Electronic Supporting Information

Synthesis and characterization of large-area and continuous MoS_2 atomic layers by RF Magnetron Sputtering

Sajjad Hussain[1,2], Muhmmad Arslan shehzad[1,2], Dhanasekaran Vikraman[1,2], Muhammad Farooq Khan[3], Jai Singh[1,2], Dong-Chul Choi[1,2] ,Yongho Seo[1,2], Jonghwa Eom[3], Wan-Gyu Lee[4], and Jongwan Jung*[1,2]*

[1]Graphene Research Institute, Sejong University, Seoul 143-747, Republic of Korea

[2]Institute of Nano and Advanced Materials Engineering, Sejong University, Seoul 143-747, Republic of Korea

[3]Department of physics and Graphene Research Institute, Sejong University, Seoul 143-747, Republic of Korea

[4]National Nano Fab Center, Daejeon, Republic of Korea.

Table.S1-a. Deposition conditions maintained during the preparation of RF magnetron sputtered MoO_3 films.

Sputter target	**Molybdenum (99 % pure) 3 ×1/8 t**
Target to substrate distance	50 mm
Base pressure	$2x10^{-6}$ torr
Working pressure	$3x10^{-3}$
Gas flow Ar /Oxygen	10/20 sccm
Sputter power	150 W
Sputter time	1L-50 Sec, 2L-80Sec, 3L 100 Sec.

After deposited films (50, 80, 100 and 150 sec) were placed in an annealing chamber and heated up to 650°C for 1 hour. The carrier gas flow rate was maintained at 100 sccm, and the pressure of chamber was kept at 2 $x10^{-2}$ Torr.

Table S1-b. The pressure of chamber during the growth.

Annealing base pressure	2×10^{-2} Torr
Ar gas pressure/100 sccm	3×10^{-1} Torr

Table S2. Preparation conditions and the number of layer of MoS_2 films

Sputtering time (sec)	Sulfur powder content (g)	Number of layer
40	0.25	No film growth
50	0.25	Monolayer
80	0.25	bilayer
100	0.25	Trilayer
150	0.25	Few layers

Table S3 Literature values comparison of observed electrical parameters for MoS_2 (mono to few-layer) grown by different methods.

Sr. No.	Growth method	**V_{ds}**	**I_{on}/I_{off}**	**Mobility cm^2/Vs**	**Ref.**
	Sputtering (MoO_3)+ CVD	1 V	~ 10^7 (2L) 10^4 ~ 10^5 (3L)	~21 (2L) ~25 (3L)	
1	Sputtering (Mo) + CVD	0.5 V	10^6	12.24	[26]
2	CVD ($MoCl_5$ + S)	2V	10^4 ~10^5	0.003–0.03	[14]
3	CVD (MoO3 + S) on rGO	2 V	~ 10^4	0.02	[33]
4	MoS_2 powder + Mo/Sapphire	1 V		192	[11]
5	E-beam (Mo) + CVD	1mV to 1V		0.004~0.04	[53]
6	CVD(MoO_3 + S)	100 mV –500 mV	~ 10^8	17	[54]
7	CVD(MoO_3 + S)	1mV - 1V	10^4 ~10^6	0.1~ 0.7	[19]
8	Thermolysis of $(NH_4)_2MoS_4$		~ 10^5	4.7 ~ 6	[10]
9	CVD(MoO_3 + S)	1 V	~ 10^3	0.09	[31]
10	Exfoliated (electrochemical)	1 V	~ 10^6	1.2	[49]
11	CVD(MoO_3 + S)	200 mV ~ 1 V	~ 10^6	2 ~ 7	[12]
12	E-beam (Mo) + CVD	1 V	~ 10^3	6.5	[13]
13	CVD(MoO_3 + S)		> 10^6 (low temp.)	45(isolated single crystal)	[6]

