Epitaxial Growth of Transition Metal Dichalcogenide Monolayers for Large Area Device Applications

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Abstract

Wafer-scale epitaxial growth of semiconducting transition metal dichalcogenide (TMD) monolayers such as MoS_2, WS_2 and WSe_2 is of significant interest for device applications to circumvent size limitations associated with the use of exfoliated flakes. Epitaxy is required to achieve single crystal films over large areas via coalescence of TMD domains. Our research has focused on epitaxial growth of 2D semiconducting TMDs on c-plane sapphire substrates using metalorganic chemical vapor deposition (MOCVD). Steps on the miscut sapphire surface serve as preferential sites for nucleation and can be used to induce a preferred crystallographic direction to the TMD domains which enables a reduction in inversion domain boundaries in coalesced films. The step-directed growth is dependent on the surface termination of the sapphire which can be altered through pre-growth annealing in H_2 and chalcogen-rich environments. Uniform growth of TMD monolayers with significantly reduced inversion domains is demonstrated on 2" diameter c-plane sapphire substrates enabling large area transfer of monolayers for characterization and device fabrication and testing. Applications for wafer-scale TMD monolayers in nanoelectronics, sensing and photonics will be discussed.

Figures

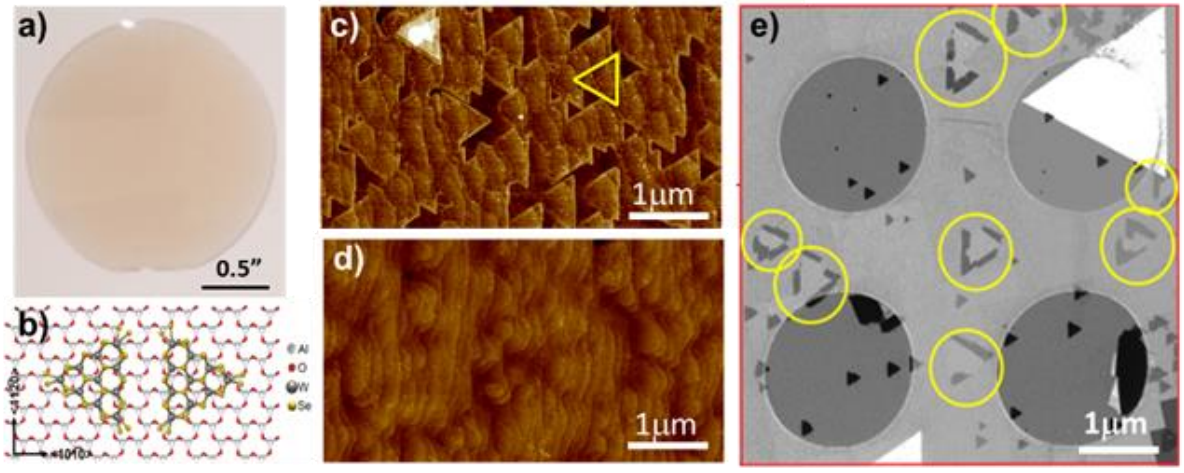

Figure 1: a) WSe_2 monolayer grown by MOCVD on 2" c-plane sapphire; b) Schematic illustration of 0° and 60° oriented WSe_2 domains on (0001) sapphire; c) Partially coalesced WSe_2 on sapphire showing dominant 0° orientation (illustrated by yellow triangle); d) Fully coalesced WSe_2 monolayer; e) Composite dark-field TEM image of WSe_2 monolayer after layer transfer from sapphire growth substrate showing uniform contrast single crystal region. Inversion domain boundaries (yellow circles) exhibit preferential etching. Small pinholes and tears are also present which result from layer transfer. (White triangles are bilayer domain and circular features are artifacts from holes in the TEM grid.)