Electronic Supplementary Information (ESI)

Highly efficient low temperature solution processible planar type CH3NH3PbI3 perovskite flexible solar cells

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Experimental

Preparation of $MAPbI_3$ perovskite solution

For preparing $MAPbI_3$ perovskite solution, MAI (methylammonium iodide) was initially synthesized by reacting 50 mL methylamine (40 % in methanol, Junsei Chemical Co. Ltd.) with 50mL hydriodic acid (57% in water, Aldrich) in a 250 mL round-bottom flask at 0 ^oC for 2h with vigorous stirring. Solid residue was obtained by evaporating the solvent on a rotary evaporator at 50 ^oC for 1h. This white solid was dissolved in ethanol, recrystallized from diethyl ether, and finally dried in a vacuum oven for 24h at room temperature to obtain pure MAI. 40 wt% $MAPbI_3$ perovskite solution was prepared by mixing 1:1 mole ratio of MAI powder and PbI_2 (Aldrich) in 1mL N,N-dimethylformamide (Aldrich) at 60 ^oC for 30 min followed by addition of 100 μL hydriodic acid (57% in water, Aldrich).

Device fabrication

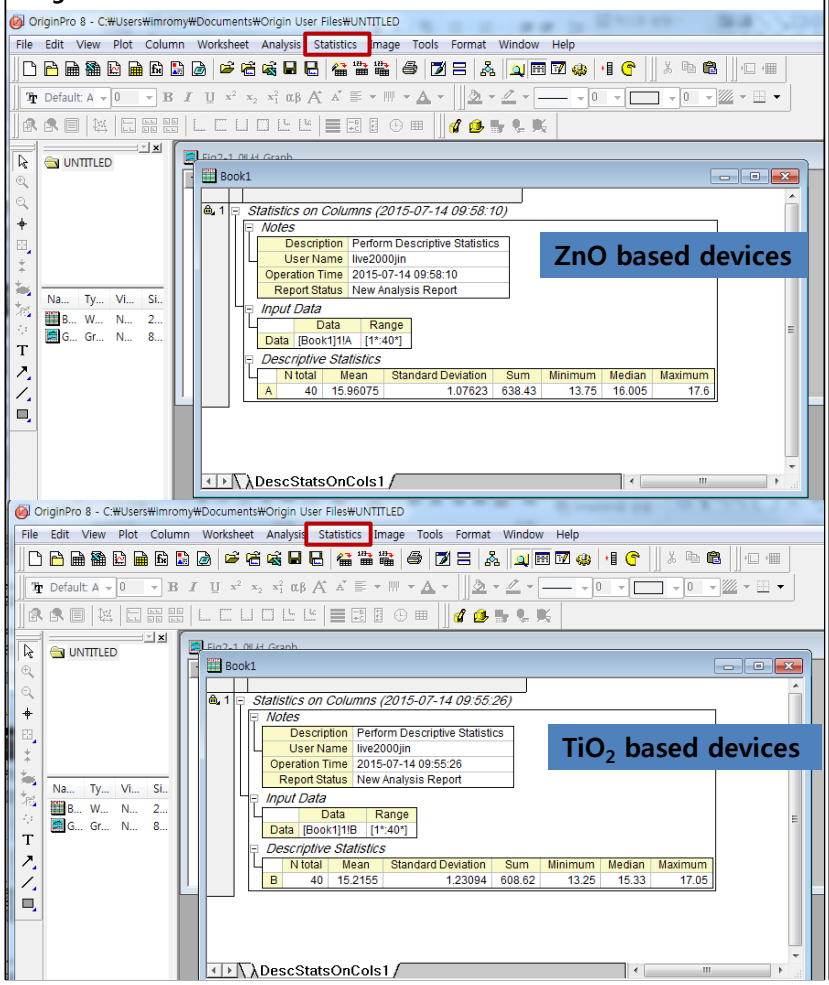
For TiO_2 electron conductor, ~50 nm-thick dense TiO_2 electron conducting layer was deposited on a partially etched F-doped tin oxide (FTO, Pilkington, TEC8) glass substrate (FTO glass size = 2.5 cm x 2.5 cm: etched area = 1 cm x 2.5 cm, unetched area = 1.5 cm x 2.5 cm) by spray pyrolysis deposition method using 20 mM of titanium diisopropoxidebis(acetylacetonate) (Aldrich) solution at 450 ^oC. A ZnO nano-sol for ZnO electron conductor, was prepared by a reported method.[11] Briefly, 1.64 g zinc acetate dihydrate (Aldrich) and 0.5 g ethanolamine (Aldrich) were dissolved with vigorous stirring in 10 g 2-methoxyethnaol (Aldrich) at 60 ^oC for 30 min. The ZnO nano-sol solution was then spin-coated on a cleaned indium tin oxide (ITO, AMG tech) glass substrate at 2000 rpm for 60 s and then dried at 150 ^oC for 10 min. 40 wt% $MAPbI_3$ perovskite solution was spin-coated on the TiO_2/FTO and ZnO/ITO substrates at 3000 rpm for 200 s and dried on the hotplate at 100 ^oC for 2 min. Poly-triarylamine (PTAA, EM index) hole conductor with additives was deposited on the $MAPbI_3/TiO_2$/FTO and $MAPbI_3$/ZnO/ITO

