Electronic Supplementary Material (ESI) for Nanoscale.
This journal is © The Royal Society of Chemistry 2020

Supporting Information

Rapid and mass-producible synthesis of high-crystallinity $MoSe_2$ nanosheets by ampoule-loaded chemical vapor deposition

Na Liu,[a] Woong Choi,[b] Hyeongi Kim,[c] Chulseung Jung,[a] Jeonghun Kim,[a] Soo Ho Choo,[a] Yena Kwon,[a] Byeong-Seon An,[a] Seongin Hong,[a] Seongjoon So,[c] Cheol-Woong Yang,*[a] Jaehyun Hur *[c] and Sunkook Kim *[a]

[a] *School of Advanced Materials Science and Engineering, Sungkyunkwan University, Suwon, 16419, Republic of Korea*

[b] *School of Advanced Materials Engineering, Kookmin University, Seoul, 02707, Republic of Korea*

[c] *Department of Chemical and Biological Engineering, Gachon University, Seongnam-si, Gyeonggi, 13120, Republic of Korea*

*Corresponding authors.

E-mail address: cwyang@skku.edu (C.-W. Yang), jhhur@gachon.ac.kr (J. Hur), seonkuk@skku.edu (S. Kim).

† N. Liu and W. Choi contributed equally to the work.

Keywords: Transition-metal dichalcogenides, Molybdenum diselenide, Chemical vapor deposition, Rapid growth, Mass-production

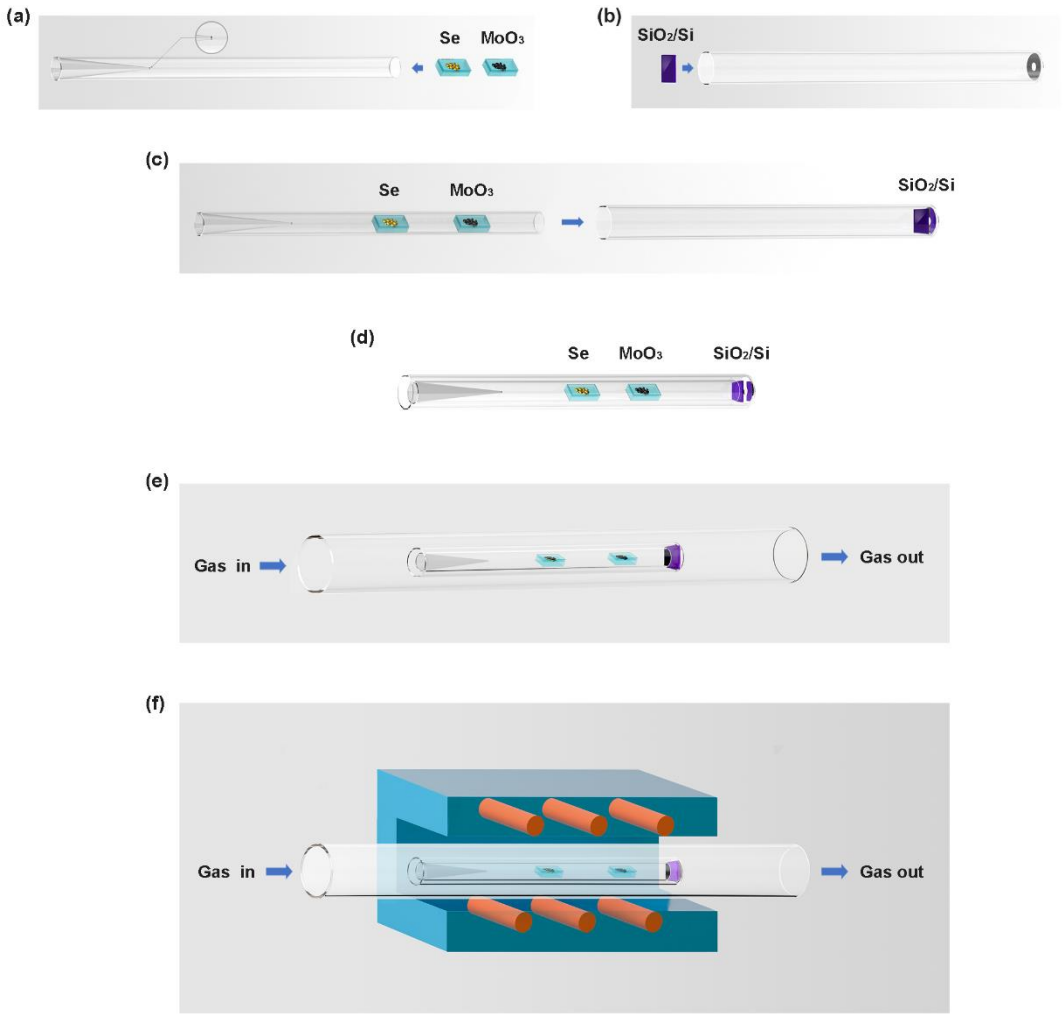


Fig. S1. (a) Put MoO_3 and Se powder into quartz tube I. (b) Put a Si substrate into quartz tube II. (c) Insert quartz tube I into quartz tube II horizontally. (d) Quartz-tube assembly. (e) Place quartz-tube assembly at the center of CVD furnace. (f) CVD growth setup for $MoSe_2$.

