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Direct contacting of 2D MoS_2 nanosheets by metallic nanoprobes

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Contents

- Transition metal dichalcogenides (MoS_2)
- Direct contacting by metallic nanoprobes
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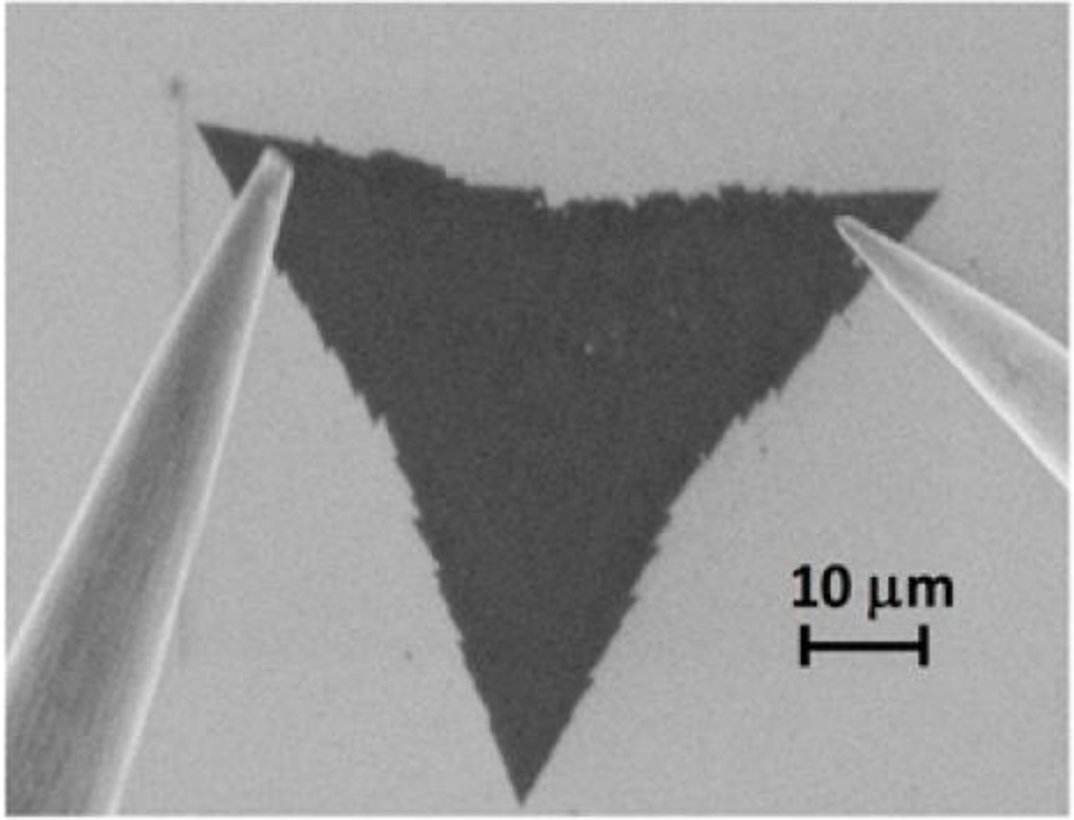
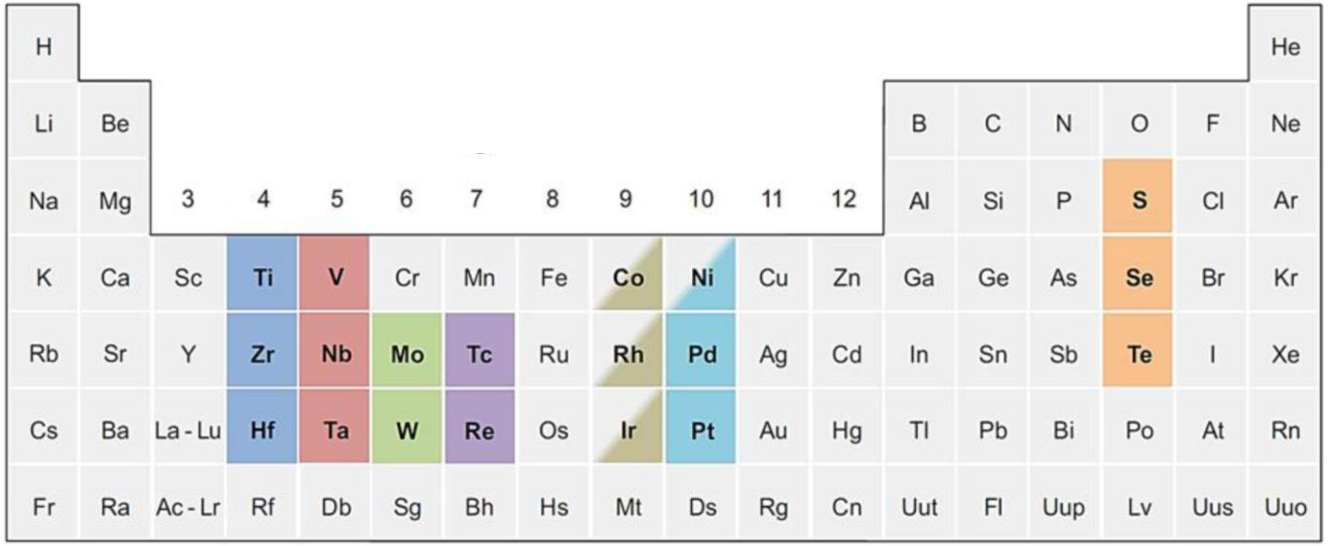


TMDs



Chhowalla, et al. Nature Chem 5, 263–275 (2013)

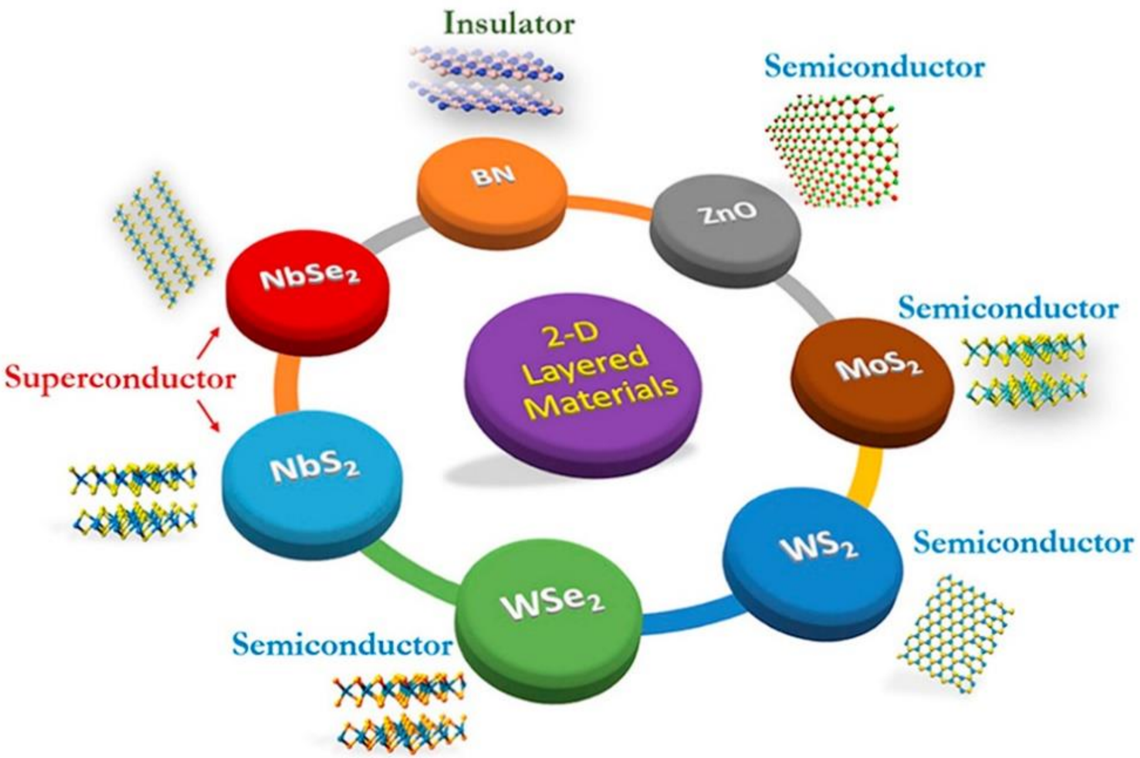
X. Duan et al. Chem. Soc. Rev., 2015, 44, 8859--8876

