Synthesis of $MoS_{2(1-x)}Se_{2x}$ and $WS_{2(1-x)}Se_{2x}$ alloy for enhanced hydrogen evolution reaction performance

Sajjad Hussain^{a,b}, Kamran Akbar^{a,c}, Dhanasekaran Vikraman^d, K. Karuppasamy^d, Hyun-Seok Kim^d, Seung-Hyun Chun^{a,c}, and Jongwan Jung^{*a,b}

^aGraphene Research Institute, Sejong University, Seoul 05006, Republic of Korea

^bInstitute of Nano and Advanced Materials Engineering, Sejong University, Seoul 05006,

Republic of Korea

^cDepartment of Physics, Sejong University, Seoul 05006, Republic of Korea.

^dDivision of Electronics and Electrical Engineering, Dongguk University-Seoul, Seoul 04620,

Republic of Korea

* Corresponding author, E-mail: jwjung@sejong.ac.kr

Table S1. Comparison of electrochemical parameters for different electrocatalysts by using Pt as counter electrode.

Sample	Overpotential (mV vs RHE) @ 10 mA·cm ⁻²	Tafel slope (mV∙decade ⁻¹)	Exchange current Density (j _o , mA·cm ⁻²)
Pt	40	52	3.01
MoS ₂	252	87	1.23 x 10 ⁻²
MoS _{2(1-x)} Se _{2x}	141	79	2.04 x 10 ⁻¹
WS ₂	283	134	6.36 x 10 ⁻²
WS _{2(1-x)} Se _{2x}	167	108	2.63 x 10 ⁻¹

1-1					Spectrum	13
(a)	Eleme	ent	Weight	%		
	CK		6.95			
	ΟK		13.78			
	SK		18.76			
	Se L		10.84			
	Mo L		13.09			
് ക് ത	Sn L	Sn L 36.58				
Sat I	Total		100.00			
M. Tal.						
0 2	4 6	8	10	12	14	16
Full Scale 17467 cts i	Cursor: 0.000					ke∀
	Elom	ant	Moight	F0/	Spectru	ım 1
(b)	Elem	ent	Weight	t%	Spectru	ım 1
(b)	Elemo C K	ent	Weight 6.82	t%	Spectru	ım 1
(b)	Elemo C K O K	ent	Weight 6.82 13.68	t%	Spectru	ım 1
(b)	Elemo C K O K S K	ent	Weight 6.82 13.68 19.42	t%	Spectru	ım 1
(b)	Elemo C K O K S K Se L	ent	Weight 6.82 13.68 19.42 10.78	t%	Spectru	ım 1
(b) §	Elemo C K O K S K Se L W L	ent	Weight 6.82 13.68 19.42 10.78 12.63	t%	Spectru	ım 1
(b)	Elemo C K O K S K Se L W L Sn L	ent	Weight 6.82 13.68 19.42 10.78 12.63 36.67	t%	Spectru	ım 1
(b) S S S	Elemo C K O K S K Se L W L Sn L Total	ent	Weight 6.82 13.68 19.42 10.78 12.63 36.67 100.00	t%	Spectru	ım 1
(b)	Elemo C K O K S K Se L W L Sn L Total	ent Ø	Weight 6.82 13.68 19.42 10.78 12.63 36.67 100.00	t%	Spectru	im 1
(b)	Elemo C K O K S K Se L W L Sn L Total	ent P	Weight 6.82 13.68 19.42 10.78 12.63 36.67 100.00	t%	Spectru	im 1 16

Figure S1 (a-b). EDS spectra of elemental composition for (a) $MoS_{2(1-x)}Se_{2x}$ and (b) $WS_{2(1-x)}Se_{2x}$ alloys.



Figure S2. (a) FESEM image of MoS_2 and (b-e) their elemental mapping images (b) O (c) Sn (d) Mo and (e) S elements.



Figure S3. (a) FESEM image of $MoS_{2(1-x)}Se_{2x}$ alloy and (b-f) their elemental mapping images (b) O, (c) Sn, (d) S, (e) Mo and (f) Se elements.



Figure S4. (a) FESEM image of WS₂ and (b-e) their elemental mapping images (b) O (c) Sn (d) W and (e) S elements.



Figure S5. (a) FESEM image of $WS_{2(1-x)}Se_{2x}$ alloy and (b-f) their elemental mapping images (b) O, (c) Sn, (d) S, (e) W and (f) Se elements.



Figure S6. (a) TEM cross-sectional micrograph and (b) zoom-in view of $FTO/MoS_{2(1-x)}Se_{2x}$ structure. (c-f) TEM cross-sectional micrograph and its elemental mapping images (d) Mo, (e) S and (f) Se elements for $MoS_{2(1-x)}Se_{2x}$.



Figure S7. (a) TEM cross-sectional micrograph and (b) zoom-in view of $FTO/WS_{2(1-x)}Se_{2x}$ structure. (c-f) TEM cross-sectional micrograph and its elemental mapping images (d) W, (e) S and (f) Se elements for $WS_{2(1-x)}Se_{2x}$.



Figure S8. Polarization curves of $MoS_{2(1-x)}Se_{2x}$ film prepared using 30 min and 1 h post-annealing time in selenium environment at 500°C.



Figure S9. Polarization curves of $WS_{2(1-x)}Se_{2x}$ film prepared using 30 min and 1 h post-annealing time in selenium environment at 500°C.



Figure S10. Stability test for $MoS_{2(1-x)}Se_{2x}$ and $WS_{2(1-x)}Se_{2x}$ alloy catalyst. (a-b) Polarization curves of $MoS_{2(1-x)}Se_{2x}$ and $WS_{2(1-x)}Se_{2x}$ alloy catalysts for before and after 20h HER performance.



Figure S11. FE-SEM and EDS element analysis after 20 h HER operation. (a, c) $MoS_{2(1-x)}Se_{2x}$ and (b, d) $WS_{2(1-x)}Se_{2x}$ alloys.