Perovskite solar cells with solvent-free laminated top electrode

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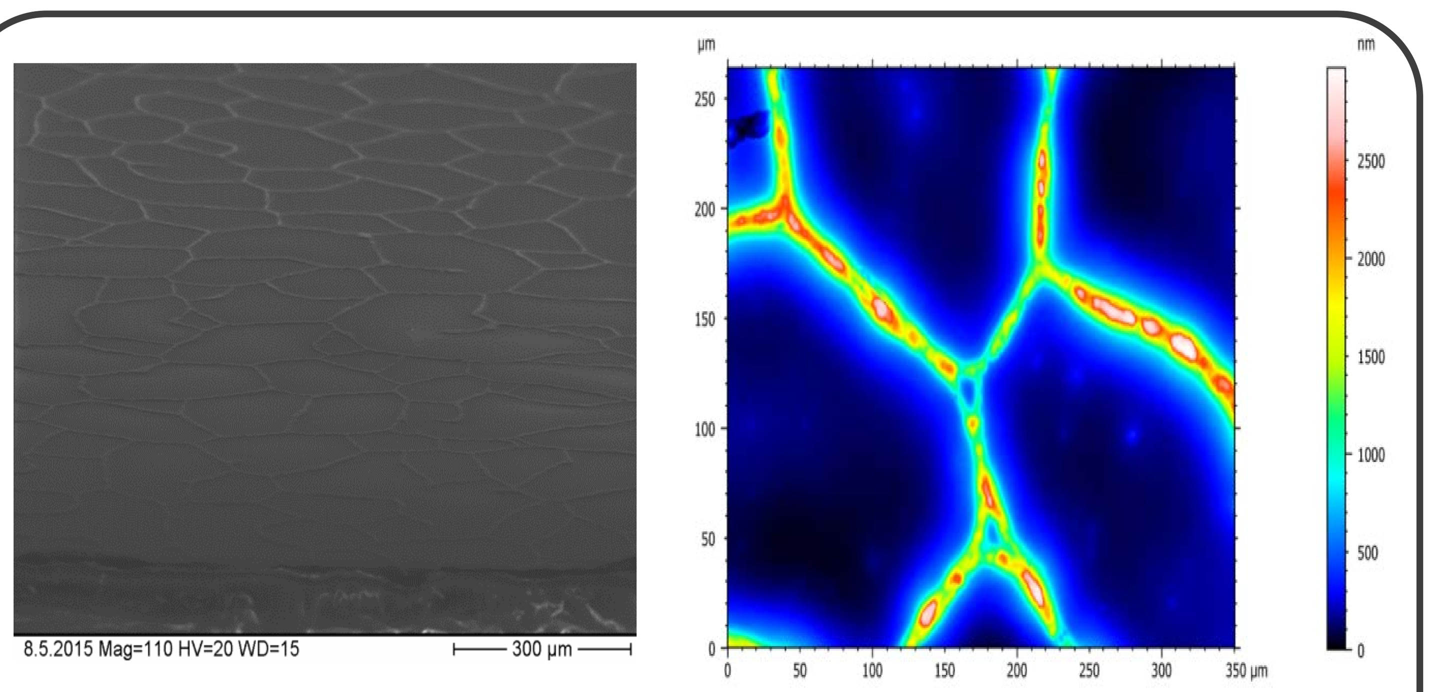
Introduction

Perovskite solar cells (PSCs) are attracting interest in research and industrial laboratories due to their potential as high-performing devices for solar energy conversion.[1,2] Similar to organic solar cells, PSCs can be fabricated from solution processing, which is attractive to deliver a low-cost technology. One issue, however, relates to the charge collection at the counter electrode. In many cases, this is achieved by evaporation of an opaque gold metallic contact on the active material. Gold makes an ohmic contact but it limits the potential for low-cost and high-volume processing.

In addition, gold prevents PSCs to be used in semitransparent applications. Several alternatives to gold as the charge-collecting top contact have been reported.[3,4,5] These include, for example, solution-processed silver nanowires such as laminated carbon nanotube networks or graphene.