Bandgap (eV)		Mo	W	Ti	Zr	Hf	V	Nb	Ta	Ni	Pd	Pt
S	monolayer	1.8-2.1	1.8-2.1	~0.65	~1.2	~1.3	~1.1	metal	metal	~0.6	~1.2	~1.9
	Bulk	1.0-1.3	1.3-1.4	~0.3	~1.6	~1.6	metal	metal	metal	~0.3	~1.1	~1.8
Se	monolayer	1.4-1.7	1.5-1.7	~0.51	~0.7	~0.7	metal	metal	metal	~0.12	~1.1	~1.5
	Bulk	1.1-1.4	1.2-1.5	metal	~0.8	~0.6	metal	metal	metal	metal	~1.3	~1.4
Te	monolayer	1.1-1.3	~1.03	~0.1	~0.4	~0.3	metal	metal	metal	metal	~0.3	~0.8
	Bulk	1.0-1.2	metal	metal	metal	metal	metal	metal	metal	metal	~0.2	~0.8

MX_2

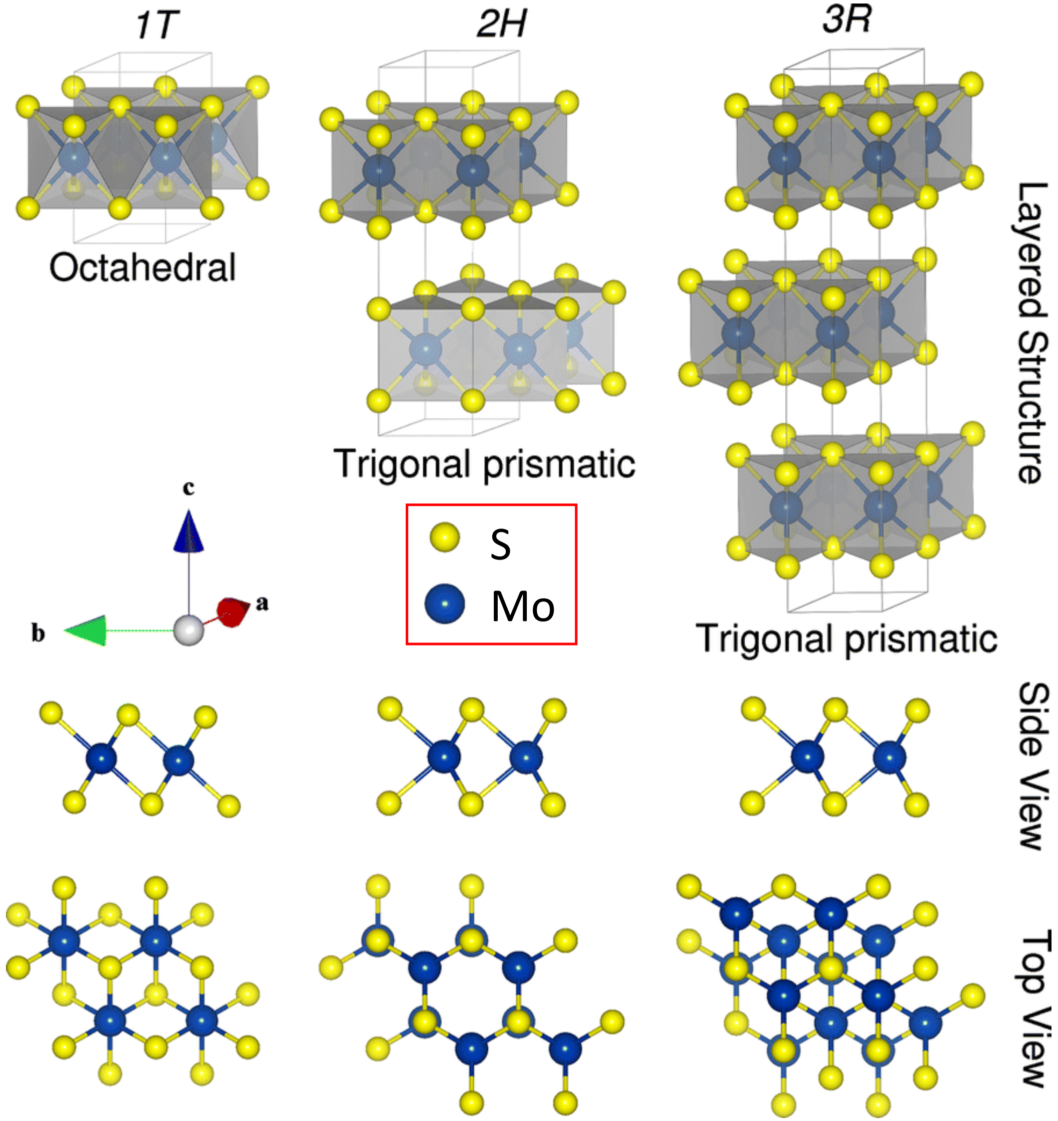
M = Transition Metal

X = Chalcogen

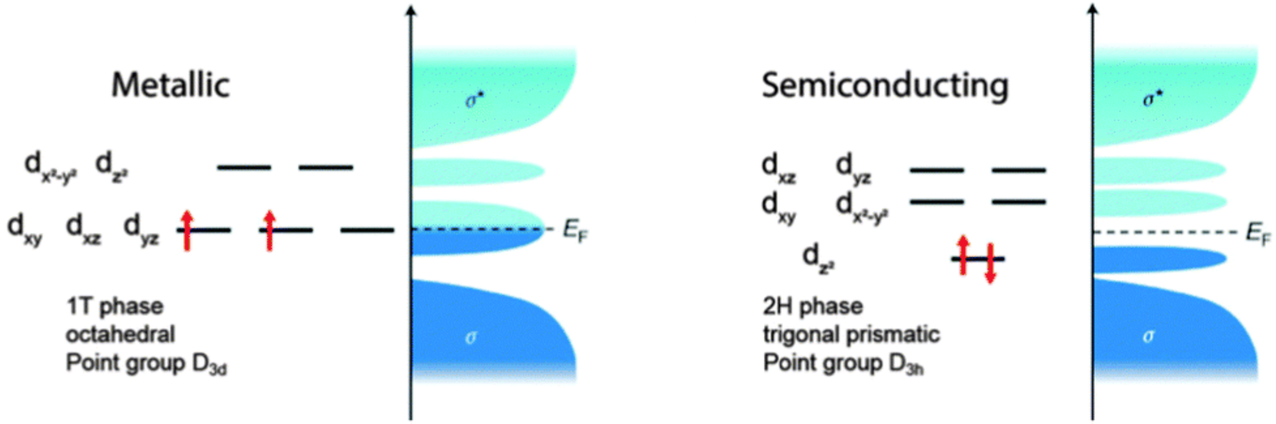


Ruitao Lv et al. Nano Today, 10(5), 559 (2015)

MoS_2



	$2H\text{-}MoS_2$	$1T\text{-}MoS_2$	$3R\text{-}MoS_2$
Layers per unit cell	2	1	3
Symmetry	hexagonal	tetragonal	rhombohedral
Metal coordination	trigonal prismatic (D3h)	octahedral (Oh)	trigonal prismatic (D3h)
Class	semiconducting	metallic	

