Electronic Supplementary Information

Towards industrialization of perovskite solar cells using slot die coating

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Slot die coated layers

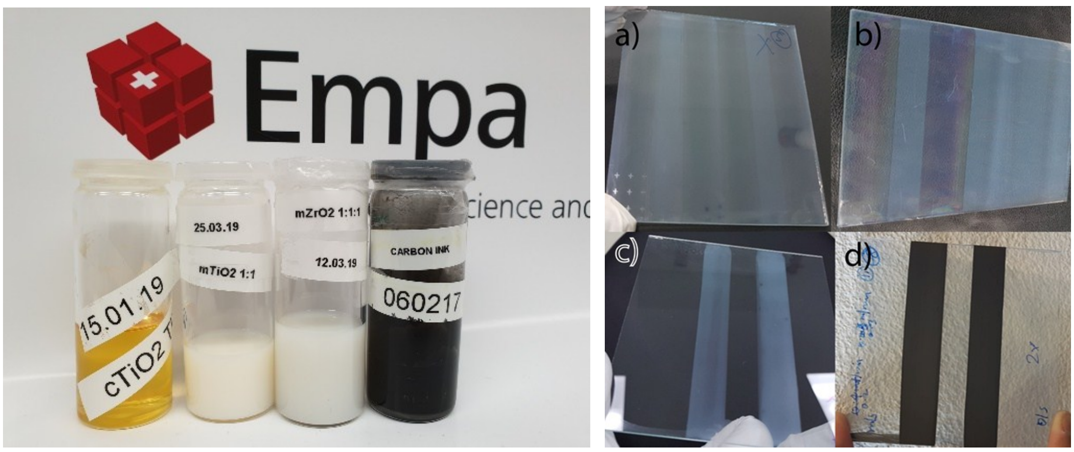

Figure S1: Left: Photographs of different inks, right: photographic images of slot die coated stripes of the different materials: (a) $cTiO_2$, (b) $mTiO_2$, (c) $mZrO_2$, (d) carbon.

Link to videos showing large area slot die coating of $mZrO_2$ and Carbon.

Perovskite infiltration

The degree of perovskite infiltration cannot be reliably extracted from SEM images. Figure S2 shows a non-infiltrated stack on the left side, and an infiltrated stack on the right side.

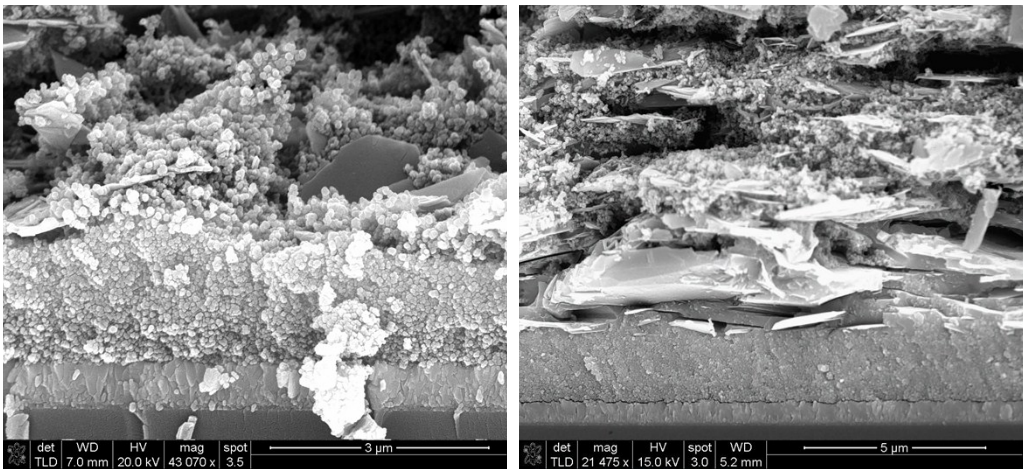

Figure S2: Cross-sectional SEM images of MPSCs without (left) and with perovskite infiltration (right).

X-ray diffraction of the $cTiO_2$ layers

Any change made to the ink can lead to different morphologies thus leading to variable device performance. X-ray diffraction proved that different methods used for deposition of $cTiO_2$ showed similar X-ray pattern.