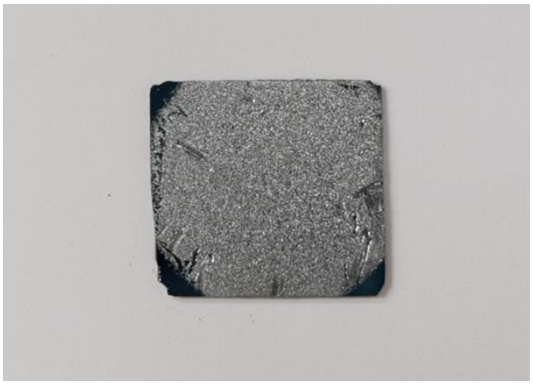
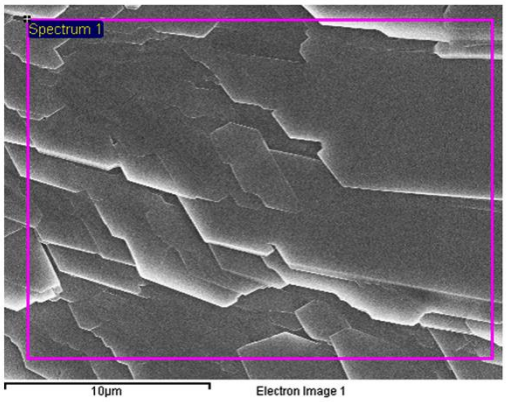
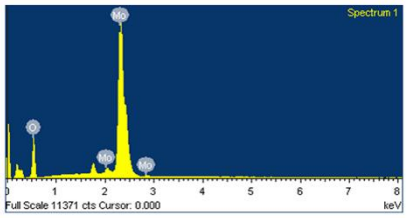


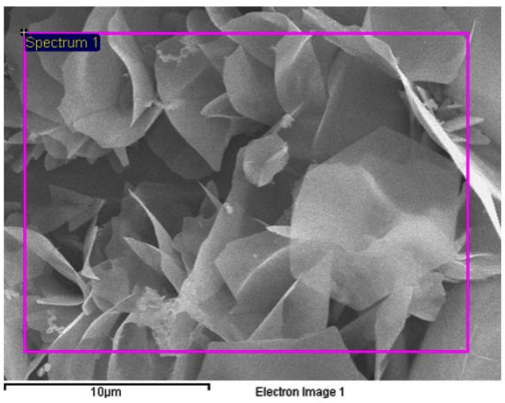
Fig. S2. Picture of a pressed 60-min CVD-grown $MoSe_2$ on SiO_2 substrates.

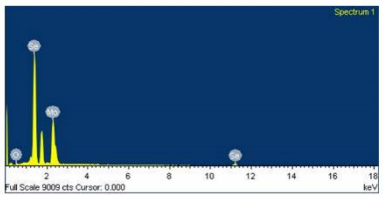




Element	Atomic%
O K	73.86
Mo L	26.14
Totals	100

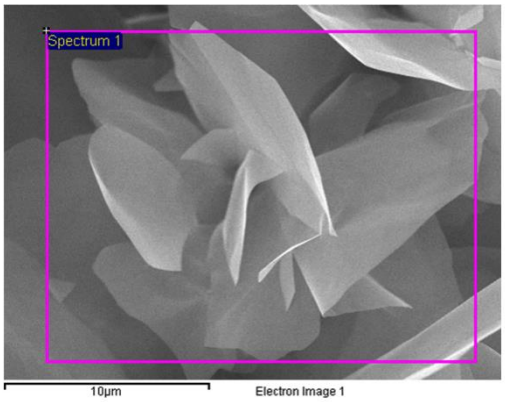
Fig. S3. EDS spectra of 5-min growing sample.

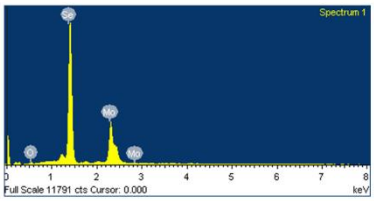




Element	Atomic%
O K	10.09
Se L	51.41
Mo L	38.50
Totals	100

Fig. S4. EDS spectra of 15-min growing sample.





