Supplementary information

Stable perovskite solar cells using tin acetylacetonate based electron transporting layers

Mousa Abuhelaiqa[a,e], Sanghyun Paek[a,e], Yonghui Lee[a,e]*, Kyung Taek Cho[a], Sung Heo[a], Emad Oveisi[b], Aron Joel Huckaba[a], Hiroyuki Kanda[a], Hobeom Kim[a], Yi Zhang[a], Robin Humphry-Baker[a], Sachin Kinge[c], Abdullah M. Asiri[d], and Mohammad Khaja Nazeeruddin[a]*

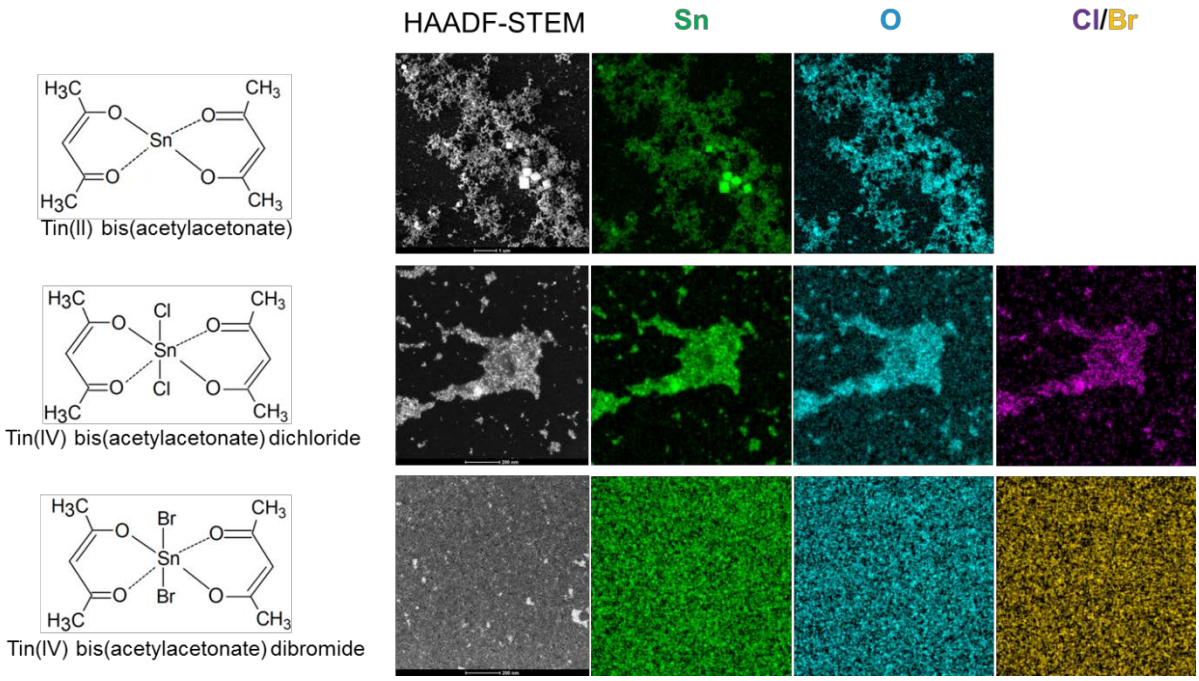


Fig. S1. EDXS-STEM analysis. HAADF scanning TEM images and corresponding elemental mapping of Sn, O, Cl and Br of the tin oxide films deposited on a carbon support grid.

