

Scribing Method for Carbon Perovskite Solar Modules

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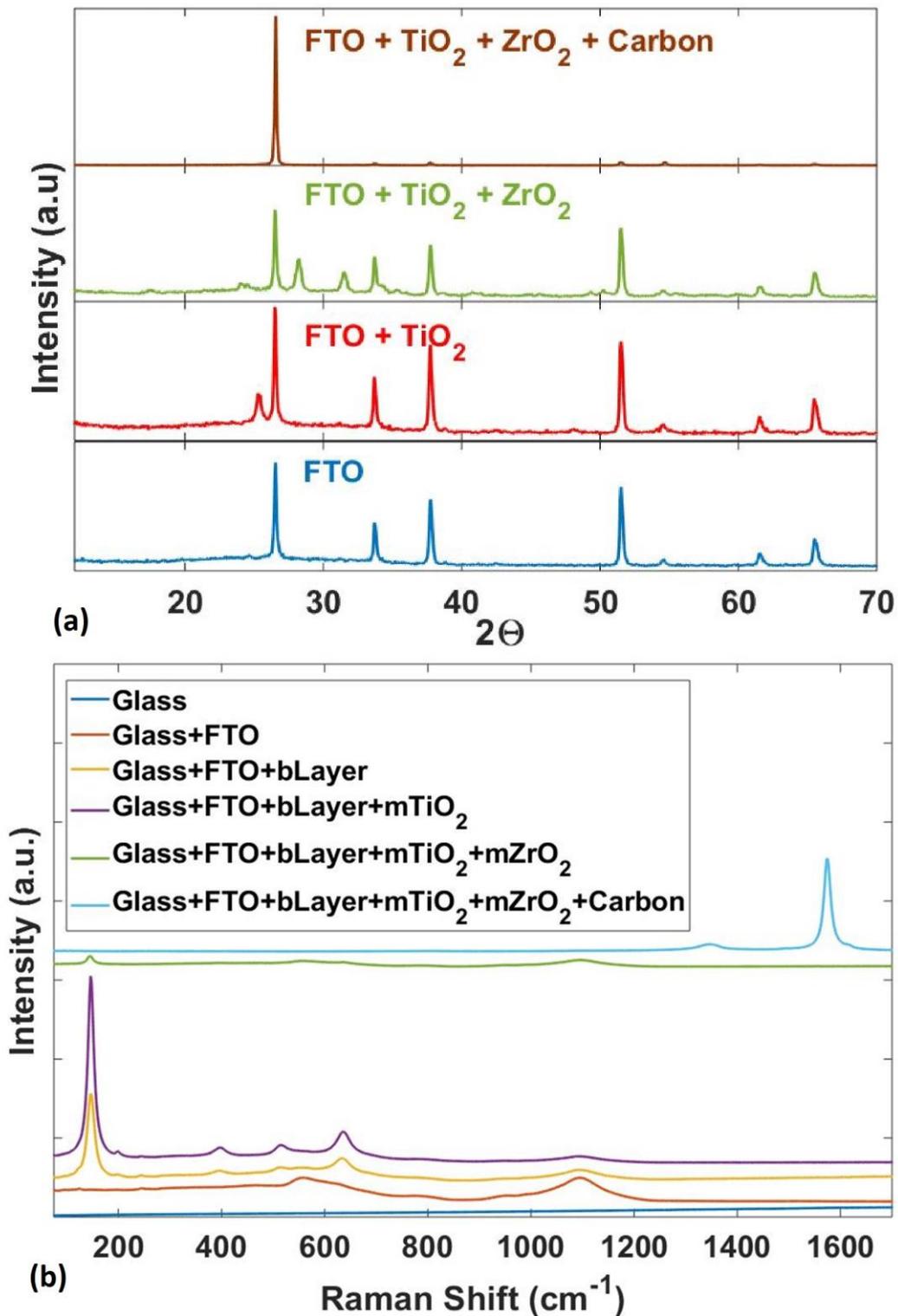


Fig S1 Characterization of each layer of the C-PSC stack after the sequential deposition on the same substrate: (a) by XRD and (b) by Raman.