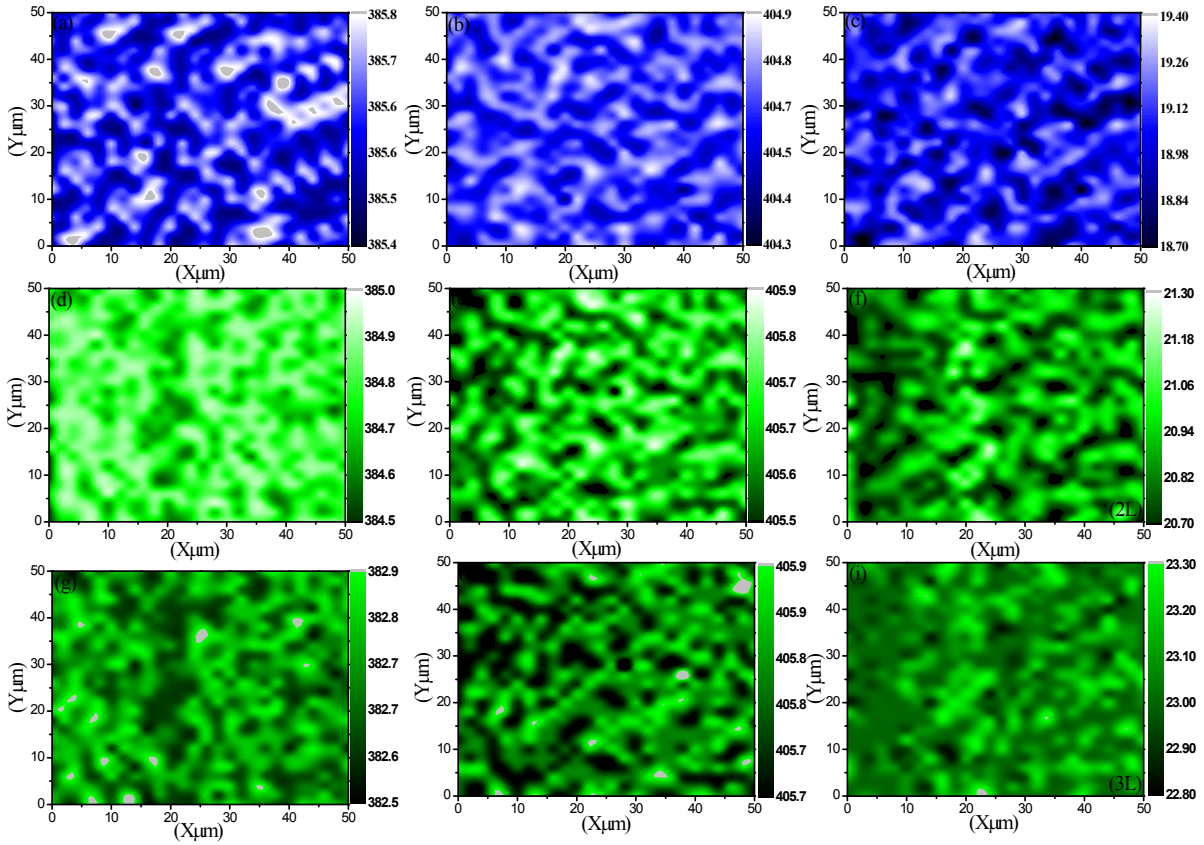

Figure S1. Statistical analysis of Raman mapping **(a-c)** E^1_{2g}, A_{1g} peak energy and Δvalue of monolayer film **(d-f)** E^1_{2g}, A_{1g} peak energy and Δvalue of bilayer film **(g-i)** E^1_{2g}, A_{1g} peak energy and Δvalue of trilayer film.

Table S4 Statistical analysis of Raman mapping of mono, bi and trilayer MoS_2 film.

		Monolayer MoS_2	Bilayer MoS_2	Trilayer MoS_2
E^1_{2g} mode	Average	385.6	384.7	382.7
	Max	385.8	385	382.9
	Min	385.4	384.5	382.5
	Standard deviation	0.11	0.11	0.11
A_{1g} mode	Average	404.6	405.6	405.8
	Max	404.9	405.9	405.9
	Min	404.3	405.5	405.7
	Standard deviation	0.12	0.11	0.07
Δ k	Average	19.0	20.8	23.0
	Max	19.4	21.3	23.3
	Min	18.7	20.7	22.8
	Standard deviation	0.17	0.12	0.10

