FYPs (2019/2020) in the Nanoelectronic Materials and Devices (NMD) Group, Tyndall National Institute, UCC

Group of Prof Paul K. Hurley, team members
Drs Scott Monaghan, Farzan Gity and Jun Lin

September 12th 2019

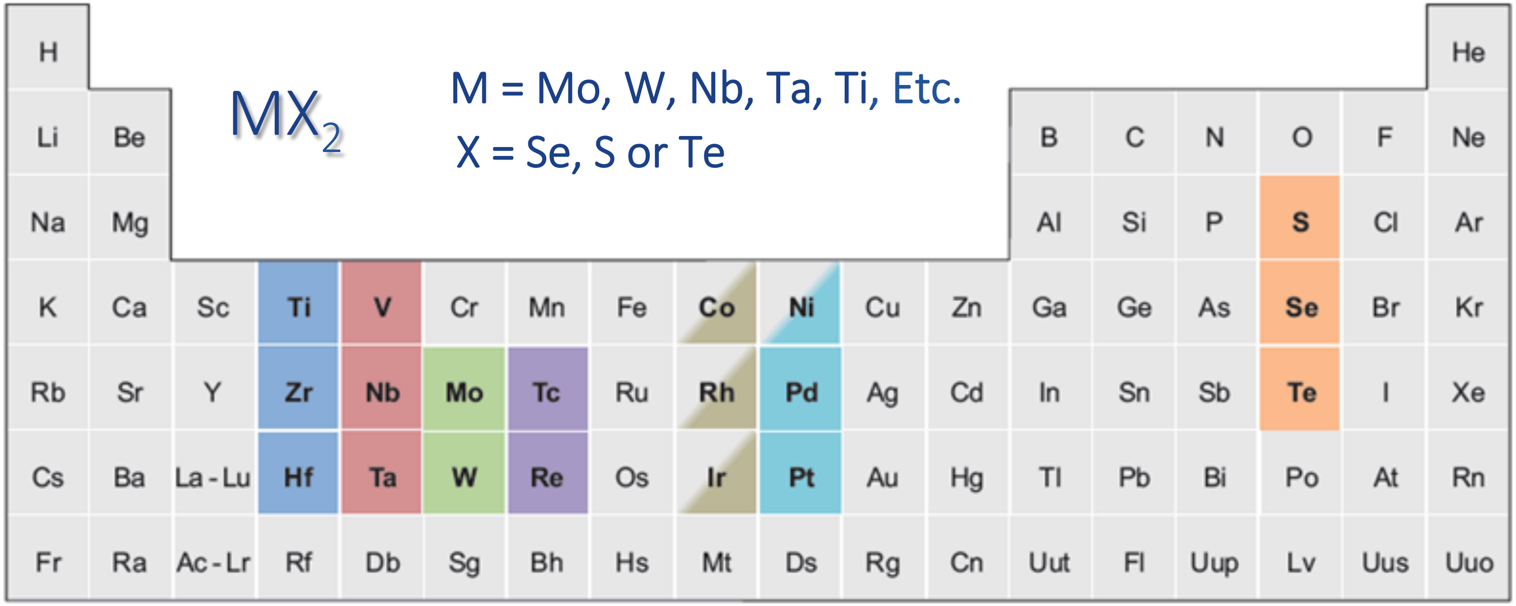
Tyndall National Institute
Institiúid Náisiúnta

UCC
Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

Outline

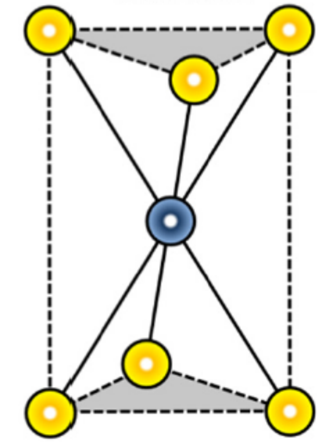
- Transition Metal Dichalcogenides (TMDs, 2D Materials)
- Characterisation methods (Circular TLM Structures, Back-Gated Junctionless Transistor, Van der Pauw 4-Point/Hall-effect) and equipment used…
- Previous FYP in 2018/2019 for TMDs with characterisation
- Up to 3 potential FYPs available in the NMD group, descriptions provided for each…