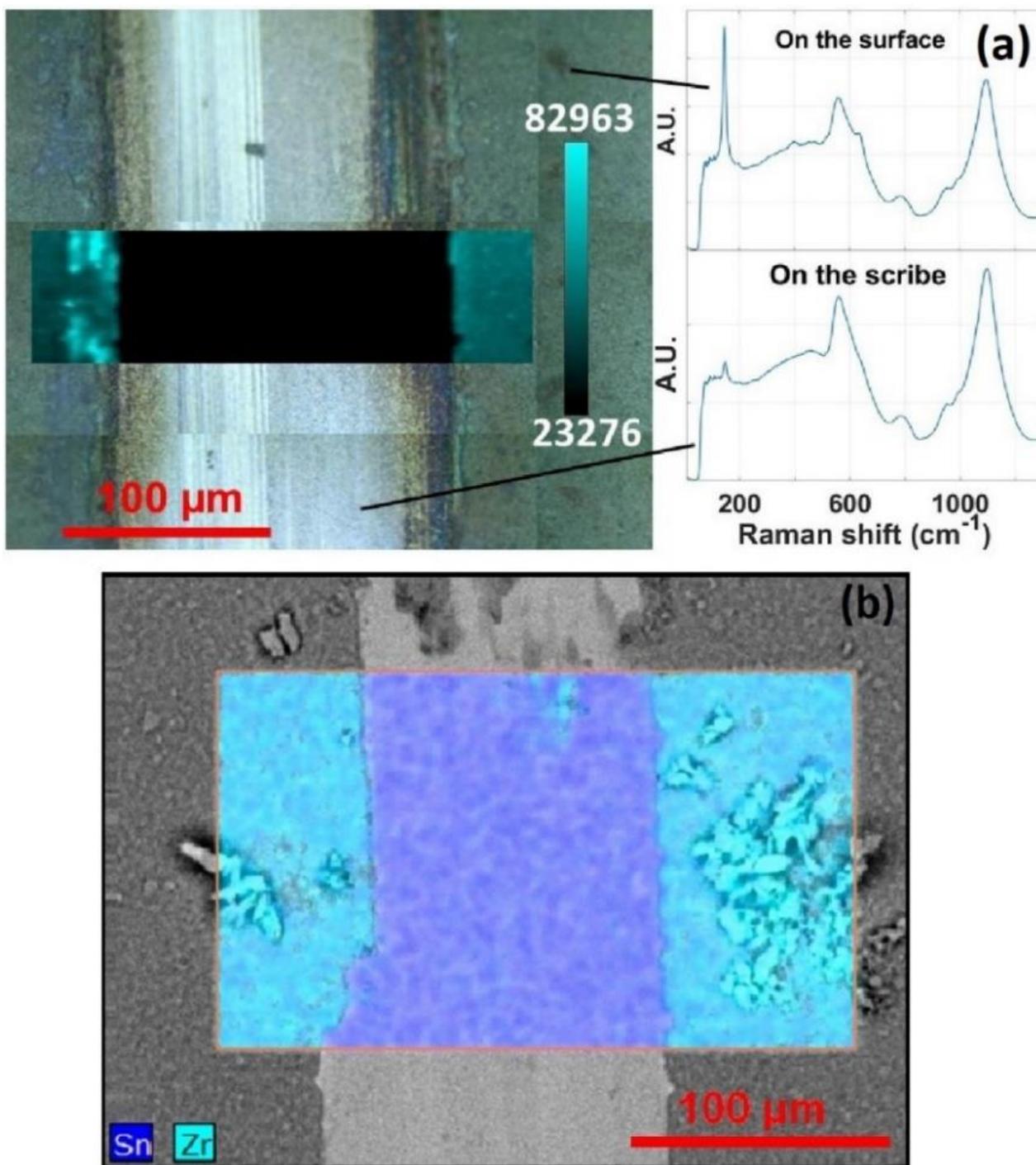


Fig S2 P2 characterization. (a) Optical microscope image and Raman map of the peak at 144 cm⁻¹ showing an anatase phase (TiO₂); inset, a false colour map of Raman signal intensity at different positions; (b) SEM image and EDX map of Zr (ZrO₂) and Sn (FTO).