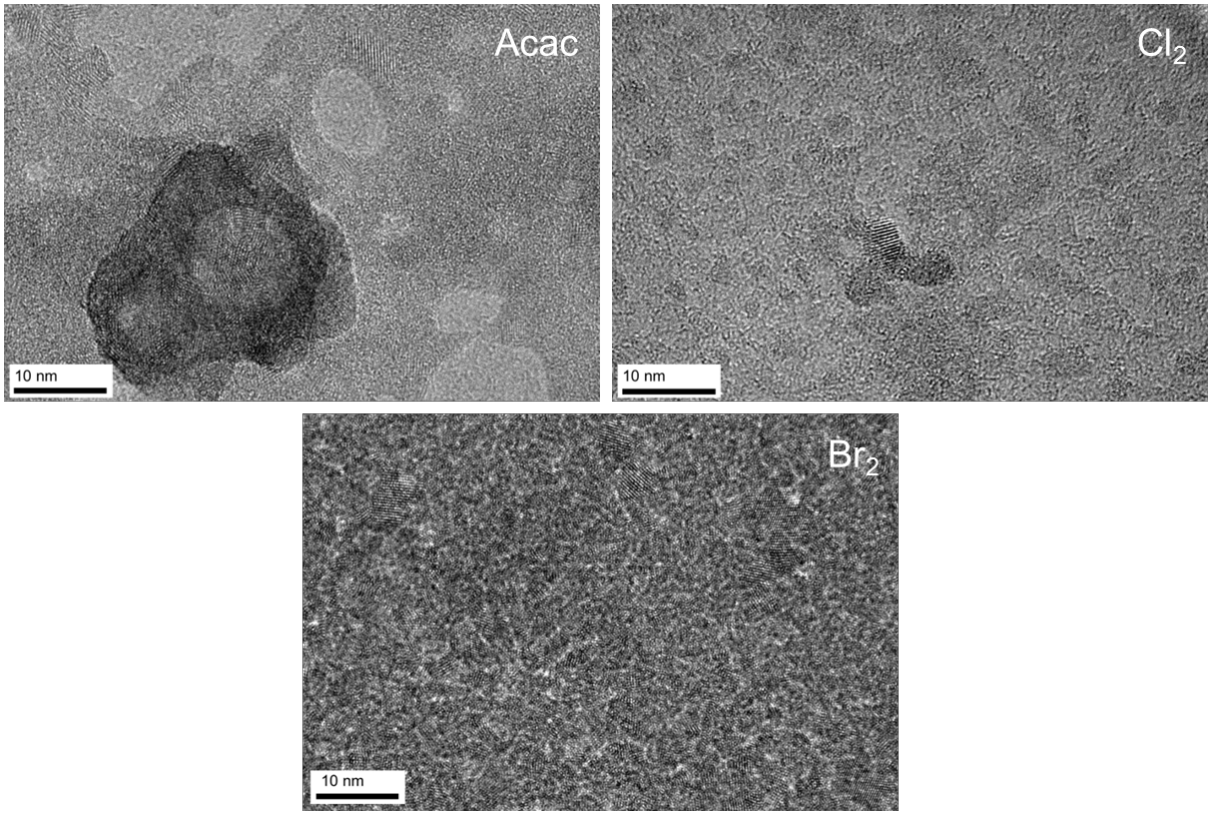


Fig. S2. HR-TEM images of Acac, Cl_2 and Br_2 annealed at 180 °C.

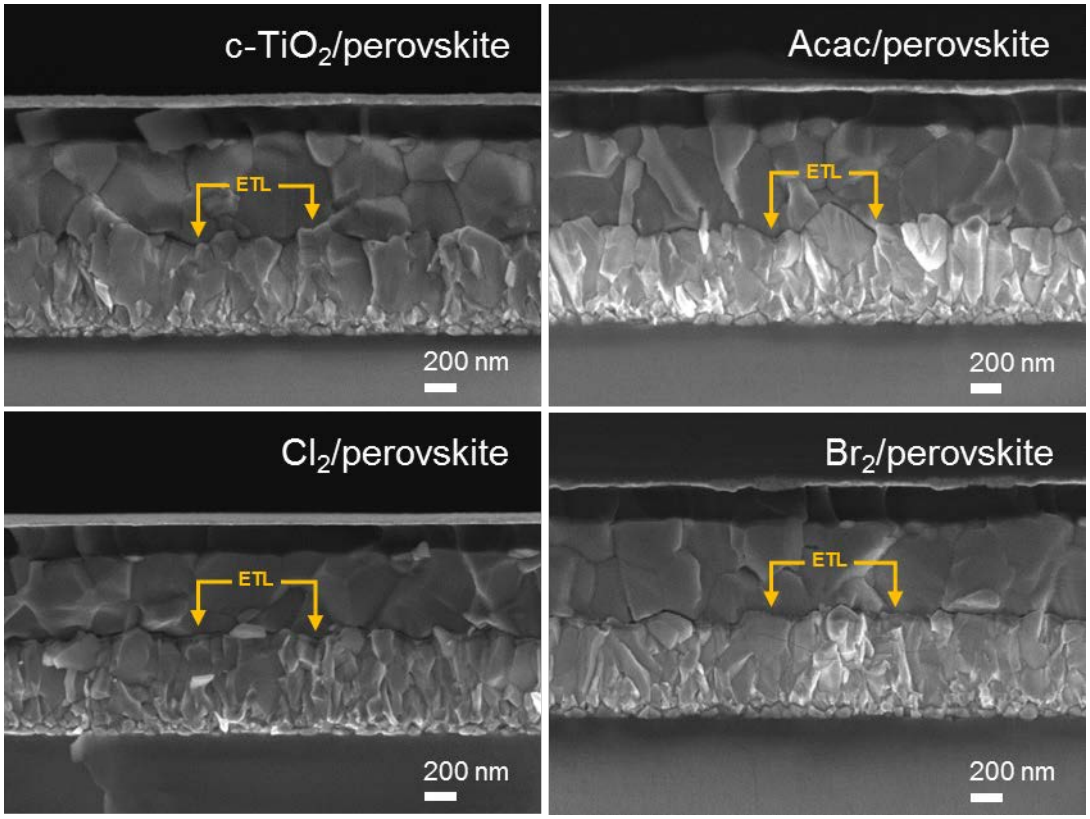


Fig. S3. SEM cross-sectional images for the complete cells. The thickness of the ETL layer is higher for Cl_2/Perovskite and Br_2/perovskite than Acac/perovskite and c-TiO_2/perovskite.

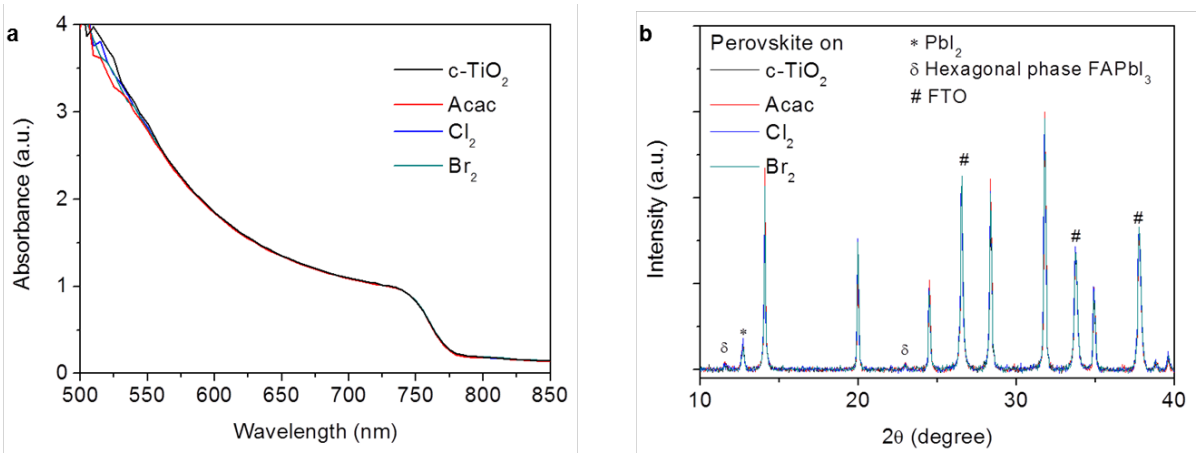


Fig. S4. Absorbance (a) and XRD patterns (b) of the perovskite film on the FTO/ETLs.