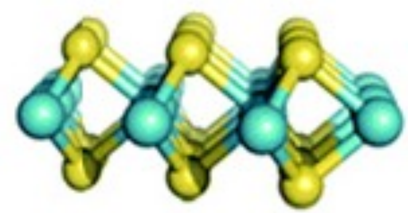
Transition Metal Dichalcogenides (TMDs, 2D Materials)

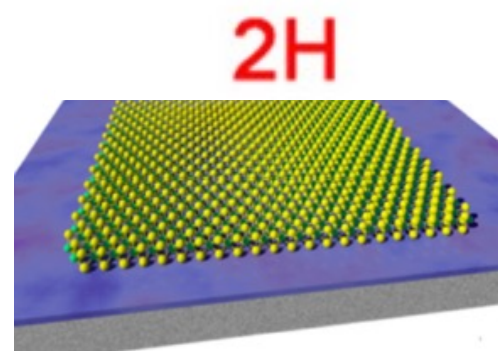


Group	M	X	Properties
4	Ti, Hf, Zr	S, Se, Te	Semiconducting (E_g = 0.2~2 eV). Diamagnetic.
5	V, Nb, Ta	S, Se, Te	Narrow band metals (ρ~10^{-4} Ω.cm) or semimetals. Superconducting. Charge density wave (CDW). Paramagnetic, antiferromagnetic, or diamagnetic.
6	Mo, W	S, Se, Te	Sulfides and selenides are semiconducting (E_g~1 eV). Tellurides are semimetallic (ρ~10^{-3} Ω cm). Diamagnetic.
7	Tc, Re	S, Se, Te	Small-gap semiconductors. Diamagnetic.
10	Pd, Pt	S, Se, Te	Sulfides and selenides are semiconducting (E_g = 0.4 eV) and diamagnetic. Tellurides are metallic and paramagnetic. $PdTe_2$ is superconducting.

