Supporting Information

Efficiency Improvement of Dye-sensitized Solar Cells by *In-situ* Fluorescence Resonance Energy Transfer

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Table S1. Photovoltaic performance of DSSCs with the doping of H-NIM in various doping ratios under one sun (AM 1.5G) illumination.

Doping concentration ratio of H-NIM	P_{max} (mW)	V_{OC} (V)	J_{SC} (mA/cm^2)	FF	η (%)
0 %	1.47	0.770	16.89	0.705	9.16
9 %	1.57	0.777	17.94	0.706	9.84
10 %	1.58	0.774	18.28	0.697	9.87
11 %	1.57	0.777	18.08	0.698	9.82
13 %	1.60	0.780	18.16	0.704	9.98
14 %	1.62	0.771	18.91	0.696	10.14
17 %	1.62	0.771	18.98	0.694	10.15
20 %	1.63	0.772	18.97	0.693	10.16
25 %	1.59	0.787	18.11	0.697	9.93
33 %	1.54	0.786	17.62	0.697	9.65
50 %	1.43	0.794	16.06	0.703	8.97
100 %	0.03	0.535	0.57	0.692	0.21

*All N719 concentrations are set at 0.4 mM in all mixing solutions except 100 % doping ratio of H-NIM.

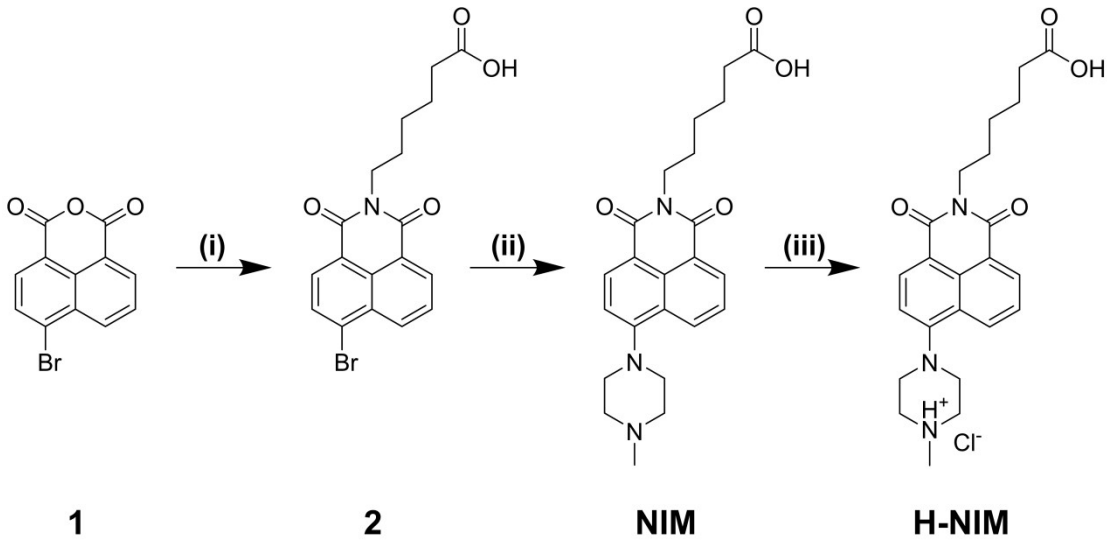
Table S2. Photovoltaic performance of DSSCs with the doping of H-NIM in various doping ratios under T5 fluorescent lamps of 600 lux illumination.

Doping concentration ratio of H-NIM	P_{max} (μW)	V_{OC} (V)	J_{SC} (μA/cm^2)	FF	η (%)
0 %	5.08	0.568	75.74	0.741	16.46
9 %	5.75	0.580	82.53	0.751	18.63
10 %	5.91	0.576	85.40	0.751	19.14
11 %	5.87	0.572	85.47	0.750	19.02
13 %	5.98	0.578	85.91	0.753	19.36
14 %	6.04	0.565	88.90	0.751	19.57
17 %	6.15	0.573	89.20	0.753	19.92
20 %	6.09	0.568	89.21	0.750	19.71
25 %	5.98	0.584	85.08	0.751	19.36
33 %	5.73	0.578	83.17	0.745	18.55
50 %	5.23	0.597	73.60	0.744	16.94
100 %	Not available due to very low values				

*All N719 concentrations are set at 0.4 mM in all mixing solutions except 100 % doping ratio of H-NIM.