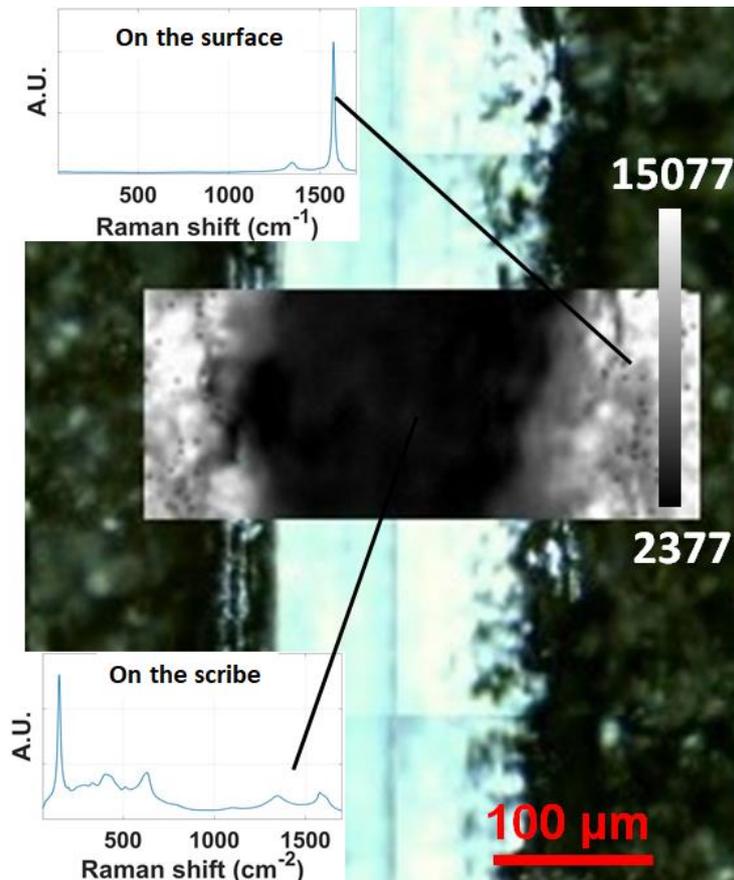


Fig S3 P3 characterization. Optical microscope image and Raman map of the peak at 1570 cm^{-1} ; inset, the Raman signals at different positions. Raman mapping can discriminate between the presence of graphite due to the excitation of the sp^2 bonds in carbon, which generate the so-called G band at around 1570 cm^{-1} . The chemical map of the P3 scribe by Raman shows a complete removal of the conductive layer; no graphite peak is detected. The result shows that an effective P3 scribe, around $200\text{ }\mu\text{m}$ wide, can be achieved by mechanical scribing, removing materials selectively.

