Supplementary Information

Photovoltaic Properties of a Triple Cation Methylammonium/Formamidinium/Phenylethylammonium Tin Iodide Perovskite

Thomas Rath,[1,*] Jasmin Handl,[1] Stefan Weber,[1] Bastian Friesenbichler,[1] Peter Fürk,[1] Lukas Troi,[1] Theodoros Dimopoulos,[2] Birgit Kunert,[3] Roland Resel,[3] Gregor Trimmel[1]

[1] Institute for Chemistry and Technology of Materials (ICTM), NAWI Graz, Graz University of Technology, Stremayrgasse 9, 8010 Graz, Austria

[2] AIT Austrian Institute of Technology, Center for Energy, Photovoltaic Systems, Giefinggasse 4, 1210 Vienna, Austria

[3] Institute of Solid State Physics, NAWI Graz, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria

* Corresponding author address: Institute for Chemistry and Technology of Materials (ICTM), NAWI Graz, Graz University of Technology, Stremayrgasse 9, 8010 Graz, Austria; Email: thomas.rath@tugraz.at

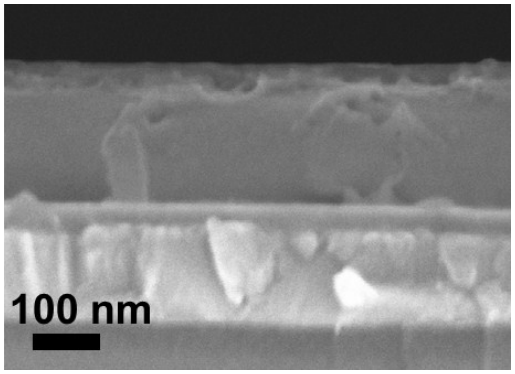

Fig. S1 SEM cross section of a glass/ITO/PEDOT:PSS/tin perovskite sample. The PEDOT:PSS layer has a thickness of 35 nm, the tin perovskite layer is 225 nm thick.

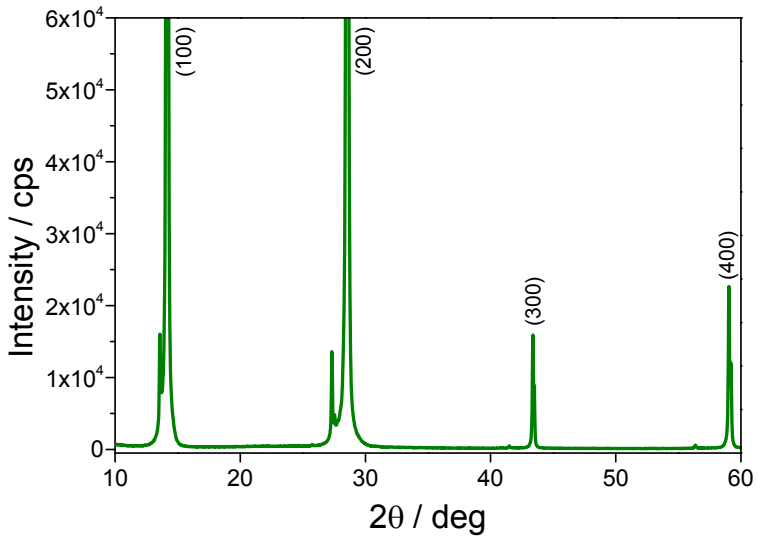

Fig. S2 X-ray diffraction pattern of a $MA_{0.75}FA_{0.15}PEA_{0.1}SnI_3$ thin film on a glass substrate (only the low intensity region is shown). The full diffractogram is depicted in Figure 2A.

