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# Wafer-Scale Synthesis of Single Crystal TMD Monolayers

Monolayer transition metal dichalcogenides (TMDs, $MoS_2$, $WSe_2$, etc.) possess a range of intriguing optical and electronic properties including direct bandgap, large exciton binding energies, valley polarization, etc. Current research is typically carried out using flakes exfoliated from bulk crystals or grown by powder vapor transport which are challenging to scale to large areas. Our research is aimed at the development of an epitaxial growth technology for layered dichalcogenides, similar to that which exists for III-Vs and other compound semiconductors, based on gas source chemical vapor deposition (CVD). This approach provides excellent control of the precursor partial pressures to achieve monolayer growth over large area wafers. Our studies have focused on the epitaxial growth of binary TMD monolayers including $MoS_2$, $WS_2$, $WSe_2$ and $MoSe_2$ using metal hexacarbonyl and hydride chalcogen precursors to deposit on 2" sapphire substrates. A multi-step precursor modulation growth method was developed to control nucleation density and the lateral growth rate of monolayer domains on the substrate [1]. Using this approach, uniform, coalesced monolayer and few-layer TMD films were obtained on 2" sapphire substrates at growth rates on the order of ~1 monolayer/hour (Fig. 1). In-plane X-ray diffraction demonstrates that the films are epitaxially oriented with respect to the sapphire with minimal rotational misorientation of domains within the basal plane [2]. Post-growth dark-field transmission electron microscopy carried out on monolayers removed from the sapphire by a wet transfer method reveals that the monolayer films are largely single crystal (65-95% coverage) but contain inversion domains that result from coalescence of $0^o$ and $180^o$ misoriented islands. This research is part of the 2D Crystal Consortium (2DCC) – an NSF-supported Materials Innovation Platform national user facility focused on advancing the synthesis and applications of 2D layered chalcogenide films and crystals. Further details on the 2DCC facilities, in-house research activities and user program will also be provided.

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## References

[1] X. Zhang, T.H. Choudhury, M. Chubarov, Y. Xiang, B. Jariwala, F. Zhang, N. Alem, G.C. Wang, J.A. Robinson and J.M. Redwing, Nano Lett. 18 (2018) 1049.
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## Figures

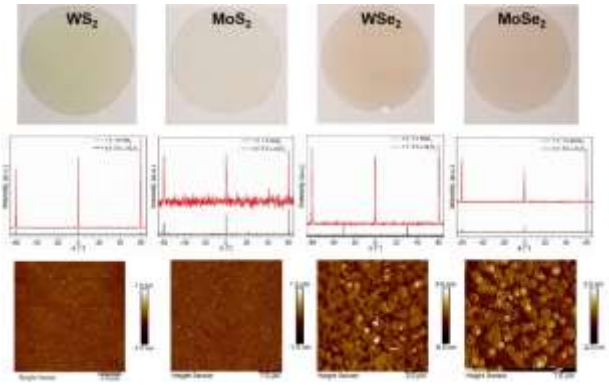


**Figure 1:** Epitaxial TMD films grown on 2" sapphire by gas source CVD