

Electronic Supplementary Information

Compact TiO₂ Films with Sandwiched Ag Nanoparticles as Electron-Collecting Layer in Planar Type Perovskites Solar Cells: Improvement in Efficiency and Stability

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Preparation of ETL Layer by Spinning Process

A three-stage spinning procedure was adopted for both c-TiO₂ layer and AgNO₃ layer in that the spin rate was programed such that first spinning at 800 rpm for 10 s, followed by spinning at 1000 rpm for 10 s and then 2000 rpm for 40 s.¹

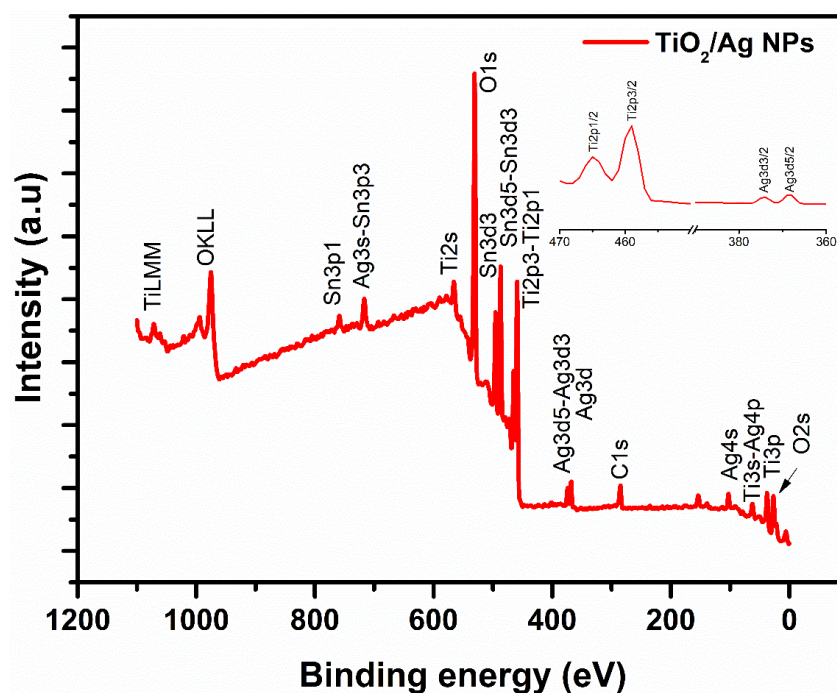


Fig. S1 XPS spectra of c-TiO₂/Ag NPs on FTO substrate. The inset shows the binding energies of Ag 3d_{5/2} and 3d_{3/2} at 368.0 and 374.1 eV respectively

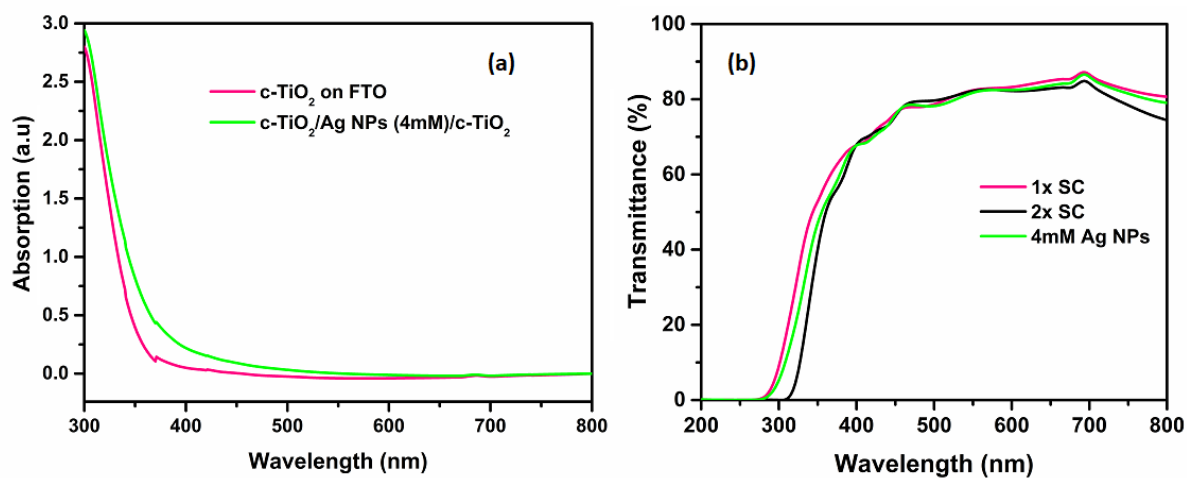


Fig. S2 UV-Vis absorption spectra of pristine c-TiO₂ and c-TiO₂/Ag NPs (4mM)/c-TiO₂ on FTO substrate (a), optical transmittance spectra for 1x SC, 2x SC and 4mM Ag NPs ETLs (b)