Element	Atomic%
O K	9.93
Se L	57.44
Mo L	32.63
Totals	100

Fig. S5. EDS spectra of 30-min growing sample.

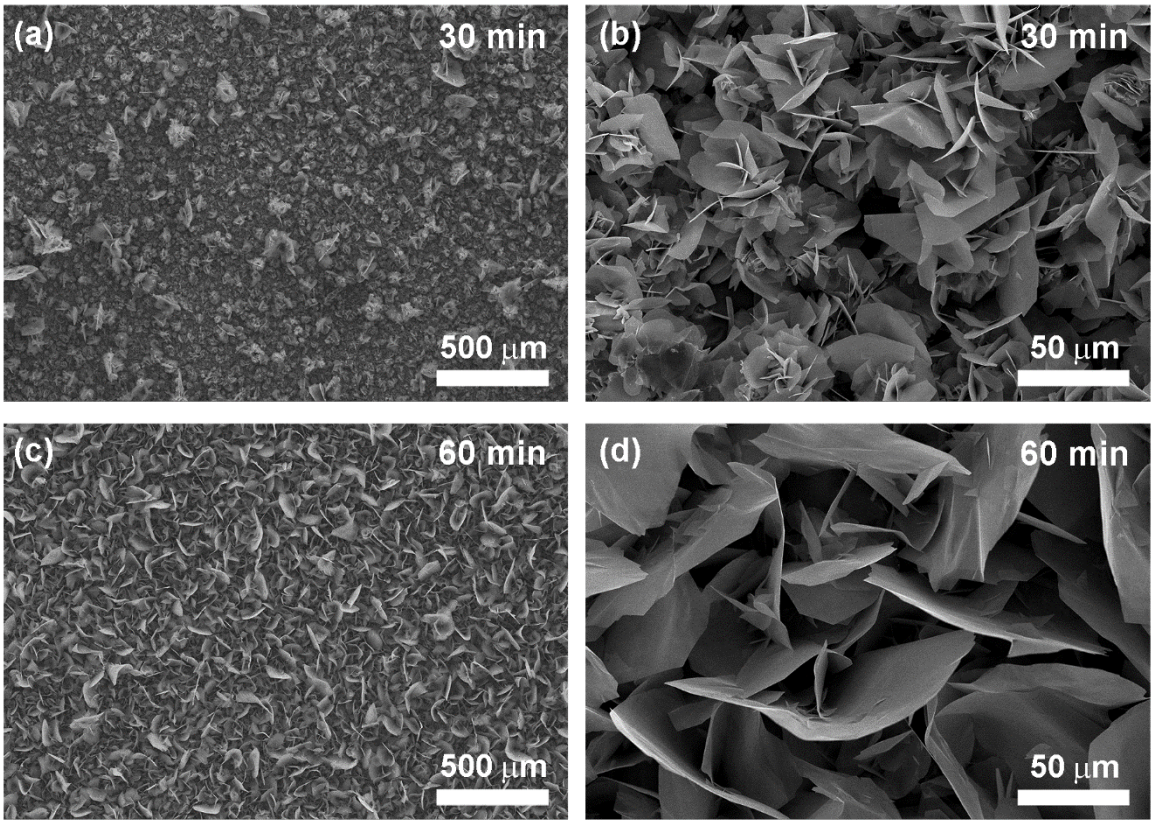


Fig. S6. SEM images of the CVD-grown $MoSe_2$ on SiO_2 substrates with the growth time of (a-b) 30 and (c-d) 60 min in different magnification, respectively.