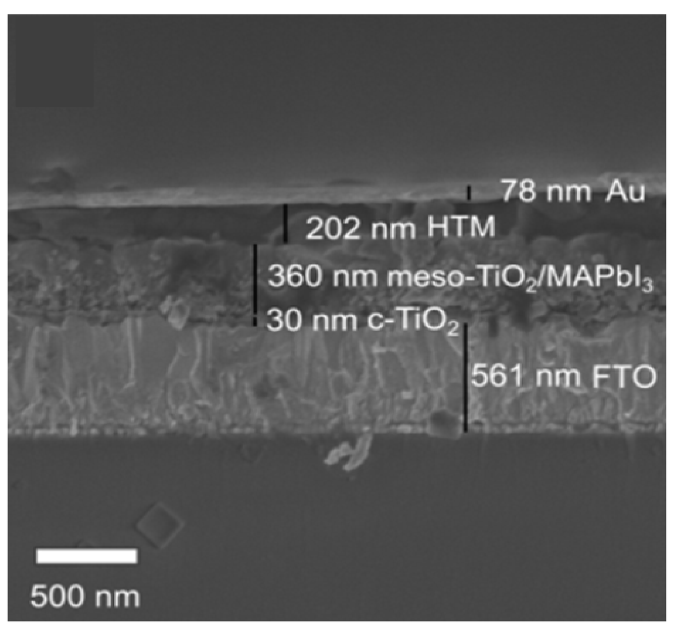
1) W. S. Yang et al., Science 2015, 348, 1234-1237; 2) S. D. Stranks, H. J. Snaith, Nature Nanotech. 2015, 10, 391-402; 3) F. Guo et al., Nanoscale 2015, 7, 1642-1649; 4) Z. Li et al., ACS Nano 2014, 8, 6797-6804; 5) P. You et al., Adv. Mater. 2015, 27, 3632-3638.

Device fabrication

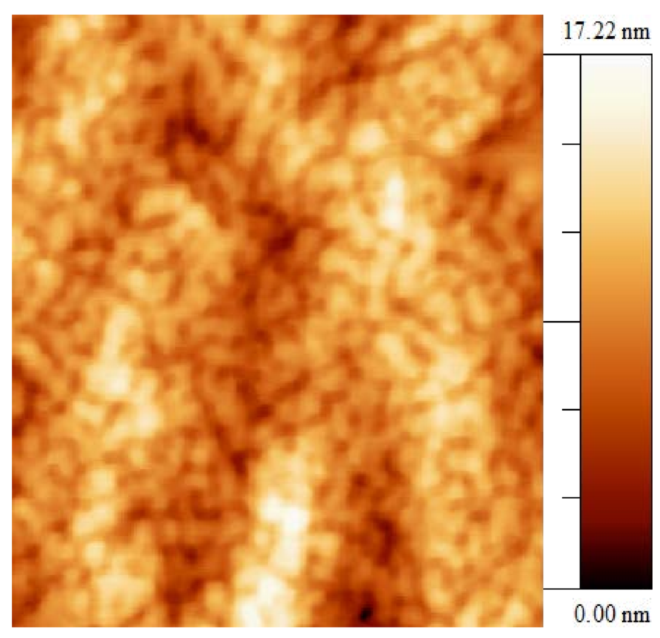


SEM and Optical microscope image of the commercial substrate (random mesh-like silver on PET)

Geometrical open area of ~90%, sheet resistance of ~13 Ω/sq, metal linewidths are ~4-12 µm with thicknesses ~0.7-1.3 µm.



Cross-sectional SEM image of the perovskite solar cell

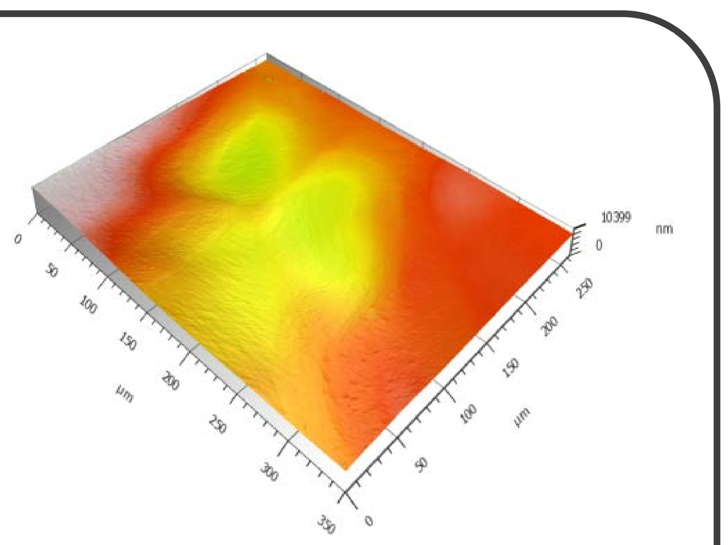


AFM topography of the surface of Spiro-OMeTAD coated on the perovskite layer.