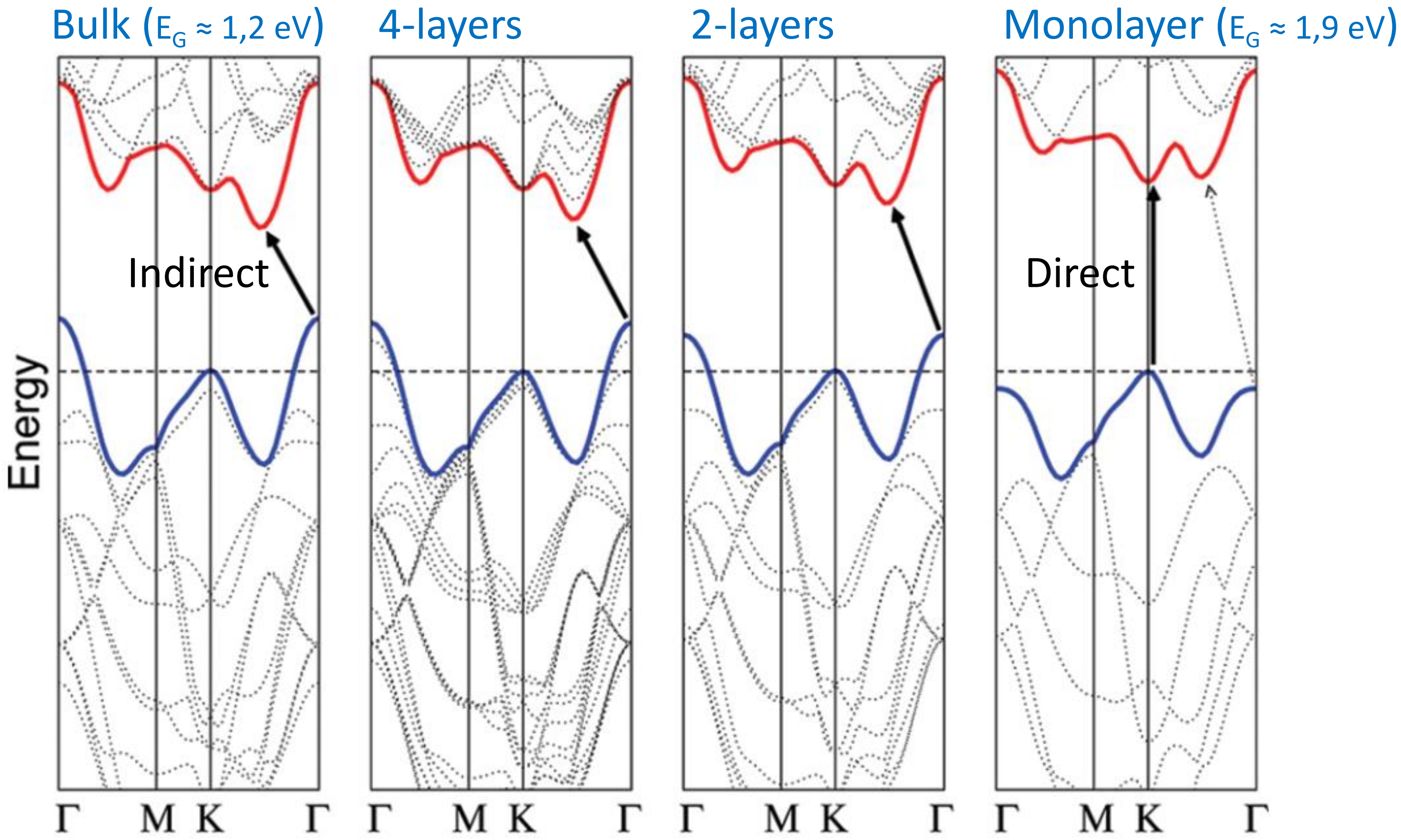


J. Lu et al. Chem. Soc. Rev., 2016, 45, 2494-2515

A. Kuc, Chemical Modelling 11, 2014, 1-29

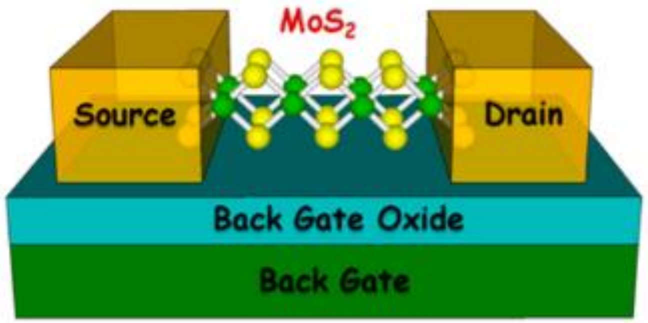
MoS_2

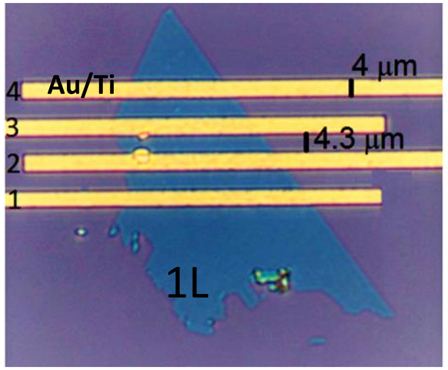
- Direct gap at monolayer
- Indirect gap with smaller E_G at few layers



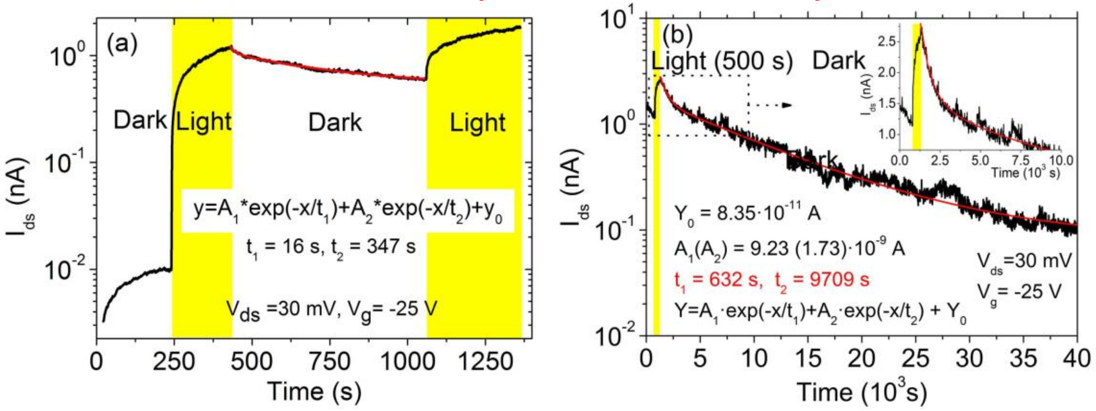
A. Splendiani et al., Nano Lett. 2010, 10, 1271–1275

