Ultra-thin 2D Semiconductors for Next Generation Devices

*C. Chen, N. Trainor, S. Kumari, K. T. V. McKnight, M. E. Leger, A. R. Graves, and J. M. Redwing

Abstract:
The field of two-dimensional (2D) materials began with the advent of graphene but has expanded to a wide class of materials that occur naturally as layered crystals. Within this class of materials, semiconducting transition metal dichalcogenides (TMDs) such as MoS_2 and WSe_2 have attracted significant interest in condensed matter physics and next generation electronics and optoelectronics. At the single layer limit, which is less than 1 nanometer in thickness, the TMDs exhibit direct band gaps which results in efficient light emission and retain good carrier mobility compared to conventional semiconductors such as silicon. Furthermore, TMD layers with different compositions and properties can be stacked to create unique heterostructures. Practical device applications, however, require large area single layer TMD films which presents unique challenges. Our work has focused on the development of metalorganic chemical vapor deposition as a manufacturing-compatible approach for wafer-scale semiconducting TMDs.

Recently, we have focused on epitaxial growth of TMDs on sapphire and studying how the effect of substrate surface chemistry, orientation and miscut angle impact the nucleation and film growth. Wafer-scaled 2D TMDs were grown on 2-inch sapphire substrates with different orientations and miscut angles. All growths were conducted in a horizontal cold-wall MOCVD system at 900-1000^{o}C using H_2S and H_2Se as chalcogen precursors, $Mo(CO)_6$ and $W(CO)_6$ as metal precursors with H_2 as the carrier gas. Surface morphology, epitaxial crystallinity, and optical properties of the grown TMDs were systematically characterized by AFM, FESEM, Raman, photoluminescence, UV-VIS-IR absorption spectrum, and In-plane XRD. Characterization results show interesting effects of substrate surface chemistry, orientation and miscut angle of the sapphire substrates on the nucleation and film growth. These studies enable a deeper understanding of the fundamental mechanisms of TMD growth which will be beneficial to the development of next generation electrical and optoelectronic devices.