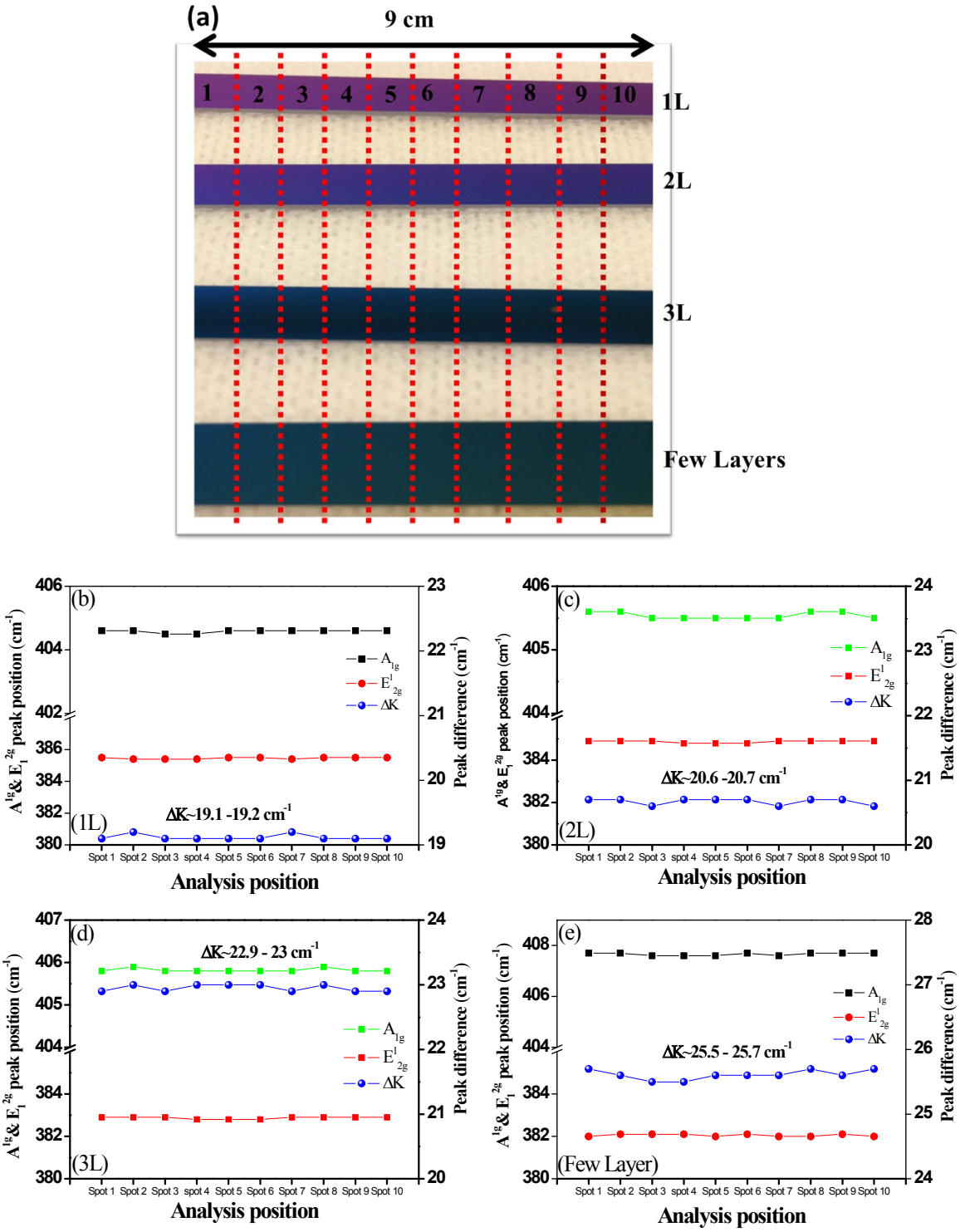

Figure 2 (a) Large-area (approximately 9 cm) mono-, bi-, tri-, and few-layer MoS_2 films on SiO_2 substrates), (c-d) relative Raman peak position of E^1_{2g}, and A_{1g} bands and the peak differences (Δk) plotted as a function of numbered spot at ten measurement points on the mono-, bi-, tri-, and few MoS_2 films. For monolayer average peak difference (Δk) values are in the range of ~19.1 –19.2 cm^{-1} (with a standard deviation ~ 0.042 cm^{-1}).For bi tri and few

layer (Δk) values are in the range of ~20.6 –20.7 cm^{-1}(with a standard deviation ~ 0.048 cm^{-1}), ~22.9 – 23 cm^{-1}(with a standard deviation ~ 0.052 cm^{-1}) and ~25.5 –25.7 cm^{-1}(with a standard deviation ~ 0.073 cm^{-1}) respectively.