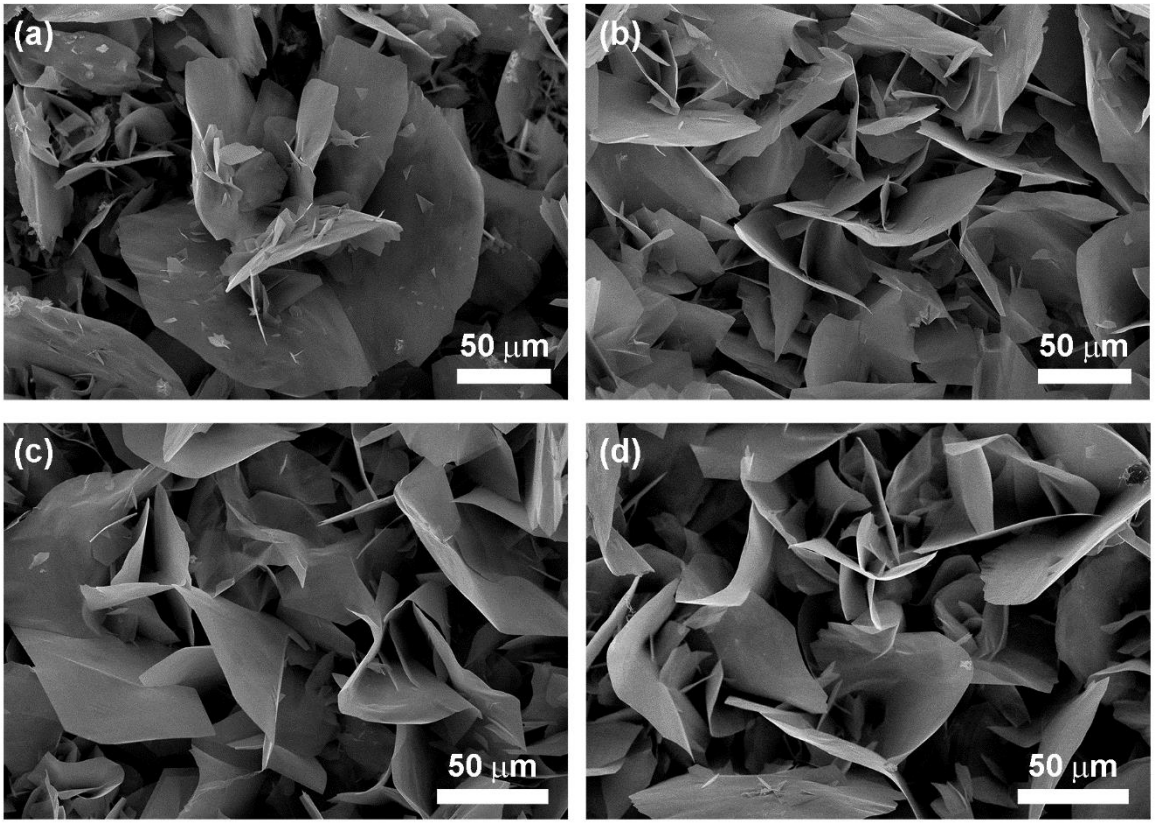


Fig. S7. (a-d) More SEM images of the 60-min CVD-grown $MoSe_2$.

