Supporting Information

In-situ growth of an opal-like TiO₂ electron transport layer by atomic layer deposition for perovskite solar cells

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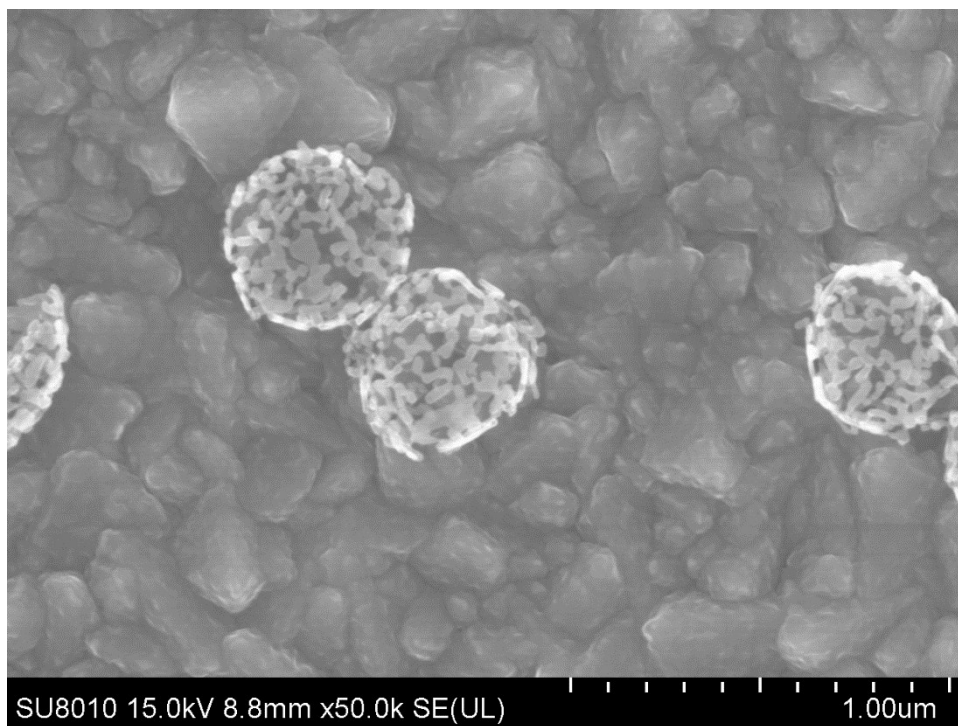Email: luhaoshaobo@163.com, haolu@usts.edu.cn

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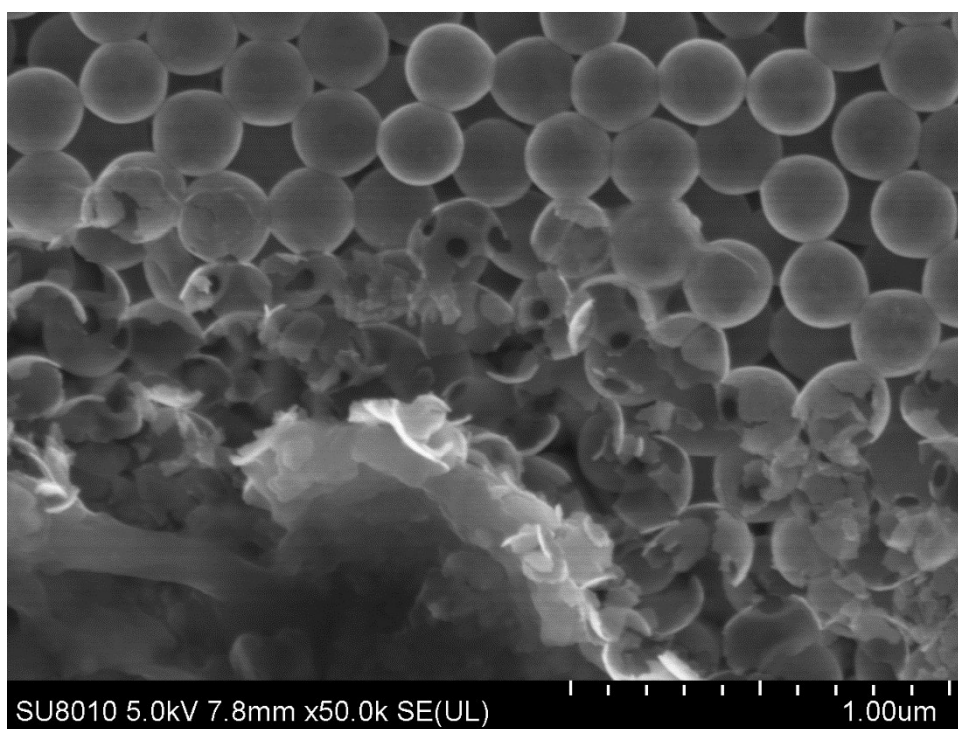**Figure S1**. SEM image of PS spheres after annealing with 5 nm ALD TiO_2 thickness.

