Fig. S12**. Kelvin probe force microscopy (KPFM) surface potential spectra of CsPbIxBr3-x films without (a) and with (b) NiI2 treatment.



**Fig. S13** The trap density of states (tDOS) of the perovskite devices with and without NiI2 treatment.



**Fig. S14** The J-V curve of silicon solar cell.

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**Fig. S15** *J-V* curves of the champion CsPbIxBr3-x/silicon tandem solar cells without and with NiI2 treatment.

**Table S1**. Summary of detailed performance parameters of CsPbIxBr3-x inorganic PSCs.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Recorded solar cell | Eff. [%] | VOC [V] | Eg [eV] | Eloss [eV] | Ref |
| CsPbBr3 | 10.65 | 1.700 | 2.30 | 0.60 | [1] |
| CsPbBr3 | 10.1 | 1.590 | 2.30 | 0.81 | [2] |
| CsPbBr3 | 10.91 | 1.498 | 2.30 | 0.90 | [3] |
| CsPbBr3 | 10.85 | 1.626 | 2.30 | 0.67 | [4] |
| CsPbIBr2 | 10.13 | 1.370 | 2.05 | 0.68 | [5] |
| CsPbI2Br | 17.45 | 1.334 | 1.92 | 0.58 | [6] |
| CsPbI2Br | 16.60 | 1.300 | 1.92 | 0.62 | [7] |
| CsPbI2Br | 16.79 | 1.320 | 1.92 | 0.60 | [8] |
| Cs0.99Rb0.01PbI2Br | 17.16 | 1.320 | 1.91 | 0.59 | [9] |
| CsPbI3-xBrx | 18.64 | 1.234 | 1.77 | 0.53 | [10] |
| CsPbI3-xBrx | 18.06 | 1.270 | 1.77 | 0.50 | [11] |
| CsPbI2.5Br0.5 | 17.10 | 1.250 | 1.83 | 0.58 | [12] |
| CsPbI3-xBrx | 17.03 | 1.090 | 1.71 | 0.62 | [13] |
| CsPbI2.85I0.15 | 19.65 | 1.230 | 1.71 | 0.48 | [14] |
| CsPbI3-xBrx | 19.53 | 1.36 | 1.80 | 0.44 | This work |

**Table S2**. The TRPL parameters of CsPbIxBr3-x perovskite films without and with NiI2 treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Type | A1 (%) | τ1 (ns) | A2 (%) | τ2 (ns) | τave (ns) |
| Control | 2.51 | 4.99 | 97.49 | 18.94 | 18.59 |
| Target | 1.06 | 6.35 | 98.94 | 28.99 | 28.75 |

**Table S3** Devices performance parameters of opaque single-junction IPSCs, semitransparent IPSCs and two-terminal IPVK/Si tandem solar cell.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type | PCE  (%) | VOC (V) | Jsc  (mA/cm2) | FF (%) |
| Opaque single junction | 19.53 | 1.36 | 17.88 | 80.54 |
| Semitransparent IPSCs | 14.41 | 1.300 | 14.68 | 75.53 |
| Two-terminal tandem solar cells | 22.95 | 2.04 | 14.36 | 78.37 |

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