substrate by spin coating PTAA/Toluene (15 mg/ 1 mL) with 7.5 μL Li-bis(trifluoromethanesulfonyl) imide (Li-TFSI, Aldrich)/Acetonitrile (170 mg/ 1mL) and 7.5 μL tert-butylpyridine (t-BP, Aldrich)/Acetonitrile (1 mL/ 1mL) additives at 3000 rpm for 30 s. Finally, Au counter electrode was deposited by thermal evaporation. Polyethylene naphthalate (PEN) /ITO substrates were used for flexible devices. The active area was fixed at 0.16 cm^2. All devices fabrication except Au deposition and measurement was conducted at air condition under controlled relative humidity below 35 %.

Device characterization

The current density-voltage curves were measured by a solar simulator (Peccell, PEC-L01) with a potentiostat (IVIUM, IviumStat) at under illumination of 1 sun (100 mW/cm^2 AM 1.5G) and a calibrated Si-reference cell certificated by JIS (Japanese Industrial Standards). The J-V curves of all devices were measured by masking the active area with metal mask of 0.096 cm^2. To measure the hysteresis of J-V curves, the forward and reverse scan rate was set to 10 mV·200 ms^{-1} as a standard condition and was varied from 10 mV·100 ms^{-1} to 10 mV·1000 ms^{-1}. The external quantum efficiency (EQE) was measured by a power source (ABET, 150W Xenon lamp, 13014) with a monochromator (DONGWOO OPTRON Co., Ltd., MonoRa-500i) and potentiostat (IVIUM, IviumStat). Intensity-modulated photocurrent and photovoltage were measured by potentiostat (IVIUM, IviumStat) with light emitting diode (LED) (IVIUM, IM1225).

Origin data: we used statistics to obtain Mean and standard deviation.



Excel result:
To confirm that the calculated means of TiO_2 and ZnO based devices are meaningful, we conducted t-test by using EXCEL program. The results confirm that the calculated means of ZnO and TiO_2 based cells are meaningful (significant level = 0.05).

t-Test: Two-Sample Assuming Equal Variances

	TiO_2	ZnO
	Variable 1	Variable 2
Mean	**15.2155**	**15.96075**
Variance	1.51521	1.158274
Observations	40	40
Pooled Variance	1.336742	
Hypothesized Mean Difference	0	
df	78	
t Stat	-2.88266	
P(T<=t) one-tail	**0.002546**	
t Critical one-tail	1.664625	
P(T<=t) two-tail	**0.005093**	
t Critical two-tail	1.990847	

Fig. S1. Efficiency deviations calculated from Statistics of Origin and t-test from Excel.