Table S3. Photovoltaic performance of DSSCs with various energy relay dyes mixed into electrolytes under one sun (AM 1.5G) illumination.

Sensitizing dye	Energy relay dye	J_{SC} (mA/cm^2)	V_{OC} (mV)	FF	η (%)	Year [Ref.]
TT1	–	6.88	562	0.65	2.55	2009
	13 mM PTCDI	8.78	553	0.66	3.21	[1]
TT1	–	8.32	582	0.72	3.49	2010
	22 mM DCM	10.61	590	0.72	4.51	[2]
SQ1 (SSDSSC)	–	2.98	807	0.58	1.40	2009
	10 mM N877	3.87	786	0.59	1.80	[3]
SQ1	–	7.48	639	0.73	3.51	2010
	10 mM N877	7.98	638	0.72	3.67	[4]
TT1	–	6.79	593	0.73	2.94	2011 [5]
	22 mM DCM	8.53	599	0.72	3.68	
	20 mM RB	7.88	580	0.72	3.29	
	DCM + RB	9.81	579	0.70	3.97	
TT1	–	6.00	623	0.67	2.51	2013 [6]
	180 mM BL302	9.70	640	0.62	3.80	
	180 mM BL315	10.80	640	0.60	4.14	
N719	–	18.34	717	0.72	9.49	2015 [7]
	5 mM DAPI	19.80	745	0.72	10.65	
	5 mM H33342	19.48	740	0.73	10.57	
N3	–	14.60	704	0.69	7.20	
	5 mM DAPI	15.77	722	0.70	7.95	
	5 mM H33342	16.20	719	0.69	8.10	
Ru505	–	11.95	691	0.69	5.70	
	5 mM DAPI	13.20	700	0.70	6.50	
	5 mM H33342	13.45	697	0.67	6.32	
Z907	–	11.53	675	0.75	5.81	
	5 mM DAPI	12.45	683	0.75	6.35	
	5 mM H33342	12.55	678	0.73	6.22	



Scheme S1. Reagents and conditions: (i) 6-aminohexanoic acid, ethanol, reflux, 2 h, (ii) 1-methylpiperazine, ethanol, reflux, 12 h, (iii) $HCl_{(g)}$, DMF/acetone.