SU8010 5.0kV 7.8mm x50.0k SE(UL)   1.00um

Figure S2. SEM image of crushed spheres.
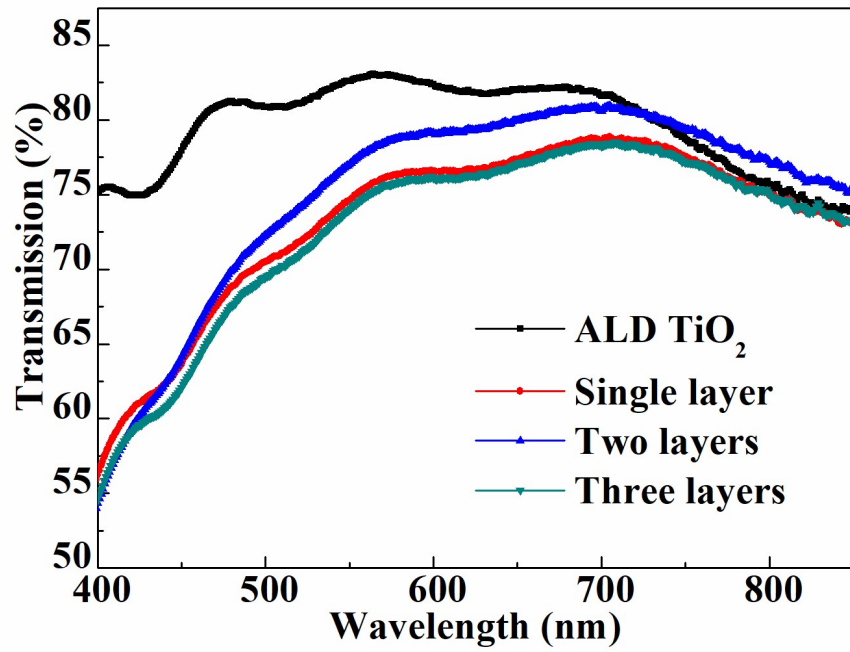
Figure S3. Transmission spectra of different TiO$_2$ ETLs.

