Electronic Supplementary Information

Polymeric Acid-doped Transparent Carbon Nanotube Electrodes in Organic Solar Cells with the Longest Doping Durability

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1. Doping Effect Comparison between CNT and Graphene

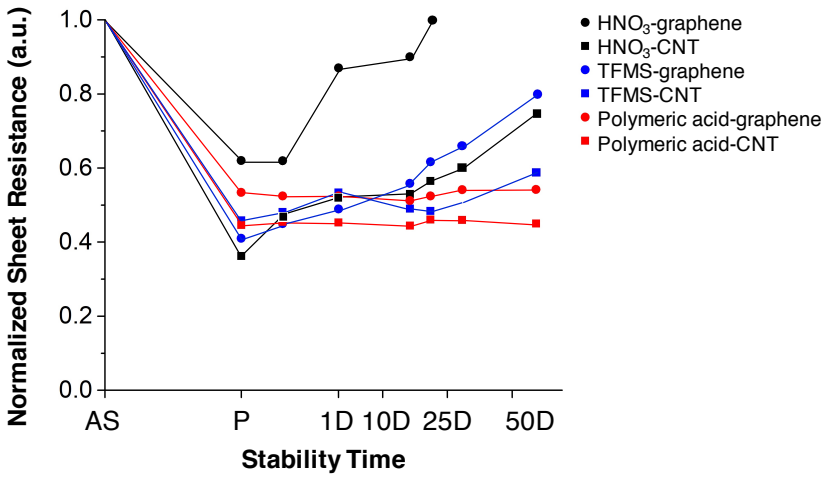

Figure S1. Normalized four-probe sheet resistance stability data for the three types of dopants applied to graphene and CNT electrodes.

2. EDX Analysis

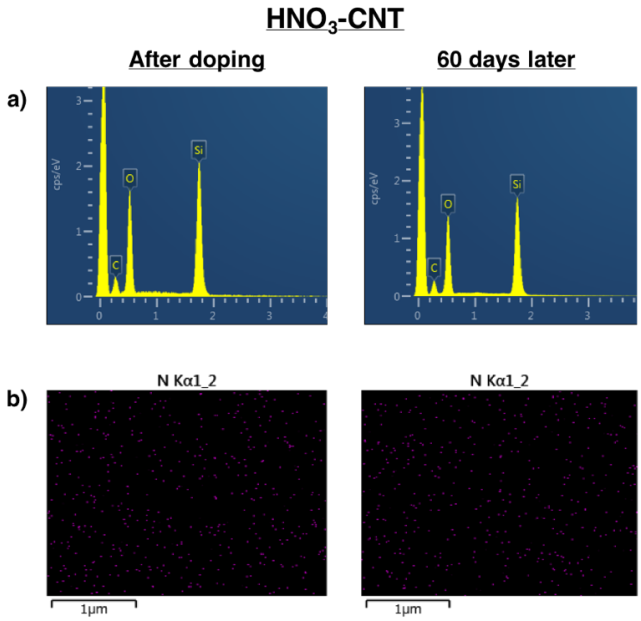

Figure S2-1. EDX analysis of a HNO_3-CNT film after doping and 60 days later. (a) cps count vs keV spectra and (b) EDX chemical mapping of nitrogen.