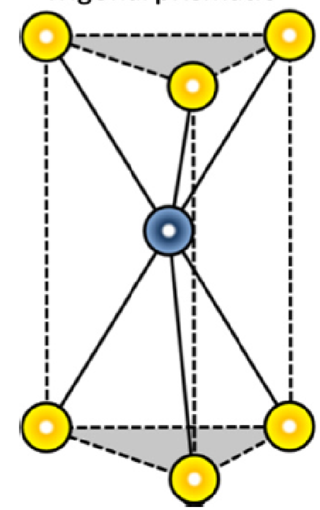
1T
Octahedral



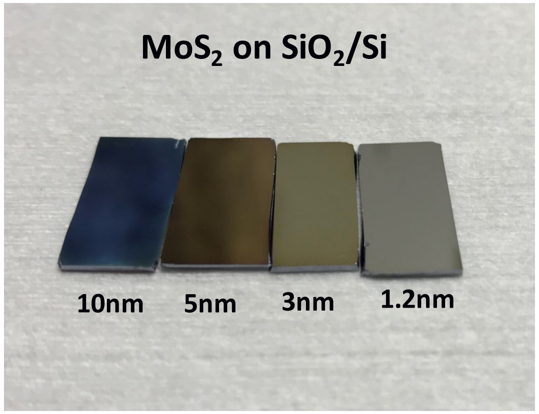


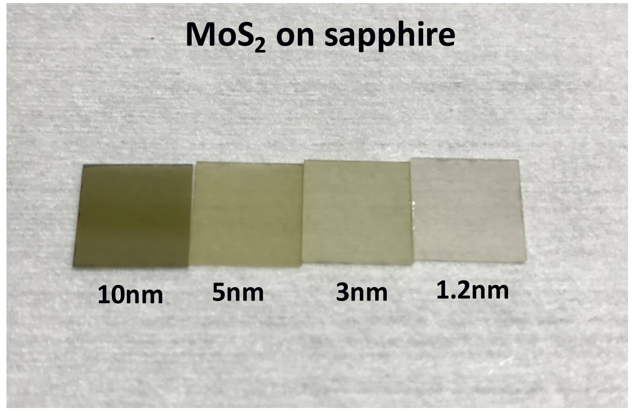


2H
Trigonal prismatic

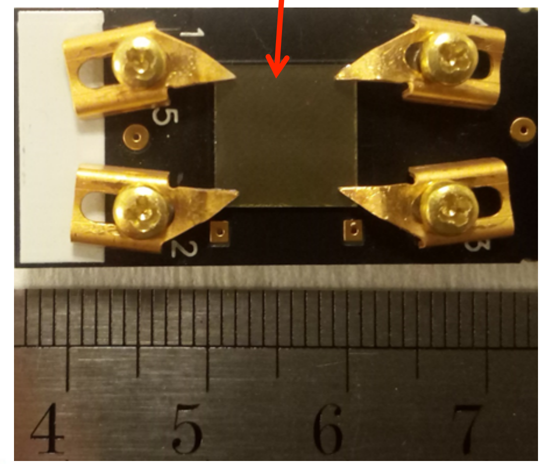


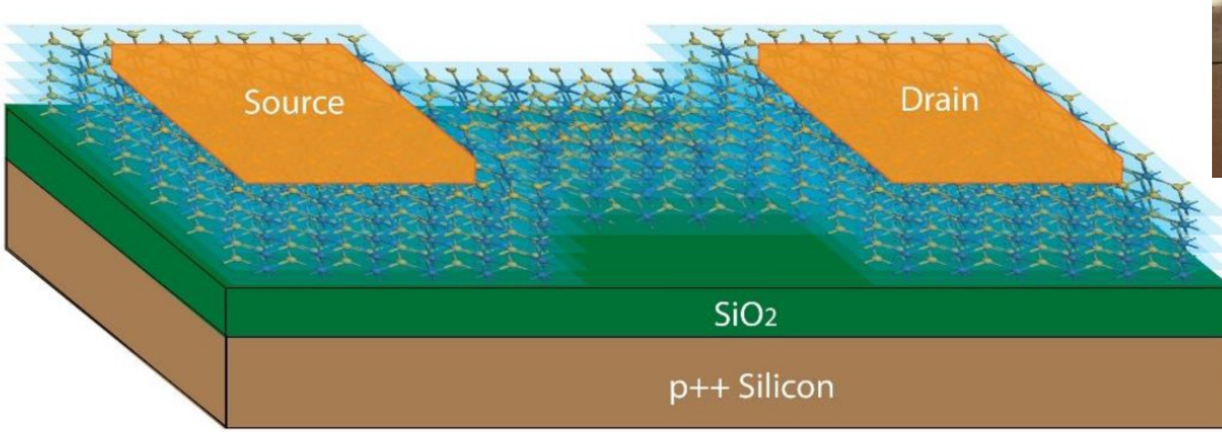
Characterisation methods (TLM, BG-JLT, 4P/Hall)

