

# Electronic Supplementary Information

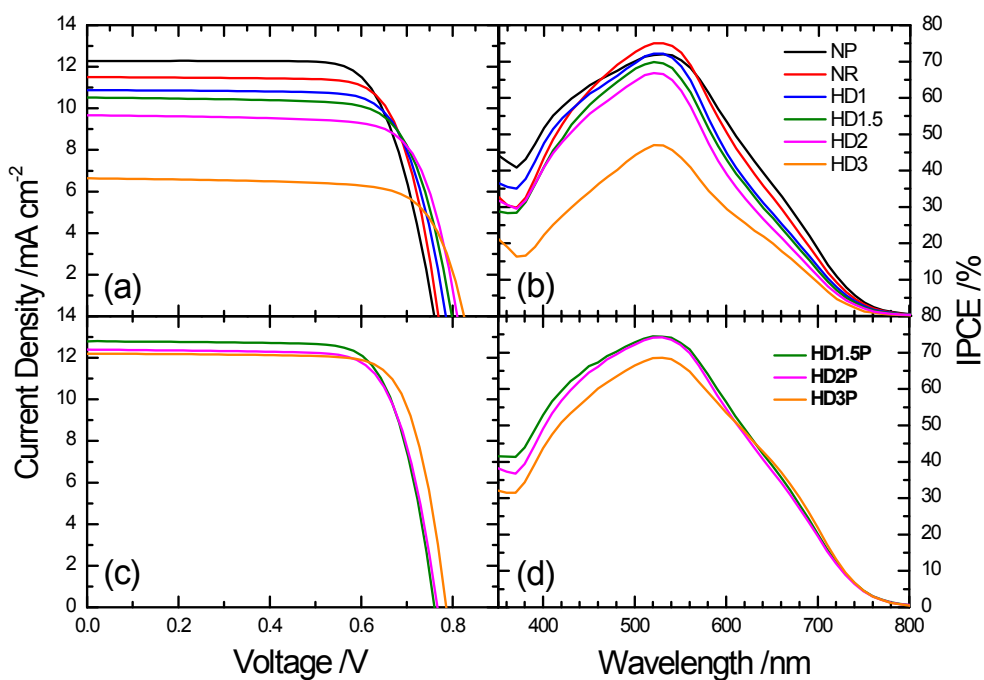
## **Construction of a photoanode with varied TiO<sub>2</sub> nanostructures for a Z907-sensitized solar cell with efficiency exceeding 10 %**

Jia-Wei Shiu, Zih-Jian Lan, Chien-Yi Chan, Hui-Ping Wu and Eric Wei-Guang Diau\*

*Department of Applied Chemistry and Institute of Molecular Science, National Chiao*

*Tung University, No.1001, Ta Hsueh Rd., Hsinchu 30010, Taiwan.*

*e-mail: [diaw@mail.nctu.edu.tw](mailto:diaw@mail.nctu.edu.tw)*



**Figure S1.** Photovoltaic characteristic plots of (a)  $JV$  curves and (b) IPCE action spectra of Z907 devices with titania photoanodes made of NP, NR, HD1, HD1.5, HD2 and HD3 at film thickness  $\sim 10$   $\mu\text{m}$ . The corresponding  $JV$  and IPCE plots for devices made of blended HD1.5P, HD2P and HD3P are shown in (c) and (d), respectively.

**Table S1.** Dye-loading (DL) and photovoltaic parameters of Z907 devices with photoanodes made of varied  $\text{TiO}_2$  nanostructures at the same film thickness ( $L \sim 10$   $\mu\text{m}$ ) under simulated AM-1.5G illumination (power density  $100 \text{ mW cm}^{-2}$ ) and active area  $0.16 \text{ cm}^2$  with a black mask of area  $0.2025 \text{ cm}^2$ .

$\text{TiO}_2$	$L$ / $\mu\text{m}$	DL / $\text{nmol cm}^{-2}$	$J_{\text{sc}}$ / $\text{mA cm}^{-2}$	$V_{\text{oc}}$ / $\text{mV}$	FF	$\eta$ /%
NP	10	121	12.28	763	0.739	6.92
NR	11	87	11.50	773	0.758	6.74
HD1	10	72	10.87	789	0.750	6.43
HD1.5	11	60	10.52	803	0.740	6.25
HD2	10	53	9.66	815	0.749	5.90
HD3	10	33	6.64	823	0.733	4.04
HD1.5P	10	93	12.80	764	0.746	7.30
HD2P	10	86	12.42	770	0.744	7.11
HD3P	10	78	11.94	784	0.750	7.02

**Table S2.** Photovoltaic parameters of devices made of Z907 dye and multi-layer (ML) TiO<sub>2</sub> films with varied film configurations defined as A-D under simulated AM-1.5G illumination (power density 100 mW cm<sup>-2</sup>) and active area 0.16 cm<sup>2</sup> with a black mask of area 0.2025 cm<sup>2</sup>.<sup>a</sup>