SU8010 15.0kV 9.0mm x15.0k SE(UL)   3.00um
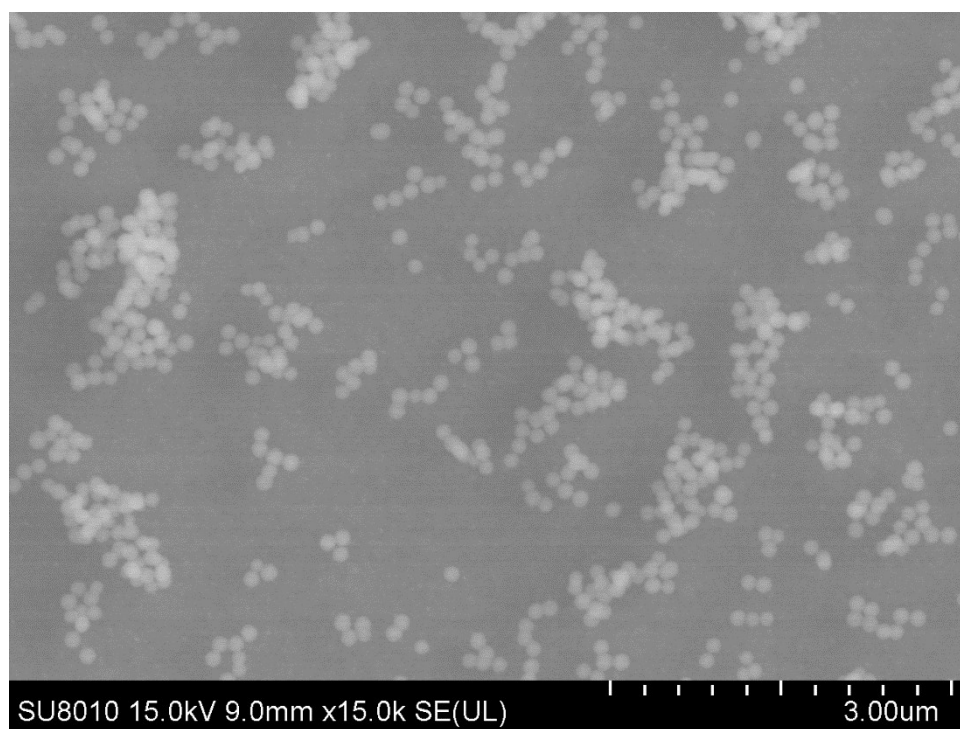
Figure S4. SEM image of 100 nm PS spheres.

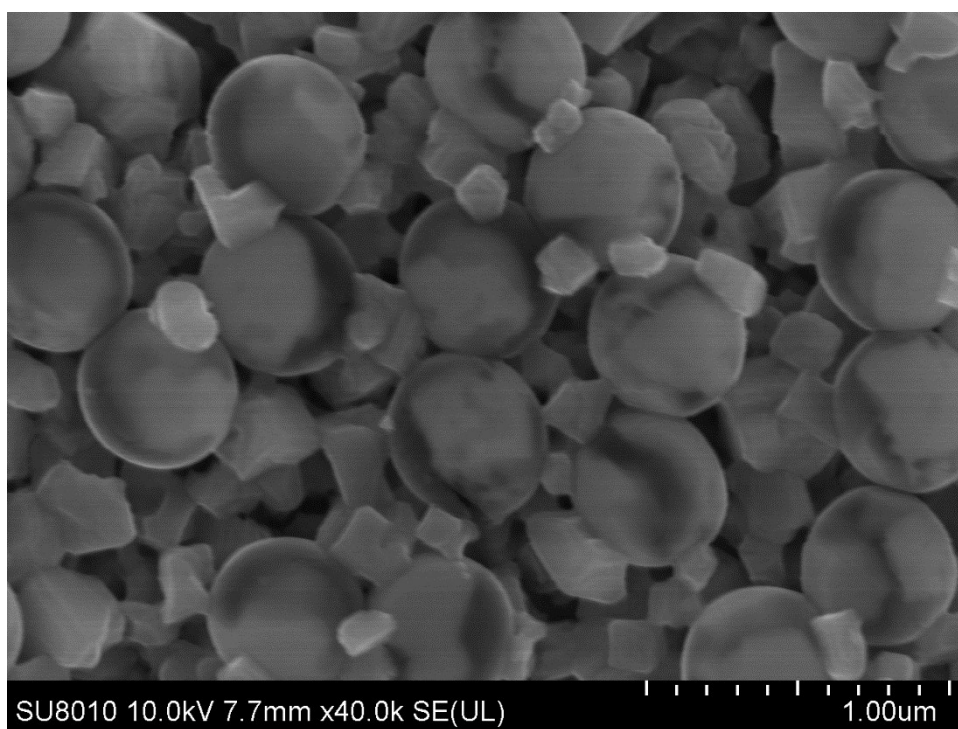SU8010 10.0kV 7.7mm x40.0k SE(UL)   1.00um

