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A Chemical Method for MoS_2 Film Synthesis

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Background

Transition metal dichalcogenides (TMDs) are a class of 2D materials possessing a direct bandgap in the monolayer (1L) limit, which facilitates myriad applications:

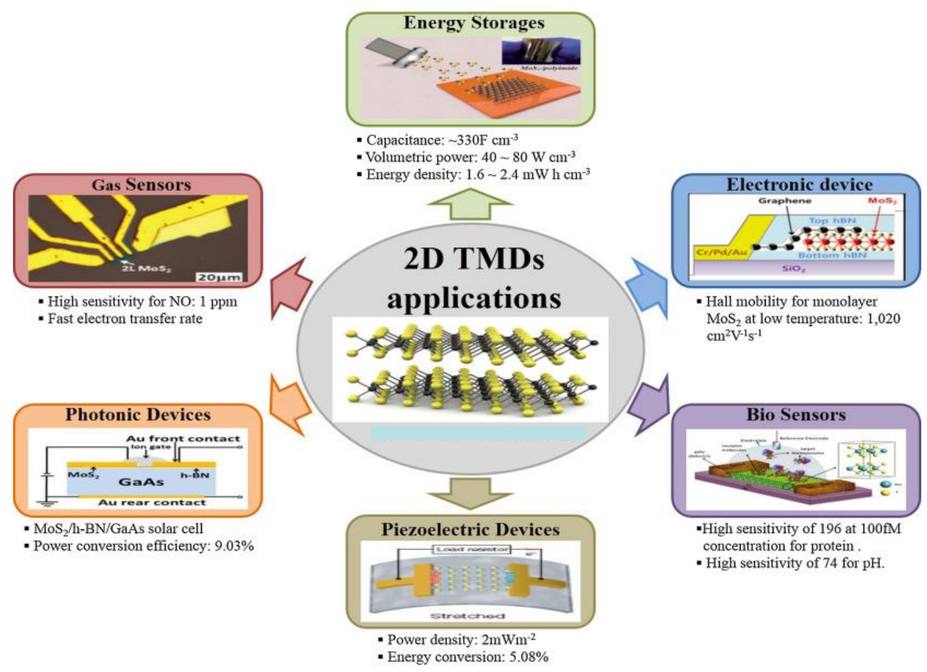


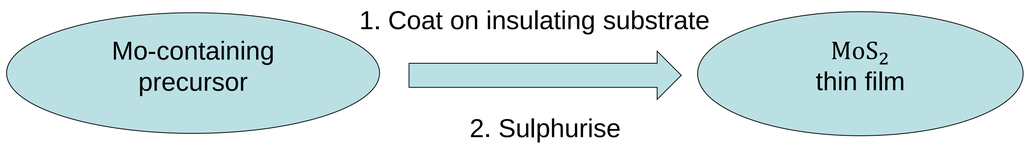
Figure 1: *TMD applications span electronics, catalysis, photonics and energy harvesting. [1]*

- Exfoliation of TMDs produces crystalline monolayers for fundamental studies and proof-of-concept devices, but scalable syntheses will have significant impact on practical applications.
- Challenges in obtaining defect-free crystals on a large scale. Physical (PVD) and chemical vapour deposition (CVD) have been studied for the synthesis of graphene, h-BN, HfO_2 and MoS_2.
- Liquid-based chemical techniques benefit from low cost and large volume. They have been used for the syntheses of metal—organic films, and metal oxides such as TiO_2.

Our work

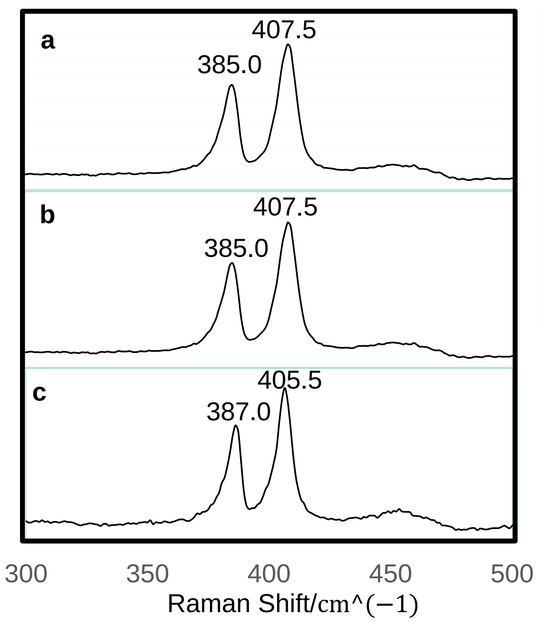
Methods

We report a surface-limited chemical method for the synthesis of MoS_2 films based on modification of deposition techniques, and the characterisation of the films by Raman spectroscopy, field-emission scanning electron microscopy (FESEM), atomic force microscopy (AFM) and photoluminescence (PL) mapping.