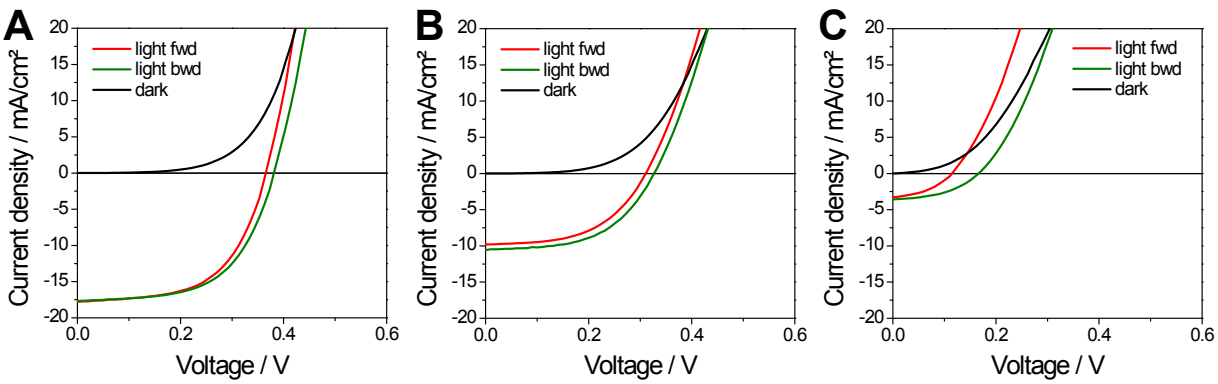

Fig. S3 Typical JV curves in the dark and under illumination measured in forward and backward sweep direction of solar cells with (A) $MA_{0.9}PEA_{0.1}SnI_3$, (B) $FA_{0.9}PEA_{0.1}SnI_3$, and (C) $MA_{0.75}FA_{0.25}SnI_3$ absorber layers.

Table S1 Characteristic parameters of the solar cells shown in Fig. S3

absorber layer	V_{oc} / V	J_{sc} / mA/cm²	FF	PCE
$MA_{0.9}PEA_{0.1}SnI_3$	(fwd: 0.383, bwd: 0.363)	(fwd: 17.6, bwd: 17.8)	(fwd: 0.57, bwd: 0.57)	(fwd: 3.83, bwd: 3.65)
$FA_{0.9}PEA_{0.1}SnI_3$	(fwd: 0.322, bwd: 0.312)	(fwd: 10.6, bwd: 9.8)	(fwd: 0.53, bwd: 0.52)	(fwd: 1.84, bwd: 1.60)
$MA_{0.75}FA_{0.25}SnI_3$	(fwd: 0.161, bwd: 0.111)	(fwd: 3.6, bwd: 3.3)	(fwd: 0.45, bwd: 0.42)	(fwd: 0.26, bwd: 0.15)

Table S2 Average values and standard deviations of the five best solar cells prepared with each composition of the double cation tin perovskite absorber layers

absorber layer	V_{oc} / V	J_{sc} / mA/cm²	FF	PCE
$MA_{0.9}PEA_{0.1}SnI_3$	0.383 ± 0.006	17.0 ± 0.7	0.63 ± 0.02	4.08 ± 0.16
$FA_{0.9}PEA_{0.1}SnI_3$	0.293 ± 0.014	10.5 ± 0.5	0.54 ± 0.02	1.65 ± 0.15
$MA_{0.75}FA_{0.25}SnI_3$	0.159 ± 0.004	5.1 ± 0.3	0.48 ± 0.01	0.38 ± 0.03