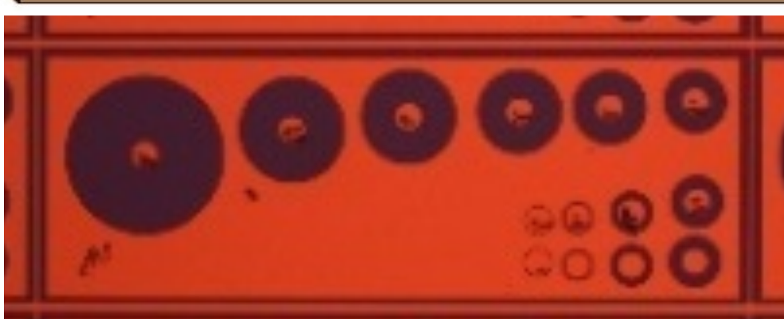


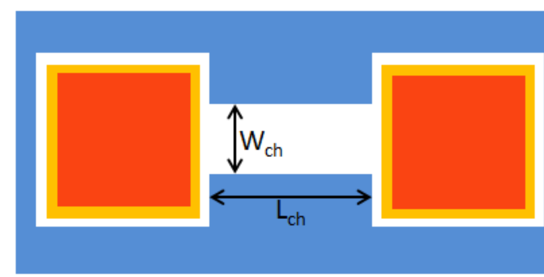


MoS_2 deposited on sapphire or Al_2O_3/sapphire substrate

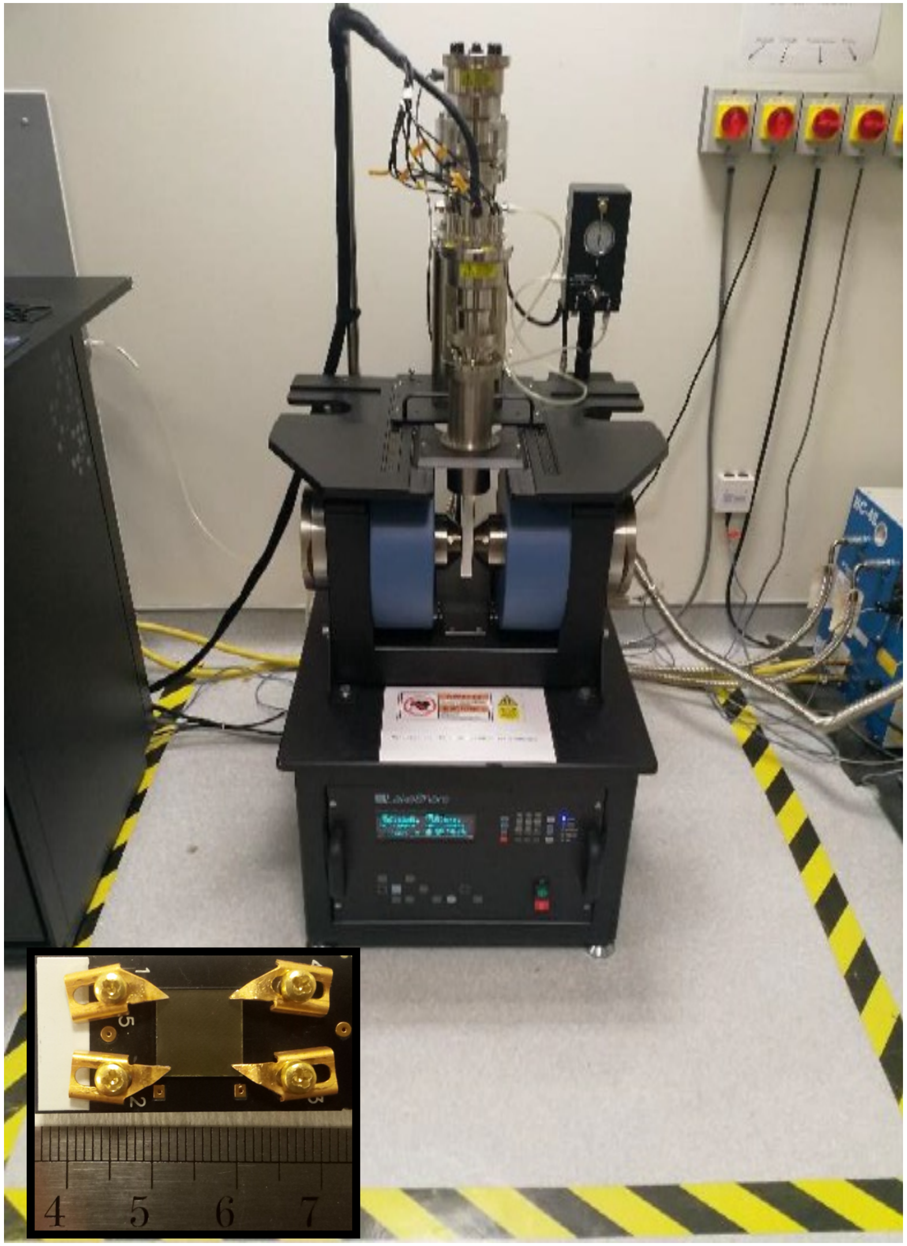


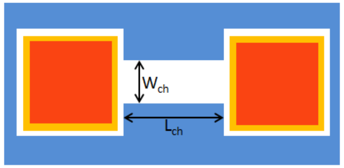






Equipment: 2P/4P/Hall System; Cascade Probe Station





Previous FYP in 2018/2019

"Study of Transition Metal Dichalcogenides for Back-End-Of-Line Switching Applications", Department of Physics, PY4115.

- Low thermal budget MoS_2 and $PtSe_2$ were grown and analyzed in different ways for their semiconductor characteristics:-
  - MoS_2 analyzed by 4-point and Hall-effect measurements
  - $PtSe_2$ by MOSFET analysis if thin-film modulation occurred

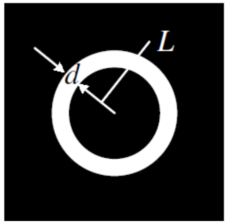
1. It was discovered that MoS_2 when doped with rhenium or niobium gives *n*-type or *p*-type material, respectively, and that non-intentionally doped MoS_2 is a defective *p*-type semiconductor.
2. $PtSe_2$ is known to be a semi-metal in bulk form and at ~4-5nm thickness we confirmed this behavior, but at a thickness of ~2.5-3 nm we discovered that $PtSe_2$ is in fact a *p*-type semiconductor.
3. Rhenium doping may additionally electrically stabilize MoS_2.