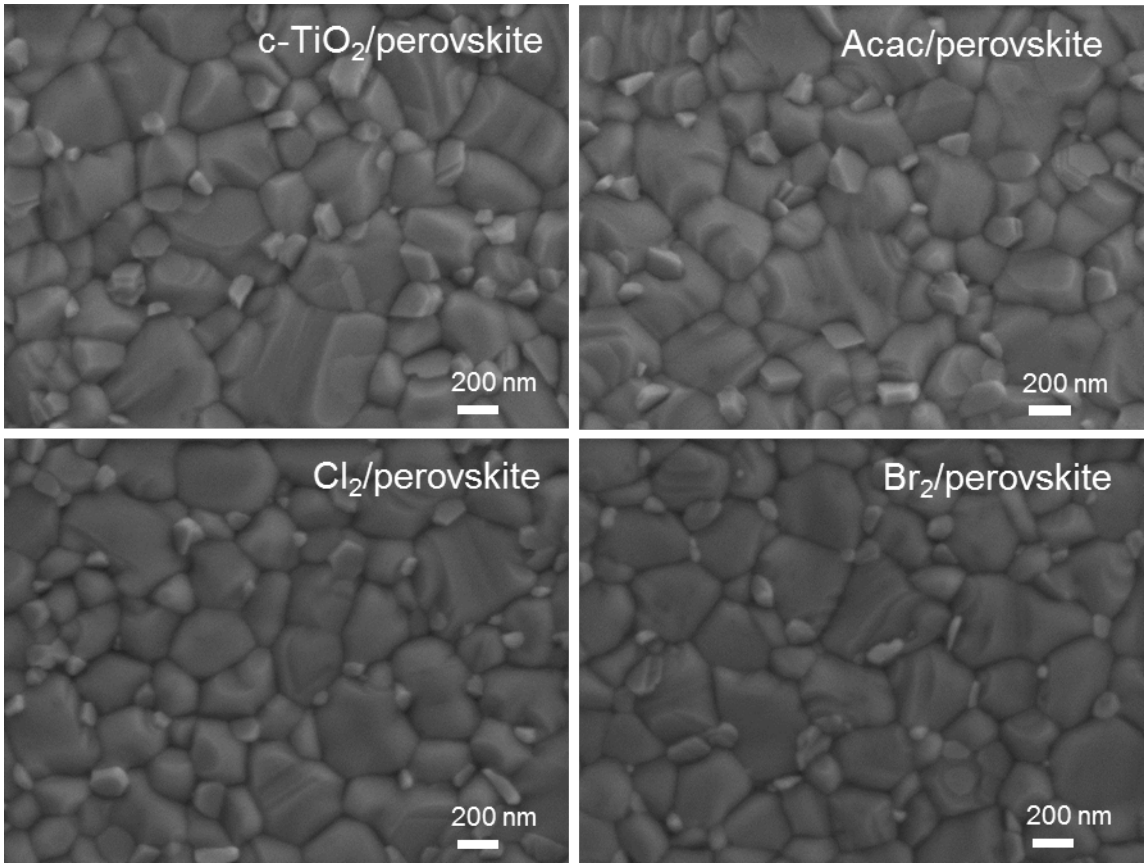


Fig. S5. Top-view SEM images of the perovskite films formed on c-TiO_2, Acac, Cl_2 and Br_2 films, respectively.