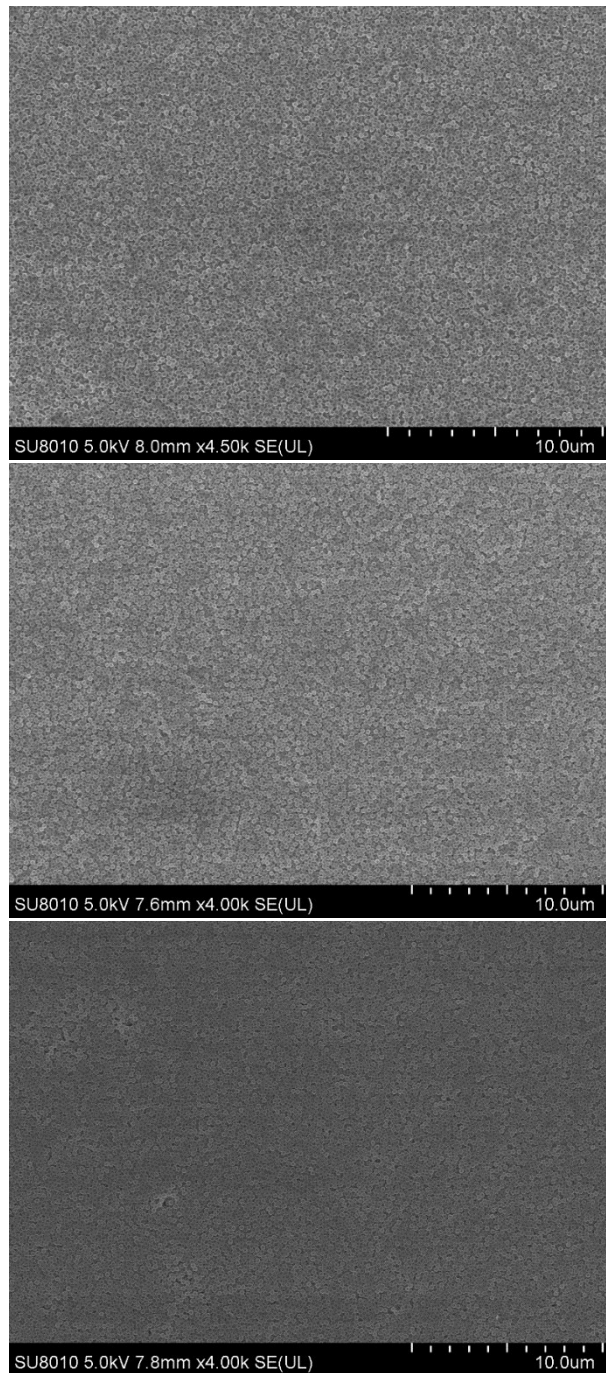**Figure S5**. SEM image of PS 500 nm spheres with perovskite layer.

