

Controlling Nucleation Density of 2D Materials: From Nanodomains to Large Single Crystals for Advanced Electronics and Optoelectronics

Dr. Pranab Mohapatra, Tel Aviv University

Host Professor: Mark Hersam, Northwestern University



Dr. Mohapatra with the Hersam Lab

2D materials, particularly van der Waals (vdW) semiconductors, such as the transition metal dichalcogenides (TMDs) family have drawn great scientific, and technological attention due to their remarkable physical and chemical properties. The most significant challenge for the synthesis of these materials is the control of the early stages of nucleation and growth of materials on preferred surfaces, which would eventually lead to either polycrystalline or single crystal domains. Despite the significant advances in the field, the growth of atomically-thin semiconductor films are far from being understood. Metal organic chemical vapor deposition (MOCVD) is one of the most promising methodologies for the large-scale formation of such films, allowing for the systematic growth mechanism studies as well.

In this project, we made significant modifications to Prof. Hersam's MOCVD system at NU, particularly by incorporating a new selenium bubbler with accessories to grow less explored selenium based TMDs and adding extra lines to accommodate the installation of a DI water bubbler. This DI water bubbler is essential for a technique previously established in Prof. Ariel Ismach's lab at TAU to ensure large grain synthesis of TMDs. Our primary objectives were to develop novel methodologies for producing high crystalline continuous monolayer TMDs films. Currently, we have developed recipes to grow continuous layer films of MoS₂ and WS₂ on sapphire substrate and further works are carried out to increase the domain size and to synthesize Se based TMDs. These materials have versatile applications, including memtransistors sensors, and single-photon emitters, etc. Additionally, we successfully demonstrated the growth of transition metal dichalcogenides (TMDs), mainly MoS₂ and WS₂ at relatively low temperatures, as low as 350 °C, compatible with back end of line (BEOL) processes, appealing for integration of TMDCs with existing state of the art technologies.

Furthermore, we conducted several experiments aimed at creating sub 10 nm nanochannels through catalytic etching of graphene layers using silver nanostructures. This approach holds substantial promise for enhancing the performance of TMDs based high-speed optoelectronic devices. Notably, this nanochannel fabrication method offers significant advantages over conventional, costly, and time-consuming lithography-based techniques. We investigated several intriguing organic semiconductors, including pentacene and C8 BTBT, as potential channel materials to assess the impact of nanochannels on their electrical and optoelectronic characteristics. Ongoing research is exploring deeper into these studies.

We studied the possibilities of synthesizing the Vander walls heterostructures by a reactive intercalation of graphene layers. In this method, we introduced transition metals like Mo or W into a few-layer and multi-layer graphene samples using metal chloride precursors within vacuum-sealed quartz ampules and selenization reaction thereafter to achieve the heterostructure formation. This collaborative effort involved working with Prof. Mercuri Kanatzidis and his postdoc, Dr. Abhishek Iyer, from the Department of Chemistry, NU. This research holds both fundamental and practical significance. It promises to offer fresh insights into the growth mechanisms of 2D materials within confined van der Waals gaps, facilitates the study of properties of less-explored ultra-thin layered compounds, and enables the creation of complex heterostructures.

Northwestern University