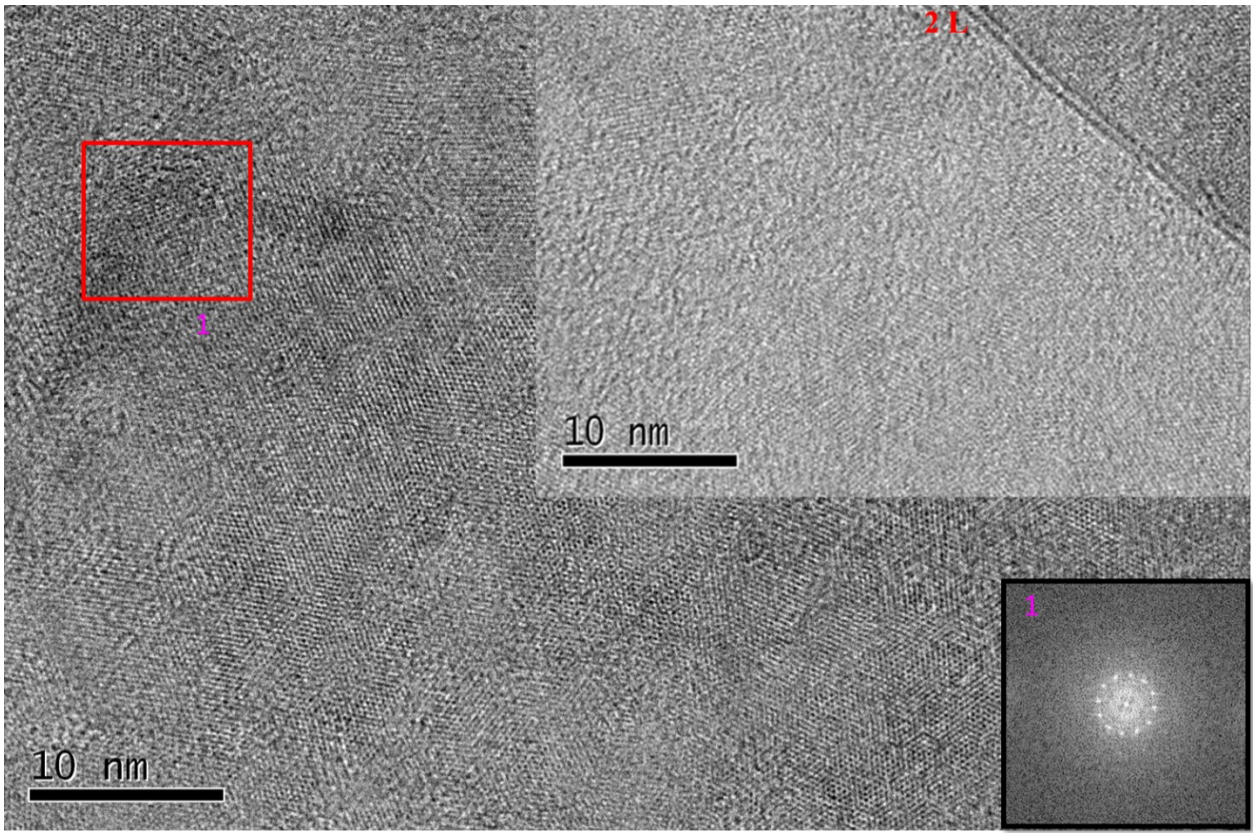

Figure S3 HRTEM image of MoS_2 film synthesized from MoO_3 sputtered at 80 sec. The observed bilayer structure and FFT pattern is inserted.

