

# Supporting Information for

## Carbon Nanotubes versus Graphene as Flexible Transparent Electrodes in Inverted Perovskite Solar Cells

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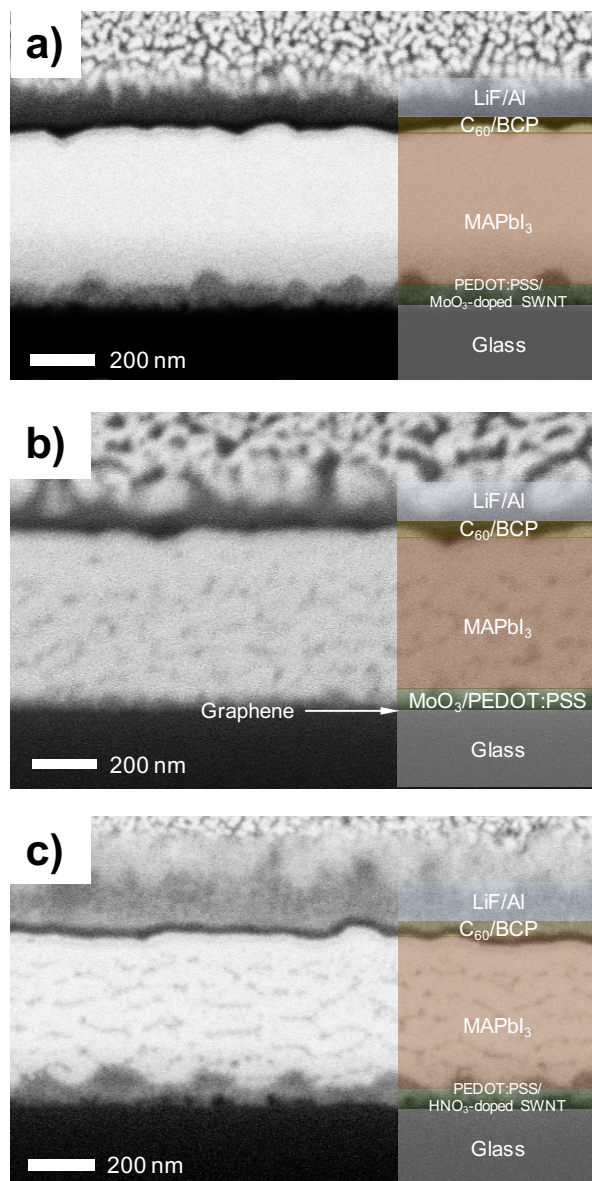
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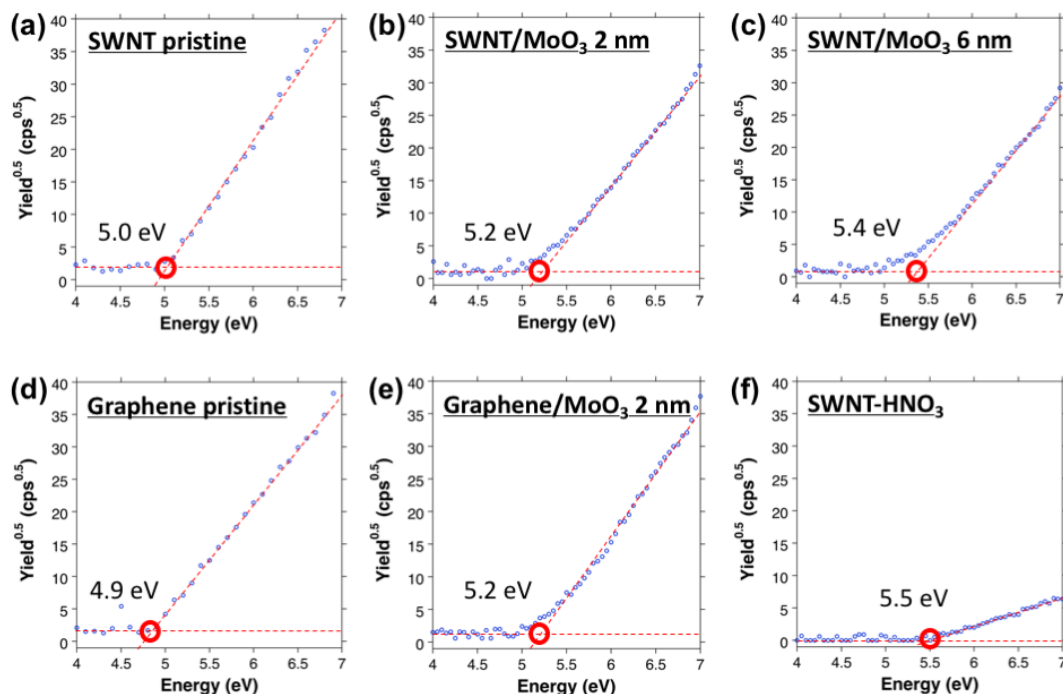
## 1. Cross-sectional SEM images