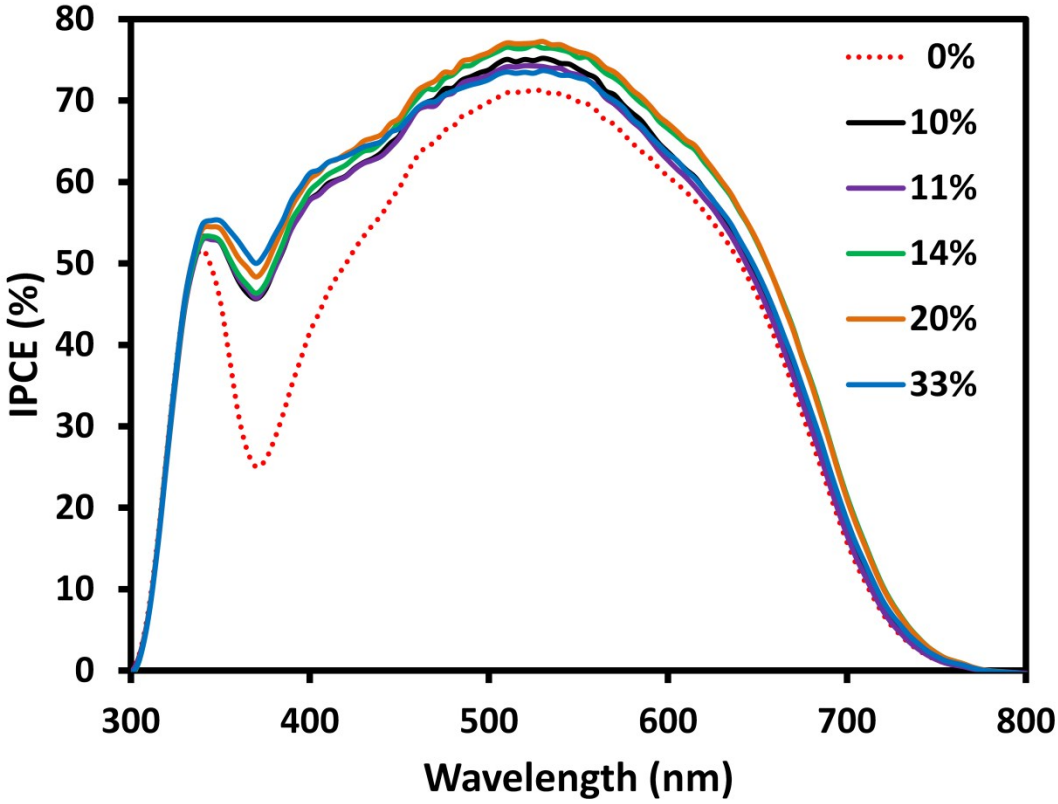


Figure S1. Incident photon to current conversion efficiency (IPCE) spectra of DSSCs with the photoanodes being soaked in various mixing solutions of N719 and H-NIM. The doping concentration ratios of H-NIM in the mixing solutions range from 0 % to 33 % with the concentration of N719 being fixed at 0.4 mM for all mixing solutions.

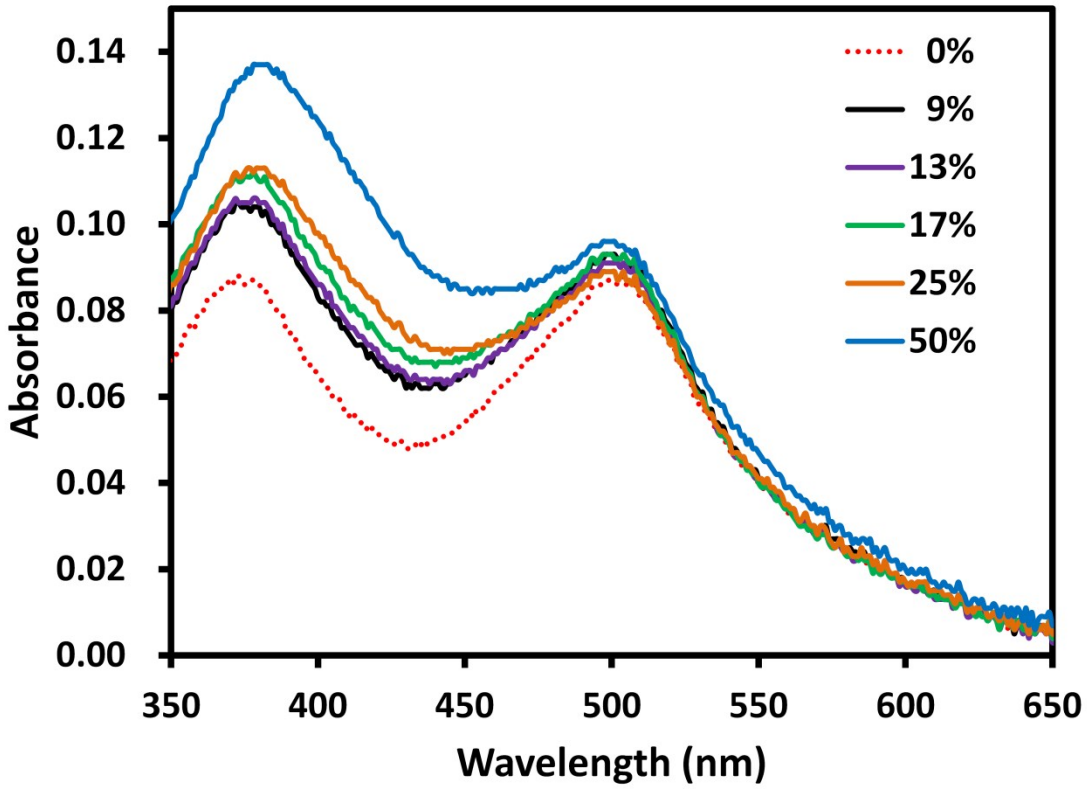


Figure S2. Absorption spectra of the solutions containing the N719 and H-NIM molecules desorbed from the TiO_2 mesoporous films. The desorption process is performed by soaking the dye-loaded TiO_2 photoanodes in a 0.1 M NaOH solution for 3.5 h.

