

## In the Lab

# Targeting Industry-Compatible Synthesis of Two-Dimensional Materials

**Johnson Matthey Technology Review features new laboratory research**

Niall McEvoy's research is primarily focused on the synthesis and characterisation of nanomaterials, particularly two-dimensional (2D) materials, and their subsequent assessment for use in a wide array of applications. A key aspect of this work involves developing and refining industry-relevant synthesis protocols for emerging 2D materials. One potentially industry-compatible way to produce these materials is using vapour-phase methodologies, such as chemical vapour deposition (CVD). Identifying 2D materials that can be synthesised at relatively low temperatures is vital if these materials are to be considered for real-world applications. Vapour-phase-grown 2D materials are of interest for diverse fields, in areas such as electronics, optoelectronics, telecommunications, sensing of analytes, detection and measurement of strain and catalysis. The innovative potential of these materials has led to considerable interest and investment from private enterprise, particularly in the information and communication technology sector.

McEvoy leads the Architecture and Synthesis of Integrated Nanostructures (ASIN) group at Trinity College Dublin, Ireland. He is a funded investigator in the Advanced Materials and BioEngineering Research Centre (AMBER), also at Trinity College Dublin. He has co-authored over 100 peer-reviewed articles in the area of nanomaterials. His group benefits from an extensive research network involving active collaborations with research groups in Ireland, the UK, China, Germany, Italy, Austria, Switzerland and Denmark. He was the recipient of a Science Foundation Ireland Technology Innovation Development Award in 2015 and a Starting Investigator Research Grant in 2016.

## The Researcher



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## About the Research

Since the isolation of graphene in 2004, research has unveiled the ever more impressive and diverse properties of 2D materials, prompting them to be linked with use in an increasing array of applications. While the properties of 2D materials are certainly revolutionary, and the associated

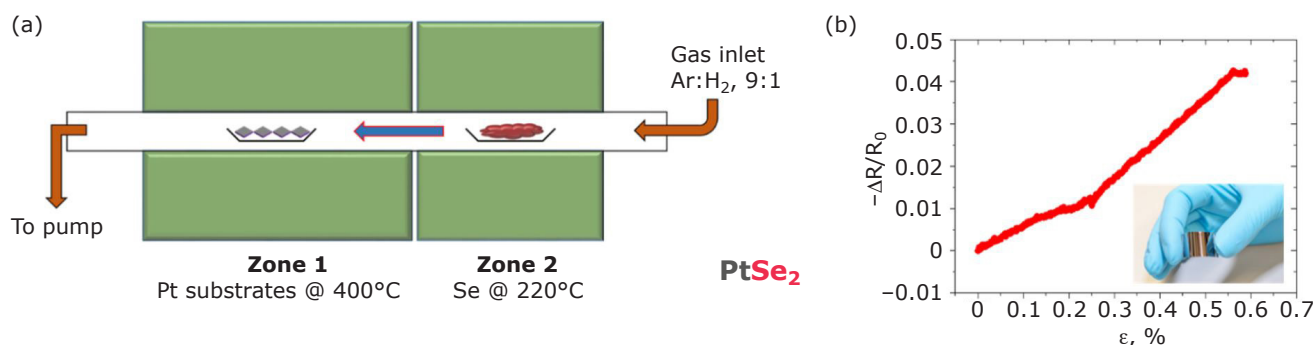


Fig. 1. (a) Schematic for synthesis of PtSe<sub>2</sub> thin films; (b) piezoresistive response of PtSe<sub>2</sub>/polyimide under flexure. Inset: photograph of PtSe<sub>2</sub> grown directly on polyimide (5)

physics and chemistry indeed very exciting, the hype surrounding the field should to some extent be tempered by practical considerations of how best they should be fabricated and subsequently processed. Many of the experimental reports on their properties have used materials prepared by mechanical exfoliation, a laborious, serendipitous and inherently unscalable production technique.

Efforts to improve the scalability of 2D materials production broadly fall into two approaches: liquid-phase exfoliation, a top-down method; and vapour-phase growth, a bottom-up method. Enormous progress has been made in these fields in recent years. The scalable production of 2D material dispersions by shear exfoliation was reported by Professor Coleman's group at Trinity College Dublin (1). On the vapour-phase growth front, recent reports from researchers in Interuniversity Microelectronics Centre (IMEC), Belgium have demonstrated wafer-scale growth of the 2D material tungsten disulfide (WS<sub>2</sub>) in a semiconductor fabrication setting (2).

Much of the research undertaken by the ASIN group is centred on developing sensible and scalable vapour-phase growth approaches for the synthesis of 2D materials. Particular focus has been placed on developing growth recipes for less-commonly studied 2D materials, for instance those whose bulk form is not naturally abundant. A recent example of the group's research efforts is the vapour-phase growth of platinum diselenide (PtSe<sub>2</sub>). PtSe<sub>2</sub> can be found in nature in the form of the mineral sudovikovite but this is quite rare. In its 2D form PtSe<sub>2</sub> benefits from a high charge-carrier mobility, good stability in ambient conditions, a thickness-dependent band structure and promising electrocatalytic behaviour.

McEvoy and coworkers developed a simple, but robust, vapour-phase process for the growth of thin films of PtSe<sub>2</sub> (Figure 1(a)). The relatively low growth temperatures involved (~400°C) mean that the material could potentially be integrated with back-end-of-line processing in the semiconductor industry (3).

The PtSe<sub>2</sub> films grown in this manner have shown very promising results in laboratory-based prototype devices. Like other 2D materials, PtSe<sub>2</sub> possesses a near ideal surface-area to volume ratio which is in part responsible for its impressive performance in gas-sensing devices (4). The relatively low growth temperature means that PtSe<sub>2</sub> can be grown directly on flexible polymer substrates (5). These polymer/PtSe<sub>2</sub> films show a piezoresistive effect (Figure 1(b)), i.e. when they are bent the resistivity changes, suggesting potential use as gauges to monitor strain. PtSe<sub>2</sub> films grown in the ASIN laboratory have also shown promise for use in photodetectors (6), transistors (7) and pressure sensors (8).

Other ongoing projects in the ASIN group are focused on CVD synthesis of 2D material heterostructures, synthesis and electrochemical applications of transition metal ditellurides, tailored functionalisation of 2D materials, resistive switching in 2D materials and scanning-probe studies of defects in 2D materials.

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