**Figure S1.** Cross-sectional SEM images of (a) the thin MoO<sub>3</sub>-doped SWNT-based PSCs, (b) the thin MoO<sub>3</sub>-doped graphene-based PSCs, and (c) the HNO<sub>3</sub>-doped SWNT-based PSCs,

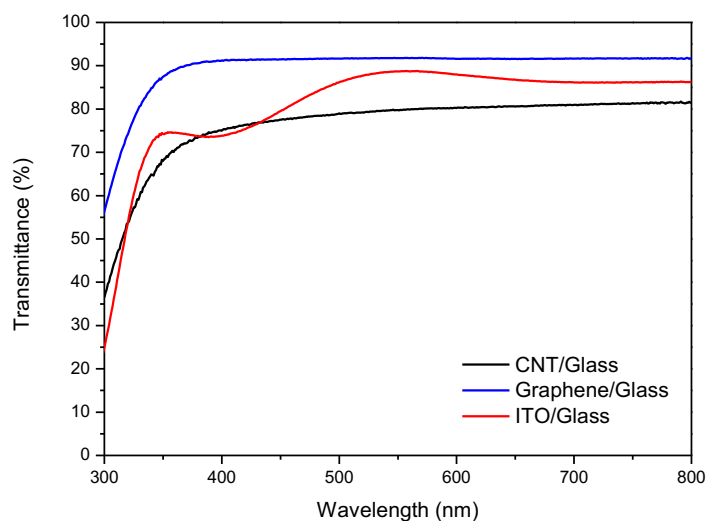


## 2. Photoelectron Yield Spectroscopy (PYS)



**Figure S2.** PYS data of (a) a pristine SWNT film on glass, (b) a glass/SWNT/MoO<sub>3</sub> (2nm) film, (c) a glass/SWNT/MoO<sub>3</sub> (6nm), (d) a pristine graphene film on glass, (e) a glass/graphene/MoO<sub>3</sub> (2 nm), and (f) a HNO<sub>3</sub>-doped SWNT film on glass.