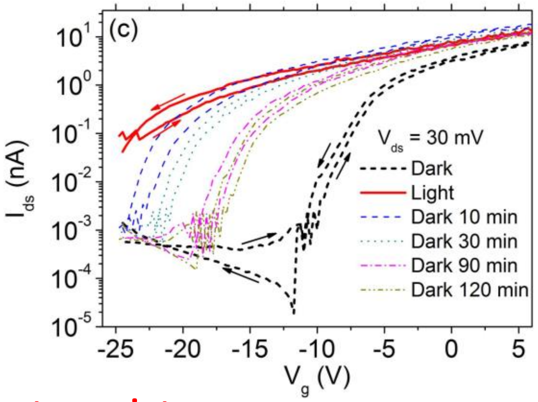
Back-gated MoS_2 FETs

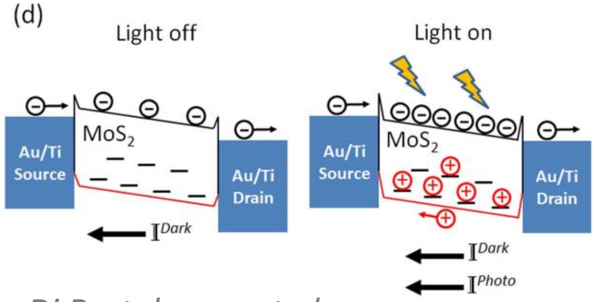




Persistent photoconductivity

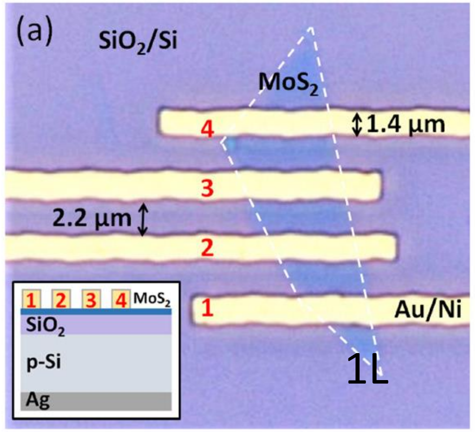


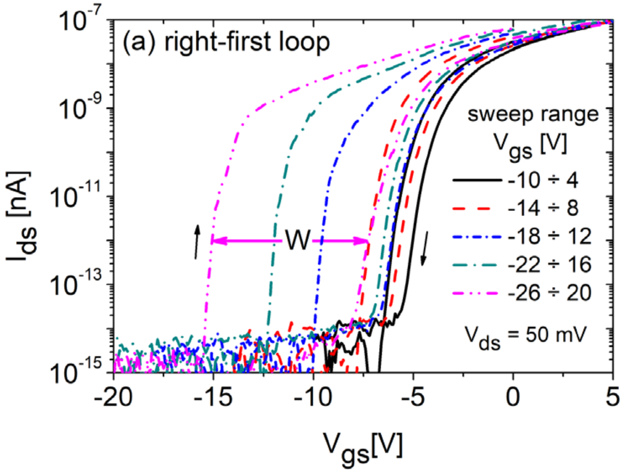


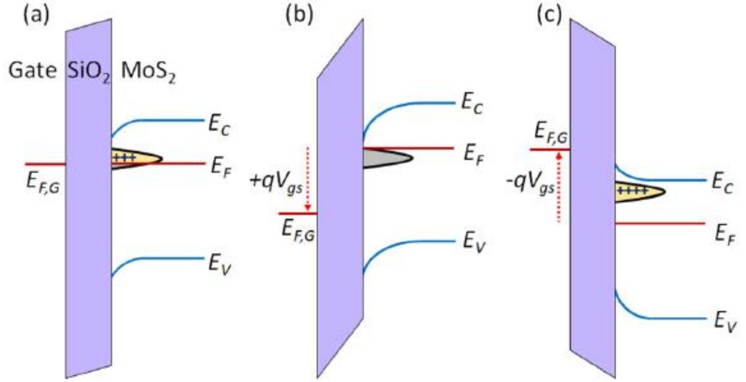


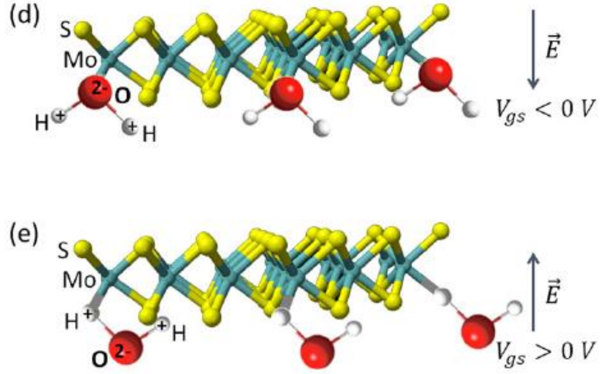
Di Bartolomeo et al. Nanotechnology 28 (2017) 214002

Hysteresis in the transfer characteristics of MoS_2 transistors





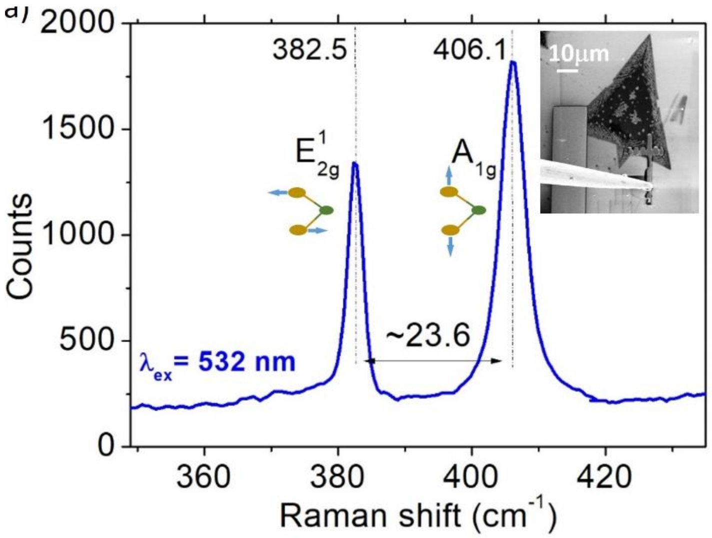


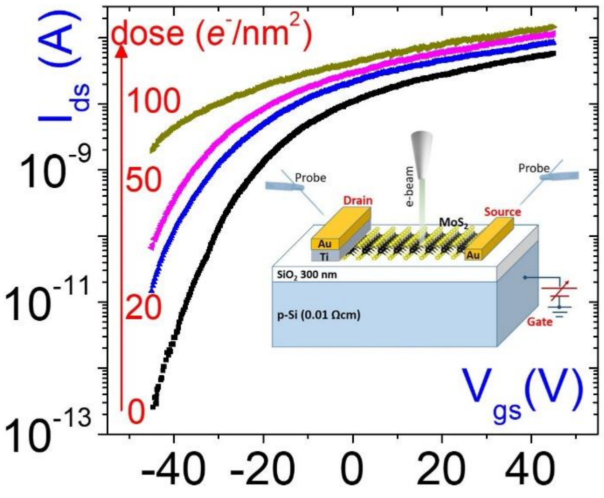


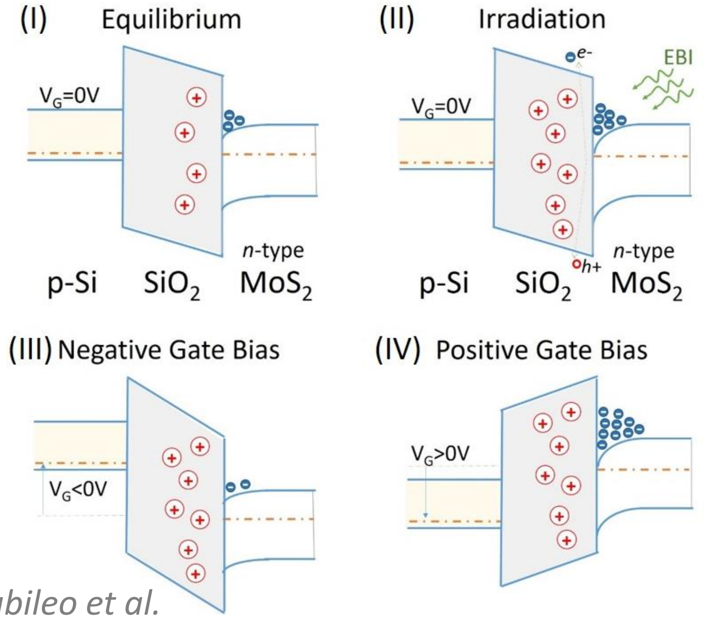
Di Bartolomeo et al 2018 2D Mater. 5 015014