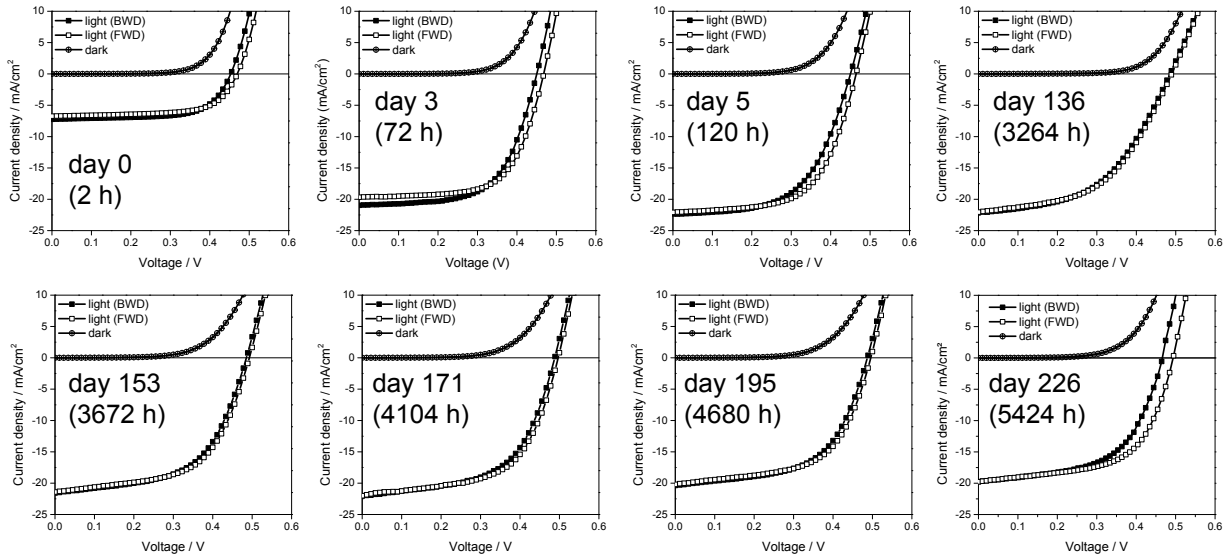

Fig. S4 JV curves of the solar cells at different stages of the stability test measured in forward (FWD) and backward (BWD) direction in the dark and under 100 mW/cm² illumination (without shadow mask). The scan rate was 110 mV/s.

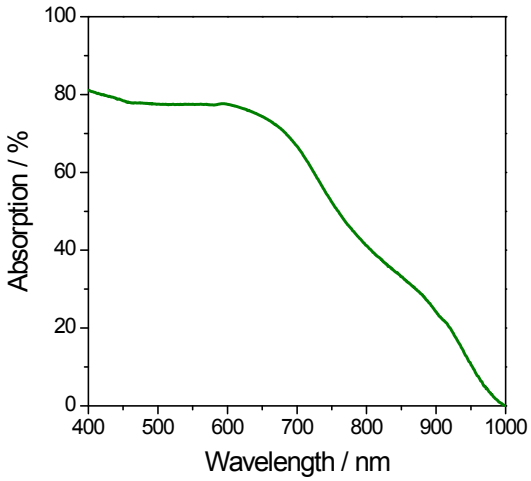

Fig. S5 Absorption spectrum of a $MA_{0.75}FA_{0.15}PEA_{0.1}SnI_3$ absorber layer with the same thickness as used in the solar cells.

Table S3 Average values and standard deviations of the characteristic parameters of the five best solar cells measured over 226 days (5424 h). These data were measured without using a shadow mask for the illumination of the solar cells

days - hours	V_{OC} / V	J_{SC} / mA/cm²	FF	PCE
0 - 2	0.431 ± 0.005	13.1 ± 2.8	0.68 ± 0.01	3.76 ± 0.78
3 - 72	0.467 ± 0.019	18.0 ± 1.9	0.65 ± 0.01	5.40 ± 0.59
5 - 120	0.464 ± 0.18	18.7 ± 3.6	0.63 ± 0.02	5.48 ± 0.80
10 - 240	0.469 ± 0.009	18.7 ± 3.9	0.61 ± 0.02	5.31 ± 0.90
14 - 336	0.471 ± 0.006	18.6 ± 3.3	0.62 ± 0.03	5.34 ± 0.78
18 - 432	0.473 ± 0.006	19.8 ± 3.2	0.61 ± 0.03	5.6 ± 0.72
48 - 1152	0.478 ± 0.001	19.1 ± 1.5	0.58 ± 0.04	5.26 ± 0.21
54 - 1296	0.480 ± 0.005	18.9 ± 1.2	0.59 ± 0.03	5.29 ± 0.10
61 - 1464	0.484 ± 0.006	19.8 ± 1.0	0.59 ± 0.03	5.49 ± 0.11
70 - 1680	0.498 ± 0.010	20.7 ± 0.07	0.56 ± 0.04	5.70 ± 0.28
80 - 1920	0.498 ± 0.10	20.4 ± 0.83	0.56 ± 0.04	5.65 ± 0.44
136 - 3264	0.497 ±0.010	19.1 ± 2.6	0.50 ± 0.04	4.77 ± 0.88
143 - 3432	0.487 ± 0.010	18.0 ± 2.3	0.52 ± 0.06	4.72 ± 1.02
153 - 3672	0.504 ± 0.012	18.2 ± 2.6	0.51 ± 0.06	4.70 ± 1.07
171 - 4104	0.509 ± 0.010	18.3 ± 3.0	0.51 ± 0.06	4.77 ± 1.20
195 - 4680	0.511 ± 0.010	16.1 ± 2.7	0.49 ± 0.06	4.10 ± 1.11
226 - 5424	0.513 ± 0.02	16.5 ± 2.5	0.51 ± 0.06	4.35 ± 1.02