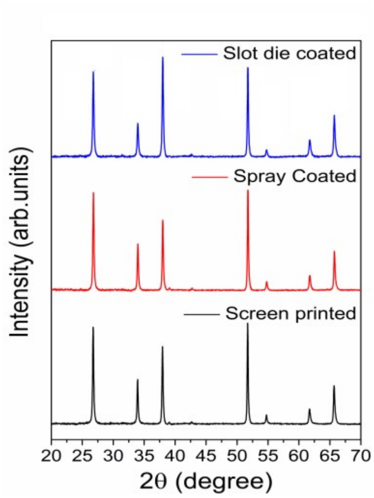

Figure S3: X-ray diffraction pattern of $cTiO_2$ layers deposited using screen printing, spray coating and slot die coating.

Efficiency measurement protocols

The measured efficiency of perovskite solar cells depends critically on the protocol followed to perform the measurement. We base our standard routine on a very slow scan rate (method 1). We compare the obtained values to values obtained by other frequently reported routines (method 2 and 3).

Method 1: measured from 1 V to -0.3 V (reverse scan), in 5 mV increments every 1.2 s.

Method 2: measured from 1.2 V to -0.2V (reverse scan), in 4 mV increments every 0.2 s.

Method 3: measured between -0.2 V and 1.0 V, both in forward and reverse direction, in 20 mV increments every 1.0 s.

For maximum power point (MPP) tracking we employed a perturb and observe algorithm, which adjust the applied voltage in order to reach the maximum power point. The starting voltage is set to be 0.1 V. The plateau of MPP can be considered as a lower efficiency boundary. The applied algorithm did not return stable plateau values for all samples.

For power measurements at fixed voltage (P at $V_{mpp,0}$), V_{mpp} was determined and the output power at this voltage was tracked during the measurement. Cell parameters following the different measurement routines are summarized in Table S1 for 4 different cells.

The fully slot die coated cell (Fully SC) here shows the lowest performance. This is not a systematic effect, but we had randomly selected the cells where all different measurement routines were applied.

Table S1: Summary of device measurement data.

Device			V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	Efficiency (%)
3 layers SC	method 1	rev	0.88	19.9	60.3	10.6
	method 2	rev	0.89	22.3	59.2	11.8
	method 3	rev	0.87	19.7	59.9	10.3
		fwd	0.87	17.9	47.0	7.4
	MPP tracking					7.0
	P at $V_{mpp,0}$					9.5 @ 0.6V
3 layers SC	method 1	rev	0.94	19.9	63.9	11.9
	method 2	rev	0.91	23.1	58.1	12.4 / 12.3 @ 0.61V
	method 3	rev	0.84	19.3	64.2	10.3
		fwd	0.86	17.4	48.4	7.6
	MPP tracking					7.2
	P at $V_{mpp,0}$					9.5 @ 0.6V

Fully SC	method 1	rev	0.86	17	63.6	9.4
	method 2	rev	0.83	22	53.7	9.9 / 10.4 @ 0.55V
	method 3	Rev	0.84	19.3	54	7.4
		Fwd	0.85	14.2	42.5	5.1
	MPP tracking					5.9
	P at $V_{mpp,0}$					6.5 @ 0.6V

Co-fired	method 1	rev	0.96	19.5	65.7	11.65
	method 2	rev				
	method 3	rev	0.86	18.2	64.9	10.1
		fwd	0.87	17.2	50.1	7.5
	MPP tracking					7.5
	P at $V_{mpp,0}$					9.2 @ 0.6V