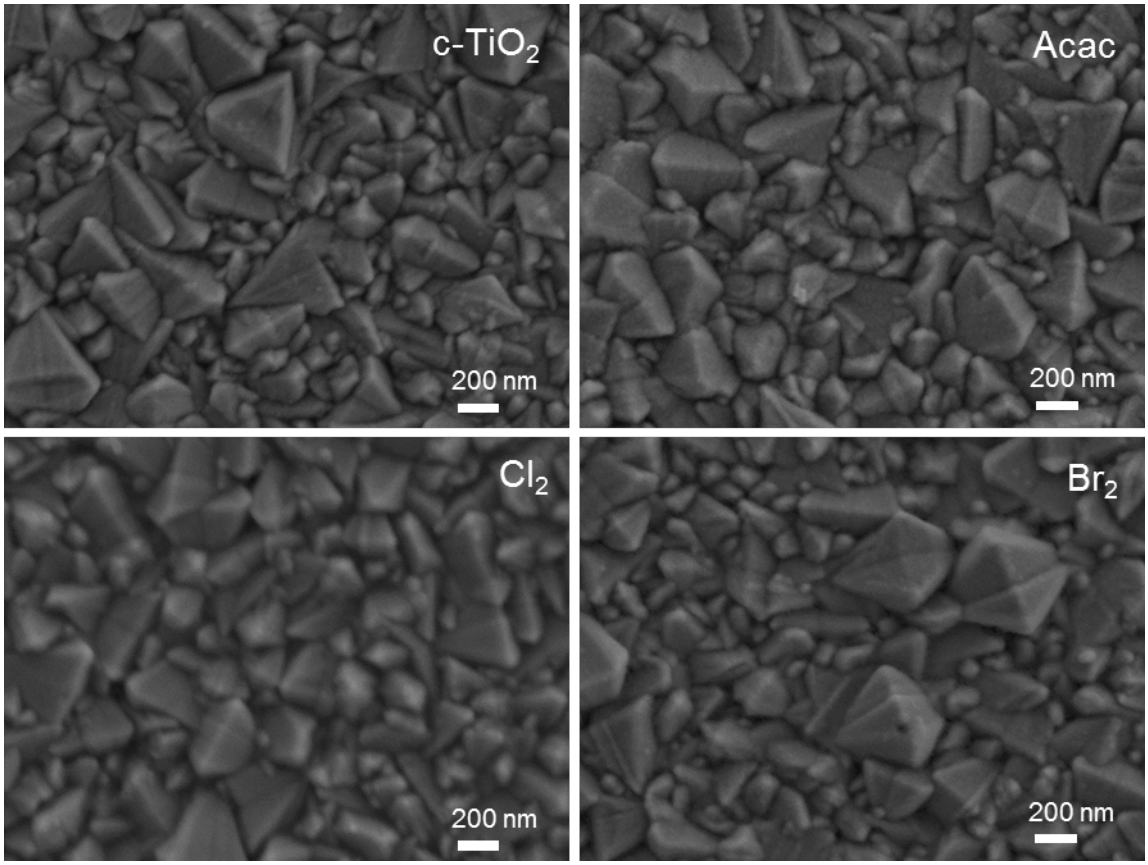


Fig. S6. Top-view images SEM of c-TiO_2, Acac, Cl_2 and Br_2 on FTO, respectively, taken at a small area. Films are annealed at 180 °C 1 h.

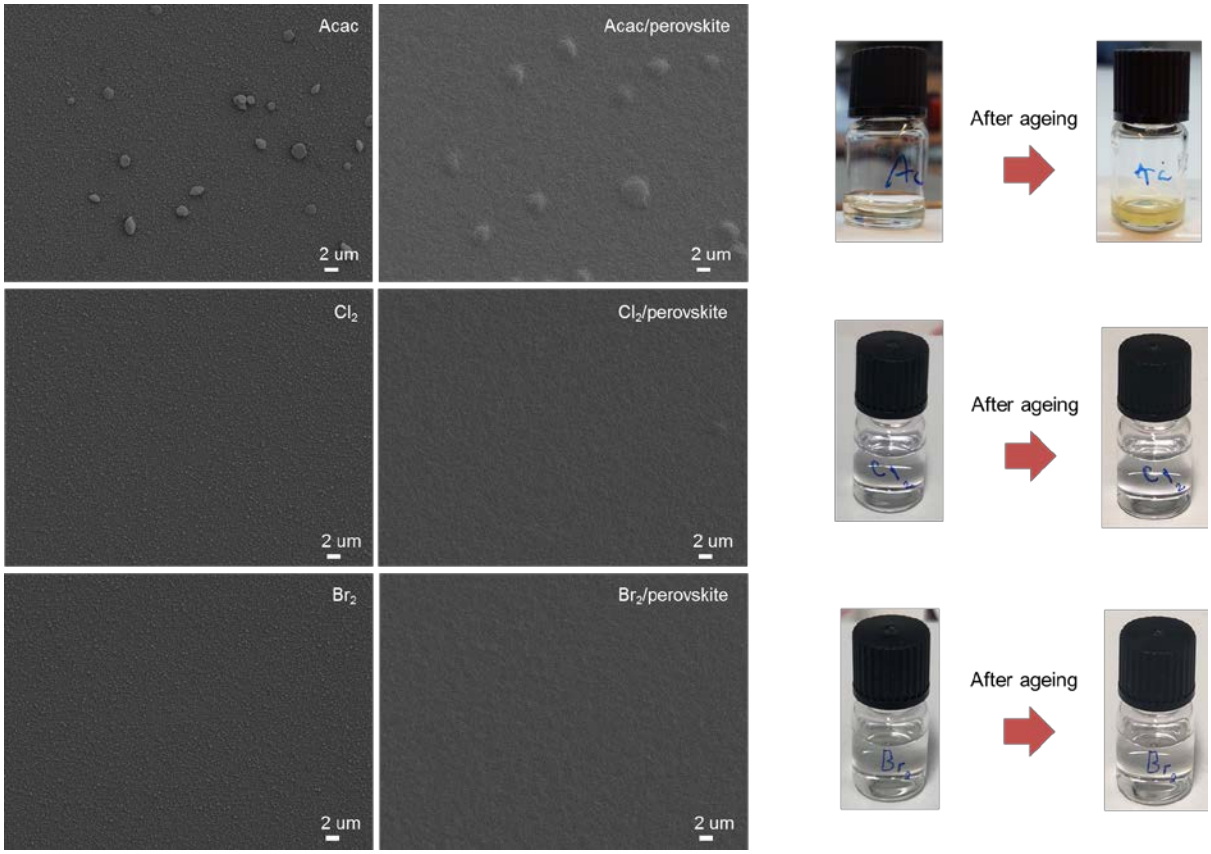


Fig. S7. Top-view SEM images of Acac, Cl_2 and Br_2 films on FTO/c-TiO_2 substrates (left), and perovskite top-surface images on each ETL. An Acac solution in DMF truns into a turbid solution in a few hours while solutions show no color or transperency change.

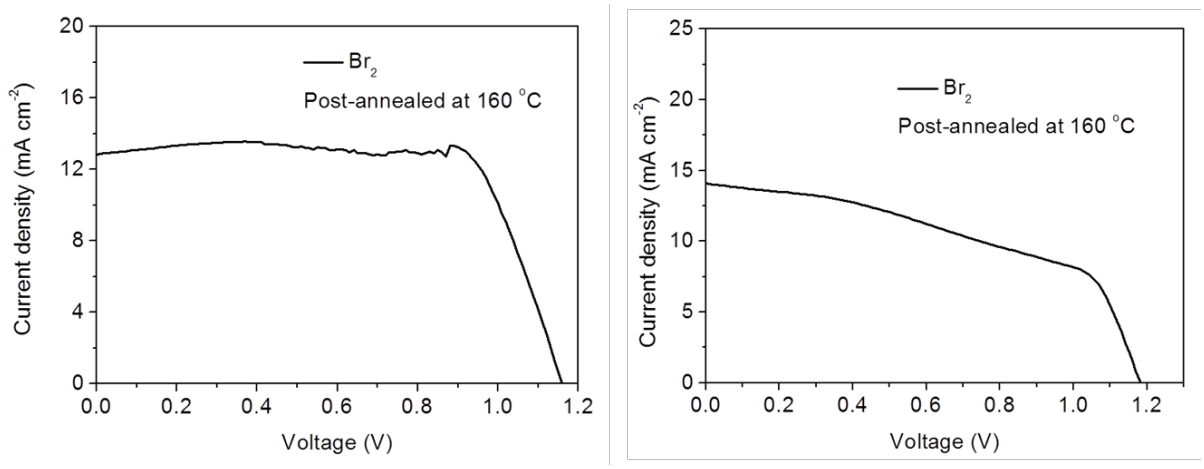


Fig. S8. Typical *J-V* curves of perovskite solar cells with c-TiO_2/Br_2 electron transporting layers prepared at 160 °C.

