NDnano Undergraduate Research Fellowship (NURF)
2025 Project Summary
NDnano Summer Undergraduate Research
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1. Student name & home university:

Guopeng Pan, Sun Yat-sen University

2. ND faculty name & department:

Professor Petr Stepanov, Physics and Astronomy

3. Summer project title:

Low-dimensional materials: Heterostructure assembly, nanofabrication and characterization

4. Briefly describe new skills you acquired during your summer research:

- Prepared WSe_2 samples on substrate
- Identified monolayer regions using optical microscopy
- Utilized PDMS and PC films to clean impurities and isolate monolayers with high precision
- Performed micro-cutting using a metal tip
- Performed angle-controlled stacking to construct twisted-angle WSe_2 heterostructures with hBN
- Assisted in the preparation of hBN-attached graphite samples for device fabrication

5. Briefly share a practical application/end use of your research:

The twisted-angle WSe_2 heterostructures assembled in this project offer a highly tunable platform for investigating a wide range of emergent quantum phenomena, including moiré excitons, correlated insulating states, superconductivity, and unconventional magnetism. Precise control of twist angle and layer alignment enables moiré superlattices with tailored band structures and enhanced many-body interactions. These heterostructures are not only critical for advancing the fundamental understanding of 2D material physics but also hold significant potential for practical applications. They can serve as the building blocks for next-generation quantum and optoelectronic devices, such as ultra-sensitive photodetectors, low-power and high-speed transistors, programmable quantum circuits, and valleytronic devices that utilize the momentum-dependent valley degrees of freedom.

6. 50- to 75-word abstract of your project:

This project focuses on the fabrication of twisted-angle WSe_2 heterostructures with hBN using micro-mechanical exfoliation, precision stacking, and angle control techniques. Monolayer WSe_2 samples were prepared, cleaned, and assembled to study interlayer interactions. These heterostructures serve as a platform for exploring novel quantum phenomena in 2D materials and may enable applications in next-generation optoelectronic and quantum devices.

7. References for papers, posters, or presentations of your research:

[1] Devakul, Trithep, et al. "Magic in twisted transition metal dichalcogenide bilayers." Nature communications 12.1 (2021): 6730.

One-page project summary that describes problem, project goal and your activities / results:

Two-dimensional (2D) materials have become a powerful platform for exploring novel quantum phenomena due to their atomically thin structure, highly tunable physical properties, and ease of stacking into customized multilayer systems. These materials allow precise control over interlayer coupling, symmetry, and band structure through stacking orientation, thickness, and encapsulation. This flexibility has enabled the discovery of many exotic physical states and behaviors not found in bulk materials.

Tungsten diselenide (WSe_2), a semiconducting transition metal dichalcogenide (TMD), is especially attractive for such studies thanks to its strong spin–orbit coupling, direct bandgap in monolayer form, and valley-selective optical transitions. When two WSe_2 monolayers are stacked at a small, controlled twist angle and encapsulated with insulating layers like hexagonal boron nitride (hBN), the resulting structure exhibits rich physical phenomena such as moiré excitons, correlated insulating states, flat-band physics, and even superconductivity. These features make it a promising material system for future quantum and optoelectronic devices.

My work focused on the exfoliation and transfer procedures essential to this fabrication. I prepared WSe_2 flakes on silicon substrates and identified monolayer regions using optical microscopy. To ensure clean surfaces, I employed dry-transfer cleaning methods using PDMS and PC films. I assisted in isolating monolayer flakes via metal-tip micro-cutting and participated in the precision stacking of WSe_2 bilayers at controlled twist angles, followed by hBN encapsulation. In addition, I helped fabricate hBN-attached graphite layers to be used in downstream device construction and transport measurements.

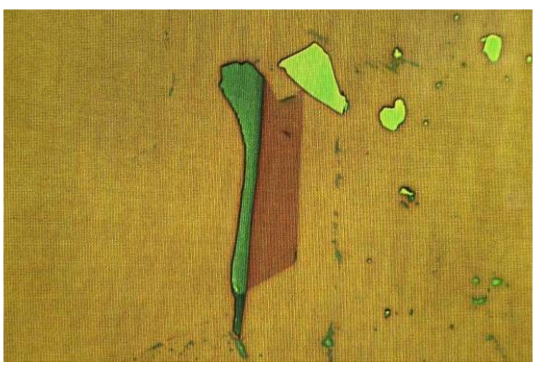

Figure 1: WSe_2 monolayer

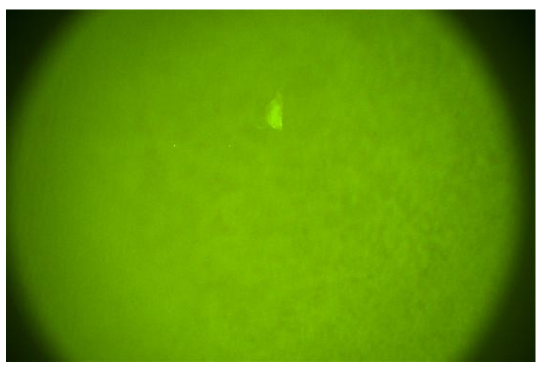

Figure 2: Twisted-angle WSe_2 with hBN

The successful assembly of these complex structures demonstrates the feasibility of constructing high-quality twisted 2D material systems through manual exfoliation and alignment techniques. These structures enable future investigations into interlayer coupling effects, angle-dependent quantum phases, and new types of optoelectronic behaviors. They also lay the foundation for fabricating next-generation devices for quantum sensing, low-power electronics, and tunable optical components.