## 3. UV-Vis Transmittance data



**Figure S3.** UV-vis spectra of a SWNT film on glass, a graphene film on glass, and ITO on glass.

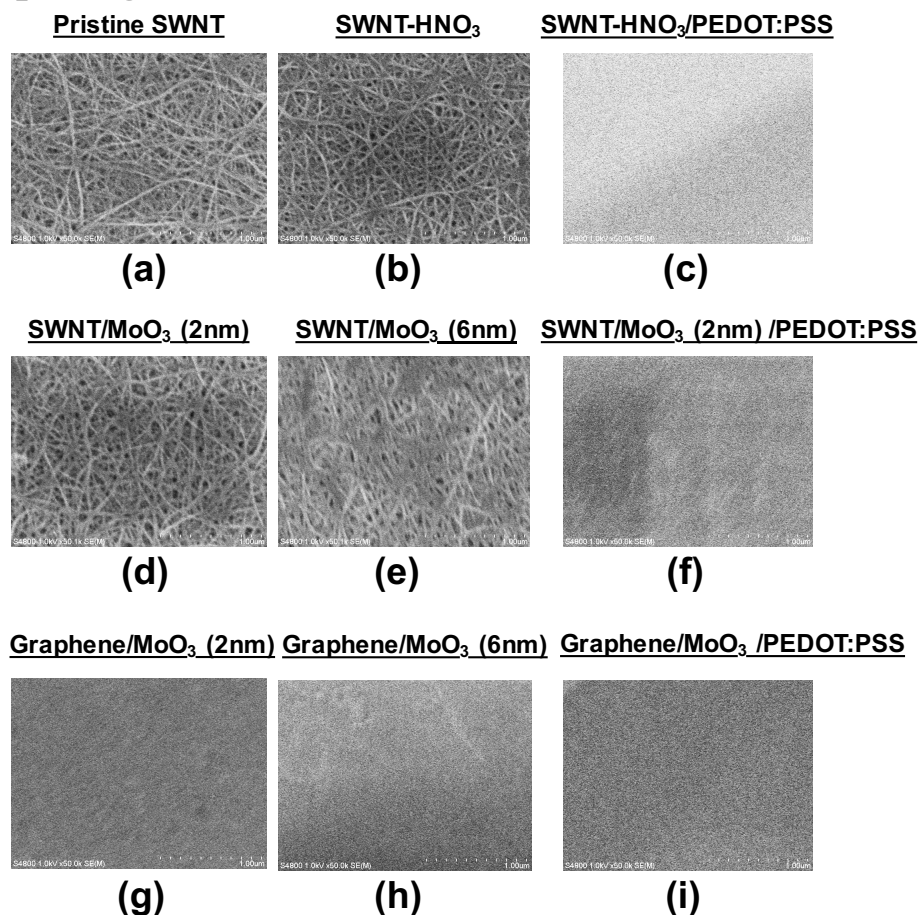


## 4. Four-probe measurement

**Table S1.** Sheet resistance data of different carbon electrode films.

Samples	Sheet Resistance ( $\Omega \text{ sq.}^{-1}$ )
Pristine SWNT	<i>ca.</i> 250
HNO <sub>3</sub> -SWNT	51 $\pm$ 10
2-nm-thick MoO <sub>3</sub> on SWNT	218 $\pm$ 5
6-nm-thick MoO <sub>3</sub> on SWNT	201 $\pm$ 7
Pristine graphene	625 $\pm$ 107
2-nm-thick MoO <sub>3</sub> on graphene	501 $\pm$ 43

