Electronic Supplementary Information

Performance enhancement of solution processed perovskite solar cells incorporating functionalized silica nanoparticles

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This paper is a follow-up to our recent communication: *"A One-Step Low Temperature Processing Route for Organolead Halide Perovskite Solar Cells"*, where we described the effects of incorporating Al_2O_3 nanoparticles into perovskite solar cell precursor solutions. In this new work we have replaced the alumina with functionalized silica (*f*-SiO_2) nanoparticles. We show performance enhancements in the planar heterojunction organolead halide perovskite solar cells incorporating *f*-SiO_2 nanoparticles and that the performance arises from the *f*-SiO_2 favourably modifying perovskite crystallization and by passivation of the compact titania layer inside pinholes formed in the perovskite layer. This ESI includes data not shown in this paper submission.

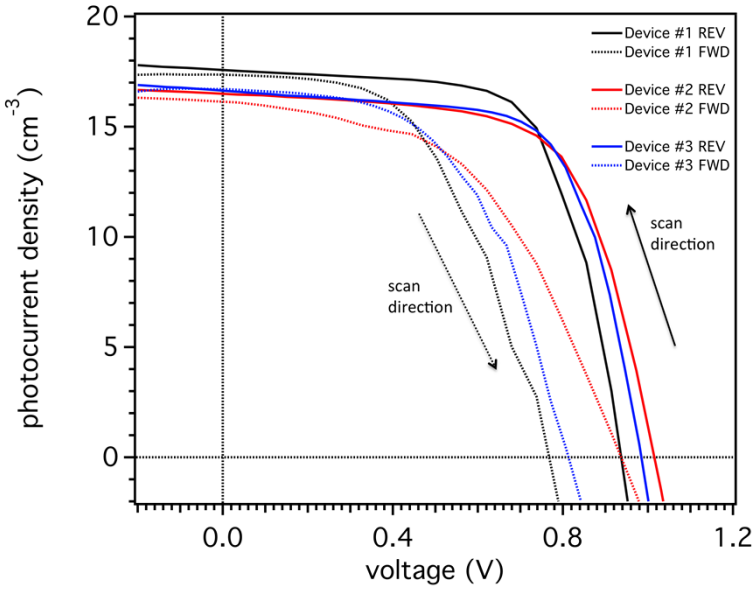

Fig S1. Examples of the hysteresis observed in some of the solar cells measured in this study. The reverse scan is shown as the solid line.The scan forward scan is shown as the dashed line.

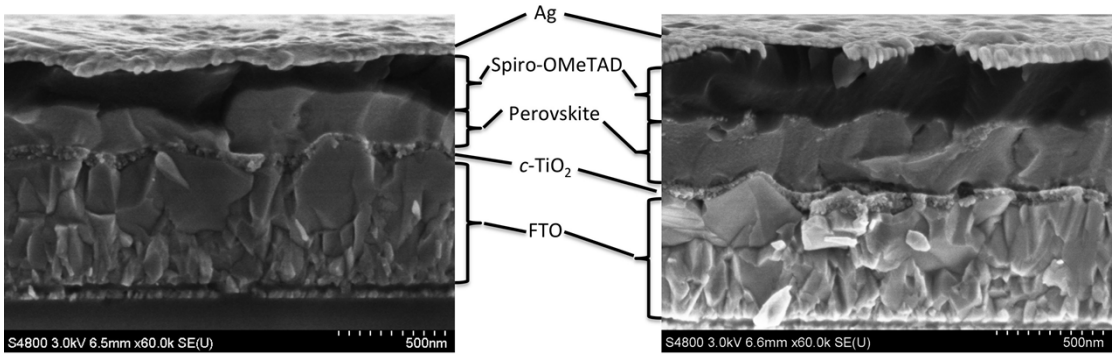

Fig S2. Cross-sectional SEM images of a 0 wt. % *f*-SiO_2 device (left) and a 1 wt. % *f*-SiO_2 device (right)