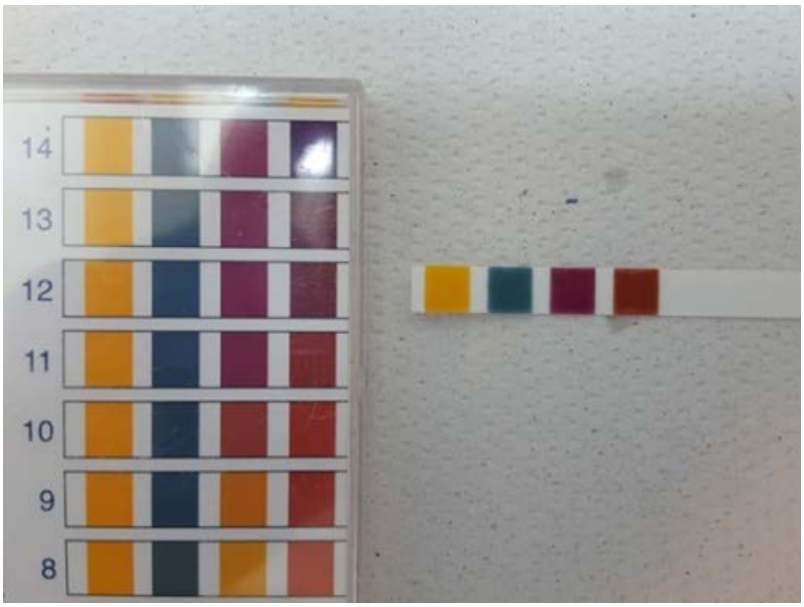


Fig. S9. pH test of the colloidal SnO_2 15% in water (AlfaAesar). The result indicates the colloidal solution is in a highly basic condition with pH=11~12.

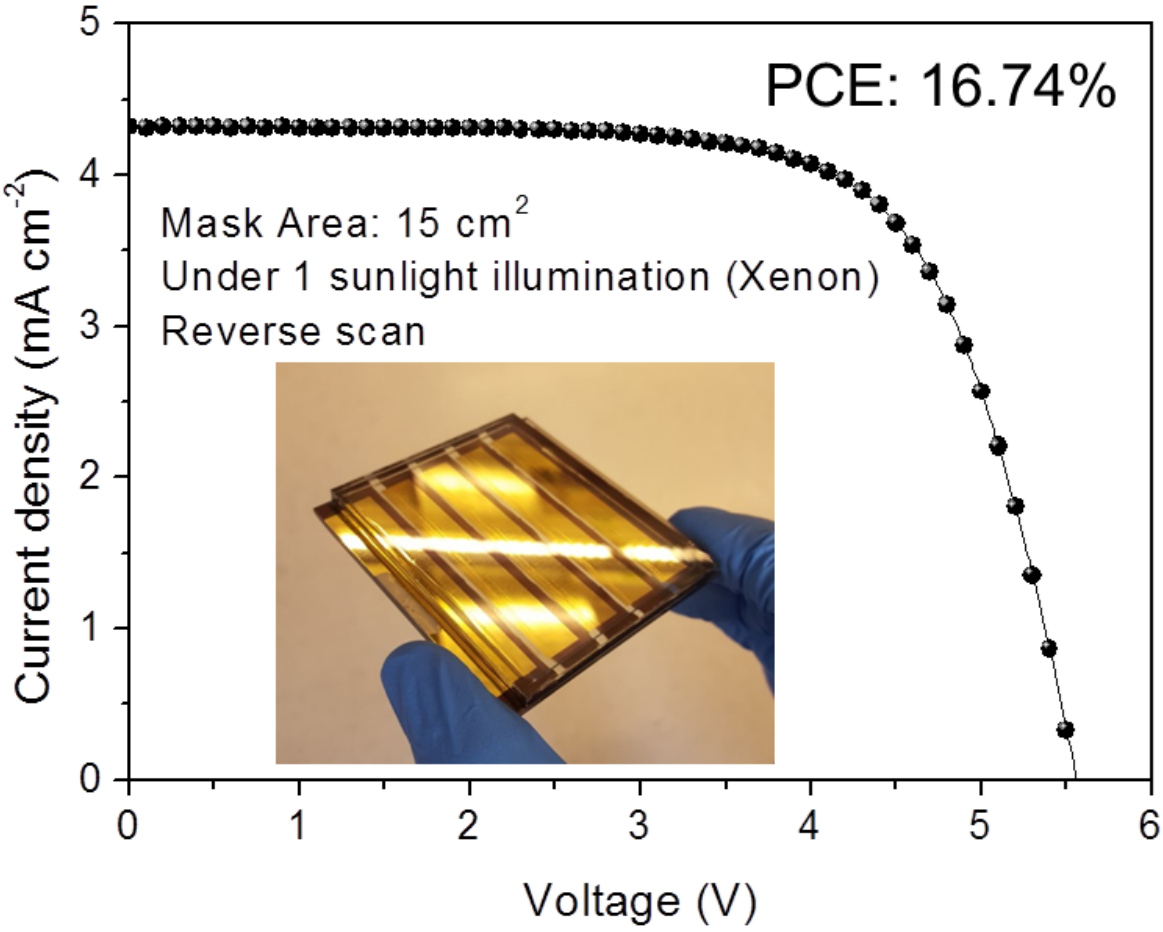


Fig. S10. A *J*-*V* curve of the planar-type perovskite mini-module.