Back-gated MoS_2 FETs

Effect of Electron Irradiation on Few-Layer MoS_2 FETs

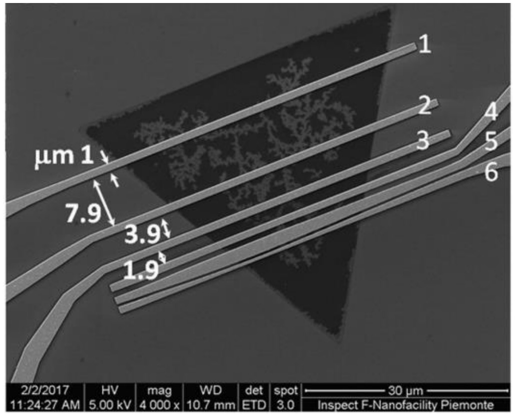


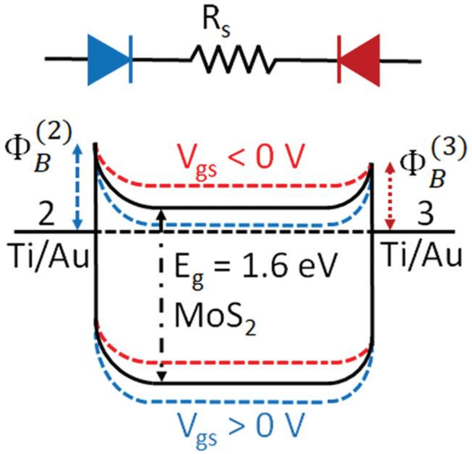


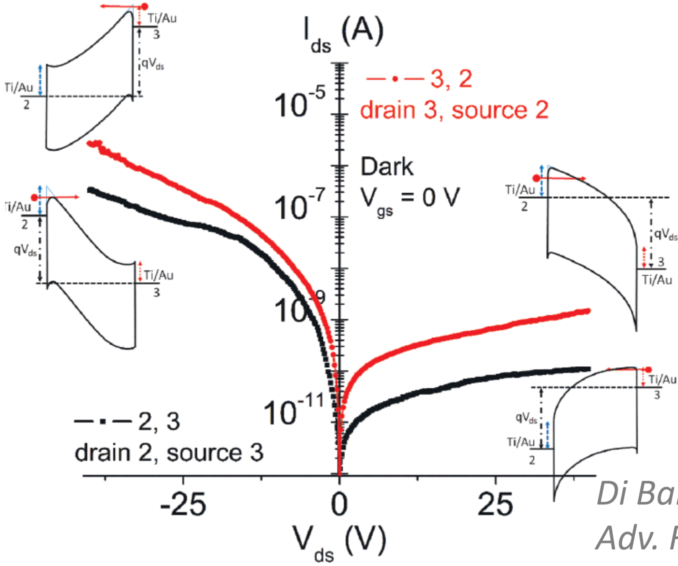


F. Giubileo et al.
J. Phys. Chem. C 123, 1454–1461 (2019)

Asymmetric Schottky Contacts in Bilayer MoS_2 FETs

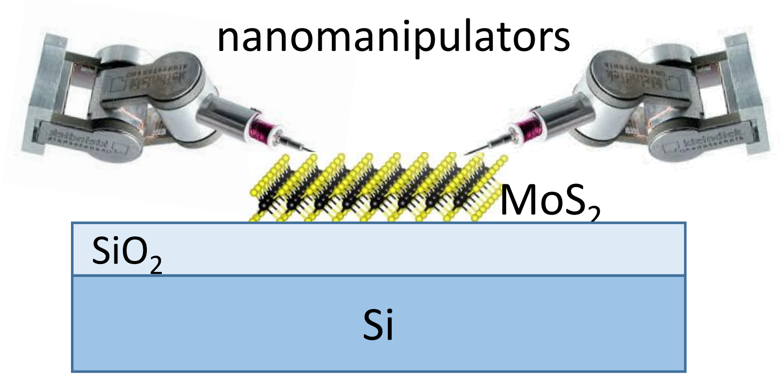


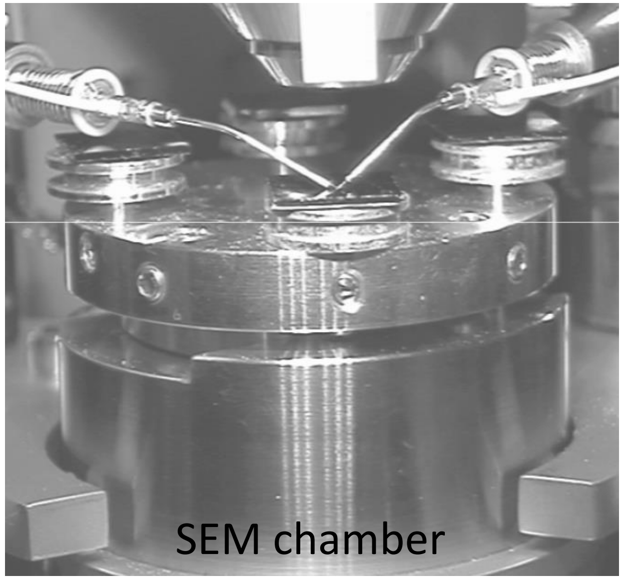


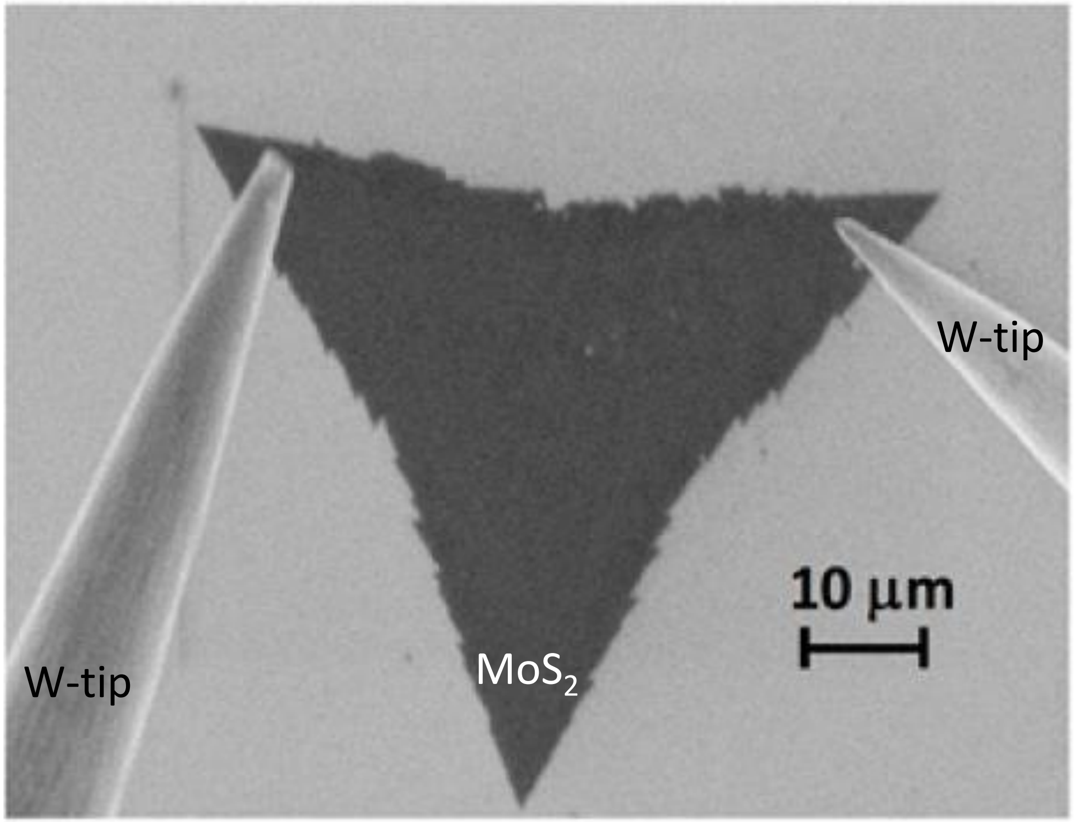


Di Bartolomeo et al.
Adv. Funct. Mater. 2018, 28, 1800657

Nanoprobes for direct contacting



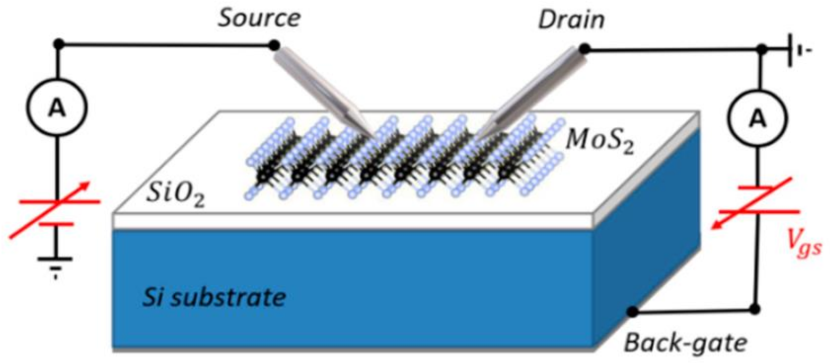




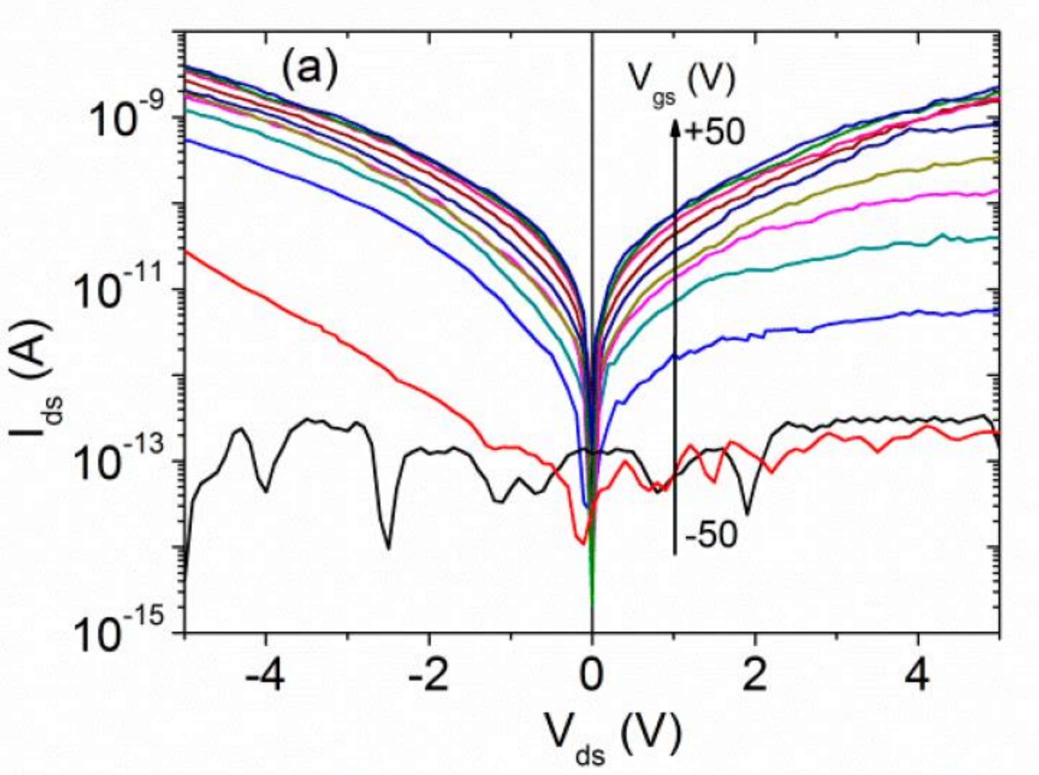
tungsten (W) tip
curvature radius < 100 nm

