Supporting Information

Spinel Co_3O_4 Nanomaterials for Efficient and Stable Large Area Carbon-based Printed Perovskite Solar Cells

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Table S1. Sheet resistance of Co_3O_4 and NiO film on glass measured using 4 probe
(Thickness is 500 nm)

Sample	Sheet resistance (Ω/sq)
Co_3O_4/ glass	1.14 E4

Table S2. Device performance for different thickness (t) of Co_3O_4 for a device glass/FTO/TiO_2/ZrO_2/Co_3O_4/C (ZrO_2 = 1.3 µm, device area = 0.8 cm^2) under 1 Sun (100mW/cm^2) light illumination

Dilution (W_{Co3O4}:$W_{Terpineol}$)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	PCE(%)
1:7	0.91	22.51	51.30	10.60
1:5	0.95	23.29	55.89	11.67
1:3	0.84	20.61	53.03	9.20
1:0	0.80	19.11	51.54	7.74

Table S3. Device performance for different thickness (t) of ZrO_2 for a device glass/FTO/TiO_2/ZrO_2/Co_3O_4 /C (Co_3O_4 = (1:5), device area = 0.8 cm^2) under 1 Sun (100mW/cm^2) light illumination

t_{ZrO2} (nm)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	PCE(%)
1300	0.95	23.29	55.89	11.67
1000	0.90	17.40	50.60	8.50
800	0.85	18.25	47.80	7.45
500	0.83	15.36	47.70	6.70

Table S4: Summary of 14 devices parameters (mean ± std Deviation) for PSC active area 0.8 cm^2 with Co_3O_4 interlayer: open circuit voltage (V_{oc}), current density (J_{sc}), fill factor (*FF*) and efficiency (η) under 1 Sun (100mW/cm^2) light illumination.

Parameters	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	PCE(%)
Average	0.90 ±0.02	22.37±1.16	52.42±2.07	10.55±0.69
Champion	0.95	23.11	53.00	11.68

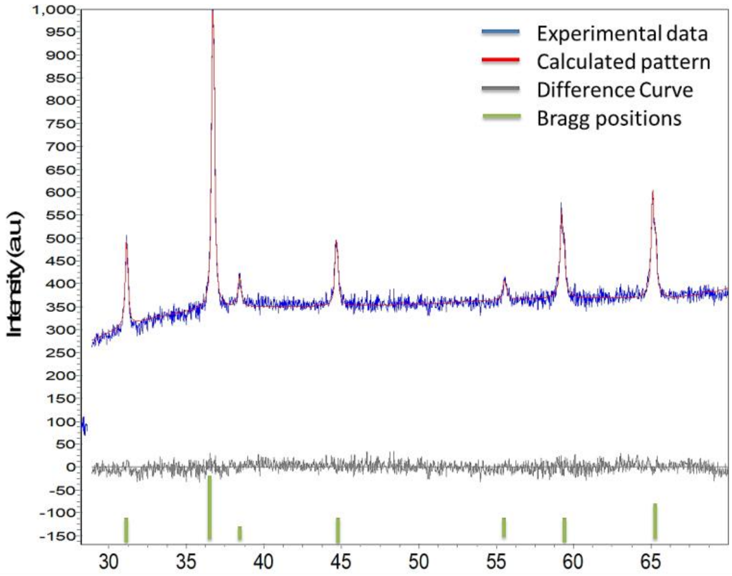


Figure S1. Experimental and calculated XRD pattern from reitveld refinement of Co_3O_4 film on glass substrate.