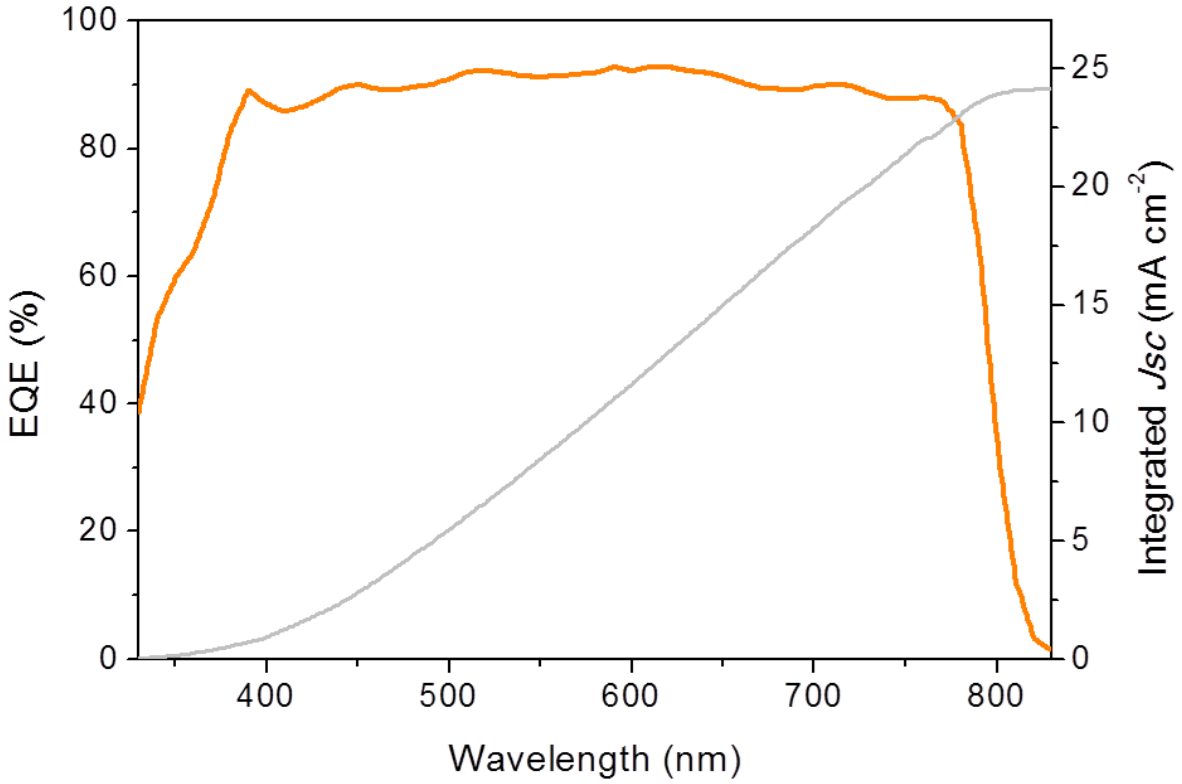


Fig. S11. External quantum efficiency (EQE) of the champion cell.

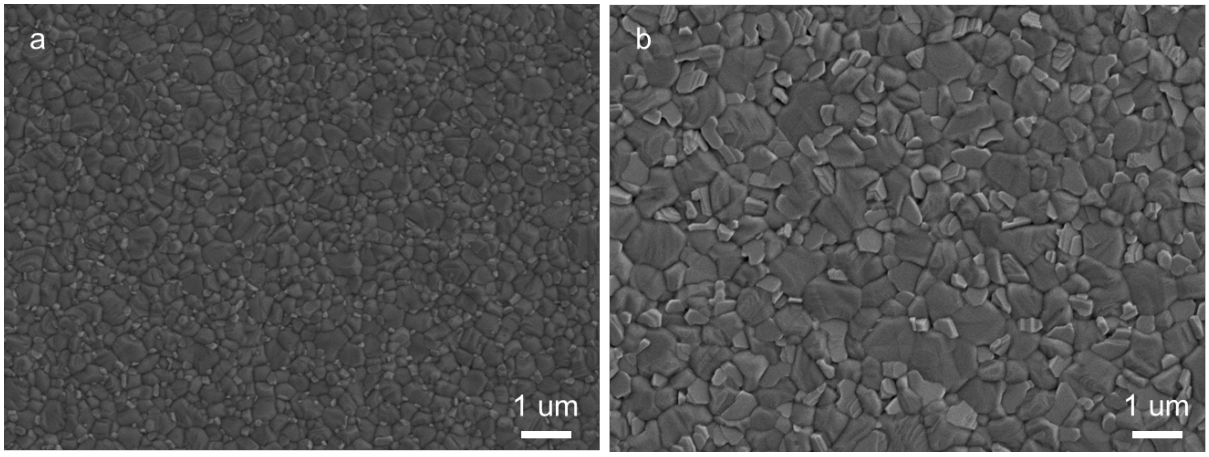


Fig. S12. SEM top-view images of the perovskite films with one-step (a) and two-step method (b).