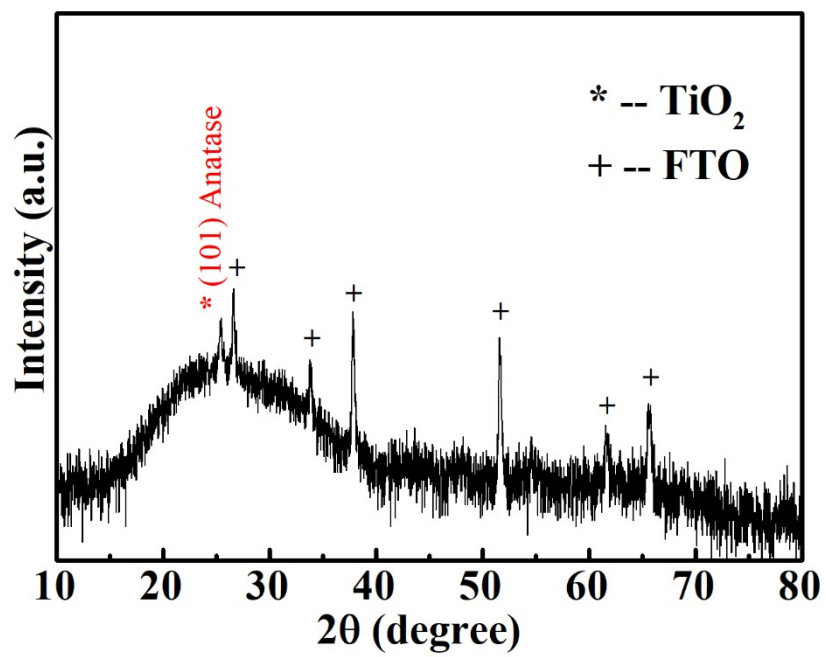**Figure S6**. SEM image of one layer, two layers and three layers samples with low-magnification.
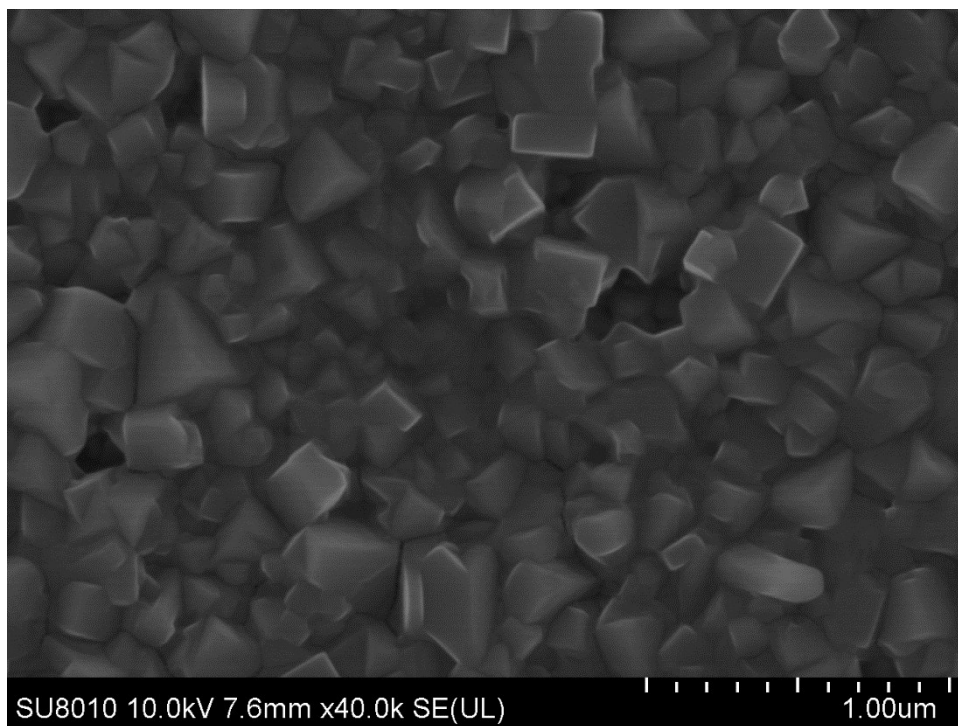
Figure S7. XRD pattern of as-prepared TiO$_2$ sample.