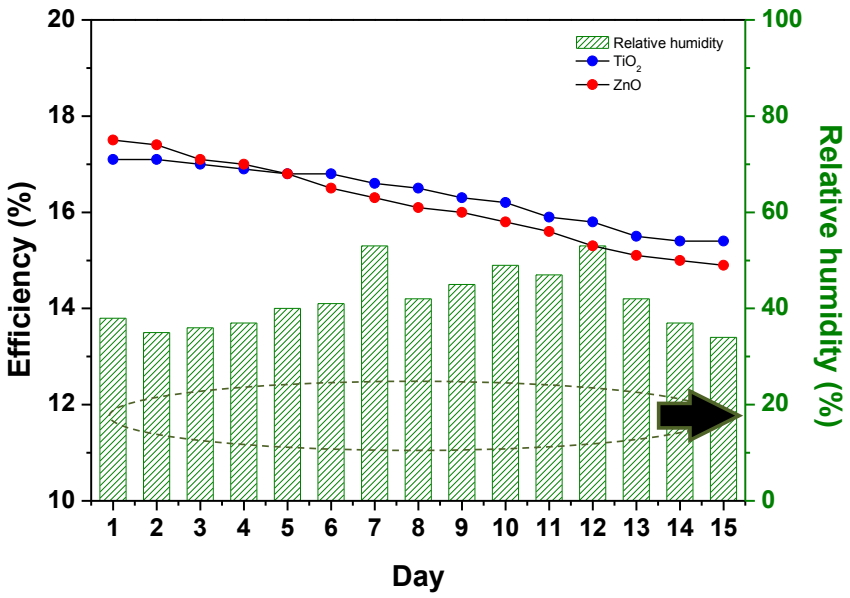


Fig. S2. Device stability of TiO_2 and ZnO electron conductor based device with time and humidity variation

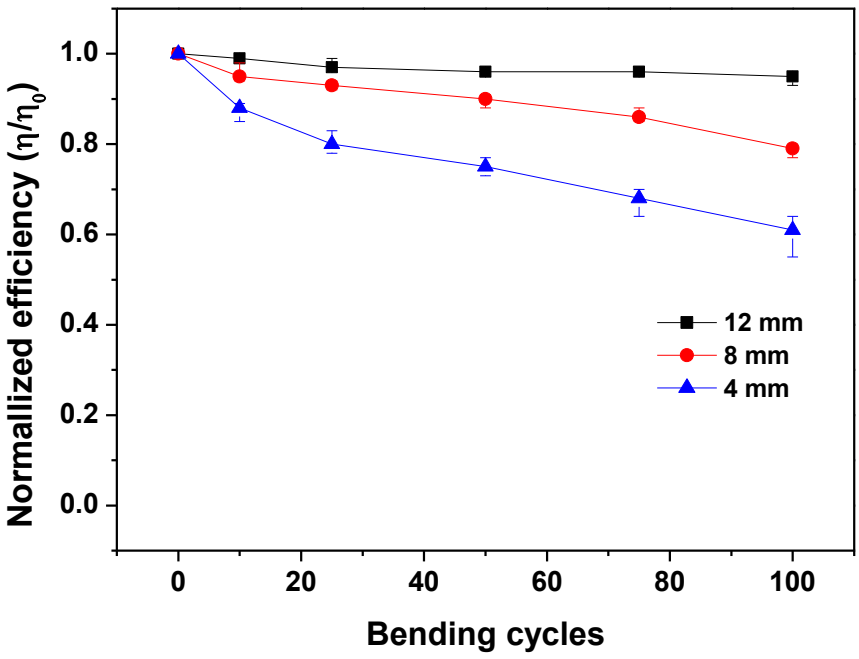


Fig. S3. Normalized power conversion efficiency of PEN/ITO/ZnO/$MAPbI_3$/PTAA/Au flexible solar cell with bending radius and bending cycles.