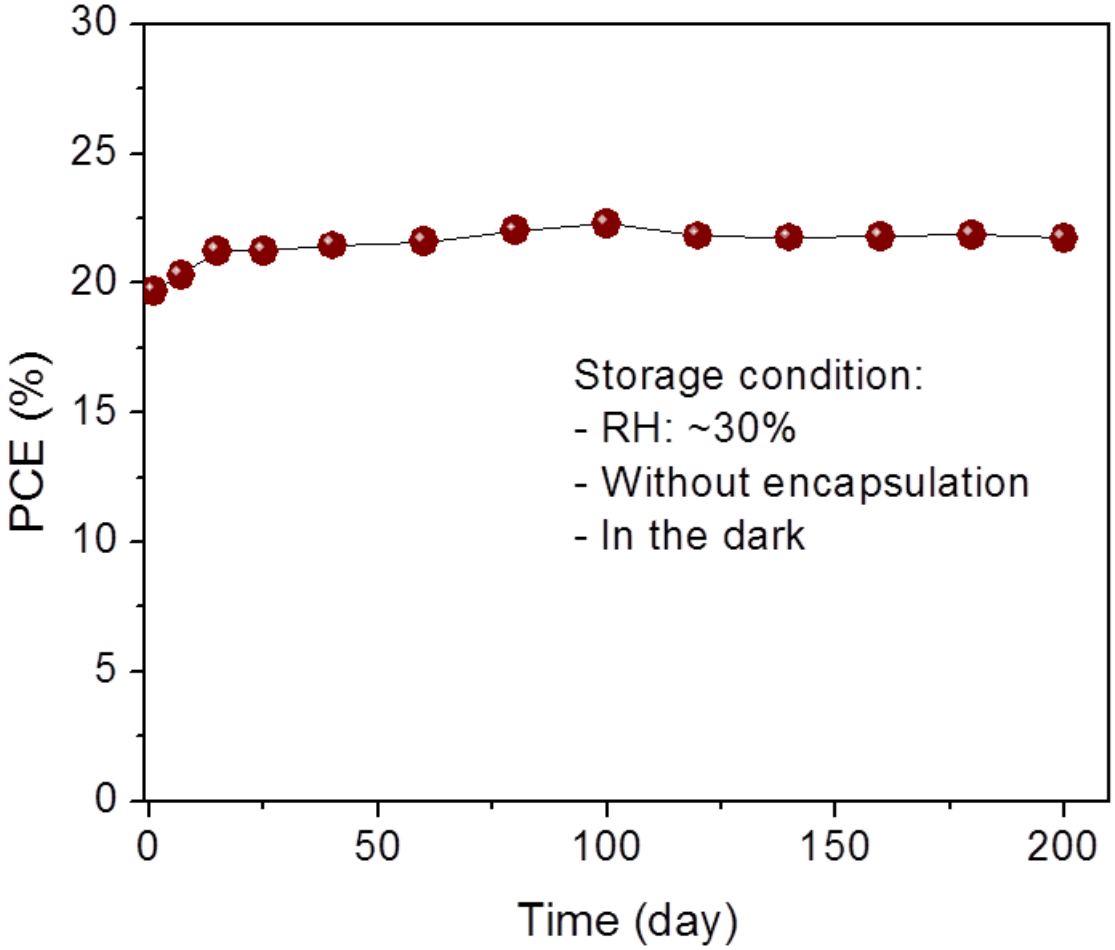
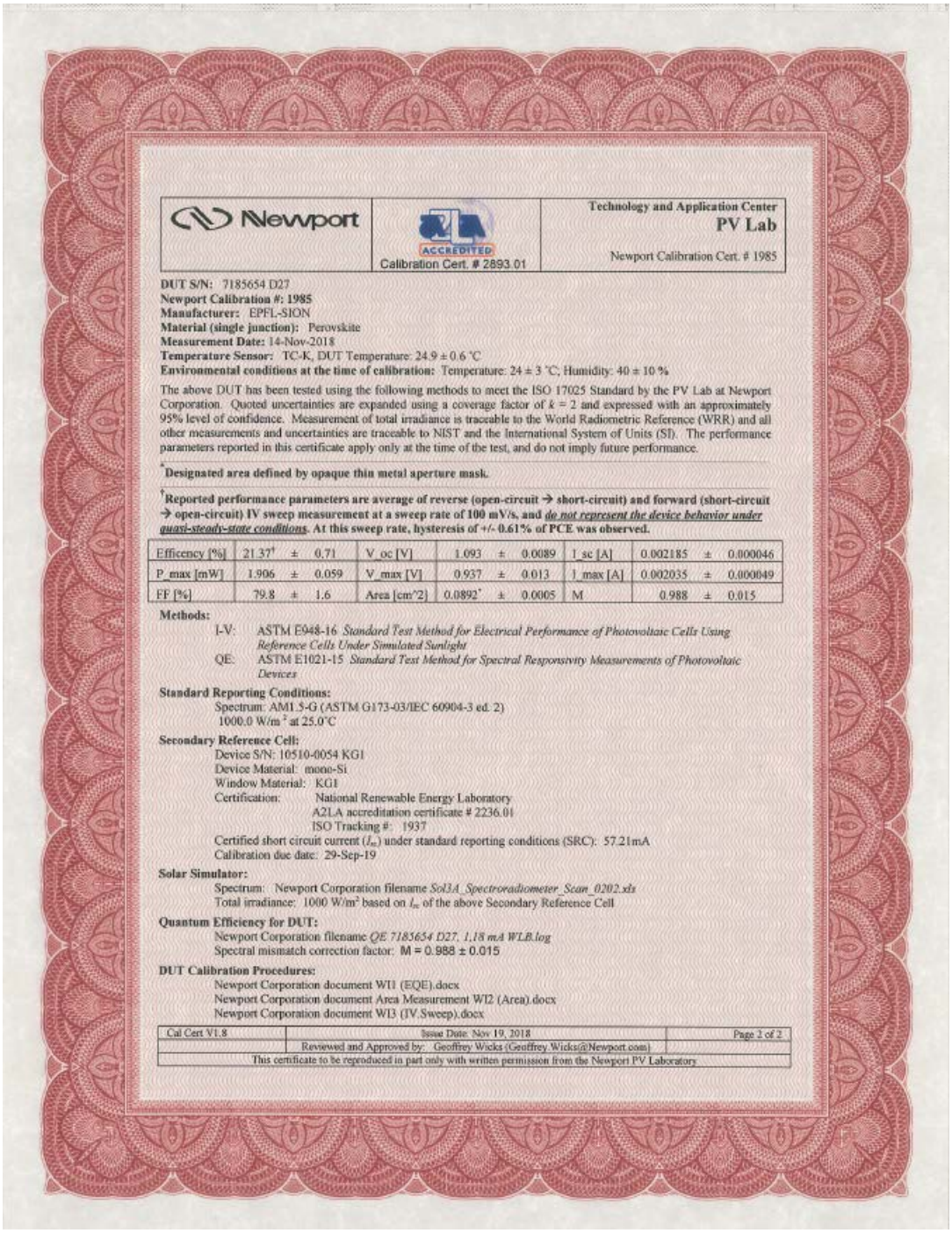


Fig. S13. Long-term stability of the champion cell.