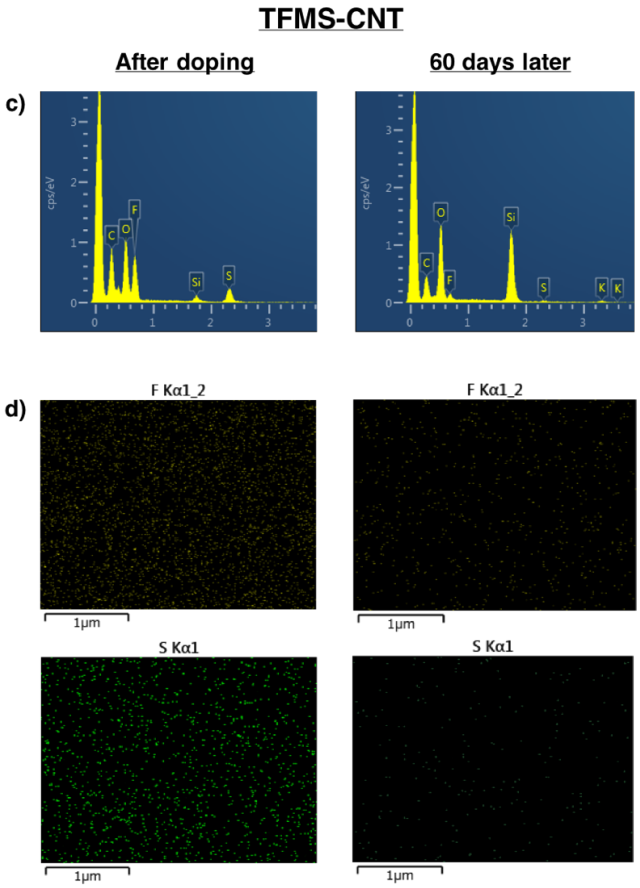

Figure S2-2. EDX analysis of a TFMS-CNT film after doping and 60 days later. (b) cps count vs keV spectra and (c) EDX chemical mapping of fluorine and sulphur.