4. Suitable for back-end-of-line logic, memory and sensor circuitry for integrated More-than-Moore and Beyond-CMOS functionality.

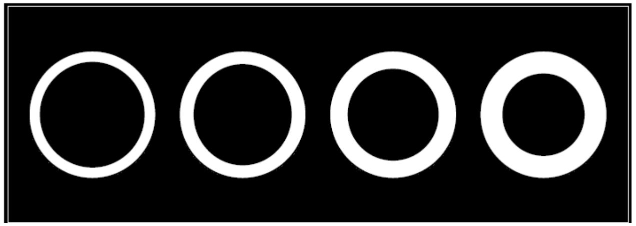
Up to 3 potential FYPs available in the NMD group

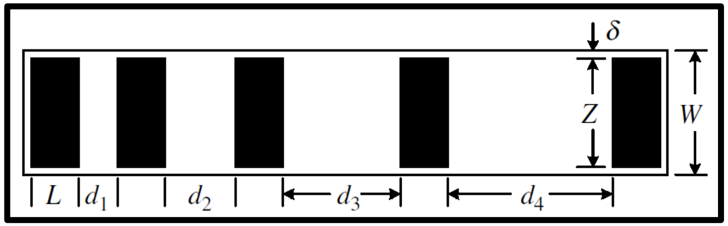
- Transition Metal Dichalcogenides for all FYPs below:-
  - FYP 1: Circular TLM assessment
  - FYP 2: Back-Gated Junctionless Transistor characterisation
  - FYP3: Van der Pauw 4-Point/Hall-effect analysis

FYP 1: Circular TLM assessment

- <u>FYP 1 Description:</u> TLM (the transmission line model, and/or the transfer length method) structures are made in a circular design (and/or in a linear design if feasible), using a TMD semiconductor such as MoS_2, WSe_2, etc. on SiO_2/Si substrates (a plan B in the event of processing problems would be to use a III-V semiconductor such as $In_{0.53}Ga_{0.47}As$). The TLM devices are then analysed by IV assessment on our Cascade Probe Station and total resistance versus distance is plotted. From these plots we can then extract the resistance components for the semiconductor: (1) sheet resistance, (2) contact resistance, (3) specific contact resistivity, and (4) transfer length.