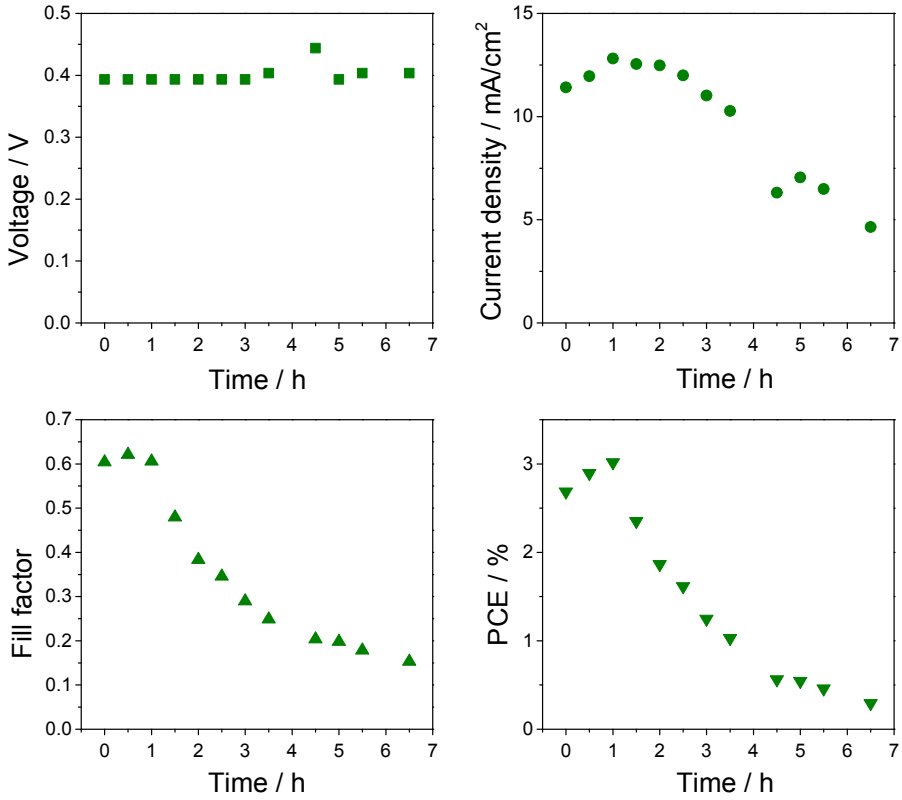

Fig. S6 Performance loss of a typical $MA_{0.75}FA_{0.15}PEA_{0.1}SnI_3$ based solar cells in ambient conditions.

Table S4 Average values and standard deviations of the characteristic parameters of six solar cells during exposure to ambient conditions over 6.5 hours. The standard deviations increase vastly during the stability test due to complete failure of some devices

Time / h	V_{OC} / V	J_{SC} / mA/cm²	FF	PCE
0	0.392 ± 0.004	11.75 ± 1.76	0.60 ± 0.03	2.71 ± 0.30
0.5	0.392 ± 0.004	12.12 ± 1.67	0.59 ± 0.04	2.79 ± 0.33
1	0.398 ± 0.005	12.85 ± 1.82	0.57 ± 0.02	2.88 ± 0.38
1.5	0.393 ± 0.006	10.72 ± 4.56	0.42 ± 0.10	1.95 ± 0.85
2	0.336 ± 0.075	9.85 ± 5.70	0.30 ± 0.07	1.43 ± 0.83
2.5	0.417 ± 0.092	9.61 ± 4.41	0.37 ± 012	1.28 ± 0.59
3	0.380 ± 0.040	8.69 ± 4.05	0.33 ± 0.08	1.00 ± 0.48
3.5	0.397 ± 0.137	6.57 ± 4.67	0.23 ± 0.04	0.71 ± 0.50
4.5	0.330 ± 0.093	3.80 ± 3.86	0.23 ± 0.04	0.36 ± 0.37
5	0.323 ± 0.120	3.30 ± 3.31	0.28 ± 0.09	0.29 ± 0.29
5.5	0.267 ± 0.157	3.03 ± 3.03	0.17 ± 0.11	0.22 ± 0.22
6.5	0.306 ± 0.103	2.37 ± 2.37	0.16 ± 0.07	0.16 ± 0.16