Table S1 Reverse and forward photovoltaic performance parameters of planar PSCs prepared on different electron transporting layers (ETLs)

ETL	Sweep Direction	Voc (V)	Jsc (mAcm ⁻²)	FF (%)	PCE(%)	Hysteresis Index
1X SC	R	0.98	18.47	68.20	12.35	0.571
	FW	0.89	15.88	41.06	5.80	
2X SC	R	0.98	21.95	70.51	15.17	0.125
	FW	0.98	21.62	68.87	14.59	
4mM	R	1.01	23.36	73.11	17.25	0.013
	FW	1.00	23.30	71.96	16.77	
12mM	R	0.99	22.52	71.41	15.92	0.045
	FW	1.00	23.26	66.13	15.38	
20mM	R	1.00	22.62	67.44	15.26	0.050
	FW	0.98	21.46	71.44	15.02	

$$\text{Hysteresis index} = \frac{J_{RS}(0.8V_{oc}) - J_{FS}(0.8V_{oc})}{J_{RS}(0.8V_{oc})}$$

Hysteresis calculation

The hysteresis index is calculated from the J-V curve. Reverse and forward J_{sc} were taken at 0.8V_{oc} in calculation.²

R_{sh} and R_s measurements

Shunting resistance (R_{sh}) is a measure of resistance to current loss, but series resistance (R_s) is a resistance to current flow. In this study we calculated R_{sh} and R_s by using slope method from the J-V curve of the devices near to the values of J_{sc} and V_{oc} respectively.³

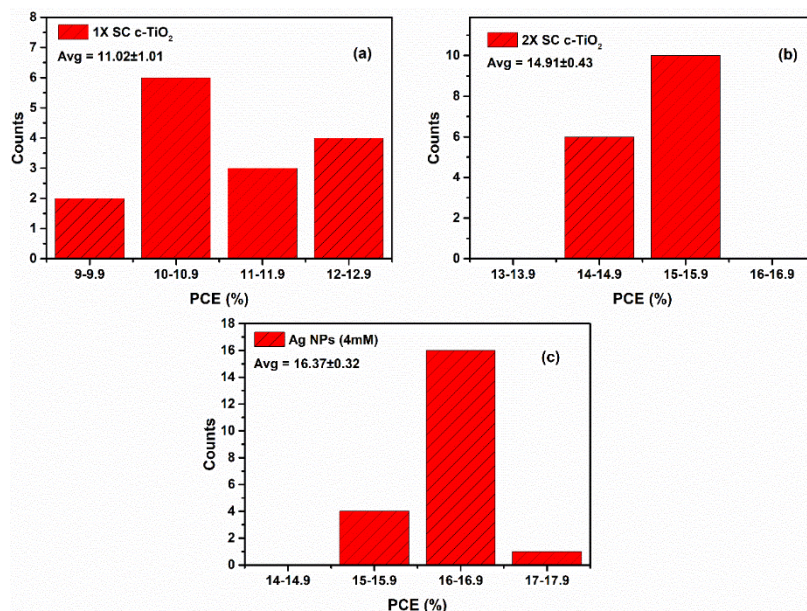


Fig. S3 Histogram comparison of PCE of devices prepared using 1X SC, 2X SC and 2XSC Ag NPs (4mM) ETLs