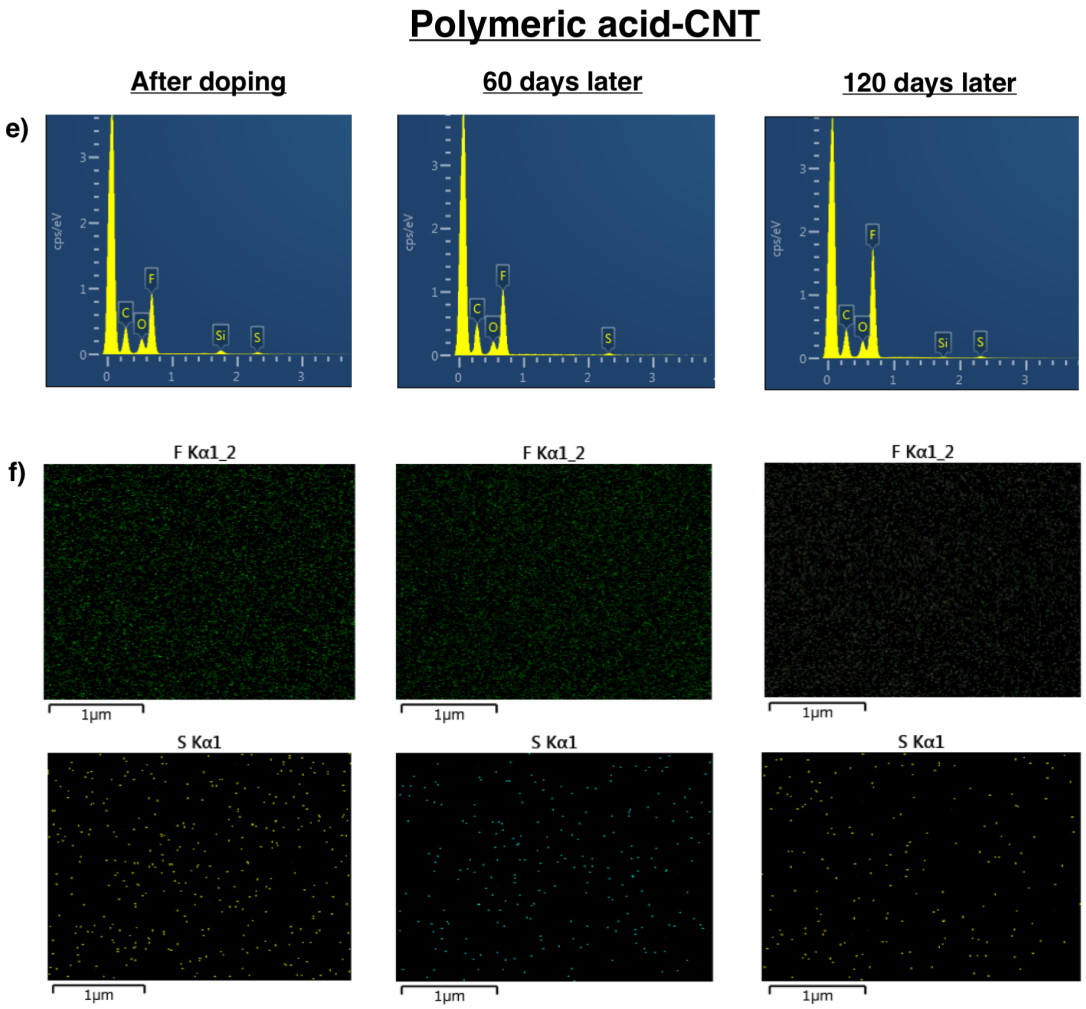

Figure S2-3. EDX analysis of a polymeric acid-CNT film after doping, 60 days later, and 120 days later. (b) cps count vs keV spectra and (c) EDX chemical mapping of fluorine and sulphur.

Table S1. EDX atomic weight% analysis results of HNO_3-CNT, TFMS-CNT, and polymeric acid-CNT after doping and 60 days later.

Sample Type	Condition	Atom	Average weight (%)	Error range (%)
HNO_3-CNT	After doping	C	9.50	±0.87
		O	32.03	±0.78
		Si	58.47	±0.66
	60 days later	C	9.70	±0.70
		O	31.50	±0.26
		Si	58.8	±0.94
TFMS-CNT	After doping	C	20.71	±6.70
		O	29.27	±1.76
		F	23.61	±7.58
		Si	12.06	±16.72
		S	14.36	±4.68
	60 days later	C	11.55	±4.69
		O	32.99	±0.95
		F	1.96	±0.64
		Si	52.26	±6.64
		S	1.22	±0.47
Polymeric acid-CNT	After doping	C	23.12	±3.90
		O	9.01	±0.88
		F	63.74	±2.55
		Si	1.11	±0.15
		S	3.03	±0.33
	60 days later	C	23.02	±5.86
		O	12.60	±4.15
		F	52.32	±15.13
		Si	2.43	±2.63
		S	4.11	±1.00

3. TEM Images

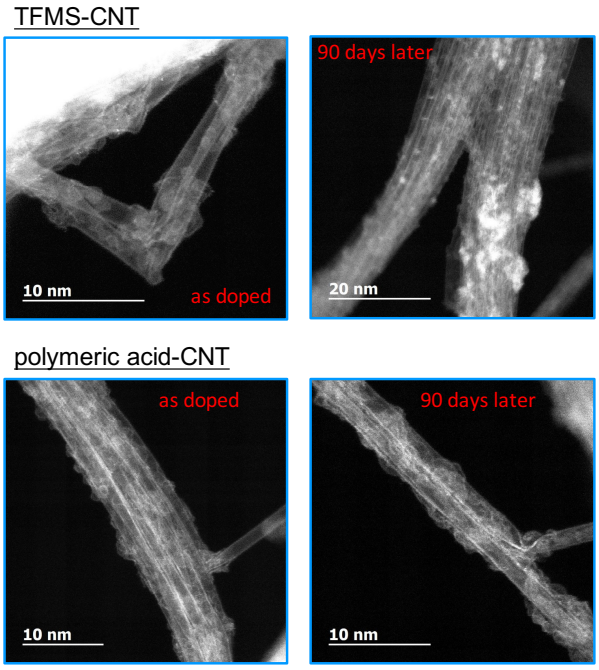

Figure S3. STEM images of TFMS-CNT and polymeric acid-CNT after doping and 90 days later.