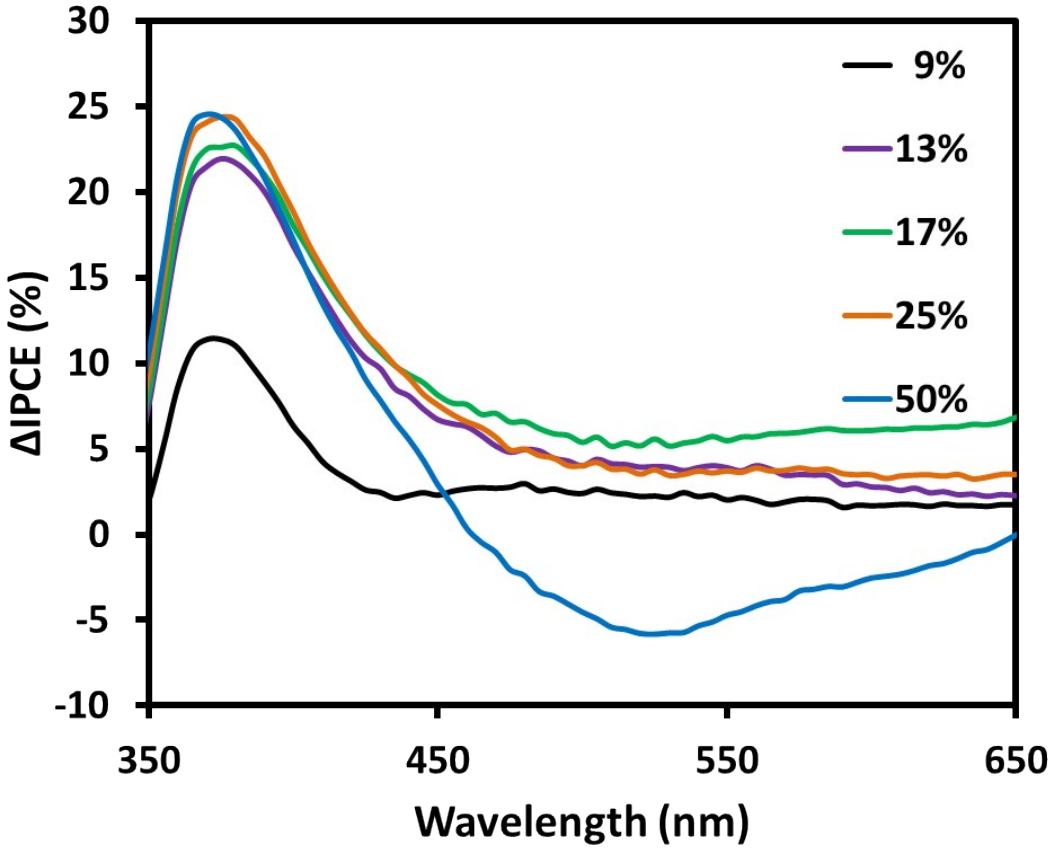


Figure S3. IPCE difference between the DSSC with the doping of H-NIM and that without the doping of H-NIM deduced from the data in Fig. 4.