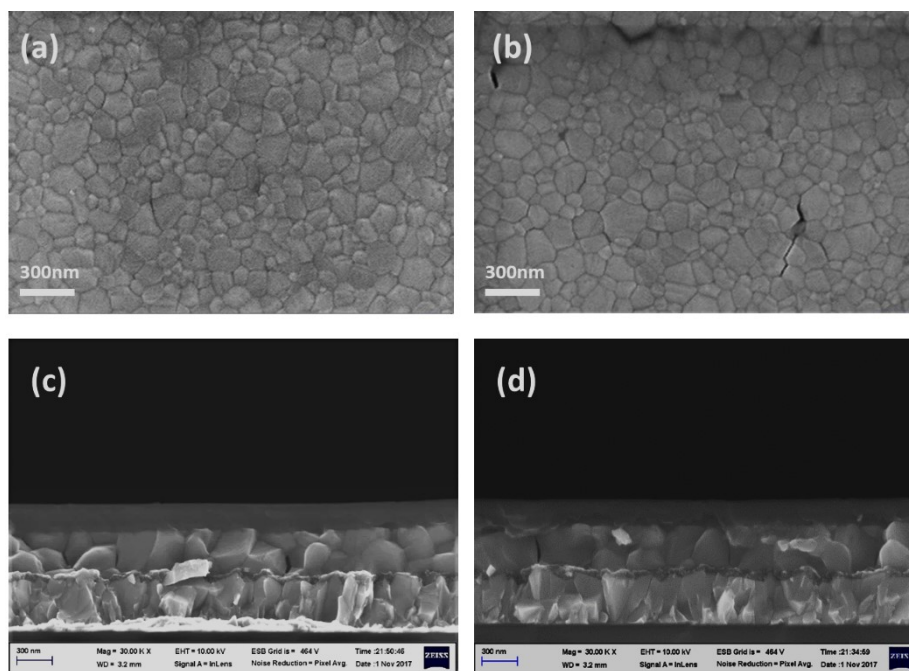


Fig. S4 Top-view SEM images of perovskite films on (a) 2XSC Ag NPs (12mM) and (b) 2XSC Ag NPs (20mM) TiO₂ surface, cross-section images of (c) FTO/1X SC/perovskite/Spiro-OMeTAD/Ag and (d) FTO/2X SC/perovskite/Spiro-OMeTAD/Ag

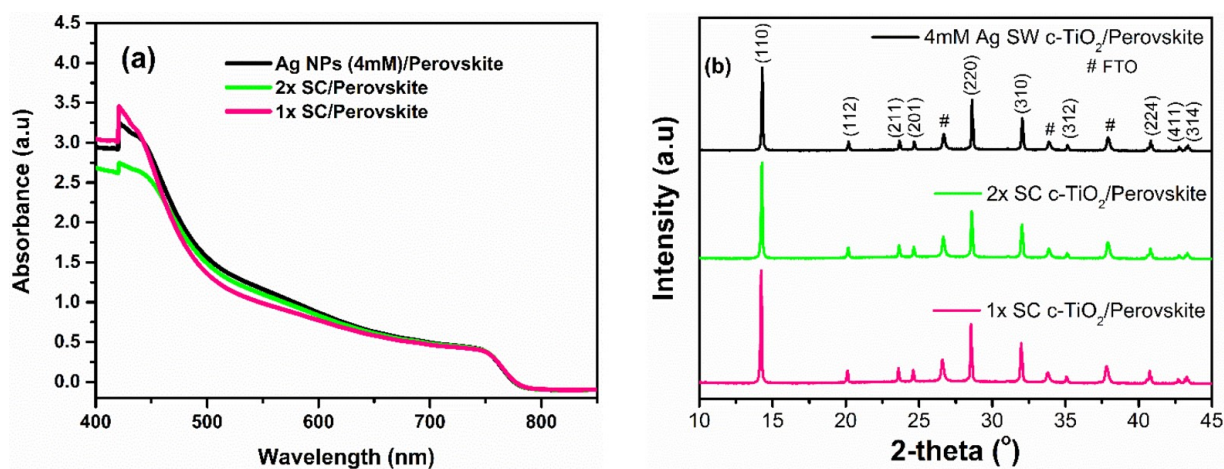


Fig. S5 (a) UV-Vis absorption spectra of perovskite film and (b) Powder XRD of perovskite film prepared on 1X SC, 2X SC and Ag₂XSC NPs (4mM) ETL

Table S2 Standard deviation of photovoltaic parameters for pristine (1X SC ETL)-based planar perovskite solar cells.

Device No.	Voc (V)	Jsc (mAcm ⁻²)	FF (%)	PCE (%)
1	0.94	16.16	66.96	10.17
2	0.94	16.68	66.59	10.44
3	0.99	14.05	67.91	9.44
4	0.94	16.19	68.49	10.42
5	0.95	17.97	66.72	11.7
6	0.98	18.47	68.2	12.35
7	0.96	15.05	71.54	10.33
8	0.95	18.73	67.92	12.08
9	0.95	17.81	72.66	12.29
10	0.94	17.35	71.37	11.64
11	0.93	17.50	72.04	11.73
12	0.94	17.30	73.86	12.01
13	0.95	17.14	66.09	10.76
14	0.97	14.63	65.93	9.35
15	0.96	16.42	67.22	10.59
Average	0.95±0.02	16.76±1.37	68.90±2.64	11.02±1.01

Table S3 Standard deviation of photovoltaic parameters for 2X SC ETL-based planar perovskite solar cells.