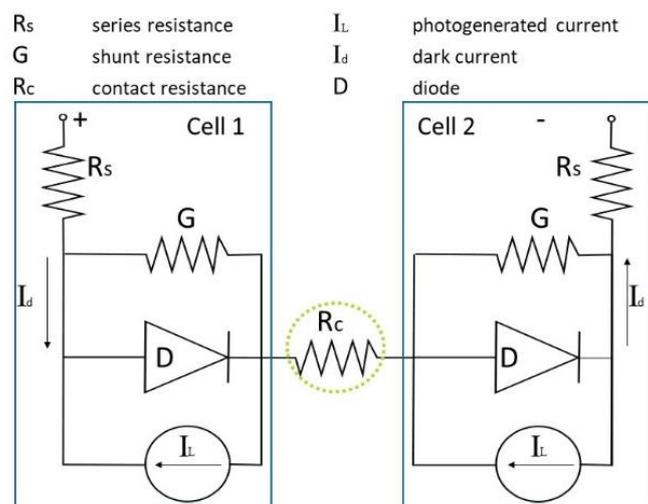


Fig S4 Equivalent circuit of a 2-cell series connected module. The contact between the two cells is ensured by R_c .

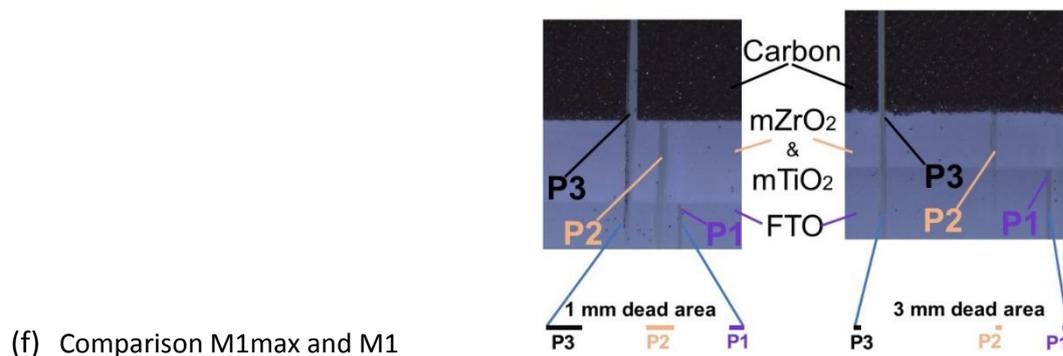
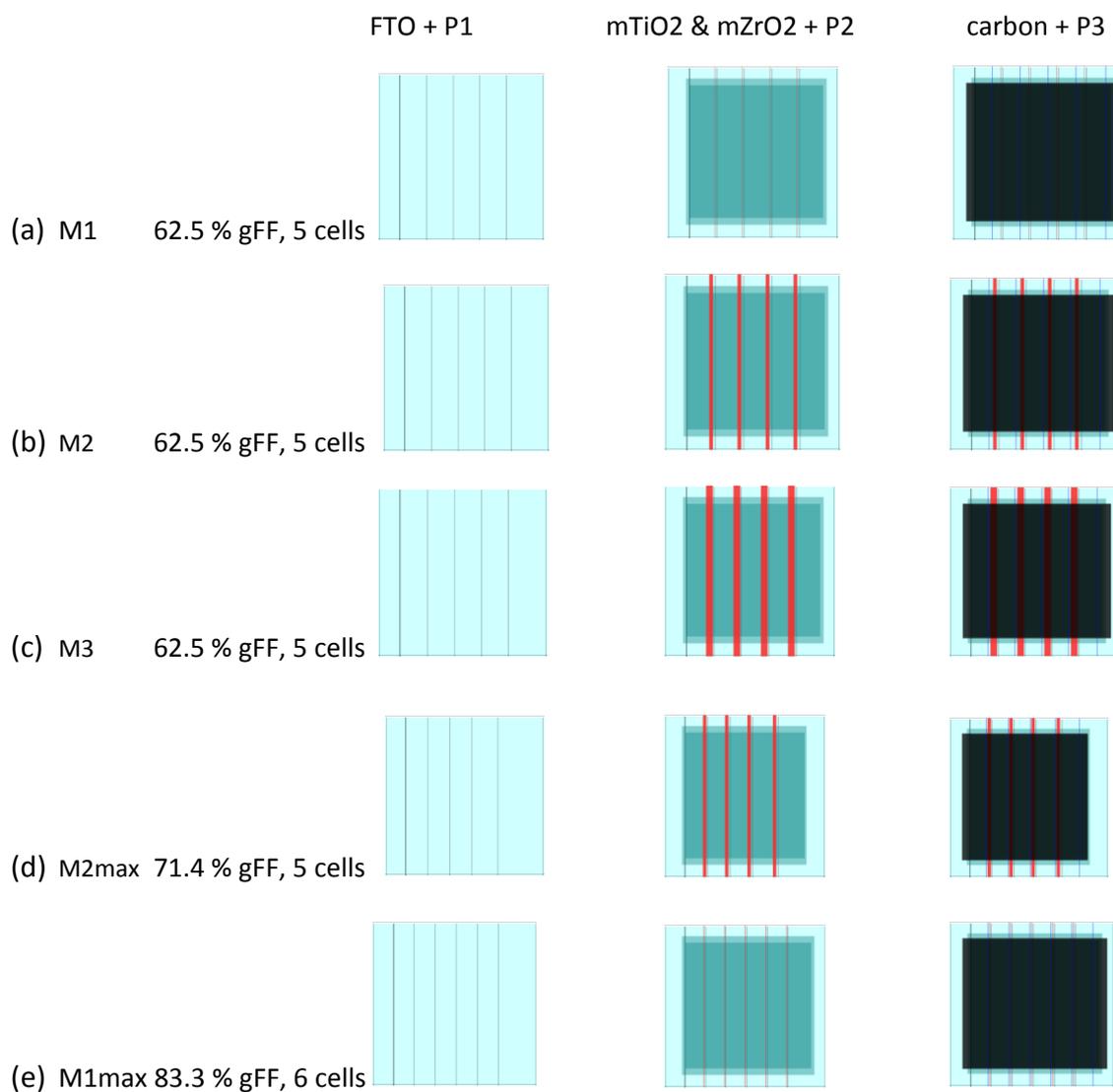