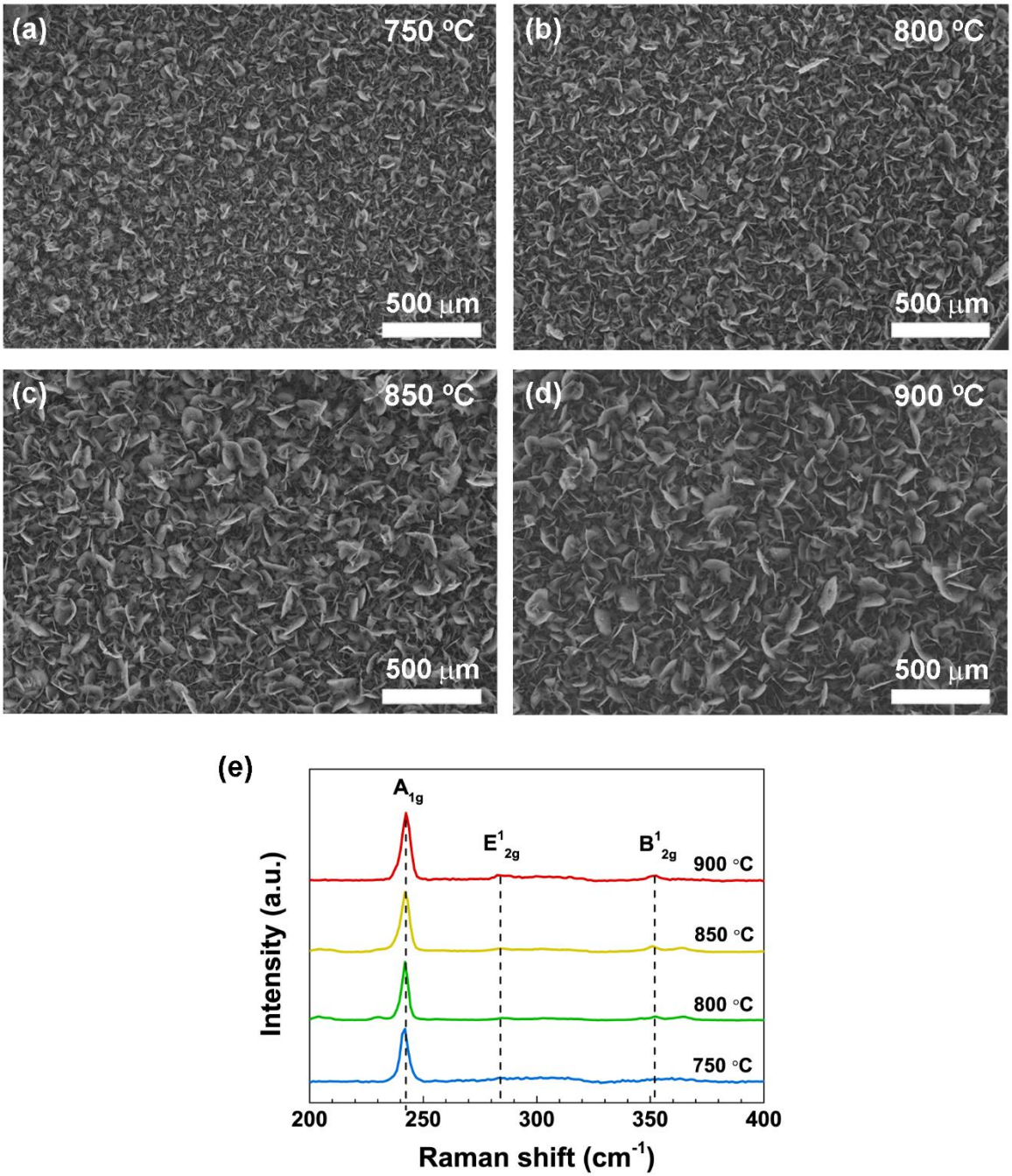


Fig. S8. (a-d) SEM images and (e) Raman spectrum of the CVD-grown $MoSe_2$ with the growth temperature of 750, 800, 850, and 900 ℃, respectively.

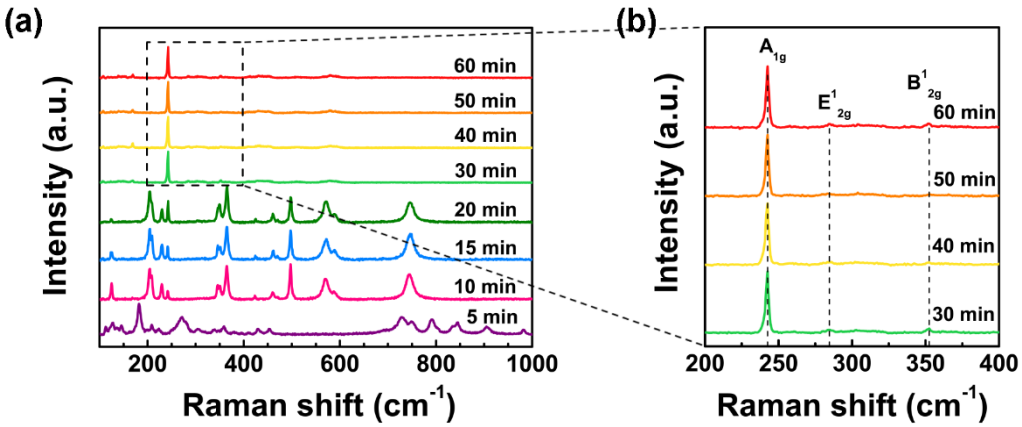


Fig. S9. (a) Raman spectra of CVD-grown crystals at growth times of 5 to 60 min. (b) Raman spectra of the part of marked in the black dashed box in (a).