Device	TiO <sub>2</sub> film configuration	Working electrode	$J_{SC}$ /mA cm <sup>-2</sup>	$V_{OC}$ /mV	FF	$\eta$ /%
A	2/3/3 <sup>b</sup>	<i>a</i>	18.00	746	0.722	9.70
		<i>b</i>	17.84	750	0.722	9.67
		<i>c</i>	18.11	749	0.711	9.64
		average	17.98±0.11	748±2	0.718±0.005	9.67±0.02
B	2/3/3 <sup>c</sup>	<i>a</i>	17.64	753	0.726	9.64
		<i>b</i>	17.53	756	0.720	9.54
		<i>c</i>	17.55	752	0.720	9.51
		average	17.57±0.05	754±2	0.722±0.003	9.56±0.06
C	2/2/1/3 <sup>d</sup>	<i>a</i>	17.46	755	0.722	9.52
		<i>b</i>	17.37	756	0.724	9.51
		<i>c</i>	17.45	756	0.720	9.51
		average	17.43±0.04	756±0	0.722±0.002	9.51±0.00
D	2/3/3 <sup>e</sup>	<i>a</i>	17.14	765	0.731	9.59
		<i>b</i>	16.91	765	0.737	9.54
		<i>c</i>	16.98	765	0.736	9.54
		average	17.01±0.10	765±0	0.735±0.003	9.56±0.02

<sup>a</sup> All TiO<sub>2</sub> working electrodes (labeled as *a-c*) were fabricated under the same experimental conditions; the uncertainties represent one standard deviation. <sup>b</sup> The TiO<sub>2</sub> film has ML configuration NP/NR/SL. <sup>c</sup> The TiO<sub>2</sub> film has ML configuration NP/HD1/SL. <sup>d</sup> The TiO<sub>2</sub> film has ML configuration NP/HD1/HD1.5/SL. <sup>e</sup> The TiO<sub>2</sub> film has ML configuration NP/HD1.5/SL.

**Table S3.** Photovoltaic parameters of devices made of Z907 dye and multi-layer (ML) TiO<sub>2</sub> films with varied film configurations defined as E-H under simulated AM-1.5G illumination (power density 100 mW cm<sup>-2</sup>) and active area 0.16 cm<sup>2</sup> with a black mask of area 0.2025 cm<sup>2</sup>.<sup>a</sup>

Device	TiO <sub>2</sub> film configuration <sup>b</sup>	Working electrodes	$J_{SC}$ /mA cm <sup>-2</sup>	$V_{OC}$ /mV	FF	$\eta$ /%
E	2/1/1/3	<i>a</i>	17.09	758	0.751	9.74
		<i>b</i>	17.36	758	0.738	9.71
		<i>c</i>	17.26	759	0.739	9.69
		average	17.24±0.11	758±0	0.743±0.006	9.71±0.02
F	2/1/2/3	<i>a</i>	17.88	750	0.736	9.87
		<i>b</i>	17.63	755	0.740	9.85
		<i>c</i>	18.02	751	0.721	9.76
		average	17.84±0.16	752±2	0.732±0.008	9.82±0.05
G	2/1/3/3	<i>a</i>	18.30	748	0.728	9.97
		<i>b</i>	18.22	749	0.724	9.88
		<i>c</i>	18.00	749	0.730	9.83
		average	18.17±0.13	749±0	0.727±0.002	9.89±0.06
H	2/1/4/3	<i>a</i>	17.44	744	0.743	9.72
		<i>b</i>	17.55	744	0.738	9.64
		<i>c</i>	17.35	742	0.747	9.61
		average	17.45±0.08	743±1	0.743±0.004	9.66±0.05

<sup>a</sup> All TiO<sub>2</sub> working electrodes (labeled as *a-c*) were fabricated under the same experimental conditions; the uncertainties represent one standard deviation. <sup>b</sup> The TiO<sub>2</sub> films have ML configuration NP/HD1.5P/HD2P/SL with varied number of layers of HD2P.

**Table S4.** Photovoltaic parameters of devices made of Z907 dye and TiO<sub>2</sub> films with the HD1/SL bi-layer (BL) configuration defined as I-M under simulated AM-1.5G illumination (power density 100 mW cm<sup>-2</sup>) and active area 0.16 cm<sup>2</sup> with a black mask of area 0.2025 cm<sup>2</sup>.<sup>a</sup>

Device	TiO <sub>2</sub> film configuration <sup>b</sup>	Working electrode	$J_{SC}$ /mA cm <sup>-2</sup>	$V_{OC}$ /mV	FF	$\eta$ /%
I	3/3	<i>a</i>	16.69	778	0.747	9.71
		<i>b</i>	16.58	778	0.748	9.64
		<i>c</i>	16.52	782	0.746	9.64
		average	16.60±0.07	779±2	0.747±0.001	9.66±0.03
J	4/3	<i>a</i>	17.10	775	0.741	9.82
		<i>b</i>	16.79	776	0.747	9.73
		<i>c</i>	17.08	774	0.736	9.72
		average	16.99±0.14	775±1	0.741±0.004	9.76±0.04
K	5/3	<i>a</i>	17.49	770	0.733	9.87
		<i>b</i>	17.35	766	0.739	9.83
		<i>c</i>	17.24	767	0.740	9.79
		average	17.36±0.10	768±2	0.737±0.003	9.83±0.03
L	6/3	<i>a</i>	17.66	760	0.740	9.94
		<i>b</i>	17.76	763	0.734	9.92
		<i>c</i>	17.83	757	0.735	9.91
		average	17.75±0.07	760±2	0.736±0.003	9.92±0.01
M	7/3	<i>a</i>	17.73	756	0.738	9.89
		<i>b</i>	17.59	758	0.740	9.87
		<i>c</i>	17.37	756	0.751	9.86
		average	17.56±0.15	757±1	0.743±0.006	9.87±0.01