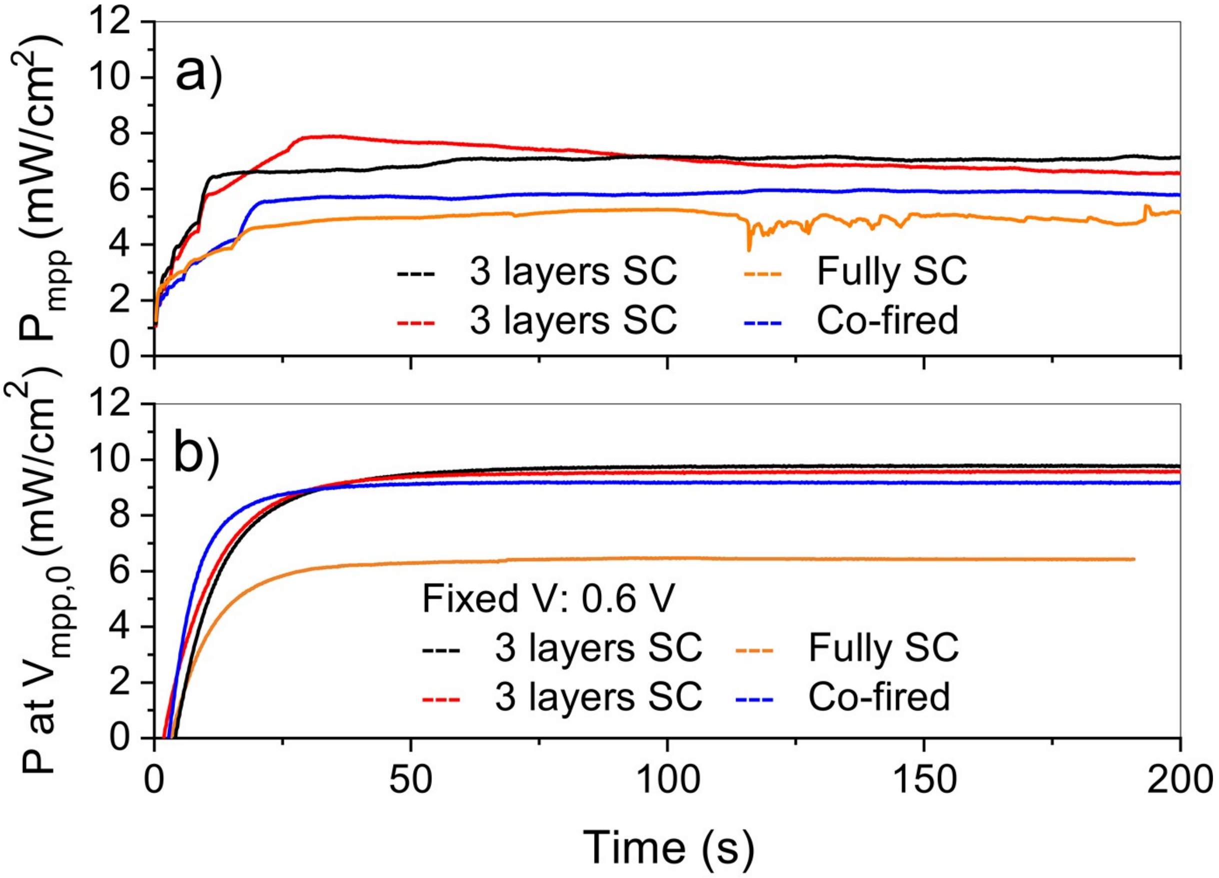

Figure S4: (a) Maximum power point tracking of slot die coated devices shows fluctuation with time. (b) Power measurement at voltage fixed at $V_{mpp,0}$.

Cell arrangement and printing geometry

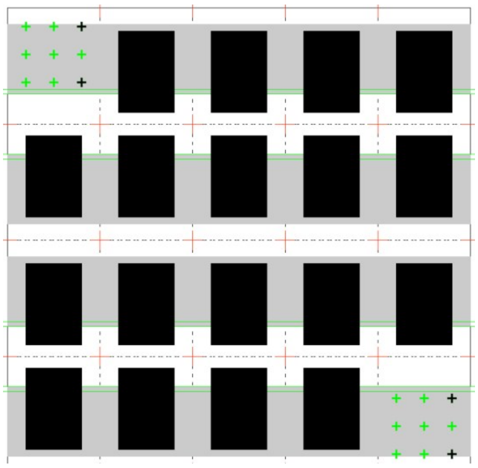

Figure S5: Layout of the 10 × 10 cm device with 18 individual cells with all oxides slot die coated (grey) and carbon screen printed (black). The P1 laser scribing is indicated by a green line.

Determination of surface tension and wetting envelope

The surface tension of the developed inks for each layer i.e. $cTiO_2$, $mTiO_2$, $mZrO_2$ and carbon are shown below. The images were taken using the DSA-drop shape analyzer camera. The surface tension is determined from a fit to the drop shape. The images are calibrated using the software and by referencing through the diameter of the needle being used for the measurement.

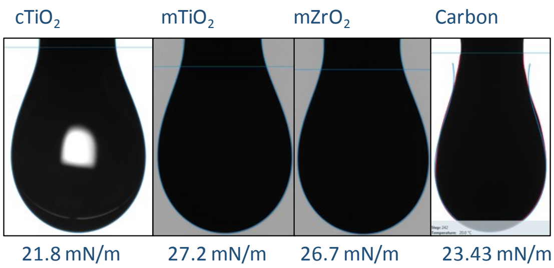

Figure S6: Surface tension of the developed inks using pendent drop method. In table 1, the average of a number of these measurements is summarized.

Table S2: Polar and disperse part of the surface energy of solvents being used in the developed inks.

Solvent	Polar component (mN/m)	Disperse component (mN/m)
Ethanol	8.8	15.8
Isopropanol	6.1	15.8
Tetralin	2	19.6
Terpineol	3.6	17.1