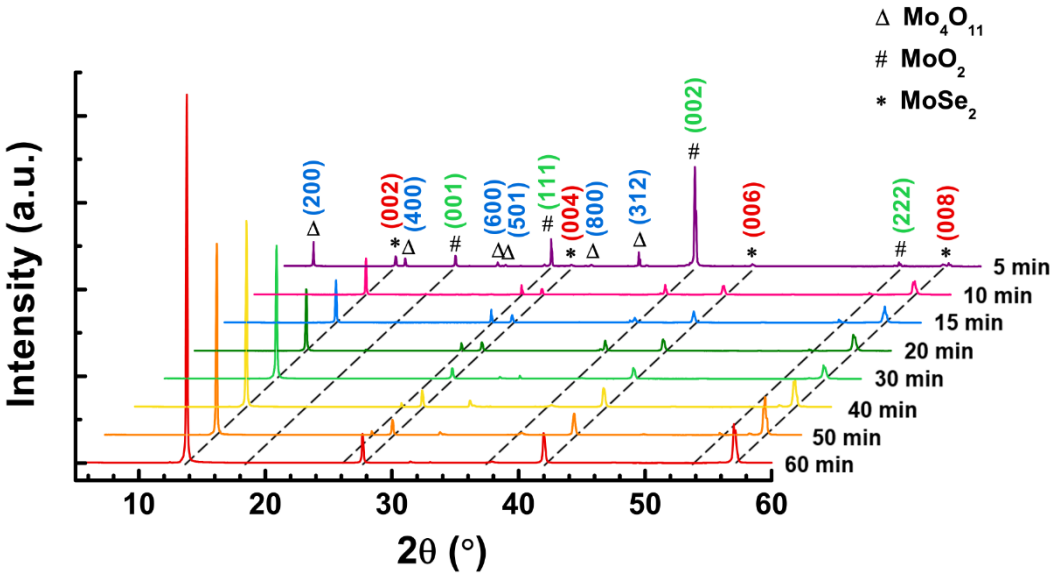


Fig. S10. XRD spectra of CVD-grown crystals at growth times of 5 to 60 min.

Table S1. XRD peaks positions and corresponding patterns in Figs. 2b and S9.

	Peak position (°) (Pattern)					
Mo_4O_{11}	7.3 (200)	14.5 (400)	21.8 (600)	22.5 (501)	29.2 (800)	33.0 (312)
MoO_2	18.5 (001)	26.1 (111)	37.4 (002)	53.7 (222)		
$MoSe_2$	13.8 (002)	27.7 (004)	42.0 (006)	57.0 (008)		