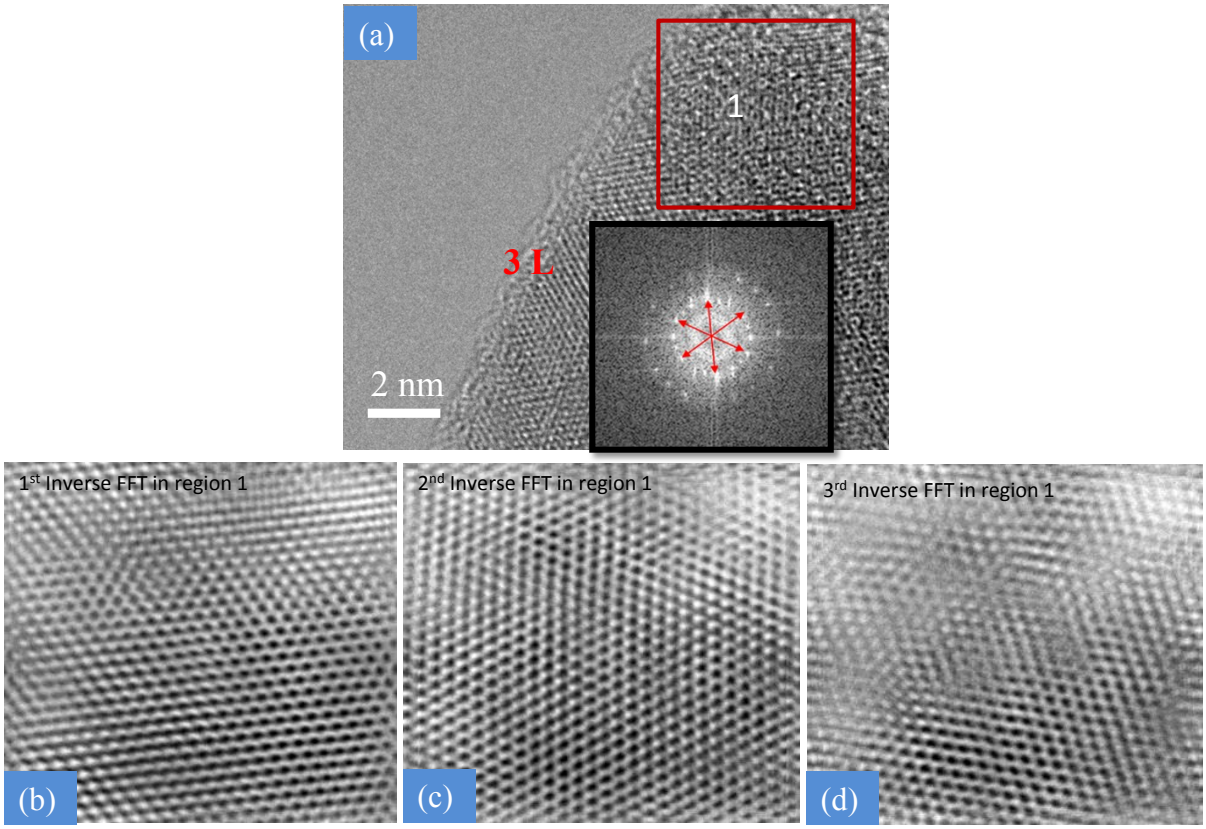

Figure S4. (a) HRTEM image of MoS_2 film synthesized from MoO_3 sputtered at 100 sec; **(b-d)** inverse FFT of diffraction patterns of region 1

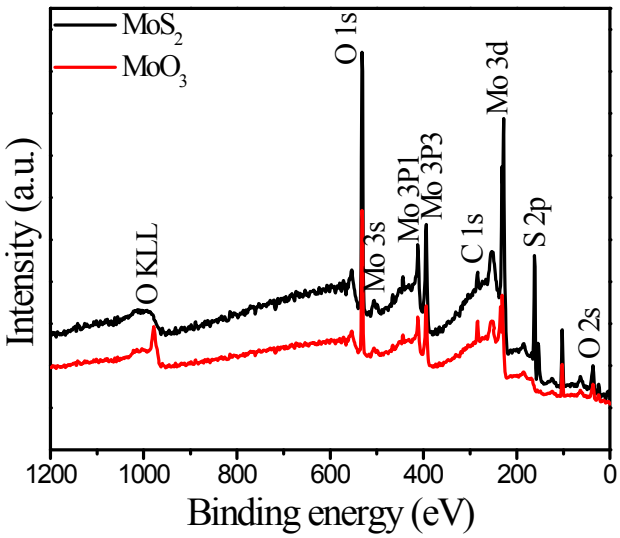

Figure S5. X-ray photoemission spectroscopy (XPS) spectra of as-sputtered MoO_3 film and MoS_2 monolayer film.

