A general approach for the synthesis of two-dimensional compounds by chemical vapour deposition

Abhay Shivayogimath[1,2], Joachim Dahl Thomsen[1,2], David M.A. Mackenzie[1], Jens Kling[3], Zoltan Imre Balogh[3], Andrea Crovetto[1,4], Patrick R. Whelan[1], Mathias Geisler[2,5], Peter Bøggild[1,2], Timothy J. Booth[1,2]

[1]*DTU Nanotech, Ørsteds Plads, Kgs. Lyngby 2800, Denmark.*
[2]*Centre for Nanostructured Graphene (CNG), Ørsteds Plads, Kgs. Lyngby 2800, Denmark.*
[3]*DTU Cen, Fysikvej, Kgs. Lyngby 2800, Denmark*
[4]*V-SUSTAIN, Kgs. Lyngby 2800, Denmark*
[5]*DTU Fotonik, Ørsteds Plads, Kgs. Lyngby 2800, Denmark*

abshi@nanotech.dtu.dk

Only a few of the vast range of potential two-dimensional materials predicted by theory have been isolated or synthesised to date. 2D materials are typically first isolated by mechanically exfoliating naturally occurring bulk crystals to produce atomically thin layers, after which a material-specific vapour synthesis method must be developed to grow interesting candidates in a scalable manner. The molybdenum and tungsten disulphides and diselenides remain among the most commonly studied 2D binary compounds due to the ready availability of bulk crystals that are amenable to mechanical exfoliation. Chemical vapour deposition (CVD) techniques for the scalable synthesis of these materials are available, but controlling the stoichiometry and defect density in synthesized films can be challenging. Such techniques typically employ solid metal oxide or metal-organic precursors which are chalcogenated at elevated temperatures. Finding appropriate metal precursors is often a limiting challenge for extending these methods to other 2D transition metal compounds, and often require dedicated processes and equipment that are highly optimised for growing one specific material. Here we present a general method for synthesizing two-dimensional binary compounds from elemental solid metal precursors, and demonstrate the growth of over 20 materials - both well-known and never-before isolated - including transition metal sulphides, selenides, tellurides, and nitrides. This approach greatly simplifies the synthesis of currently known materials, and provides a general framework for synthesising both predicted and unexpected new 2D compounds.

Figures

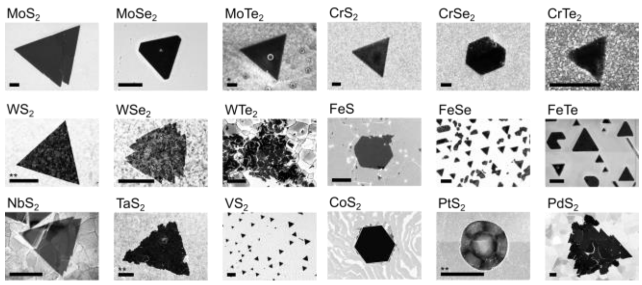

Figure 1: SEM images of the various transition metal chalcogenides grown by the present method. All presented materials are grown under identical process conditions, varying only M and X. Scale bars are 1 μm except where marked: *: 100 nm, **: 10 μm.