Fig S5 Dimensions of the modules. From the left to the right: FTO substrate with P1 laser scribe; mTiO₂ and ZrO₂ layers with P2 scribe; carbon with P3 scribe. (a) M1 module with single P2 scribe; (b) M2 module with 1 mm P2 scribe; (c) M3 module with 1.85 mm P2 scribe; (d) M2max module with 1 mm P2 scribe and maximised g-FF; (e) M1max module with single P2 scribe and maximised g-FF; to be noted an additional cell is present in design M1max in order to avoid a significant change in the separation between the electrical contacts. (f) optical microscope image at the edge of the M1max and M1 modules with the P1, P2, and P3 scribes and relative spacing.

Tab S1 Measured data from JV measurement of the modules under study.

	PCE rev (%)	PCE for (%)	FF rev (%)	Isc rev (mA)	Voc rev (V)	Voc per cell (mV)	Number of cells	Single cell area (cm ²)	
M1	A	6.22	4.95	53.02	28.25	4.01	801.3	5	1.95
	B	5.58	5.54	39.67	39.91	3.41	681.0	5	1.95
	C	5.67	5.43	44.04	34.77	3.57	714.8	5	1.95
M1 max	A	6.71	5.56	47.12	31.19	5.29	881.5	6	1.95
	B	7.79	6.99	42.61	40.50	5.23	870.9	6	1.95
	C	8.33	7.57	46.92	39.72	5.18	863.3	6	1.95
M2	A	8.70	7.26	53.29	37.38	4.21	843.0	5	1.95
	B	8.04	7.40	46.48	42.48	3.93	786.8	5	1.95
	C	8.24	7.46	48.92	39.34	4.13	826.9	5	1.95
M2 max	A	9.88	8.97	50.13	43.73	4.35	870.1	5	1.95
	B	9.49	8.88	49.99	42.14	4.35	869.5	5	1.95
	C	7.99	7.03	50.18	35.76	4.30	859.3	5	1.95
M3	A	8.24	7.13	52.27	35.35	4.30	860.6	5	1.95
	B	8.34	6.93	52.90	38.00	4.01	802.5	5	1.95
	C	10.29	9.12	52.02	43.82	4.35	871.0	5	1.95