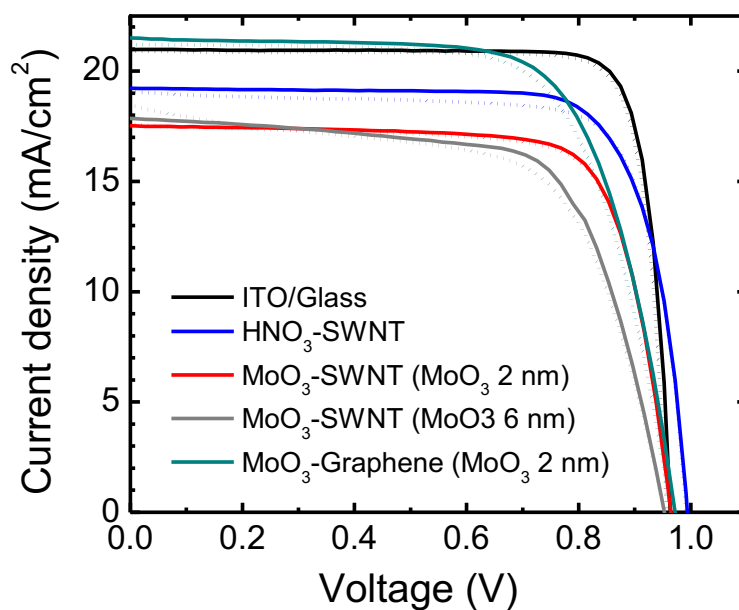
## 5. SEM top images



**Figure S4.** SEM images of (a) a pristine SWNT film, (b) a HNO<sub>3</sub>-doped SWNT film, (c) a HNO<sub>3</sub>-doped SWNT film with a PEDOT:PSS overcoat, (d) a 2-nm-thick MoO<sub>3</sub>-deposited SWNT film, (e) a 6-nm-thick MoO<sub>3</sub>-deposited SWNT film, (f) a 2-nm-thick MoO<sub>3</sub>-deposited SWNT film with a PEDOT:PSS overcoat (g) a pristine graphene (h) a 2-nm-thick MoO<sub>3</sub>-deposited graphene, and (i) a 2-nm-thick MoO<sub>3</sub>-deposited graphene with a PEDOT:PSS overcoat.



## 6. Hysteresis Data



**Figure S5.**  $J$ - $V$  hysteresis curves of the devices tested in this study. Reverse bias is represented in solid lines, and forward bias is represented in dotted lines.

## 7. Statistical Analysis

**Table S2.** Statistical analysis of the carbon electrode-based PSCs in this work.

Substrate	Anode	$V_{oc}$ (V)	$J_{sc}$ ( $\text{mA cm}^{-2}$ )	FF	PCE
glass	SWNT/MoO <sub>3</sub> (2nm)/PEDOT:PSS	0.94 $\pm$ 0.05	18.6 $\pm$ 0.9	0.68 $\pm$ 0.05	11.8% $\pm$ 1.0
	SWNT/MoO <sub>3</sub> (6nm)/PEDOT:PSS	0.90 $\pm$ 0.04	18.5 $\pm$ 0.4	0.67 $\pm$ 0.03	11.1% $\pm$ 0.7
	graphene/ MoO <sub>3</sub> (2nm)/PEDOT:PSS	0.98 $\pm$ 0.02	21.3 $\pm$ 0.5	0.69 $\pm$ 0.04	14.2% $\pm$ 0.7
	SWNT-HNO <sub>3</sub> /PEDOT:PSS	0.94 $\pm$ 0.06	19.8 $\pm$ 0.6	0.74 $\pm$ 0.03	13.7% $\pm$ 1.3
PEN	SWNT/MoO <sub>3</sub> /PEDOT:PSS	0.92 $\pm$ 0.01	18.5 $\pm$ 0.7	0.60 $\pm$ 0.05	10.2% $\pm$ 0.9
	graphene/MoO <sub>3</sub> /PEDOT:PSS	0.99 $\pm$ 0.01	19.9 $\pm$ 0.2	0.68 $\pm$ 0.09	13.4% $\pm$ 0.2