L. Iemmo et al. Nanomaterials 2020, 10(1), 106

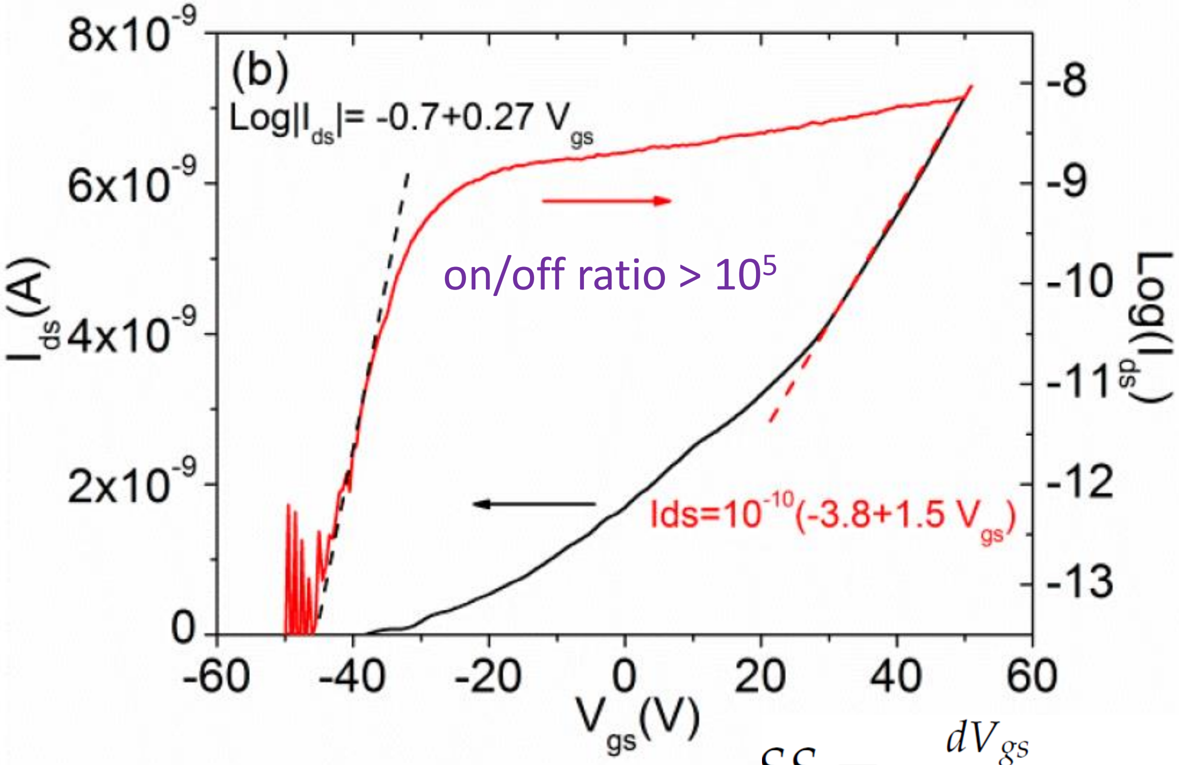
Transistor characterization



I_{ds}-V_{ds} Output characteristics



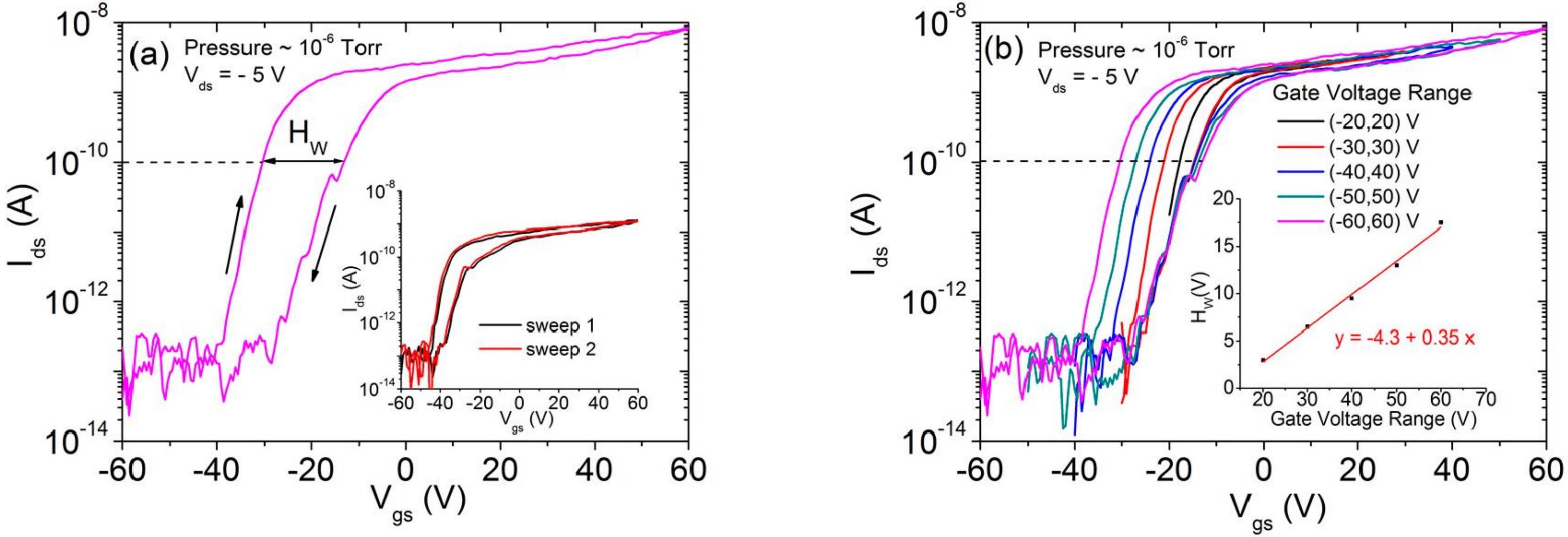
I_{ds}-V_{gs} Transfer characteristic



$$SS = \frac{dV_{gs}}{dLog(I_{ds})} \sim 4\ \frac{\text{V}}{\text{decade}}$$

$$\mu = \frac{L}{W}\frac{1}{C_{SiO_2}}\frac{1}{V_{ds}}\frac{dI_{ds}}{dV_{gs}} \sim 1\ \text{cm}^2\text{V}^{-1}\text{s}^{-1}$$