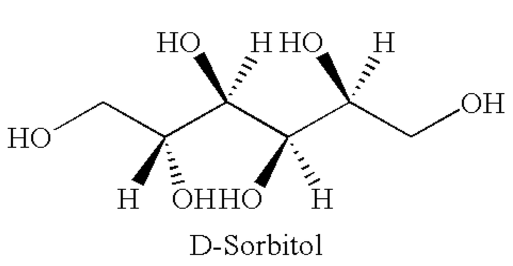
The perovskite layer was prepared by coating a mixture of PbI_2 and MAI in DMSO and adding chlorobenzene at the end of the spin-coating process. The roughness of the perovskite/Spiro-OMeTAD bilayer was 2.3 nm.

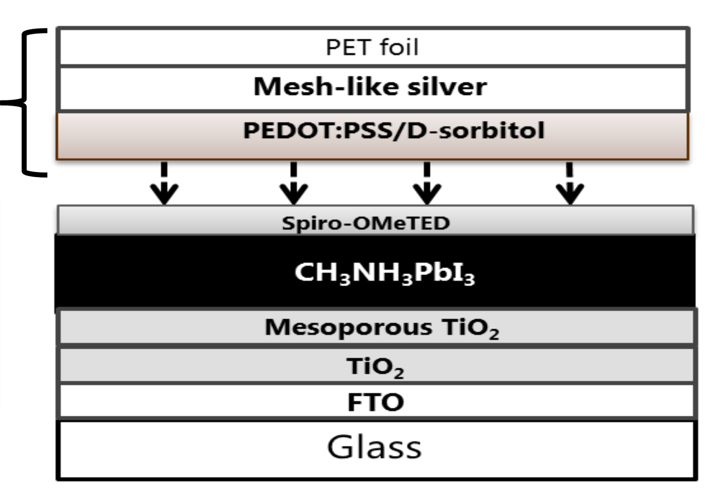
The substrate was coated with highly conductive PEDOT:PSS dispersions containing 0-~30% by weight, of sorbitol to:

1- Smoothen and planarize the metal network;
2- Collect and transport holes;
3-Promote adhesion to the HTM layer.



Substrate coated with PEDOT:PSS/D-sorbitol

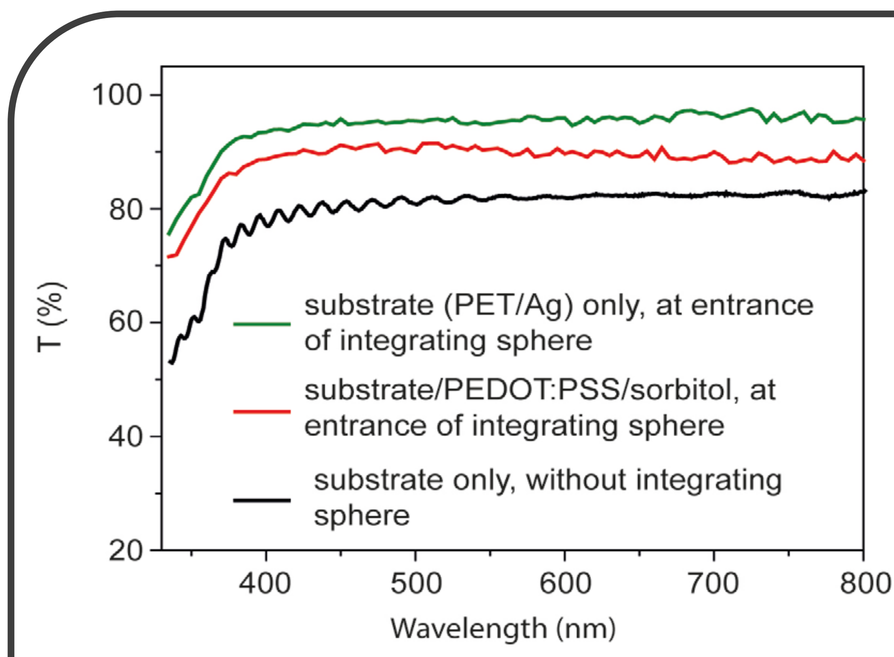




Electrodes were pre-annealed at 120°C/10min and laminated directly onto the Spiro-OMeTAD layer.