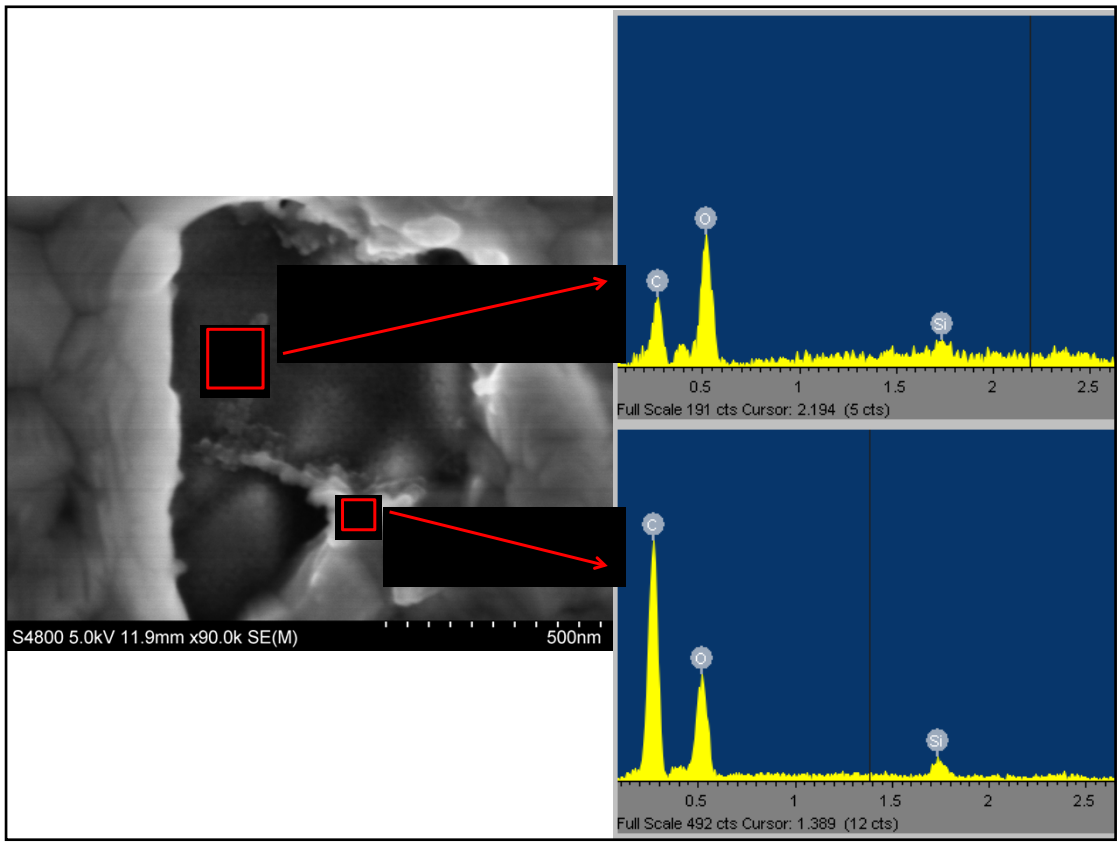

Fig S3. SEM image of a pinhole void, showing energy-dispersive X-ray spectroscopy (EDS) of two areas within the void. The upper analytical section shows an area deep within the void. The lower analytical area shows a build up of nanoparticles at the edge of the void. Both areas show a strong Si EDS signal.