Figure S8. SEM image of perovskite layer on single layer TiO_2 ETLs.
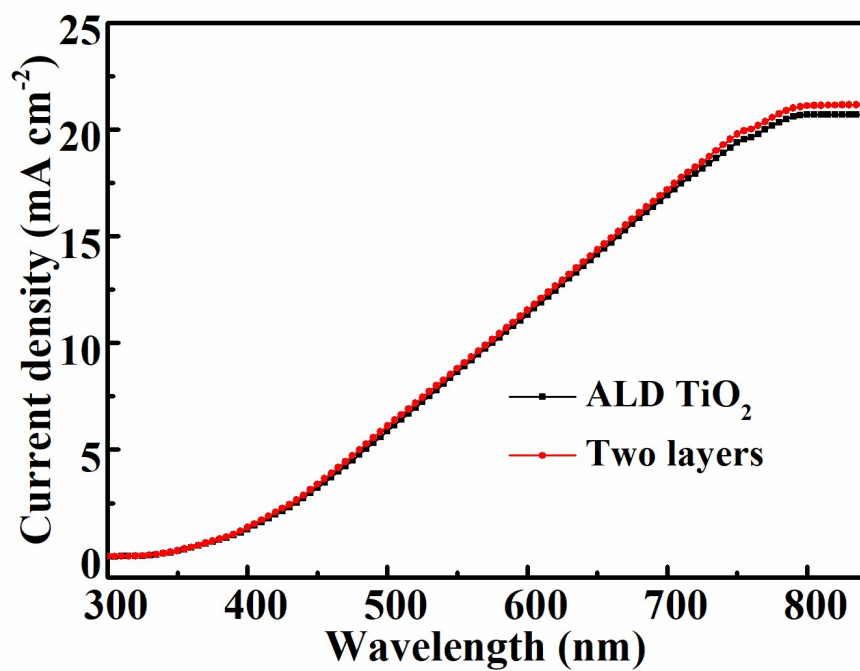
Figure S9. The integrated current density of ALD TiO_2 and Two layers TiO_2 based devices.
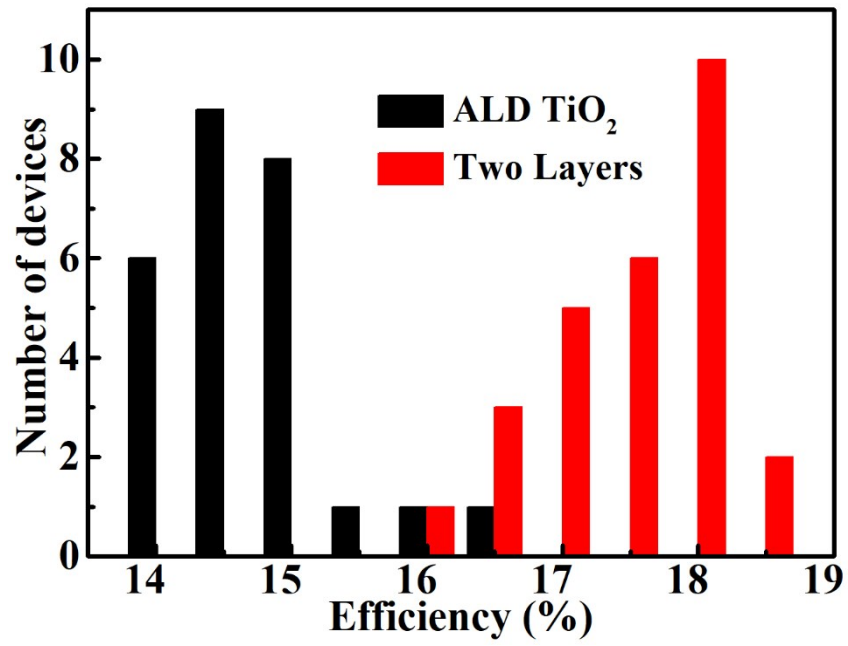
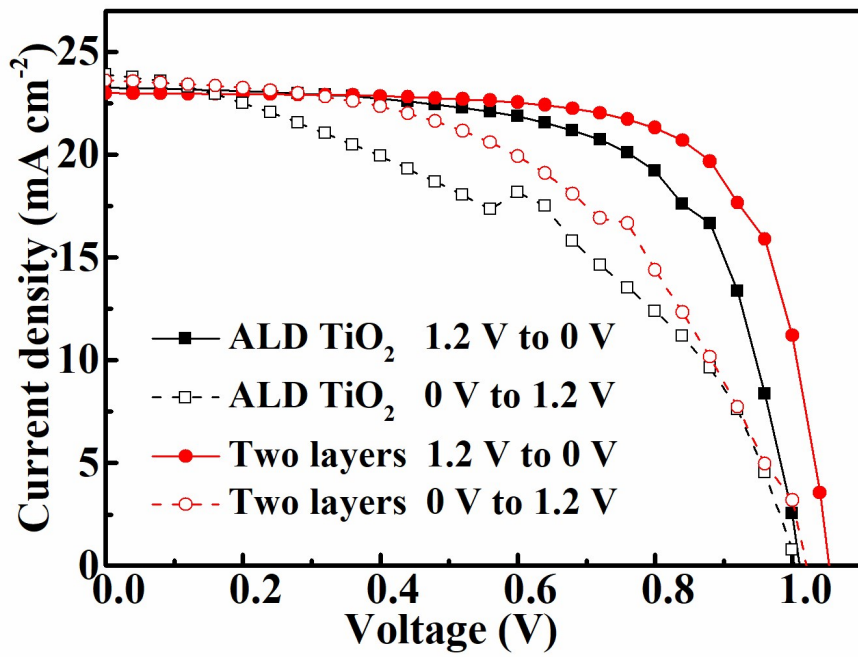**Figure S10**. The repeatability of 26 devices of ALD and two layers samples.