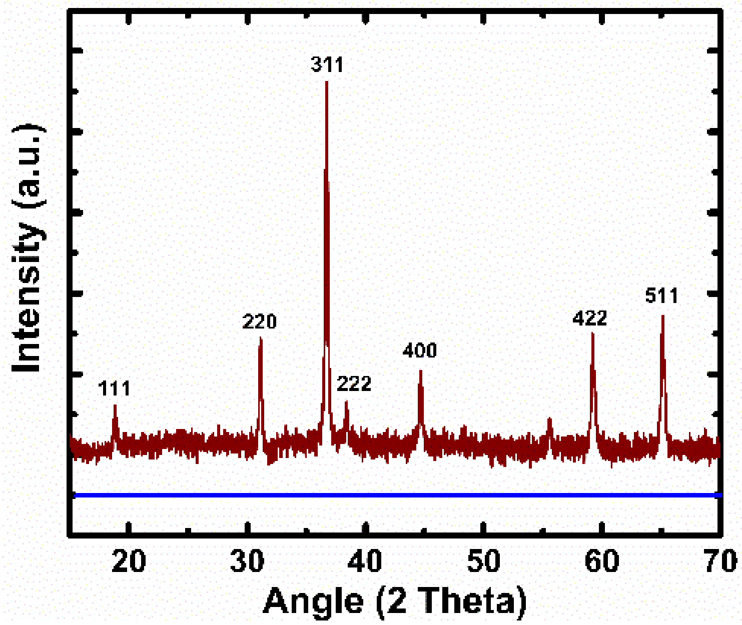


Figure S2. (a) Thin film XRD pattern of screen printed Co_3O_4 film

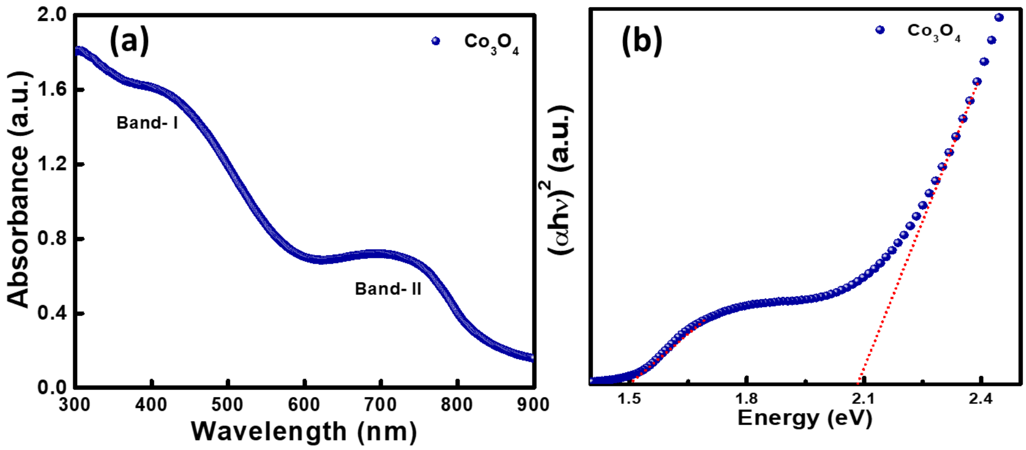


Figure S3: (a) optical absorption spectra for the Co_3O_4 film, (b) optical band gap for Co_3O_4 film

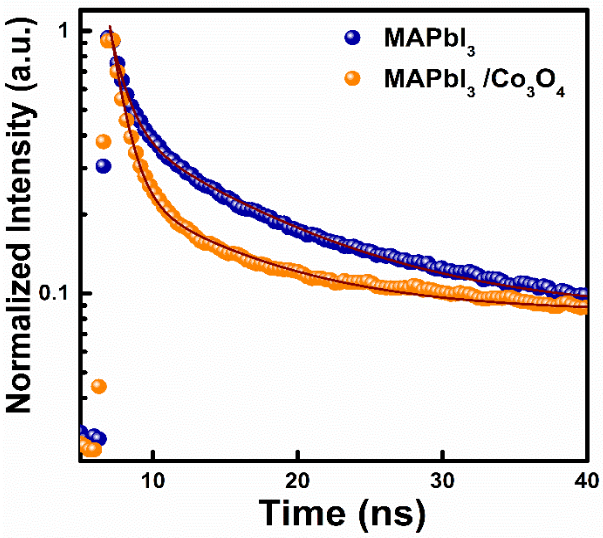


Figure S4: Transient PL (TrPL)Spectra of pristine $MAPbI_3$, $MAPbI_3/Co_3O_4$ on glass.