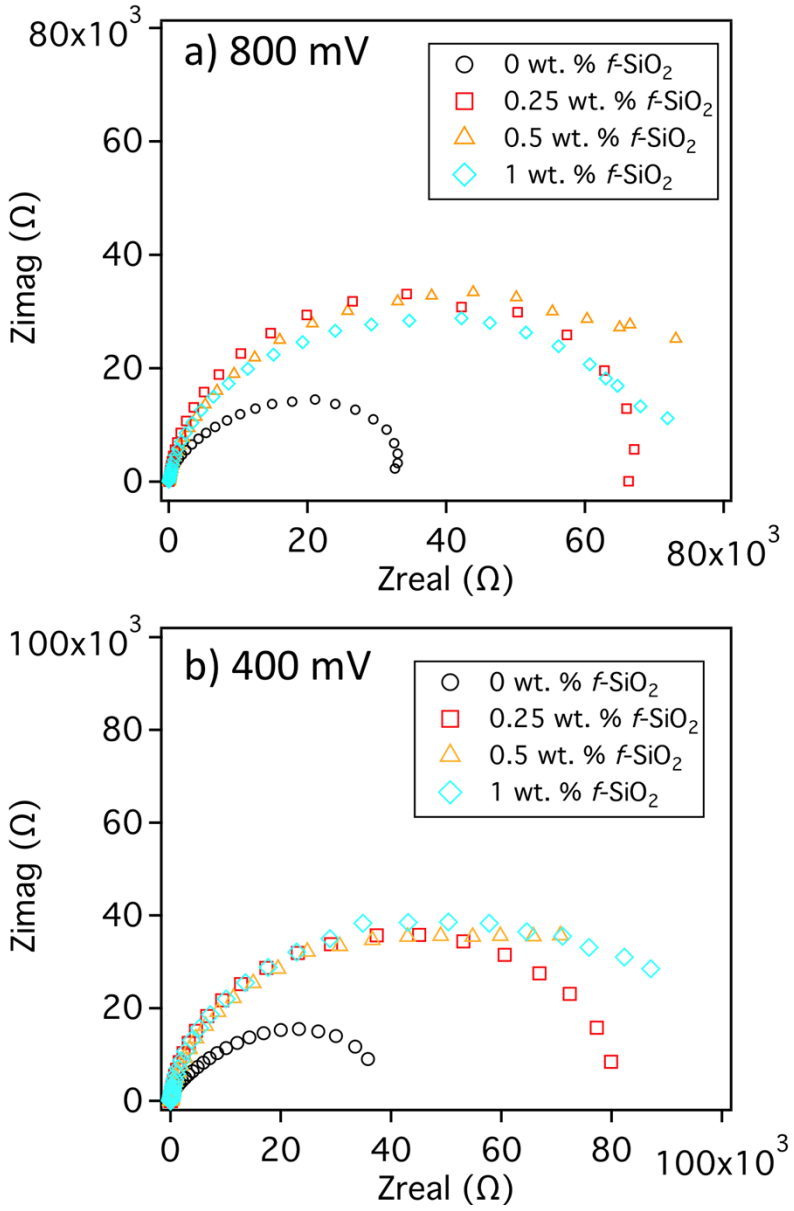

Fig S4. Nyquist plots measured in the dark and at an applied bias of a) 800 mV and b) 400 mV of the devices shown. The data here seems to support the transient decay data in Fig 6. The resistance of the main arc increases when 0.25 wt. % *f*-SiO_2 is present in the precursor solution and no significant improvement is observed upon further wt. % increases.

Table S1. IV data for all devices measured and summarised in Fig. 2

Table S1(a). Devices made with 0 wt. % *f*-SiO_2 nanoparticles

Device No	V_{OC} (V)	Fill factor	J_{SC} (mA cm^{-2})	PCE (%)
1	0.946	69.7	15.94	10.51
2	0.949	69.5	15.93	10.50
3	0.936	70.1	15.59	10.23
4	0.917	71.4	15.20	9.94
5	0.934	66.7	15.56	9.70
6	0.946	65.0	15.70	9.65
7	0.913	71.0	14.71	9.53
8	0.867	64.5	16.53	9.24
9	0.888	66.2	15.64	9.19
10	0.891	63.7	16.11	9.13
11	0.886	65.1	15.58	8.98
12	0.907	69.9	14.14	8.97
13	0.919	60.8	15.98	8.92
14	0.877	64.1	15.78	8.87
15	0.856	57.7	17.84	8.82
16	0.885	65.4	14.92	8.63
17	0.900	59.8	15.81	8.51
18	0.877	62.8	15.21	8.38
Mean	**0.905**	**65.7**	**15.68**	**9.32**
Std. deviation	**0.029**	**4.0**	**0.77**	**0.65**

Table S1(b). Devices made with 0.25 wt. % *f*-SiO_2 nanoparticles

Device No	V_{OC} (V)	Fill factor	J_{SC} (mA cm^{-2})	PCE (%)
1	0.936	67.3	17.88	11.26
2	0.921	69.7	16.98	10.89
3	0.936	67.5	17.11	10.81
4	0.947	68.3	16.61	10.74
5	0.949	68.3	16.42	10.64
6	0.918	68.1	16.82	10.51
7	0.934	68.8	16.31	10.47
8	0.939	68.5	16.07	10.34
9	0.914	65.6	17.14	10.29
10	0.919	66.2	16.08	9.77
11	0.947	64.3	15.84	9.65
12	0.919	64.1	16.17	9.52
13	0.924	67.7	15.10	9.44
14	0.918	64.8	15.63	9.31
15	0.886	64.2	15.24	8.68
16	0.873	62.5	15.79	8.61
17	0.885	60.0	16.14	8.57
18	0.913	62.9	14.64	8.40
Mean	**0.921**	**66.0**	**16.22**	**9.88**
Std. deviation	**0.022**	**2.6**	**0.80**	**0.90**

