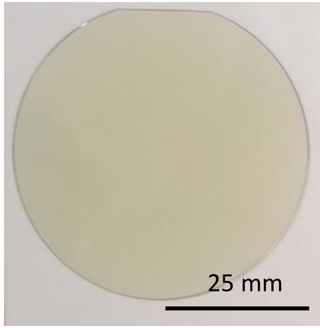
Wafer scale epitaxial growth of unidirectional WS_2 monolayers on sapphire

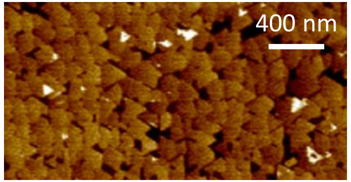
M. Chubarov, T.H. Choudhury, D. R. Hickey, H. Zhu, S. Das, M. Terrones, N. Alem and J.M. Redwing (2DCC, Penn State)

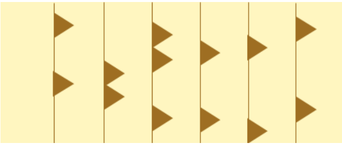
Project Summary: Realization of wafer-scale single-crystal films of transition metal dichalcogenides (TMDs) such as WS_2 requires epitaxial growth and coalescence of oriented domains to form a continuous monolayer. The domains must be oriented in the same crystallographic direction on the substrate to inhibit the formation of inversion domain boundaries (IDBs), which form when oppositely oriented triangular domains coalesce. Here we demonstrate fully coalesced unidirectional WS_2 monolayers on 2 in. diameter *c*-plane sapphire by metalorganic chemical vapor deposition (MOCVD) using a multistep growth process to achieve epitaxial WS_2 monolayers. Transmission electron microscopy analysis reveals that the WS_2 monolayers are largely free of IDBs but instead have translational boundaries that arise when WS_2 domains with slightly offset lattices merge together. The unidirectional orientation of domains is attributed to the presence of steps on the sapphire surface coupled with growth conditions that preserve the aligned domain structure. The results demonstrate the potential of achieving wafer-scale TMD monolayers free of inversion domains with optical and transport properties approaching those of exfoliated flakes.

Published in: *ACS Nano 15,2, 2532-2541 (2021).*

2DCC Role: The MOCVD growth studies were carried out in the 2DCC Thin Films facility (Redwing). Structural and optical characterization of the layers were carried out by 2DCC-affiliated faculty (Alem, Terrones) and transport measurements were performed by an internal user (Das).







Steps on the sapphire surface induce a preferred alignment of WS_2 triangular domains which coalesce seamlessly to form large single crystal monolayer regions. Domains that are aligned but have slightly off-set lattices result in translational boundaries.