Schematic structure of cells with laminated top electrodes

Results



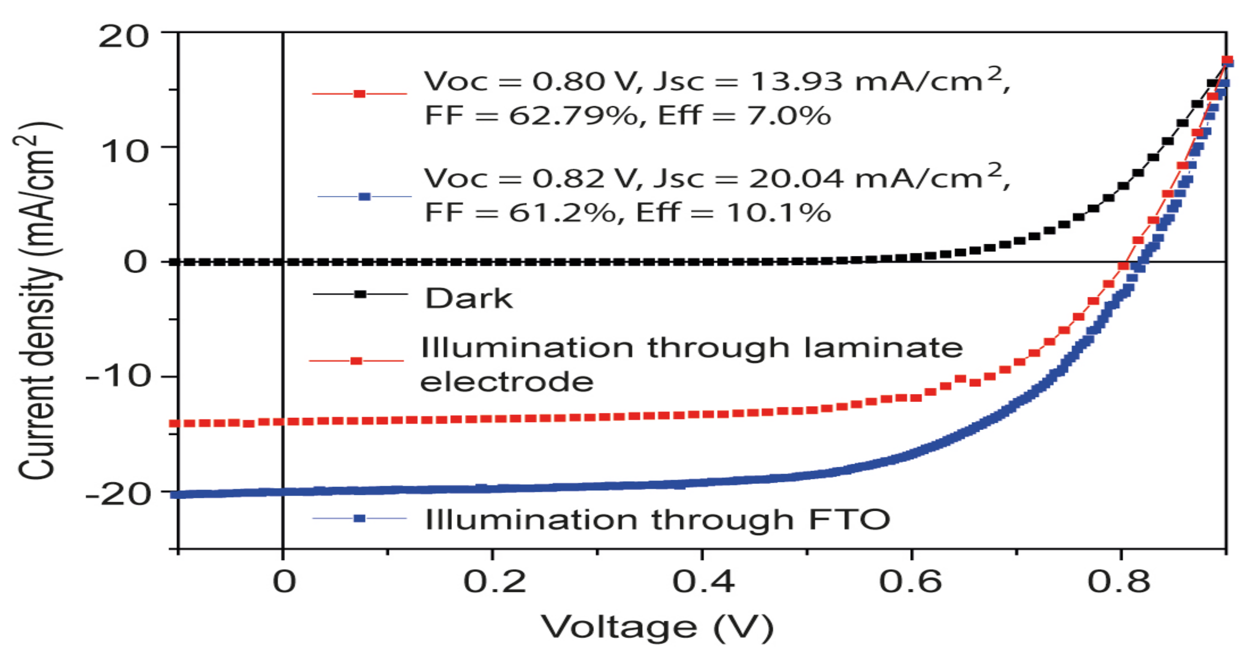
Transmission spectra of the electrode substrate and the laminate electrode

- Above 450 nm, 12% of light scattered (95% of light is transmitted within an aperture angle of ± 4°).
- ~3.6% of light is reflected by the metal mesh.
- Full transmission of the substrate/adhesive glue is ~85% (low weight fraction of PEDOT:PSS).

Solar cell performance parameters

	Evaporated electrode		Laminated electrode		
	Reverse Scan (26)	Forward Scan (7)	FTO illum., reverse scan (26)	Laminate illum., reverse scan (9)	FTO illum., forward scan (5)
Voc (V)	0.91±0.06	0.91±0.03	0.86±0.05	0.80±0.01	0.84±0.07
Jsc (mA/cm²)	17.06±2.00	16.95±2.15	15.69±2.69	13.65±0.44	12.19±2.79
FF (%)	65.5±4.4	58.4±8.3	63.7±6.3	60.5±5.4	60.2±2.2
Eff (%)	10.2±1.8	9.0±1.5	8.6±1.0	6.6±0.6	6.2±0.6

- The higher Jsc and Voc of PSCs with a gold top electrode is due to reflection by the Au electrode and lowered work function of doped PEDOT:PSS.
- When measuring the current over time for cells at their maximum power points, currents stabilized after ~10 sec and the corresponding stabilized average efficiency was (7.6 ± 1.1)%.
- Because of the hygroscopic nature of PEDOT:PSS, storing cells with laminated electrodes in ambient air for 7 days induced a substantial performance decrease of ~20%.



JV-scans and for the best-performing cell

Jsc was higher when illuminating through FTO due to:
- Absorption of Spiro-OMeTAD in the ultraviolet region;
- Overall charge generation and extraction efficiency;
- Efficient charge collection in proximity to TiO_2, in contrast to the HTM.

Conclusion

- For solution-processed PSCs, lamination of the top electrode provides a low-cost and roll-to-roll compatible alternative to a gold evaporated contact;
- The concept is applicable to other conductive substrates (e.g. integrated barrier properties against water and oxygen ingress);
- Flexible and semitransparent devices can be made.

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