Table S1(c). Devices made with 0.5 wt. % *f*-SiO_2 nanoparticles

Device No	V_{OC} (V)	Fill factor	J_{SC} (mA cm^{-2})	PCE (%)
1	0.971	70.1	17.46	11.88
2	0.952	71.8	17.19	11.75
3	0.991	72.2	16.09	11.52
4	0.949	69.4	17.40	11.46
5	0.960	70.6	16.77	11.36
6	0.977	71.2	16.22	11.28
7	0.955	71.8	16.40	11.25
8	0.946	70.5	16.82	11.21
9	0.954	68.3	16.89	11.01
10	0.955	71.2	16.15	10.98
11	0.942	70.2	16.42	10.86
12	0.937	69.0	16.76	10.84
13	0.939	69.1	16.48	10.70
14	0.955	70.3	15.77	10.59
15	0.936	68.7	16.03	10.31
16	0.940	69.3	15.80	10.29
17	0.953	65.0	16.56	10.26
18	0.954	56.9	18.68	10.15
Mean	**0.954**	**69.2**	**16.66**	**10.98**
Std. deviation	**0.014**	**3.5**	**0.71**	**0.53**

Table S1(d). Devices made with 0.75 wt. % *f*-SiO_2 nanoparticles

Device No	V_{OC} (V)	Fill factor	J_{SC} (mA cm^{-2})	PCE (%)
1	0.996	68.6	18.17	12.42
2	1.007	68.7	17.79	12.30
3	0.987	70.3	17.19	11.93
4	0.969	71.7	16.41	11.40
5	0.961	68.8	17.19	11.36
6	0.959	65.5	17.83	11.20
7	0.966	68.6	16.78	11.13
8	0.932	69.2	17.19	11.09
9	0.996	70.3	15.17	10.63
10	0.948	65.7	15.60	9.72
11	0.945	63.9	15.96	9.64
12	0.891	61.4	17.23	9.43
13	0.922	63.2	15.52	9.04
14	0.910	63.6	15.44	8.93
15	0.914	64.5	15.13	8.91
16	0.904	59.2	16.33	8.74
17	0.906	61.2	15.29	8.48
18	0.849	58.5	16.87	8.38
Mean	**0.942**	**65.7**	**16.51**	**10.26**
Std. deviation	**0.042**	**4.0**	**0.99**	**1.37**

Table S1(e). Devices made with 1.0 wt. % *f*-SiO_2 nanoparticles

Device No	V_{OC} (V)	Fill factor	J_{SC} (mA cm^{-2})	PCE (%)
1	0.997	70.4	17.39	12.21
2	0.998	70.8	17.03	12.03
3	0.984	70.4	16.73	11.59
4	0.972	69.8	17.03	11.56
5	0.972	69.8	16.73	11.35
6	0.948	68.2	17.41	11.26
7	0.972	70.9	16.31	11.24
8	0.985	71.5	15.94	11.23
9	0.986	69.2	16.41	11.20
10	0.951	68.4	16.80	10.93
11	0.949	64.2	16.50	10.05
12	0.925	62.6	17.19	9.96
13	0.942	68.0	15.17	9.72
14	0.932	62.9	16.55	9.70
15	0.955	66.4	14.66	9.29
16	0.904	54.4	16.27	8.01
17	0.865	52.8	15.45	7.06
Mean	**0.955**	**66.5**	**16.45**	**10.49**
Std. deviation	**0.035**	**5.6**	**0.77**	**1.41**

Table S1(f). Devices made with 1.25 wt. % *f*-SiO_2 nanoparticles

Device No	V_{OC} (V)	Fill factor	J_{SC} (mA cm^{-2})	PCE (%)
1	0.976	71.1	16.53	11.48
2	0.954	70.8	16.12	10.90
3	0.955	70.0	16.27	10.87
4	0.952	69.5	16.30	10.79
5	0.964	69.7	16.02	10.76
6	0.972	69.7	15.89	10.75
7	0.969	70.2	15.73	10.70
8	0.940	67.3	16.67	10.54
9	0.964	68.3	15.56	10.24
10	0.934	67.9	15.81	10.02
11	0.916	67.6	15.98	9.89
12	0.923	67.0	15.23	9.41
13	0.897	64.4	16.25	9.38
14	0.921	67.7	14.95	9.32
15	0.936	60.5	15.61	8.84
16	0.899	56.5	16.94	8.60
17	0.905	58.1	16.33	8.59
18	0.859	51.5	16.66	7.37
Mean	**0.935**	**66.0**	**16.05**	**9.91**
Std. deviation	**0.032**	**5.6**	**0.52**	**1.07**

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