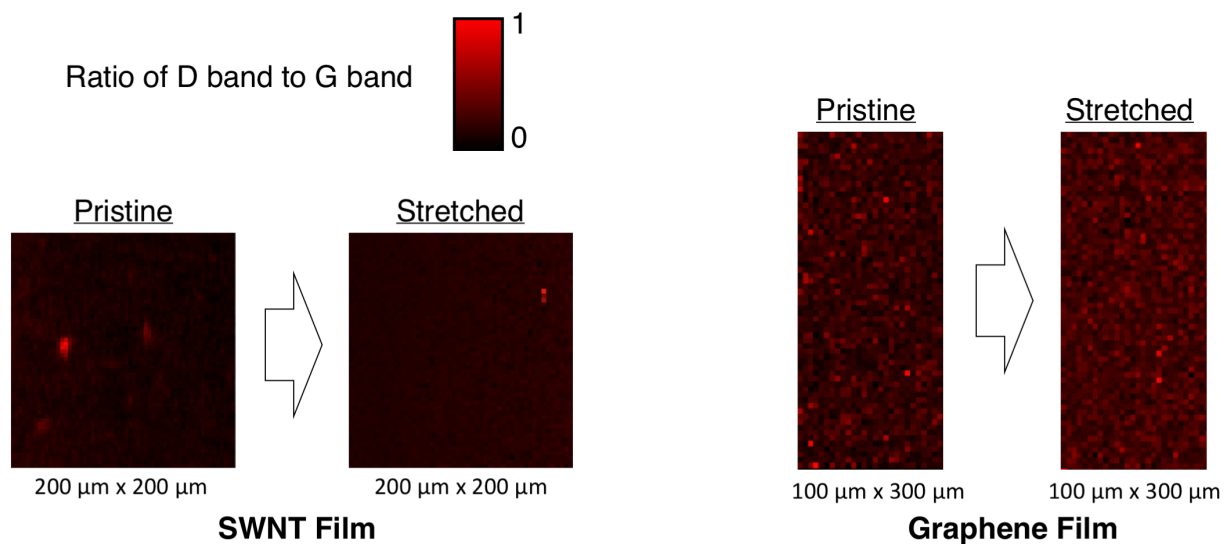


## 8. Four-Probe Tests involving Bending and Stretching

**Table S3.**  $R_{\text{Sheet}}$  of SWNT and graphene on PDMS after stretching 0.2% for 200 times.

Samples	Sheet Resistance ( $\Omega \text{ sq.}^{-1}$ )
SWNT on PDMS	250 $\pm$ 30
SWNT on PDMS after 200 times stretching	261 $\pm$ 25
graphene on PDMS	625 $\pm$ 107
graphene on PDMS after 200 times stretching	771 $\pm$ 214

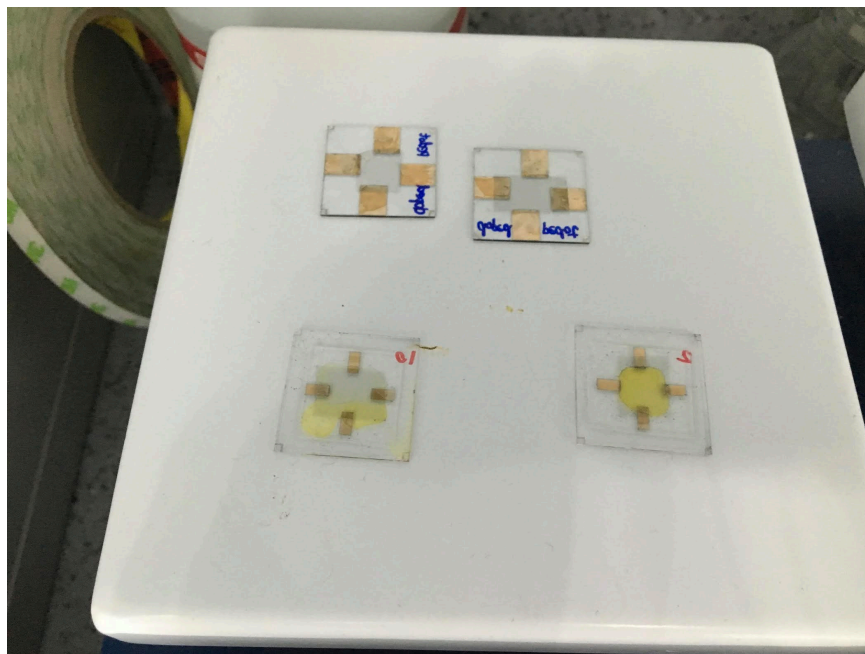
## 9. Raman Mapping



**Figure S6.** Raman spectroscopy mapping image of the SWNT film and graphene film. The image indicates ratio of D band to G band in which defects are indicated by the color, red.



## 10. $\text{HNO}_3$ doping on SWNT on PEN



**Figure S7.** Picture of  $\text{HNO}_3$ -doped SWNT on PEN.