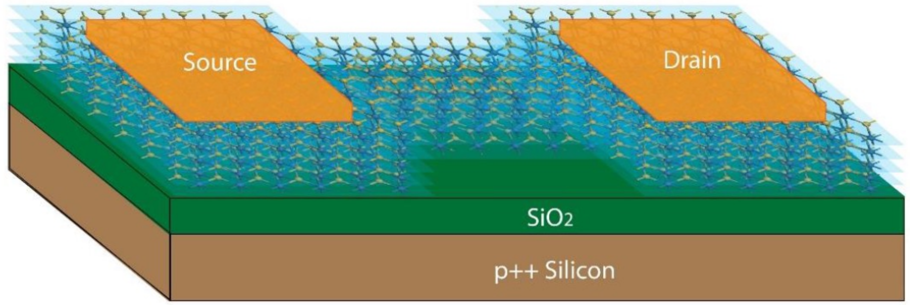


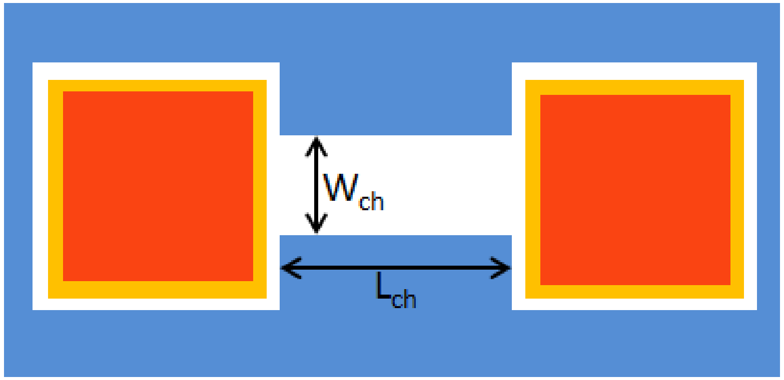




FYP 2: Back-Gated Junctionless Transistor assessment

- FYP 2 Description: Back-gated junctionless transistor (BG-JLT) structures will be formed using a TMD semiconductor such as MoS_2, WSe_2, etc. on SiO_2/Si substrates (a plan B in the event of processing problems would be to use a III-V semiconductor such as $In_{0.53}Ga_{0.47}As$). The BG-JLT devices are then analysed by I_{ds}-V_{ds} and I_{ds}-V_{bg} assessment on our Cascade Probe Station to determine field-effect modulation and performance. These output and transfer characteristics can potentially determine field-effect mobility, threshold voltage, subthreshold slope, etc.





FYP 3: Van der Pauw 4-Point/Hall-effect analysis

- FYP 3 Description: Van der Pauw (VdP) structures will be formed using a TMD semiconductor such as MoS_2, WSe_2, etc. on an insulating substrate (a plan B in the event of processing problems would be to use a III-V semiconductor such as $In_{0.53}Ga_{0.47}As$). The VdP devices are then analysed by 2-point, 4-point and Hall-effect measurements on our Lakeshore Hall Measurement System (HMS) which has very broad I.R=V capability and an electromagnet powered for a range of ~±1.7 Tesla in DC mode and up to ~+1.24 Tesla RMS in AC mode. We will determine semiconductor resistivity, contact resistance, Hall coefficient, carrier concentration, dominant carrier type and Hall-effect mobility.