Device No.	Voc (V)	Jsc (mAcm ⁻²)	FF (%)	PCE (%)
1	1.00	21.70	69.66	15.12
2	1.00	21.57	70.7	15.25
3	1.00	22.49	68.00	15.30
4	0.98	21.36	67.73	14.18
5	0.98	21.23	70.06	14.58
6	0.98	21.95	70.51	15.17
7	0.99	21.64	70.29	15.06
8	0.98	21.67	71.44	15.18
9	0.98	21.59	71.84	15.20
10	0.99	21.67	67.12	14.40
11	0.99	22.83	67.56	15.27
12	0.98	21.36	67.56	14.15
13	0.99	22.07	69.64	15.22
14	0.98	21.45	69.49	14.61
15	0.98	21.34	69.4	14.52
16	0.99	22.77	68.33	15.40
Average	0.99±0.01	21.79±0.50	69.33±1.46	14.91±0.43

Table S4 Standard deviation of photovoltaic parameters for Ag NPs (4mM)-embedded ETL-based planar perovskite solar cells.

Device No.	Voc (V)	Jsc (mAcm ⁻²)	FF (%)	PCE (%)
1	1.00	22.57	71.47	16.13
2	0.99	22.47	73.05	16.25
3	0.99	22.35	73.54	16.27
4	0.99	22.4	74.32	16.48
5	0.99	22.38	72.16	15.99
6	1.01	22.72	70.09	16.08
7	1.01	23.42	68.92	16.30
8	1.01	23.35	69.8	16.46
9	1.01	23.36	73.11	17.25
10	1.00	23.35	70.41	16.44
11	1.00	23.21	70.95	16.47
12	1.01	22.71	72.42	16.61
13	0.99	22.50	73.8	16.44
14	1.00	23.17	68.5	15.87
15	1.00	22.79	70.00	15.95
16	1.00	23.22	68.84	15.98
17	0.98	23.29	72.46	16.54
18	1.01	23.32	69.16	16.29
19	1.01	22.6	72.59	16.57
20	1.01	22.65	73.05	16.71
21	1.01	23.33	70.78	16.67
Average	1.00±0.01	22.91±0.39	71.40±1.81	16.37±0.32

Table S5 Standard deviation of photovoltaic parameters for Ag NPs (12mM)-embedded ETL-based planar perovskite solar cells

Device No.	Voc (V)	Jsc (mAcm ⁻²)	FF (%)	PCE (%)
1	0.99	22.63	68.05	15.24
2	1.00	22.46	65.50	14.71
3	0.99	22.52	71.41	15.92
4	0.98	22.77	67.37	15.03
5	1.00	21.32	70.20	14.96
6	1.00	23.15	67.43	15.61
7	1.00	22.68	66.84	15.16
8	0.97	21.21	69.61	14.32
9	1.00	22.48	66.11	14.86
10	0.99	22.31	65.29	14.42
11	0.99	23.49	66.25	15.41
12	1.00	22.52	67.54	15.21
13	0.97	22.11	67.91	14.56
14	1.00	22.30	67.35	15.01
15	0.97	22.06	70.53	15.09
Average	0.99±0.01	22.40±0.59	67.83±1.85	15.03±0.43

Table S6 Standard deviation of photovoltaic parameters for Ag NPs (20mM)-embedded ETL-based planar perovskite solar cells

Device No.	Voc (V)	Jsc (mAcm ⁻²)	FF (%)	PCE (%)
1	0.97	22.18	68.91	14.83
2	0.99	20.99	71.88	14.94
3	0.98	19.86	69.97	13.62
4	0.99	21.75	64.27	13.84
5	0.99	21.71	64.78	13.92
6	1.00	21.16	70.96	15.02
7	0.98	19.78	71.07	13.78
8	0.97	22.45	68.55	14.93
9	0.98	19.90	68.04	13.27
10	1.01	20.55	67.82	14.08
11	0.99	19.90	66.78	13.16
12	1.00	20.90	71.57	14.95
13	1.00	22.62	67.44	15.26
14	0.98	19.80	70.76	13.73
15	0.99	21.35	65.82	13.91
16	0.99	22.66	65.01	14.58
Average	0.99±0.01	21.09±1.06	67.38±2.54	14.23±0.68

Notes and references

- 1 N. Ahn, D.-Y. Son, I.-H. Jang, S. M. Kang, M. Choi and N.-G. Park, *J. Am. Chem. Soc.*, 2015, **137**, 8696.
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- 3 H.-K. Lin, Y.-W. Su, H.-C. Chen, Y.-J. Huang and K.-H. Wei, *ACS Appl. Mater. Interfaces*, 2016, **8**, 24603.