**Electronic Supplementary Information (ESI)** 

## Development of WS<sub>2</sub>/MoTe<sub>2</sub> heterostructure as a counter electrode for the improved performance in dye-sensitized solar cells

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Figure S1 (a) Optical image of the S3  $WS_2/MoTe_2$  with the area of 1 ×10 cm<sup>2</sup>; (b-d) FESEM image of the blue, orange and yellow line indicated sites.



**Figure S2. (a)** FESEM image of WS<sub>2</sub>/MoTe<sub>2</sub> heterostructures and **(b-f)** their elemental mapping images; (b) Sn; (c) Mo; (d) W; (e) S and (f) Te elements.



**Figure S3**. (a) FESEM image of MoTe<sub>2</sub> film and (b-d) their elemental mapping images (b) Sn; (c) Mo; (d) Te; elements. (e) FESEM image of WS<sub>2</sub> film and (f-h) their elemental mapping images (f) Sn (g) W (h) S elements.



**Figure S4.** (a) Raman analysis performed at the different places indicated as 1 to 5 on largesized S3; and (b) their Raman spectra.



Figure S5. Raman mapping of S3 WS<sub>2</sub>/MoTe<sub>2</sub> heterostructure over an area of 50  $\mu$ m × 50  $\mu$ m for (a) A<sub>1g</sub>, (b) E<sub>2g</sub> and (c) A<sub>g</sub> modes of vibration.



**Figure S6.** XPS survey spectra of  $WS_2/MoTe_2$  heterostructure (a) before etching (0 s) and (b) after etching (344 s sputter time).



**Figure S7**. Photocurrent density versus photovoltage (J-V) curves of DSSC with MoTe<sub>2</sub> and WS<sub>2</sub> as a counter electrode. (RSC Adv., 2015, 5, 103567-103572) & (Scientific Reports (2018) 8:29 DOI:10.1038/s41598-017-18067-6).

Table S1. DSSC	parameters of	$WS_2$ and	MoTe <sub>2</sub> CEs.
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Type of CE	V <sub>oc</sub> (V)	J <sub>sc</sub> (mA cm <sup>-2</sup> )	FF	PCE (η)%
MoTe <sub>2</sub>	0.69	16.00	65.64	7.25
WS <sub>2</sub>	0.71	13.17	66.01	6.3



Figure S8. (a) Cross-sectional image of sample S4. (b) J-V curve of sample S4.

<b>Table S2.</b> DSSC parameters of sample S4 CE.	
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Type of CE	V <sub>oc</sub> (V)	J <sub>sc</sub> (mA cm <sup>-2</sup> )	FF	PCE (η)%
<b>S</b> 4	0.84	13.22	54.45	6.07



Figure S9. (a) Cross-sectional image of sample S5. (b) J-V curve of sample S5.

Table S3. DSSC	parameters of	sample S5 CE.
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Type of CE	V <sub>oc</sub> (V)	J <sub>sc</sub> (mA cm <sup>-2</sup> )	FF	PCE (η)%
<b>S</b> 5	0.75	15.93	62.37	7.53



Figure S10. (a) Cross-sectional image of sample S6. (b) J-V curve of sample S6.

Type of CE	V <sub>oc</sub> (V)	J <sub>sc</sub> (mA cm <sup>-2</sup> )	FF	PCE (η)%
<b>S6</b>	0.74	16.65	60.0	7.40



**Figure S11.** Durability test of 120 consecutive CVs for the  $I^-/I_3^-$  redox behavior using the S3 CE

at a scan rate of 10 mV s<sup>-1</sup>.