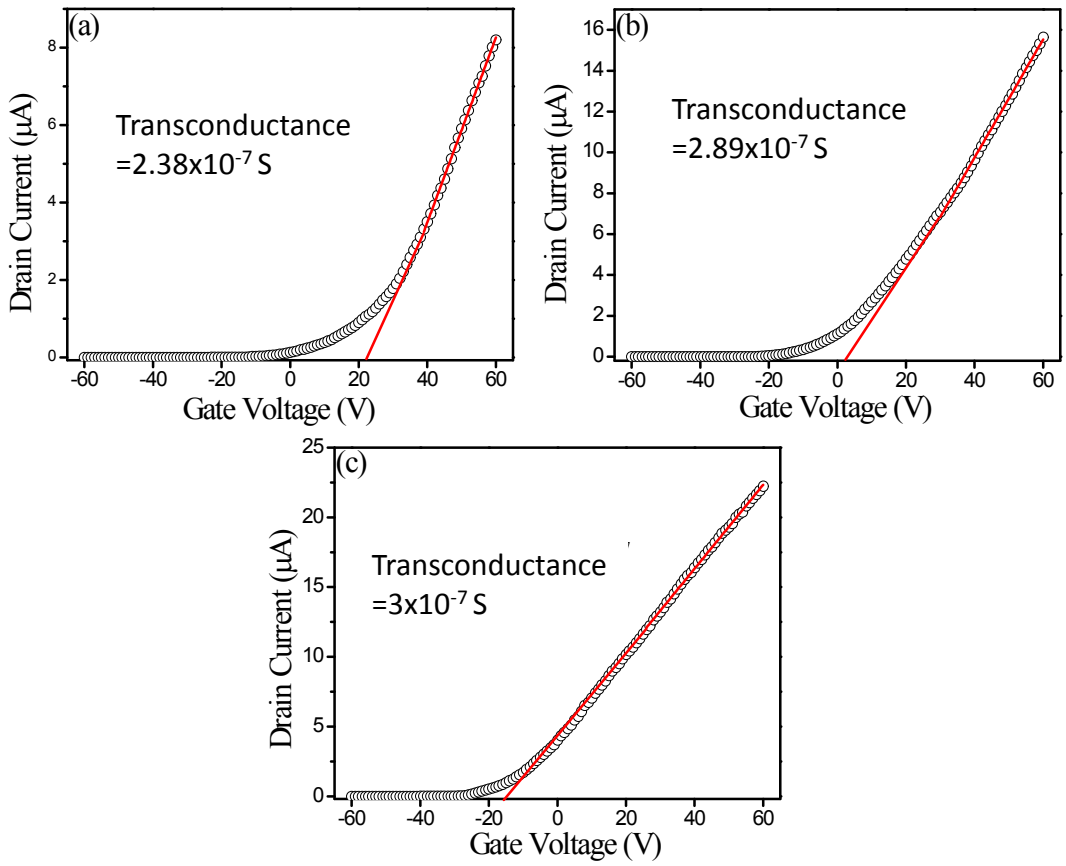

Figure S6. Transfer curves of MoS_2 FETs synthesized at different sputtering time of MoO_3 of (a) 80 sec (b) 100 sec (c) 150 sec (V_{ds} = 1V). Red line is a transconductance. The extracted transconductance values of the bilayer (80 sec), trilayer (100 sec) and few-layer (150 sec) FETs are 2.38×10^{-7} S, 2.89×10^{-7} S and 3.00×10^{-7} S, respectively.