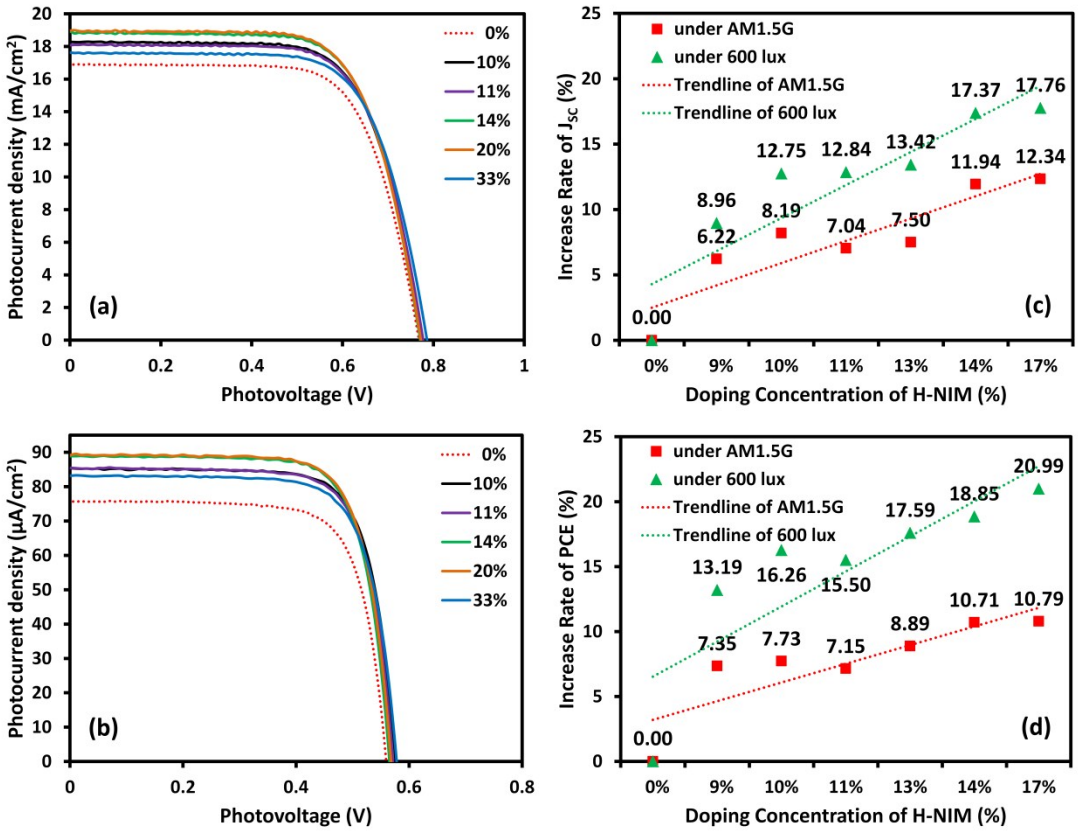
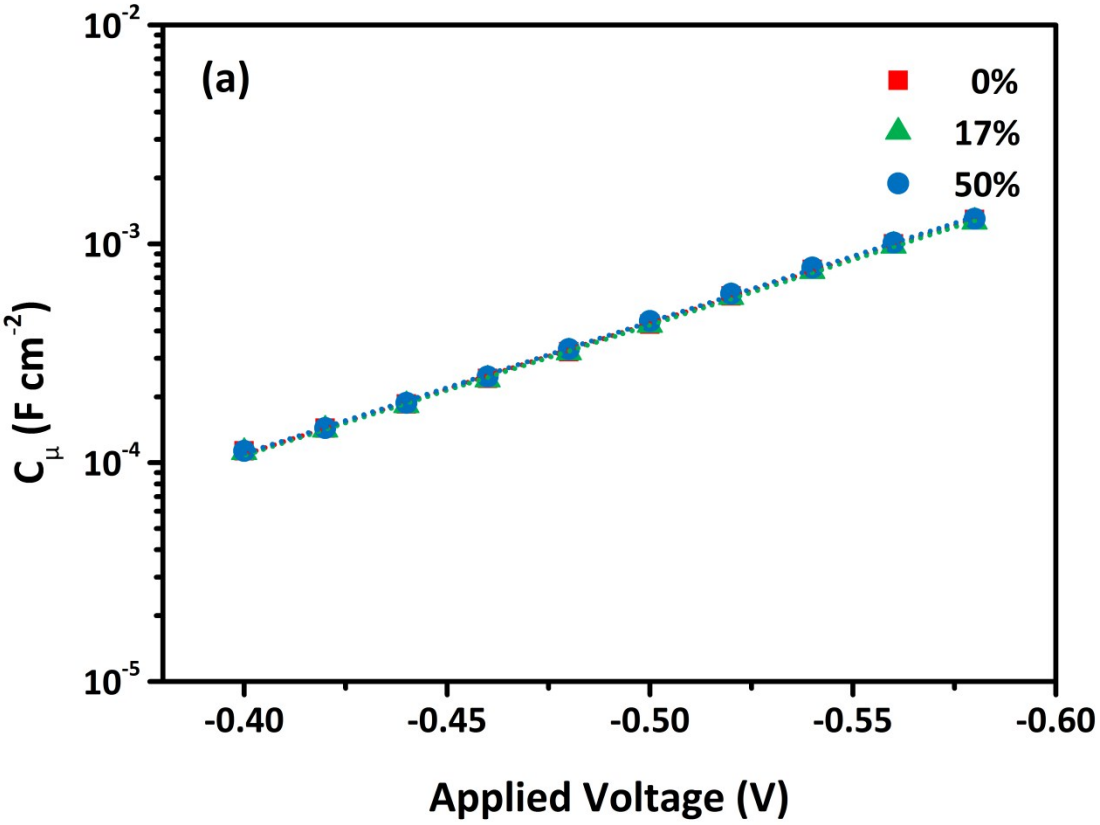