4. AFM Morphology Analysis

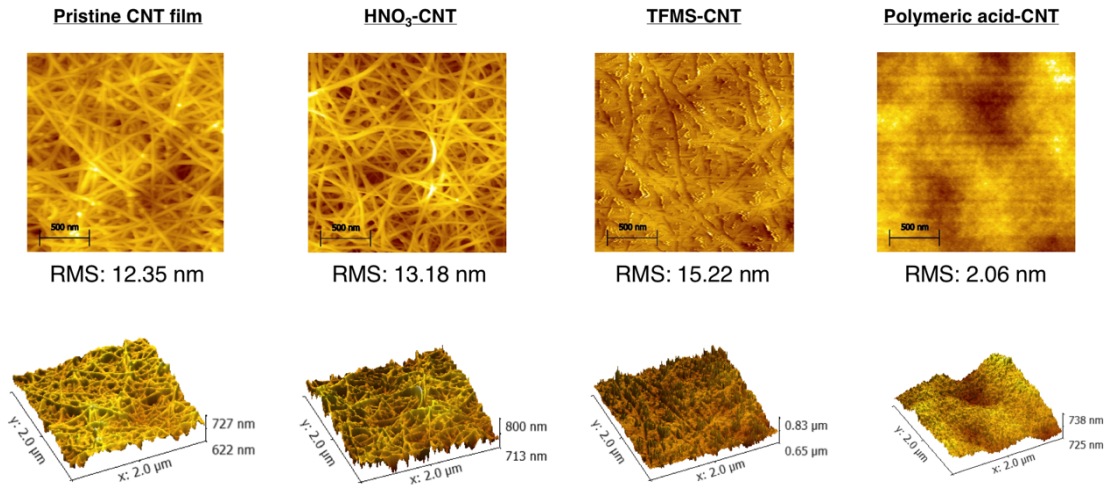

Figure S4. AFM 2D and 3D images, and the roughness mean squared of (a) a pristine CNT film, (b) a HNO_3-CNT film, (c) a TFMS-CNT film, and (d) a polymeric acid-CNT film.

5. Cross-sectional SEM

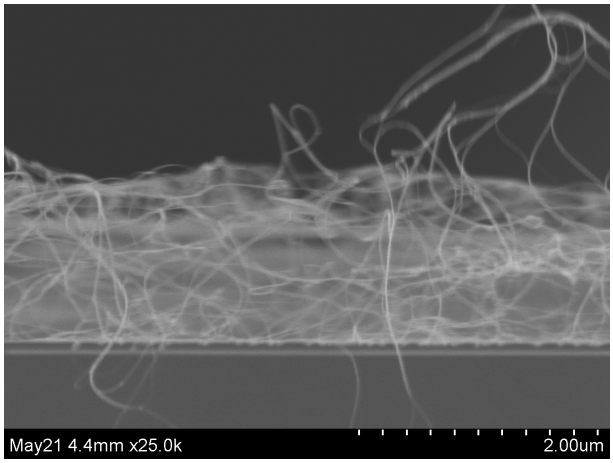

Figure S5. Cross-section SEM image of 2%-diluted Nafion-deposited CNT film.

6. Water Contact Angle Test

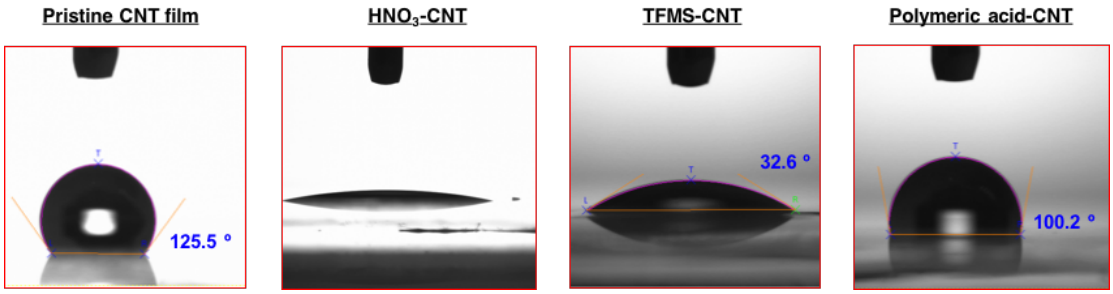

Figure S6. Water contact angle data showing the surface energy of (a) a pristine CNT film, (b) a HNO_3-CNT film, (c) a TFMS-CNT film, and (d) a polymeric acid-CNT film.

7. Surfactant-added PEDOT:PSS-used Device

Table S2. Photovoltaic performance comparison of surfactant-added PEDOT:PSS-used devices and MoO_3/PEDOT:PSS-used devices in a structural configuration of polymeric acid-CNT/HTL/ PBTZT-stat-BDTT-8:$PC_{71}BM$/LiF/Al.