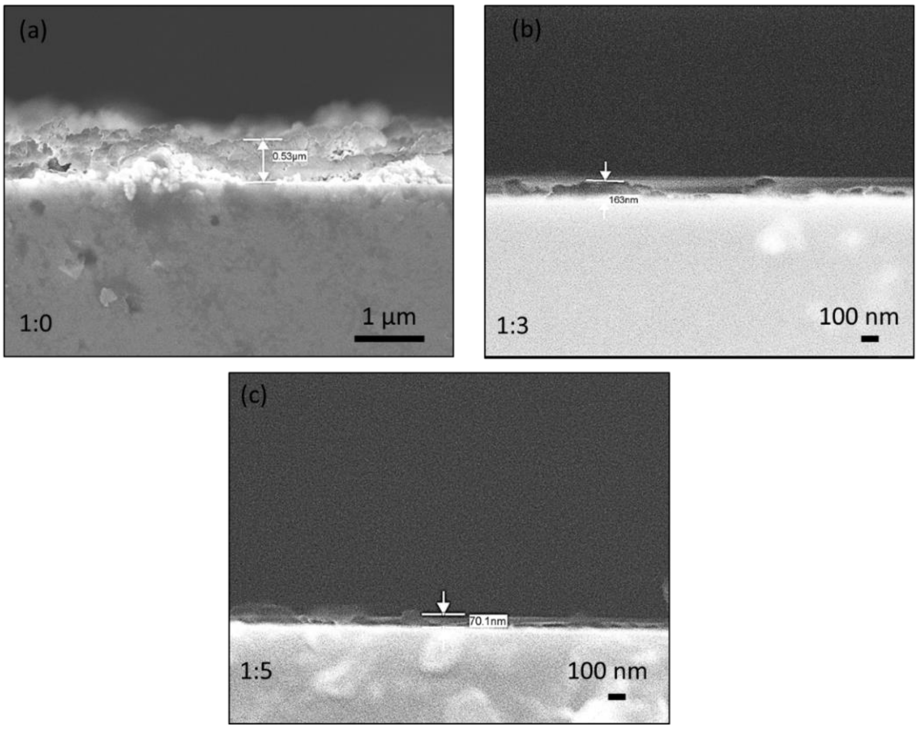
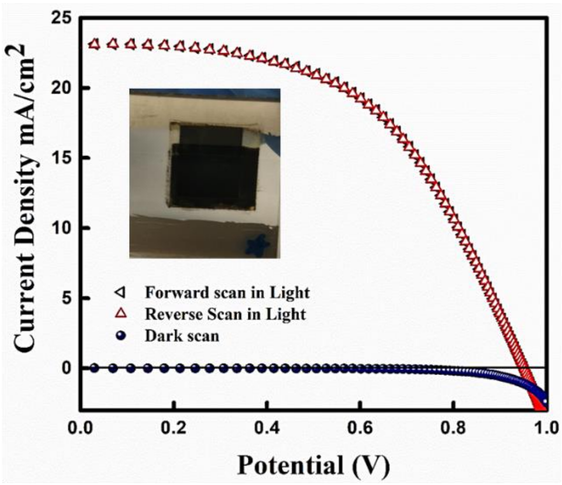


Figure.S5 Thicknesses of Co_3O_4 with different dilutions, (a) Orignial paste (1:0), (b) 1:3, (c) 1:5

(a)



(b)

Parametera	Without Co_3O_4		With Co_3O_4	
Parameters	Reverse	Forward	Reverse	Forward
Voc (V)	0.84	0.83	0.95	0.95
Jsc (mA/cm2)	21.77	21.91	23.10	23.11
FF	0.51	0.50	0.53	0.53
PCE (%)	9.20	9.31	11.65	11.68

Figure S6. (a). J-V characteristics of standard carbon cell with Co_3O_4 (Co_3O_4/C) layer with an active area of 0.8 cm^2 under 1 Sun (100mW/cm^2) light illumination,(b) Solar cell parameters for standard carbon cell without and with Co_3O_4 layer with an aperture area of 0.8 cm^2 under 1 Sun (100mW/cm^2) light illumination.

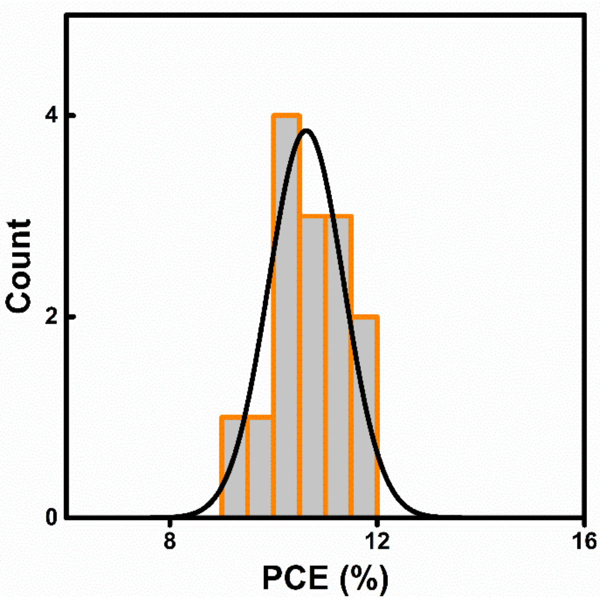


Figure S7. PCE histogram of the 14 solar cells made with Co_3O_4 HTL, performance was measured under AM 1.5 illumination with active area of 0.8 cm^2.