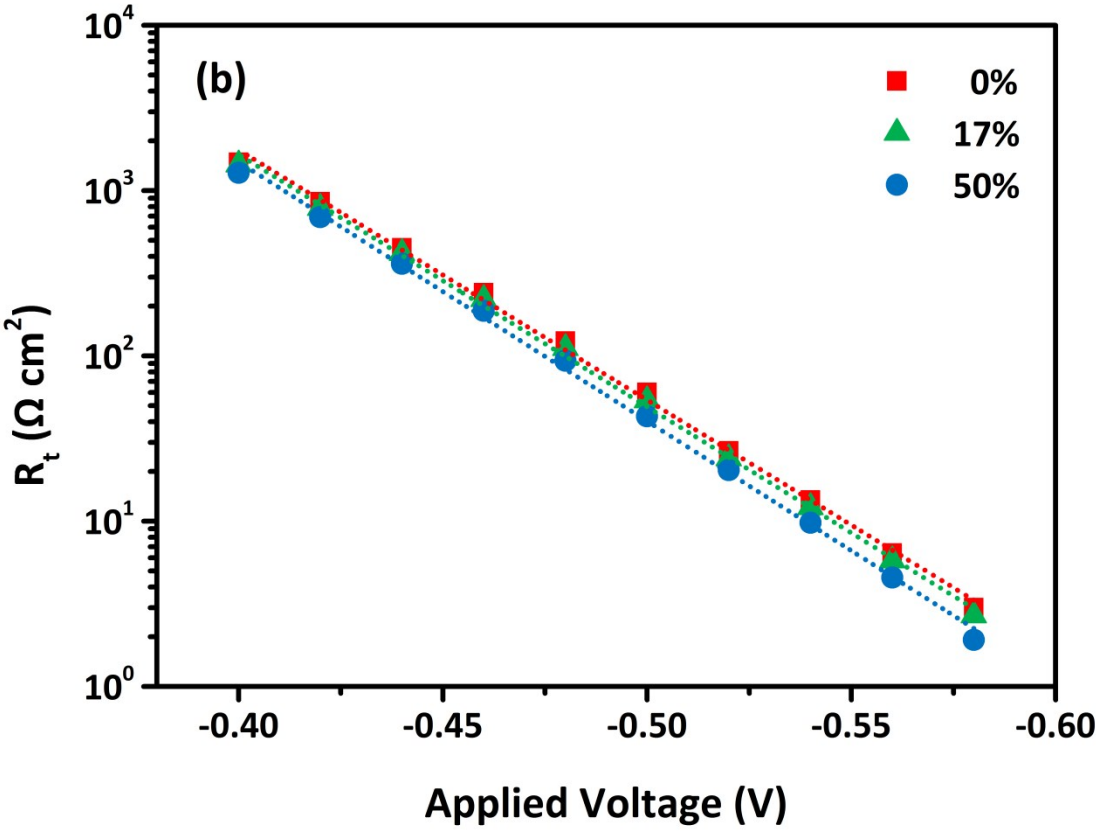