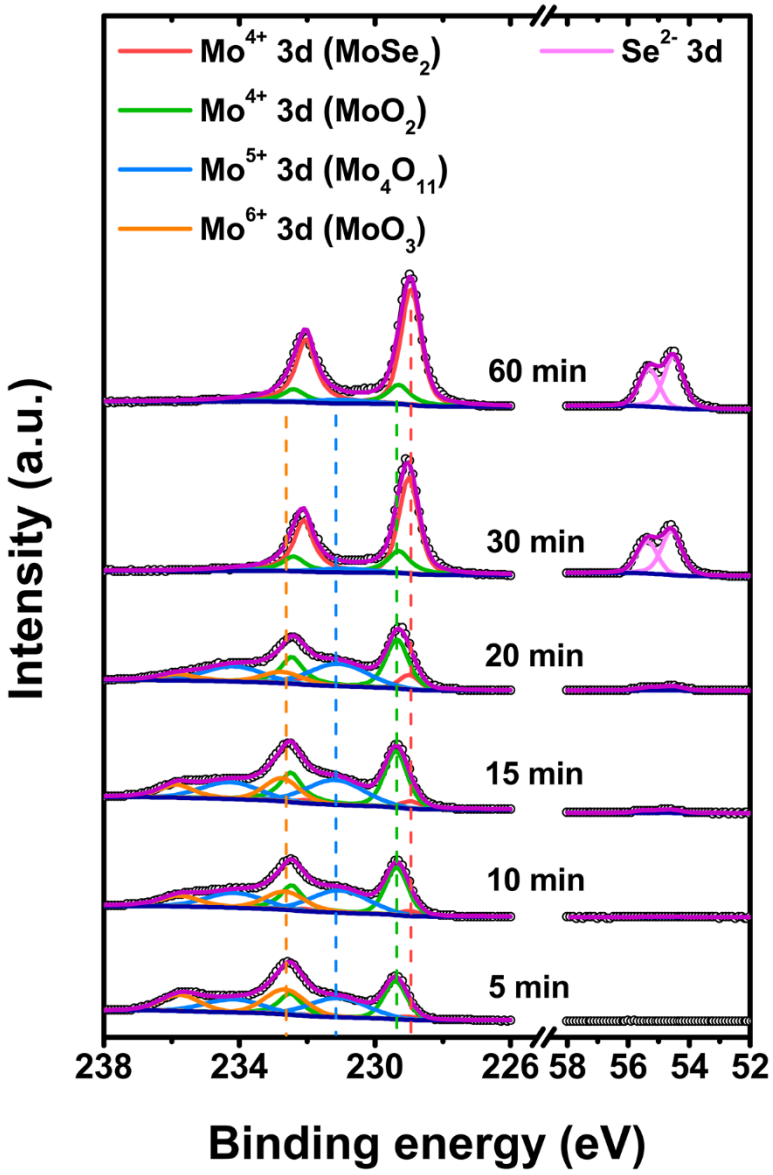
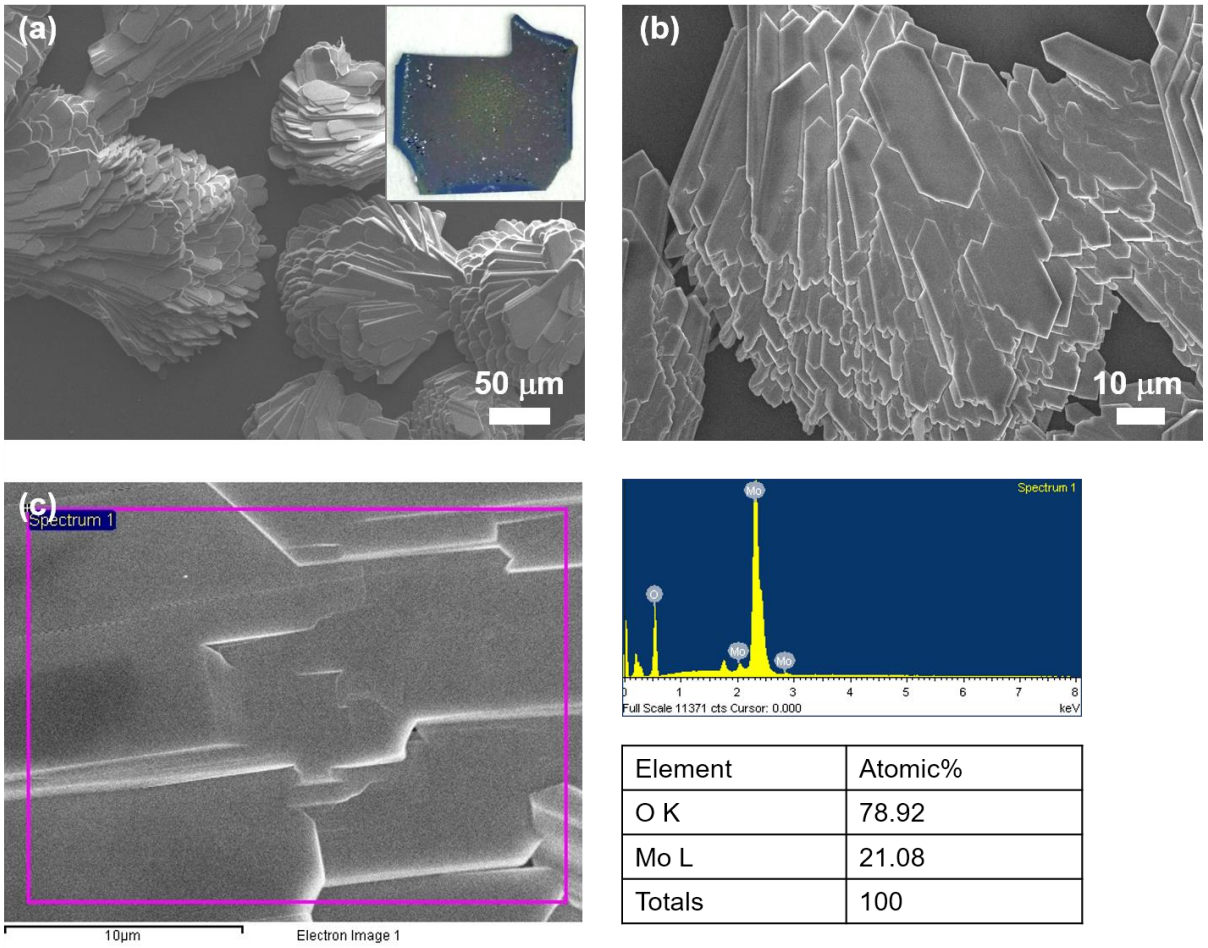


Fig. S11. XPS spectra of CVD-grown crystals at growth times of 5 to 60 min.

Table S2. Atomic fraction of four valance species of Mo *3d* in Figure 2c and S10.

Sample	Mo^{6+} *3d* (MoO_3)	Mo^{5+} *3d* (Mo_4O_{11})	Mo^{4+} *3d* (MoO_2)	Mo^{4+} *3d* ($MoSe_2$)	Total
5 min	32.72 at.%	35.07 at.%	30.21 at.%	2.00 at.%	100 at.%
10 min	24.66 at.%	36.99 at.%	35.45 at.%	2.90 at.%	100 at.%
15 min	22.48 at.%	36.31 at.%	37.39 at.%	3.82 at.%	100 at.%
20 min	14.81 at.%	37.96 at.%	38.80 at.%	8.43 at.%	100 at.%
30 min	-	6.38 at.%	23.15 at.%	70.47 at.%	100 at.%
60 min	-	5.42 at.%	17.83 at.%	76.75 at.%	100 at.%



Element	Atomic%
O K	78.92
Mo L	21.08
Totals	100

Fig. S12. (a) and (b) SEM images and (c) EDS of CVD-grown products using MoO_3 and Se precursors without hydrogen injection. Inset of (a) is a picture of the products.