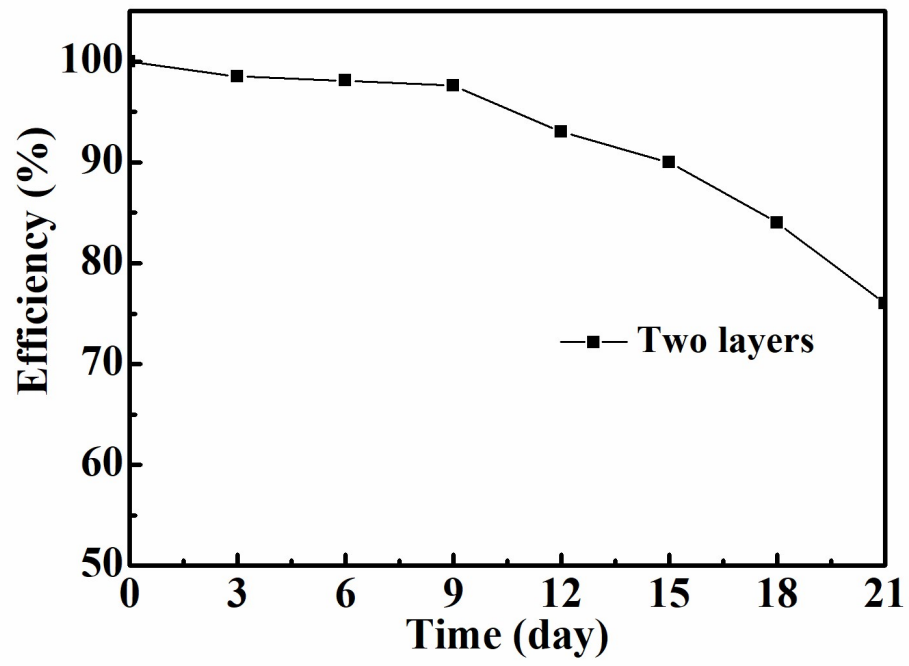**Figure S11**. Forward and reverse scan of two layers and ALD TiO_2 devices.

Figure S12. Long time measurement of two layers sample.

Sample	V_{oc} (V)	J_{sc} (mA cm^{-2})	Fill Factor (%)	Efficiency (%)
Planar	0.99 ± 0.02	23.09 ± 0.28	63.32 ± 4.14	14.95 ± 0.53
Single	1.03 ± 0.02	23.63 ± 0.57	67 ± 2.94	16.43 ± 0.75
Two	1.05 ± 0.01	23.76 ± 0.16	69.96 ± 1.65	17.5 ± 0.55
Three	0.91 ± 0.03	23.77 ± 0.35	57.60 ± 5.54	12.47 ± 1.27

Table S1. The photovoltaic parameters of different TiO$_2$ ETLs based devices.

Sample	R_s (Ω)	R_{ct1} (Ω)	R_{ct2} (Ω)	$R_{ct} = R_{ct1} + R_{ct2}$ (Ω)	R_{rec} (Ω)
Planar	65.3	152.4	178.9	331.3	1181.5
Single	52.4	155.1	235.1	390.2	1277.1
Two	49.4	132.9	121.0	253.9	2431.6
Three	22.3	208.4	64.87	273.3	11323

Table S2. The fitted value of R_{ct} and R_{rec} of different TiO_2 ETLs based devices.