Figure S4. Photocurrent-photovoltage (J-V) curves of DSSCs with the doping of H-NIM fluorophore in the N719-loaded TiO_2 mesoporous films under (a) one sun (AM1.5G) and (b) T5 fluorescent lamps of 600 lux illumination. The increase rates of photocurrent density (J_{SC}) and power conversion efficiency (PCE), calculated from the data in (a) and (b), are shown in (c) and (d), respectively. The dotted trend lines show that the increase rates of J_{SC} and PCE are enhanced with increasing the doping concentration of H-NIM from 0 % to 17 %, and the enhancement is more pronounced for the T5 fluorescent lamps of 600 lux illumination.


(a)
0%
17%
50%
10^{-2}
10^{-3}
10^{-4}
10^{-5}
C_μ (F cm^{-2})
-0.40
-0.45
-0.50
-0.55
-0.60
Applied Voltage (V)


(b)
0%
17%
50%
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
R_t (Ω cm^2)
-0.40
-0.45
-0.50
-0.55
-0.60
Applied Voltage (V)

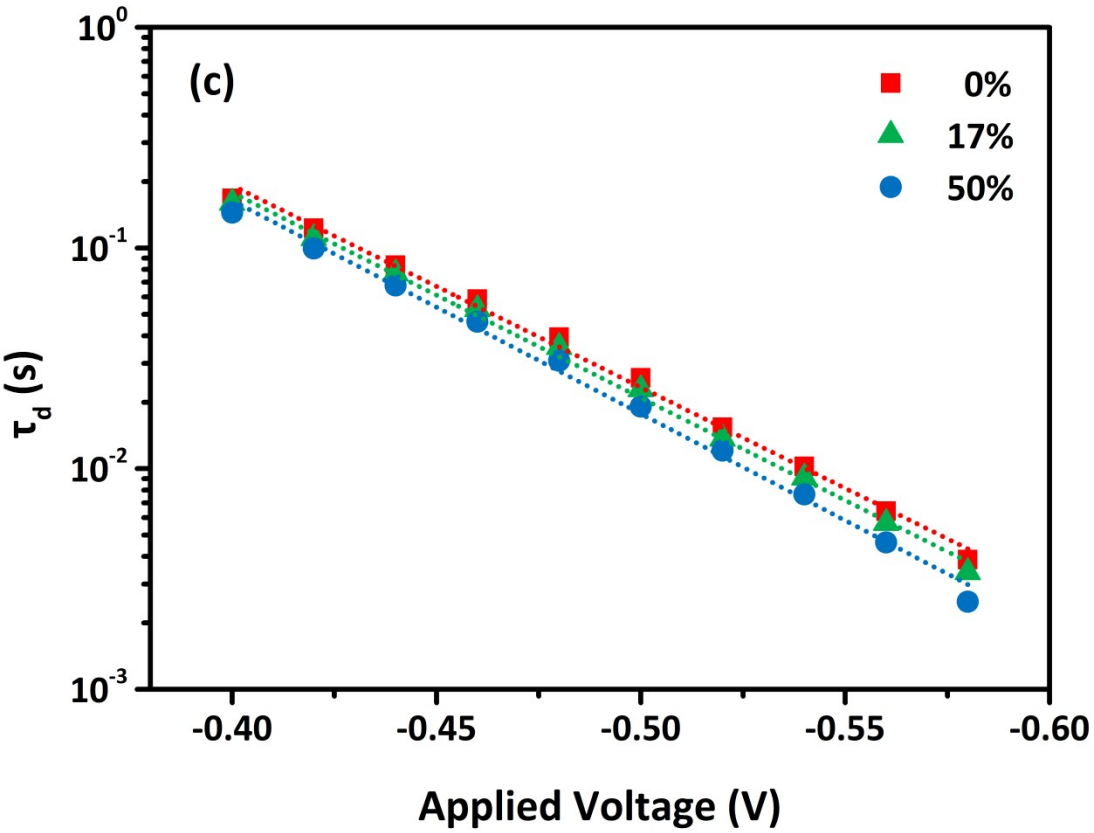


Figure S5. Logarithmic dependence of (a) chemical capacitance, C_μ, (b) transport resistance in the TiO_2 film, R_t, and (c) the transit time of carriers across the TiO_2 active layer, τ_d, with various bias potentials under dark condition.

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