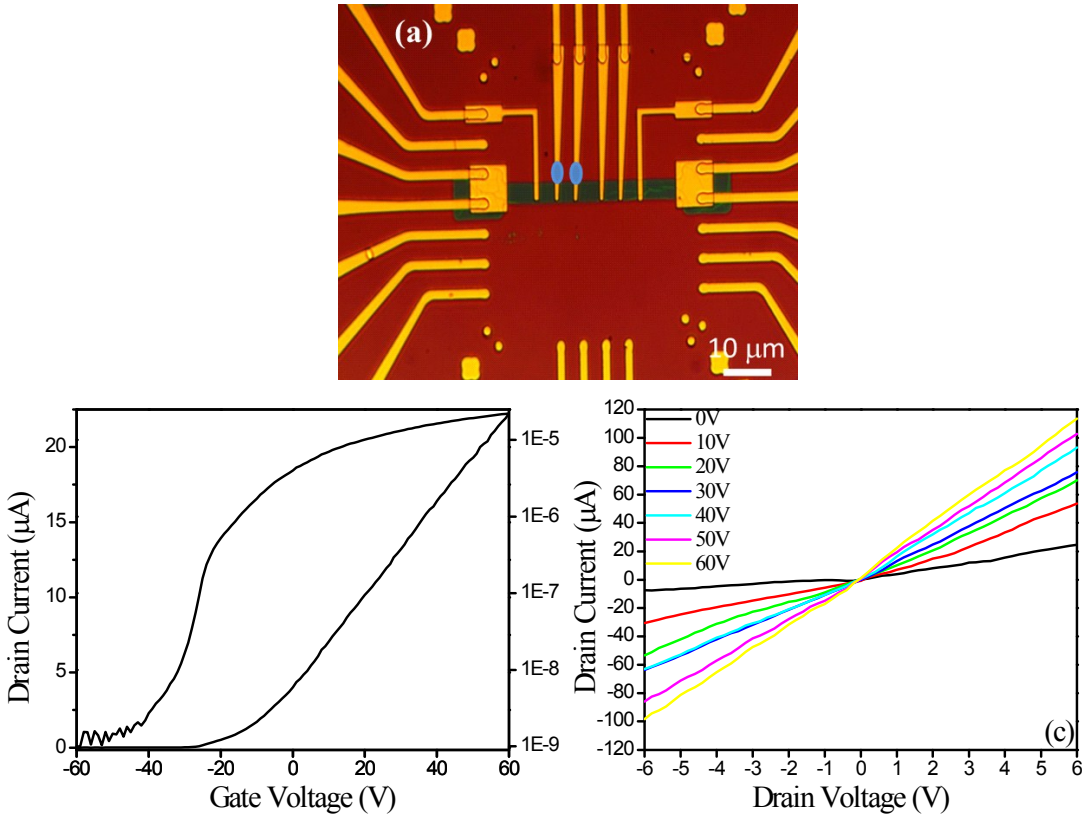

Figure S7. Electrical properties of few-layer MoS_2 FET. **(a)** Optical images of the fabricated MoS_2 FET. The blue-marked electrodes were used for electrical transport measurements. **(b)** Drain-source current (I_{ds}) as a function of back-gate voltage (V_{gs}) at fixed drain-source bias (V_{ds}) = 1V. **(c)** Drain-source current (I_{ds}) versus drain-voltage (V_{ds}) at different back gate voltage V_{gs}.

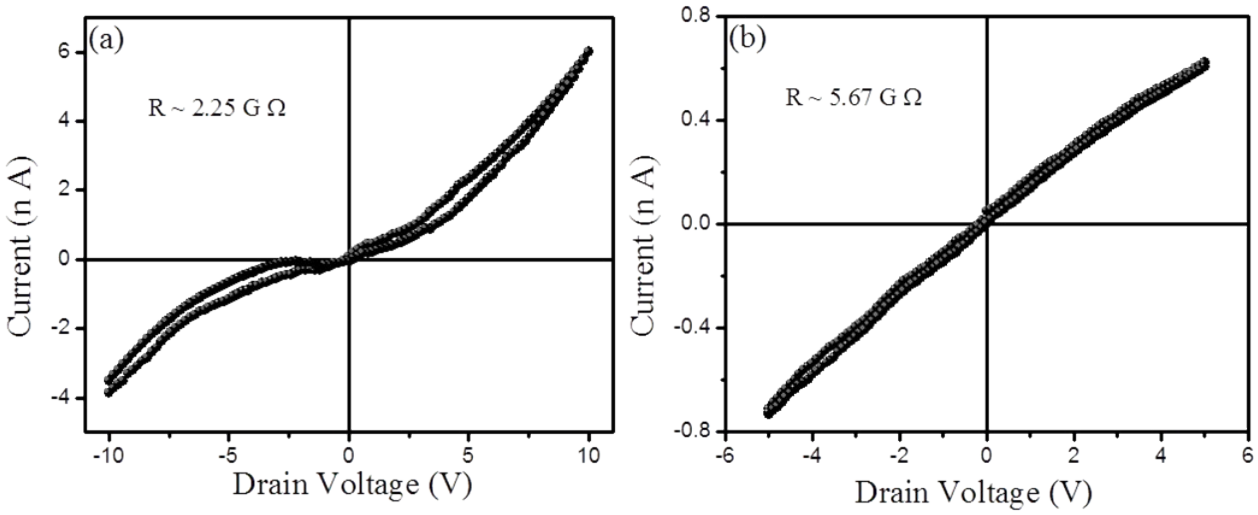

Figure S8. Electrical properties of monolayer MoS_2 FET with different electrode metals. **(a)** Au/Cr metal; **(b)** Ni metal.