Hole-Transporting Layer (HTL)	J_{SC} (mA cm^{-2})	V_{OC} (V)	FF	PCE (%)
Surfactant-added PEDOT:PSS	14.9	0.78	0.65	7.6
MoO_3/PEDOT:PSS	14.3	0.80	0.70	8.0

8. Current Density–Voltage (*J*–*V*) Curves

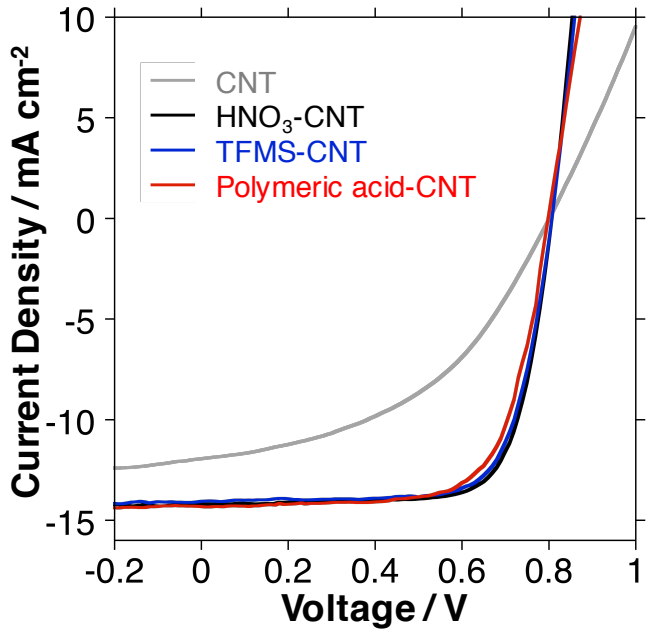

Figure S7. *J*–*V* curves of the OSCs using bare CNT, HNO_3-doped CNT films, TFMS-doped CNT films, and polymeric acid-doped CNT films.

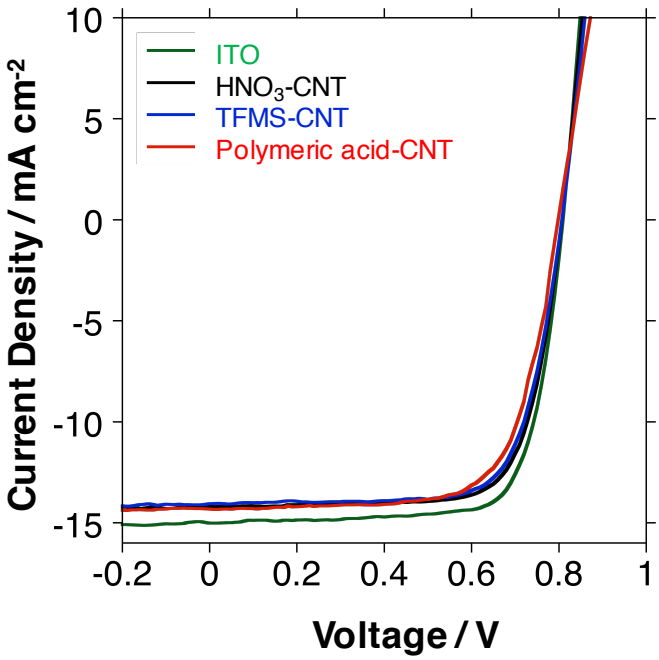

Figure S8. *J*–*V* curves of the OSCs using ITO, HNO_3-doped CNT films, TFMS-doped CNT films, and polymeric acid-doped CNT films.

9. Statistical Analysis

Table S3. Statistical Analysis of the average device PCEs and their error ranges.

Electrode	PCE (%) After doping	PCE (%) 60 days later
ITO	8.7 ±0.48	6.5 ±0.53
CNT	4.0 ±0.49	2.0 ±0.97
HNO_3-CNT	8.2 ±0.17	2.4 ±1.11
TFMS-CNT	8.1 ±0.38	4.2 ±1.12
polymeric acid-CNT	7.0 ±0.94	6.5 ±1.39