Chemically Functionalized Two-Dimensional Nanoelectronic Heterostructures

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Two-dimensional materials have emerged as promising candidates for next-generation electronic and optoelectronic applications. As is common for new materials, much of the early work has focused on measuring and optimizing intrinsic properties on small samples (e.g., micromechanically exfoliated flakes) under idealized conditions (e.g., vacuum and/or cryogenic temperature environments). However, real-world devices and systems inevitably require large-area samples that are integrated with dielectrics, contacts, and other semiconductors at standard temperature and pressure conditions. These requirements are particularly challenging to realize for two-dimensional materials since their properties are highly sensitive to surface chemistry, defects, and the surrounding environment. This talk will thus explore methods for improving the uniformity of solution-processed two-dimensional materials with an eye toward realizing scalable processing of large-area thin-films. For example, density gradient ultracentrifugation allows the solution-based isolation of transition metal dichalcogenides and boron nitride with homogeneous thickness down to the single-layer level. Similarly, two-dimensional black phosphorus is isolated in solution with the resulting flakes showing field-effect transistor mobilities and on/off ratios that are comparable to micromechanically exfoliated flakes. In addition to solution processing, this talk will also report on the integration of two-dimensional materials with dielectrics and other semiconductors. In particular, atomic layer deposition of dielectrics and covalent organic adlayers on two-dimensional black phosphorus suppresses ambient degradation, thereby preserving electronic properties in field-effect transistors at atmospheric pressure conditions. Finally, gate-tunable p-n heterojunction diodes with Type I and Type II band alignments are demonstrated by integrating n-type single-layer MoS_2 with p-type semiconducting single-walled carbon nanotubes and pentacene, respectively.