Newport

ACCREDITED
Calibration Cert. # 2893.01

Technology and Application Center
PV Lab
Newport Calibration Cert. # 1985

DUT S/N: 7185654 D27
Newport Calibration #: 1985
Manufacturer: EPFL-SION
Material (single junction): Perovskite
Measurement Date: 14-Nov-2018
Temperature Sensor: TC-K, DUT Temperature: 24.9 ± 0.6 °C
Environmental conditions at the time of calibration: Temperature: 24 ± 3 °C; Humidity: 40 ± 10 %

The above DUT has been tested using the following methods to meet the ISO 17025 Standard by the PV Lab at Newport Corporation. Quoted uncertainties are expanded using a coverage factor of $k = 2$ and expressed with an approximately 95% level of confidence. Measurement of total irradiance is traceable to the World Radiometric Reference (WRR) and all other measurements and uncertainties are traceable to NIST and the International System of Units (SI). The performance parameters reported in this certificate apply only at the time of the test, and do not imply future performance.

* **Designated area defined by opaque thin metal aperture mask.**

† **Reported performance parameters are average of reverse (open-circuit → short-circuit) and forward (short-circuit → open-circuit) IV sweep measurement at a sweep rate of 100 mV/s, and *do not represent the device behavior under quasi-steady-state conditions*. At this sweep rate, hysteresis of +/- 0.61% of PCE was observed.**

Efficiency [%]	21.37†	±	0.71	V_oc [V]	1.093	±	0.0089	I_sc [A]	0.002185	±	0.000046
P_max [mW]	1.906	±	0.059	V_max [V]	0.937	±	0.013	I_max [A]	0.002035	±	0.000049
FF [%]	79.8	±	1.6	Area [cm^2]	0.0892*	±	0.0005	M	0.988	±	0.015

Methods:
I-V: ASTM E948-16 *Standard Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight*
QE: ASTM E1021-15 *Standard Test Method for Spectral Responsivity Measurements of Photovoltaic Devices*

Standard Reporting Conditions:
Spectrum: AM1.5-G (ASTM G173-03/IEC 60904-3 ed. 2)
1000.0 W/m^2 at 25.0°C

Secondary Reference Cell:
Device S/N: 10510-0054 KG1
Device Material: mono-Si
Window Material: KG1
Certification: National Renewable Energy Laboratory
A2LA accreditation certificate # 2236.01
ISO Tracking #: 1937
Certified short circuit current (I_{sc}) under standard reporting conditions (SRC): 57.21mA
Calibration due date: 29-Sep-19

Solar Simulator:
Spectrum: Newport Corporation filename *Sol3A_Spectroradiometer_Scan_0202.xls*
Total irradiance: 1000 W/m^2 based on I_{sc} of the above Secondary Reference Cell

Quantum Efficiency for DUT:
Newport Corporation filename *QE 7185654 D27, 1.18 mA WLB.log*
Spectral mismatch correction factor: M = 0.988 ± 0.015

DUT Calibration Procedures:
Newport Corporation document WI1 (EQE).docx
Newport Corporation document Area Measurement WI2 (Area).docx
Newport Corporation document WI3 (IV Sweep).docx

Fig. S14. A certificate of the solar cell measured at the Newport.

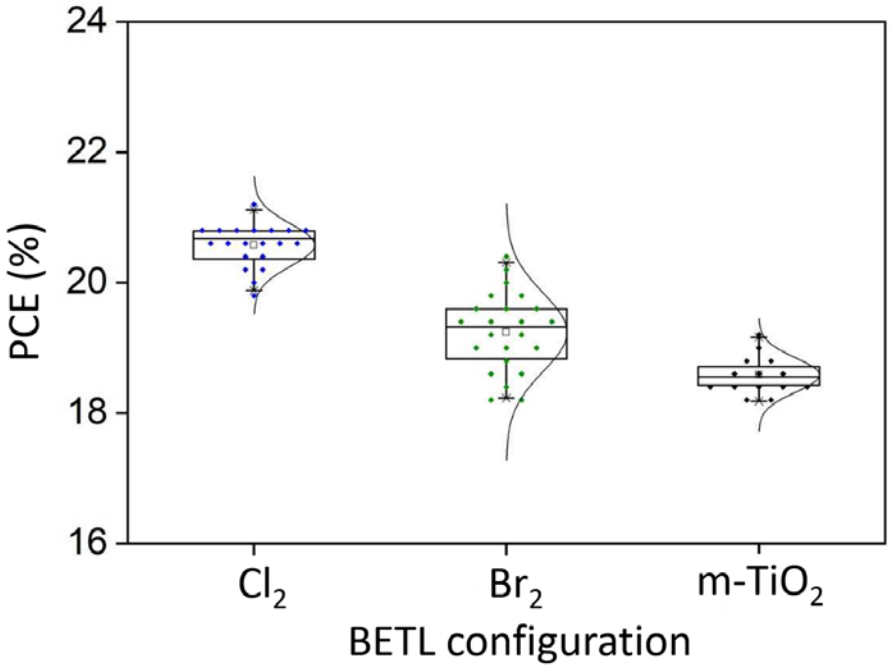


Fig. S15. Box plot for device PCE for Cl_2, Br_2 and m-TiO_2 BETL configurations.