Characterisation

1. Raman spectroscopy confirms material presence and good crystallinity



Flake	E_{2g}/ cm^{-1}	A_{1g}/ cm^{-1}	Δf/ cm^{-1}	Inference
a	385.0	407.5	22.5	3L
b	385.0	407.5	22.5	3L
c	387.0	405.5	18.5	1L

Figure 2: *Representative Raman spectra of three flakes at 532 nm show characteristic in-plane E_{2g} and out-of-plane A_{1g} vibrations and confirm presence of MoS_2. Peak separation (Δf) confirms (a, b) 3L flakes and (c) a 1L flake. Peak sharpness suggests high crystallinity.*

2. FESEM and AFM confirm triangular-faceted morphology and 1-4L thickness

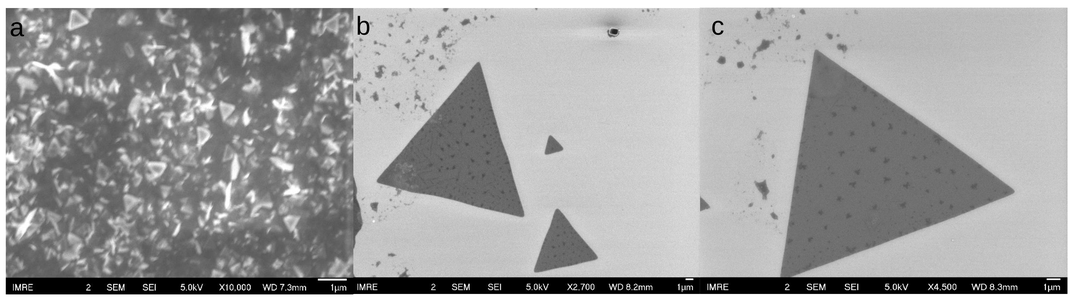


Figure 3: (a-c) *FESEM images of crystal facets grown by our technique. Morphology is in accordance with CVD [2]. Figure 3a is a low-magnification image of multiple facets on SiO_2/Si substrate. Figures 3b and 3c* are *high-magnification FESEM images of individual MoS_2 facets with ~15 x 15 μm lateral size, comparable to CVD.*

Figure 4: *Optical reflection image of CVD growth of MoS_2 on SiO_2/Si for comparison [2].*

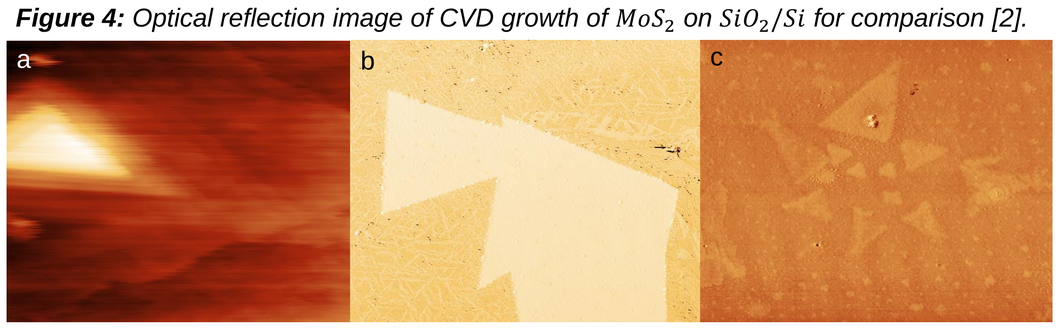


Figure 5: (a-c) *Tapping-mode AFM images show triangular-faceted crystals grown by our technique. Figure 5a shows layer-by-layer stacking of crystals. Figures 5b and 5c show flakes with heights ~7.0-28.0 Å, 1-4L.*

3. PL mapping confirms high-quality monolayers

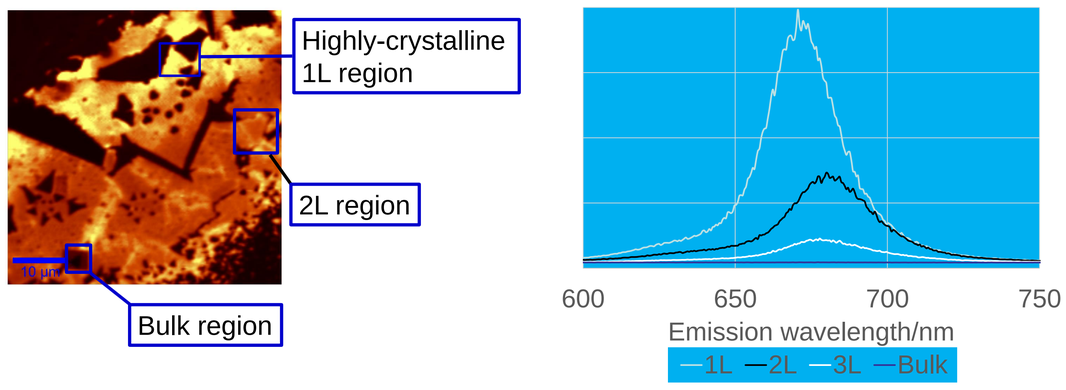


Figure 6: *(L) 50 x 50 μm PL map obtained at 213 K. (R) High-quality 1L MoS_2 flakes exhibit a peak at 670.6 nm (1.85 eV), but intensity falls off as layer thickness increases. Redshift to 677.7 and 679.9 nm (1.81-1.80 eV) at 2-3L attributable to changes in electronic band structure. PL only appreciable in the 1L limit, so relative intensity confirms presence of highly-crystalline MoS_2 monolayer.*

Discussion & Future

Our results are consistent with few-layer growth:

- Raman spectra show characteristic MoS_2 peaks; Δf confirms 1-3L growth.
- Crystallinity confirmed by Raman peak sharpness, and SEM and AFM data, which show micron-scale, triangular-faceted crystals.
- PL data show an intense peak at 1.85 eV, evidence of highly-crystalline monolayers.

- Our method could provide a new avenue towards large-scale, low-cost growth of highly-crystalline monolayer MoS_2.
- This method could be tailored to the growth of other TMDs.
- We will aim to fabricate devices using monolayers synthesised by our method.

References

1. Radisavljevic, B., *et al.* Single-Layer MoS_2 Transistor. *Nature Nanotechnol.,* **6**, 147-50 (2011).
2. van der Zande, A., *et al.* Grains & Grain Boundaries in Highly-Crystalline Monolayer MoS_2. *Nat. Mater.*, **12,** 554 (2013).

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