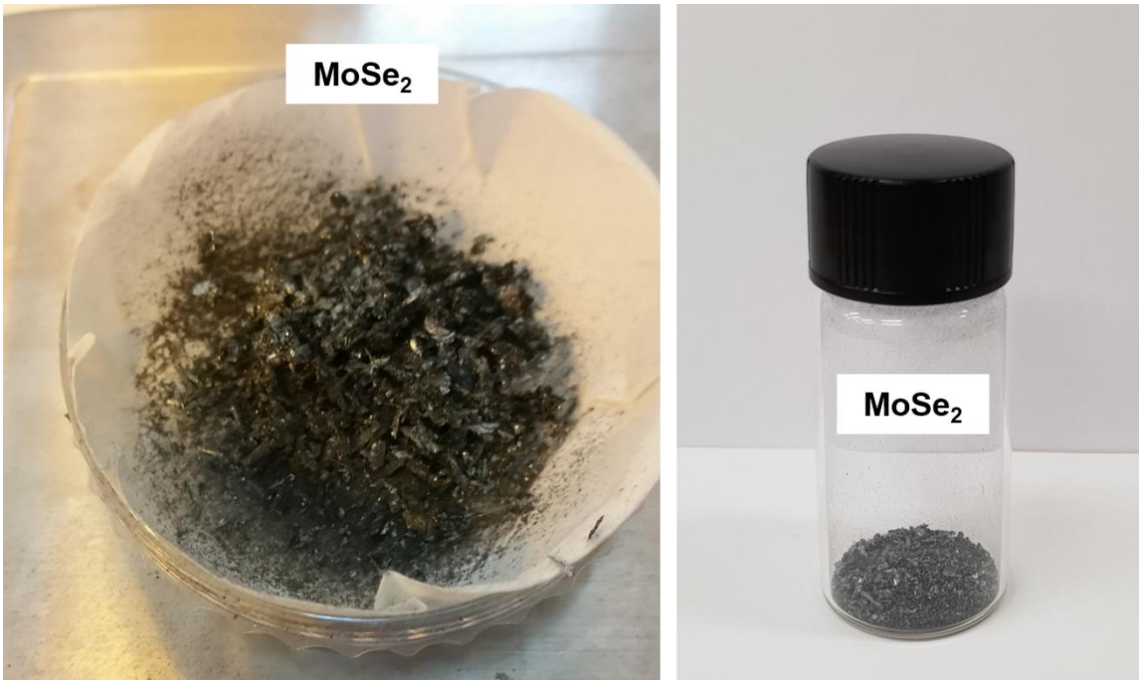


Fig. S13. Pictures of collected as-grown $MoSe_2$ nanosheets.

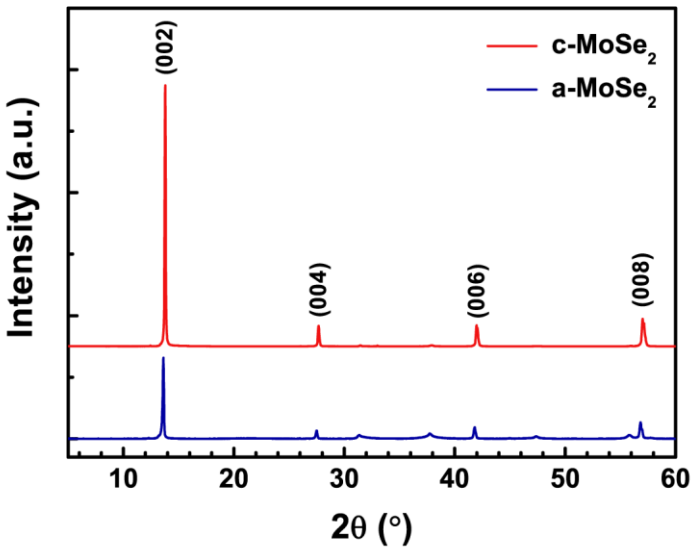


Fig. S14. XRD spectra of c-$MoSe_2$ and a-$MoSe_2$.

Table S3. Coulombic efficiency of c-$MoSe_2$@G, a-$MoSe_2$@G, and c-$MoSe_2$.

	Coulombic efficiency (%)		
	c-$MoSe_2$@G	a-$MoSe_2$@G	c-$MoSe_2$
1st	71.8	61.7	79.7
2nd	96.8	83.4	94.8
3rd	97.8	93.0	95.4