2D Materials & Devices

One of the most promising candidates as substitution for silicon in modern electronics devices are Transition-Metal-Dichalcogenides (TMDs). These are semiconductors in the form of MX$_2$, where M is a transition metal (Mo, W, Hf), and X is a chalcogen (S, Se, Te). Due to the performance and economic benefit obtained by scaling, future semiconductor electron devices for logic functions will progress toward ultra-thin-body channels and 2-dimensional (2D) high carrier mobility materials.

Scanning Electron Microscopy image of the contacted MoS$_2$ device, with the contact tracks numbered 1 to 4.
The application of these materials in transistors could prolong the battery charge life of portable devices and phones, as well as having applications in larger more power intensive operations like data storage and server centres. This will have obvious environmental benefits through the reduction of electrical energy consumed by information and communication technologies as well as benefitting consumers.

In the Nanomaterials and Devices (NMD) group we have demonstrated a junctionless transistor based on highly doped MoS\textsubscript{2} exfoliated from a bulk crystal. The p-type switching behavior of the flake, expected since it is doped with Nb atoms, was confirmed by electrical device measurements and by Hall-effect measurements that indicated a high carrier concentration of $4.3 \times 10^{19} \text{ cm}^{-3}$. The high doping can be the key to the introduction of TMD-based junctionless transistors, in which the beneficial characteristics of TMDs and the uncomplicated process required by this kind of architecture may be combined.

Furthermore we have characterised MoS\textsubscript{2} devices, fabricated based on Thermal Assisted Conversion (TAC) of metal layers, using material analysis combined with electrical device parameter extraction.

![A schematic shows the lattice spacing in MoS\textsubscript{2}. The lattice spacing of 6.15 Ångstrom allows us to identify the regions of MoS\textsubscript{2}](image)

This work is done in collaboration with Prof. Georg Duesberg’s group in CRANN, Trinity College Dublin. Prof Robert Wallace’s group at the University of Texas at Dallas, Prof. Greg Hughes’s group in Dublin City University, and Dr. David McNeill’s group in Queens University Belfast.
Two-dimensional materials (e.g. MoS\textsubscript{2}, MoSe\textsubscript{2}, WSe\textsubscript{2}, etc.) and devices

One class of materials which demonstrates considerable promise as the active semiconductor layer for improved energy efficiency in electronic, optical and sensing devices are called transition metal dichalcogenides (TMDs), otherwise known as two-dimensional (2D) materials. Examples of TMDs or 2D materials are: MoS\textsubscript{2}, WSe\textsubscript{2}, HfSe\textsubscript{2}, MoTe\textsubscript{2} and MoSe\textsubscript{2}.
What is particularly exciting about this general class of semiconductor is that they have a range of energy gaps which span from semi-metals through to wide band gap semiconductors, and as a consequence open up a range of potential applications in electronic devices, sensors, through to applications in flexible electronics, photovoltaics, and the production of solar fuels using photo-electrochemical cells.

While progress has been made in fabricating sensors, optical devices, and MOSFETs using TMDs, the synthetic formation of TMDs and the control and understanding of doping TMDs remain at an early stage of research and development. The NMD group activities are focused on the development of synthetic TMD growth development and doping techniques, top gate and back gate MOSFET device formation, and advanced electrical characterization including systematic studies of carrier concentration, carrier type and carrier mobility by Hall effect analysis of natural and synthetic TMD materials.

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Related Publications

- Back-gated Nb-doped MoS2 junctionless field-effect-transistors
  AIP Advances volume 6 issue 2 page 025323 (2016)
  Authors: Gioele Mirabelli, Michael Schmidt, Brendan Sheehan, Karim Cherkaoui, Scott Monaghan, Ian Povey, Melissa McCarthy, Alan P. Bell, Roger Nagle, Felice Crupi, Paul K. Hurley, Ray Duffy

- Structural and Electrical Investigation of MoS2 Thin Films Formed by Thermal Assisted Conversion of Mo Metal
  Authors: Ray Duffy, Patrick Foley, Bruno Filippone, Gioele Mirabelli, Dan O'Connell, Brendan Sheehan, Pat Carolan, Michael Schmidt, Karim Cherkaoui, Riley Gatensby, Toby Hallam, Georg Duesberg, Felice Crupi, Roger Nagle, Paul K. Hurley