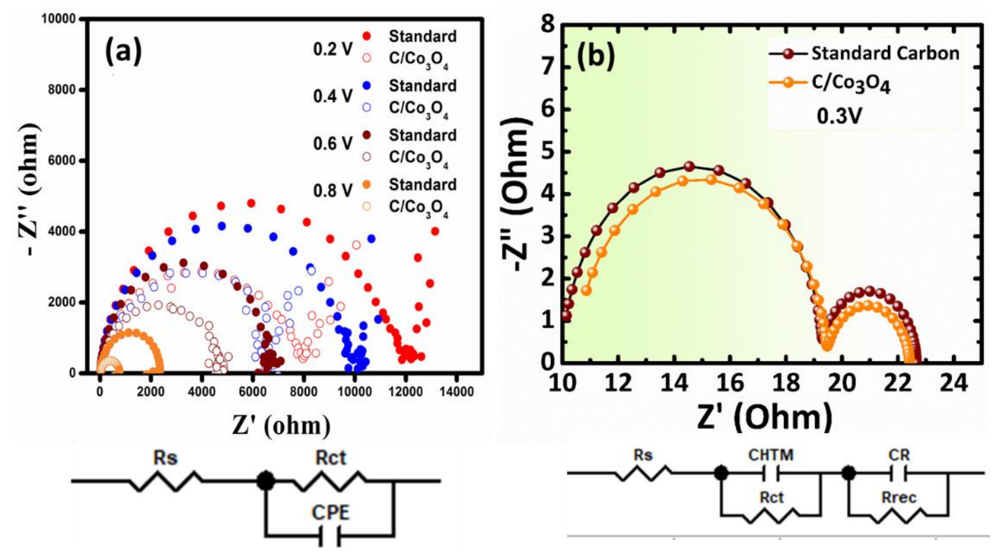
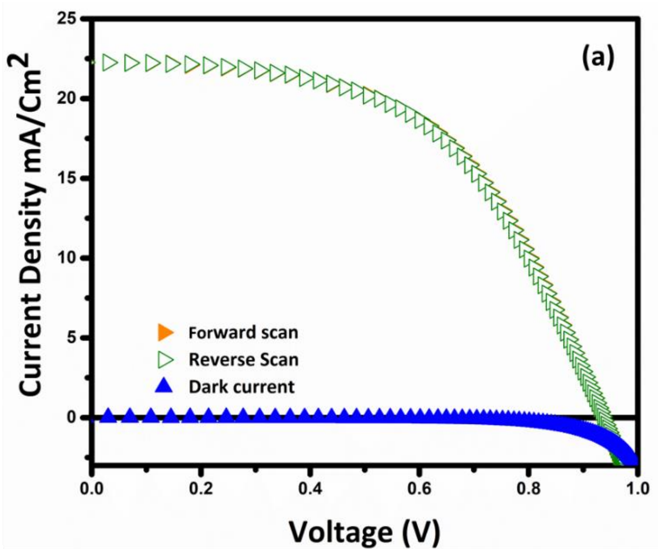


Figure S8. (a) Nyquist plots of devices, standard carbon and Co_3O_4/C at different bias under dark with equivalent circuit diagram, with an active area of 0.8 cm^2 (a) Nyquist plots of devices, standard carbon and Co_3O_4/C at 0.3V bias under 1 sun illumination with equivalent circuit diagram, with an active area of 0.8 cm^2



(b)

Parameters	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	PCE (%)	I_{sc} (mA)	V_{mp} (V)	I_{mp} (mA)	P_{max} (mW)
	0.94	22.27	0.54	11.32	15.59	0.63	12.50	7.92

Figure.S9 J-V characteristics of standard carbon cell with Co_3O_4 (Co_3O_4/C) layer with an (a) active area of 0.8 cm^2 under 1 Sun (100mW/cm^2) light illumination, (b) Corresonding device parametrs under 1 Sun (100mW/cm^2) light illumination.