Transistor characterization

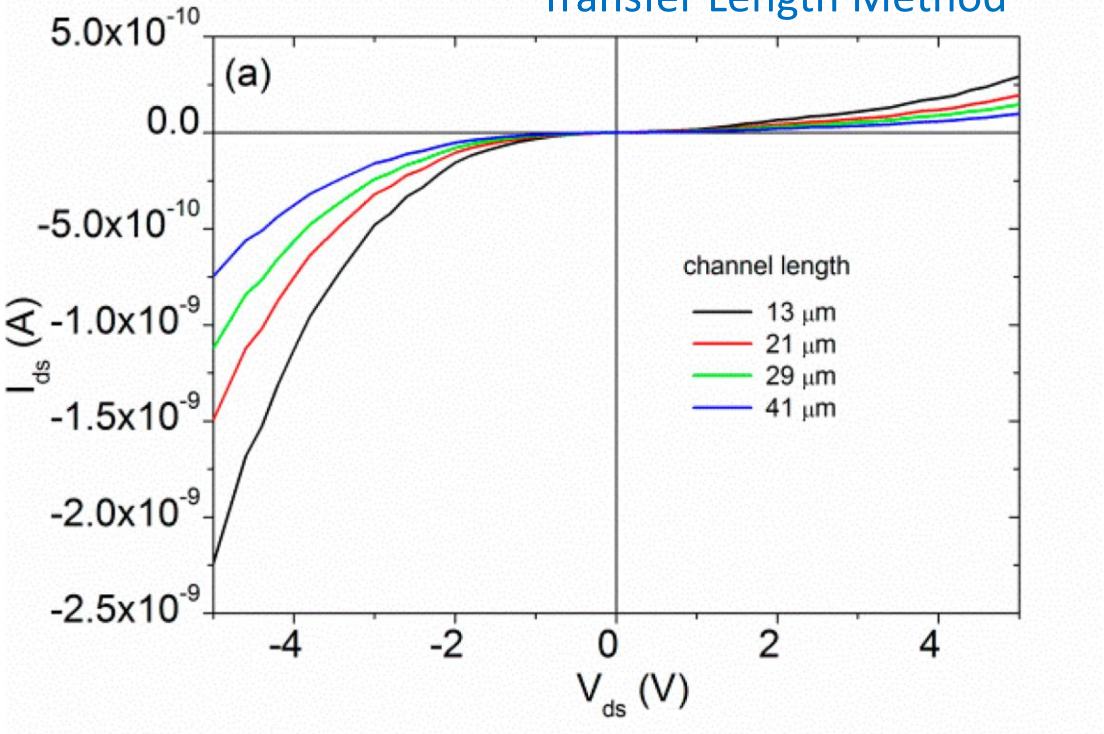


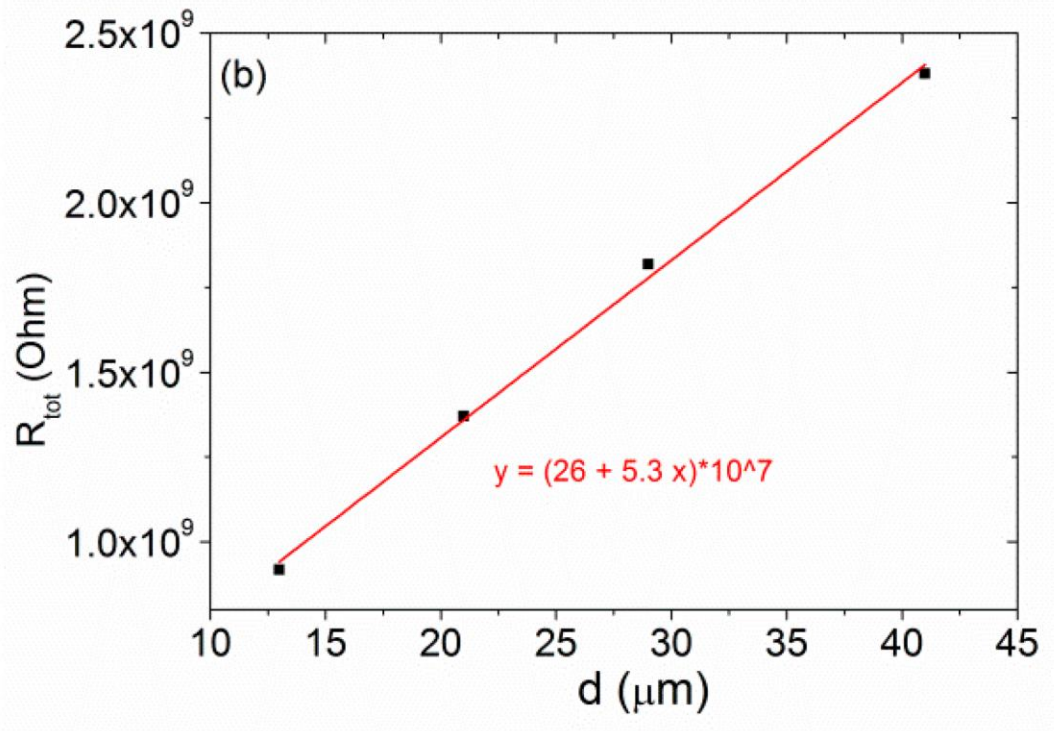
MoS_2/W-tip interface

$$R_{Tot} = 2R_C + R_{channel}$$

$$R_{channel} = R_{sheet} W\, d$$

Transfer Length Method

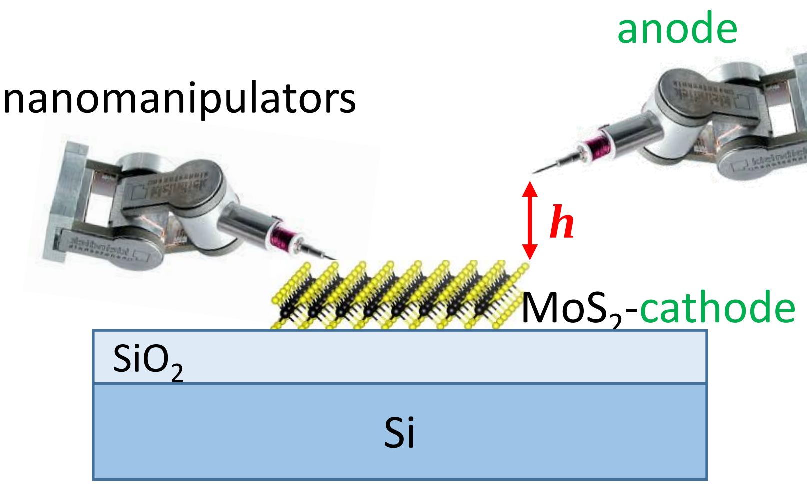




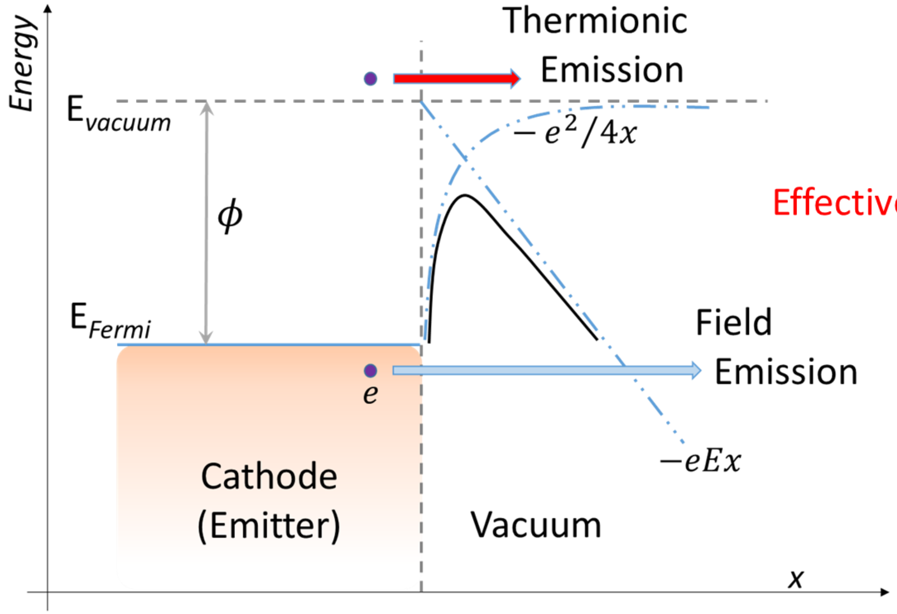
slope ➡ $R_{sheet} \approx 10^8 \Omega/\square$

intercept ➡ $\rho_C \approx 4 \times 10^{-2} \Omega cm^2$

Field emission characterization



Field Emission



Fowler-Nordheim Theory

Field enhancement factor

Effective emitting area

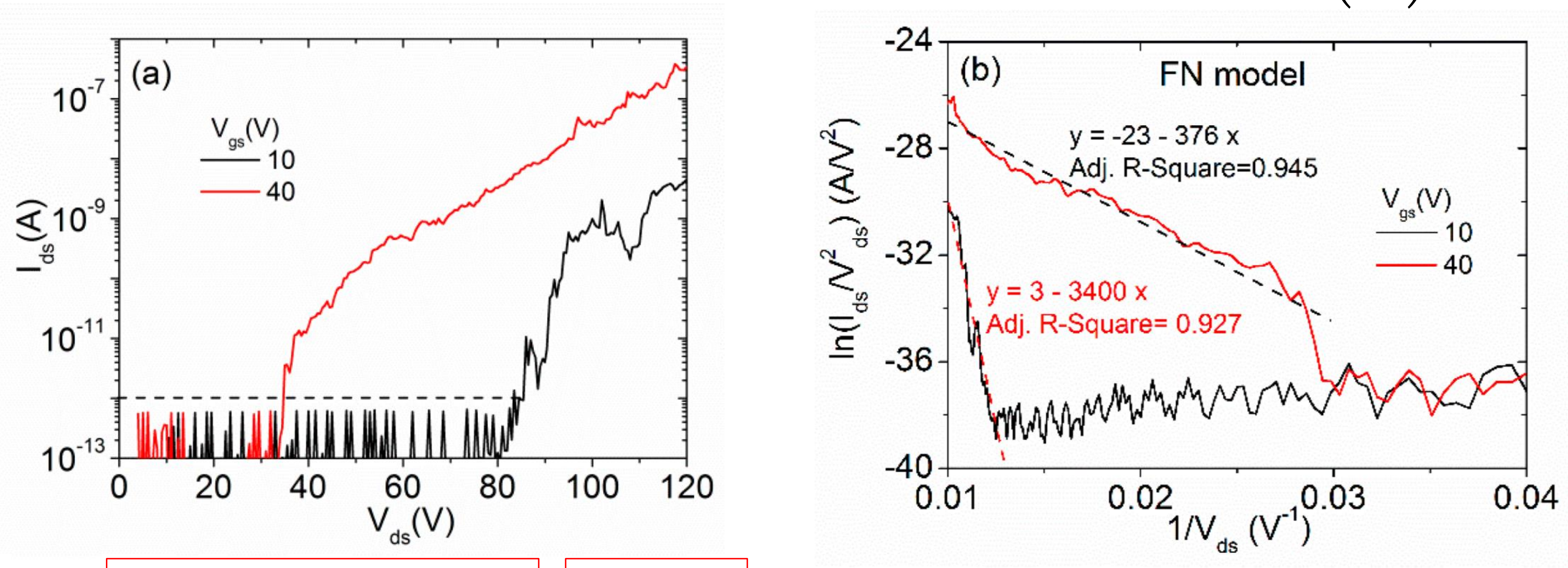
Electric field

$$I = S \cdot a \frac{\beta^2 E^2}{\varphi} exp\left(-b \frac{\varphi^{3/2}}{\beta E}\right)$$

Work function

Field emission characterization

$$\ln\left(\frac{I}{V^2}\right) \sim \frac{1}{V}$$



$E_{Turn-on} \approx 40V/\mu m$ $\beta \approx 200$ for $h = 900\ nm$

An increased gate voltage enhances the n-doping of the flake and favours field emission

Conclusions

- We contacted MoS_2 nanosheets by nanomanipulated W-tips
- We characterized the MoS_2 transistor
  - $\mu \approx 1cm^2V^{-1}s^{-1}$
  - $SS \approx 4V/decade$
  - $R_{sheet} \approx 10^8\Omega/\square$
  - $\rho_C \approx 4 \times 10^{-2}\Omega\text{cm}^2$
- We characterized the FE properties of MoS_2 nanosheet
  - $\beta \approx 200$ and $E_{Turn-on} \approx 40V/\mu m$ at $h = 900\ nm$
- FE current is modulated by the gate