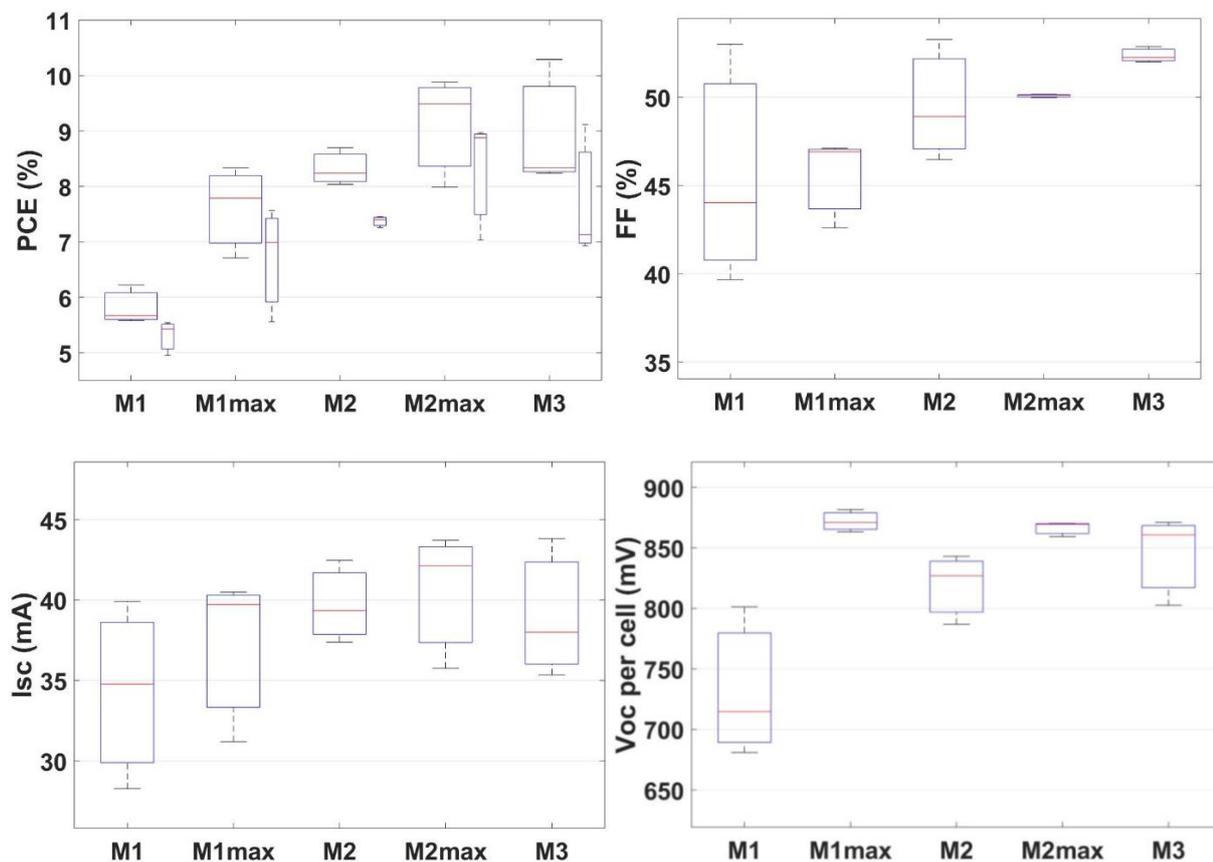


Fig S6 Statistical analysis of JV data comparing modules with different design (Tab 1, Fig S6) for all three modules fabricated of each type. The PCE data is derived from both reverse and forward scan and the V_{oc} value is shown divided by the number of cells.