<sup>a</sup> All TiO<sub>2</sub> working electrodes (labeled as *a-c*) were fabricated under the same experimental conditions; the uncertainties represent one standard deviation. <sup>b</sup> The TiO<sub>2</sub> films have BL configuration HD1/SL with varied number of layers of HD1.

**Table S5.** Photovoltaic parameters of 20 Z907 devices fabricated according to the HDP-ML film configuration of device G under simulated AM-1.5G illumination (power density  $100 \text{ mW cm}^{-2}$ ) and active area  $0.16 \text{ cm}^2$  with a black mask of area  $0.2025 \text{ cm}^2$ .<sup>a</sup>

Working electrode	$J_{SC}$ / $\text{mA cm}^{-2}$	$V_{OC}$ / $\text{mV}$	FF	$\eta$ / $\%$	$\eta_s^b$ / $\%$	Counts
1	17.46	759	0.743	9.85	9.85	1
2	17.55	761	0.743	9.92	9.90	1
3	17.44	756	0.753	9.93	9.95	3
4	17.90	752	0.741	9.97	9.95	
5	18.30	748	0.728	9.97	9.95	
6	17.79	751	0.747	9.98	10.00	8
7	17.66	753	0.751	9.99	10.00	
8	17.39	758	0.758	9.99	10.00	
9	17.45	761	0.752	9.99	10.00	
10	17.41	758	0.757	9.99	10.00	
11	18.29	757	0.723	10.01	10.00	
12	17.55	762	0.749	10.02	10.00	
13	17.99	750	0.743	10.02	10.00	
14	18.21	758	0.727	10.03	10.05	5
15	18.32	757	0.724	10.04	10.05	
16	17.66	756	0.752	10.04	10.05	
17	18.21	753	0.733	10.05	10.05	
18	18.30	750	0.734	10.07	10.05	
19	18.32	755	0.729	10.08	10.10	1
20	18.63	752	0.723	10.13	10.15	1
average	$17.89 \pm 0.39$	$755 \pm 4$	$0.741 \pm 0.012$	$10.00 \pm 0.06$	$10.01 \pm 0.07$	Total = 20

<sup>a</sup> All  $\text{TiO}_2$  working electrodes (labeled as 1-20) were fabricated under the same experimental conditions; the uncertainties represent one standard deviation. <sup>b</sup> The efficiencies were rounded up or down in a step 0.05 % to make the distribution plot shown in Figure 7a.

**Table S6.** Photovoltaic parameters of 20 Z907 devices fabricated according to the HD1-BL film configuration of device L under simulated AM-1.5G illumination (power density  $100 \text{ mW cm}^{-2}$ ) and active area  $0.16 \text{ cm}^2$  with a black mask of area  $0.2025 \text{ cm}^2$ .<sup>a</sup>

Working electrode	$J_{sc}$ / $\text{mA cm}^{-2}$	$V_{oc}$ / $\text{mV}$	FF	$\eta$ /%	$\eta_s^b$ /%	Counts
1	17.67	765	0.730	9.87	9.85	1
2	17.70	763	0.734	9.91	9.90	1
3	17.52	769	0.738	9.94	9.95	3
4	17.54	762	0.746	9.97	9.95	
5	17.20	771	0.752	9.97	9.95	
6	17.46	765	0.748	9.99	10.00	5
7	17.54	763	0.747	10.00	10.00	
8	17.75	758	0.743	10.00	10.00	
9	17.58	769	0.740	10.00	10.00	
10	17.61	764	0.745	10.02	10.00	
11	17.79	763	0.739	10.03	10.05	5
12	17.66	759	0.749	10.04	10.05	
13	17.57	762	0.751	10.05	10.05	
14	17.71	762	0.746	10.07	10.05	
15	17.97	759	0.738	10.07	10.05	
16	17.59	761	0.753	10.08	10.10	3
17	17.71	762	0.748	10.09	10.10	
18	17.72	765	0.745	10.10	10.10	
19	17.77	763	0.750	10.17	10.15	1
20	17.88	758	0.753	10.21	10.20	1
average	$17.65 \pm 0.16$	$763 \pm 3$	$0.745 \pm 0.006$	$10.03 \pm 0.08$	$10.03 \pm 0.08$	Total = 20

<sup>a</sup> All  $\text{TiO}_2$  working electrodes (labeled as 1-20) were fabricated under the same experimental conditions; the uncertainties represent one standard deviation. <sup>b</sup> The efficiencies were rounded up or down in a step 0.05 % to make the distribution plot shown in Figure 7b.