RESEARCH STATEMENT

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The development, utilization, and dissemination of new knowledge are fundamental to the advancement of engineering education, experimentation, and research. I hope to become a leader and to use innovative and creative technological research on the engineering community.

Nanotechnology holds great promise in the development of novel applications in areas ranging from energy conversion to high-performance electronics. The ultimate goal of my research is to develop high-performance nanoelectronic devices by investigating charge injection and transport mechanism, and exploiting these properties for next-generation electronic applications. My current research interests are **1)** fundamentally understanding physical, chemical, and mechanical properties, electronic charge transport properties of nano-scale materials, **2)** design high-performance electronic devices using novel nanomaterials and patterning techniques, and **3)** build prototype applications that can provide valuable insights and evidence for use in advanced manufacturing and materials processing. High-performance electronic devices that use the novel semiconductors are essential to the development of future flexible, wearable, and transparent electronics such as displays, sensors, and solar cells. My research program is a unique combination; it includes the development of new experimental apparatuses, micro- and nanoscale fabrication processes, measurement techniques, and both theoretical and computational modeling.

Past Research Experience

Emerging 2D Materials for Nanoelectronics and Optoelectronics

The ability to tune the properties of nano-scale materials is key to the development of many novel applications. In the case of bulk semiconductors, creating and manipulating defects is an essential to the control of the host materials' the electrical, magnetic, and optical properties. Although the role of defects in bulk semiconductors is well-understood, their role in emerging two-dimensional (2D) layered semiconductors has received little attention, which has prevented their full exploitation in tailored 2D nanoelectronic and photonic devices. In this project, I investigated the controllable, and tailored properties of layered transition metal dichalcogenides (TMDs), which are important materials in 2D device engineering. Molybdenum disulfide (MoS_2), which is composed of weak van der Waals bonds of S-Mo-S units, offers a large intrinsic bandgap that is strongly dependent on the number of layers, with an indirect bandgap (1.2eV) in bulk MoS_2 transitioning to a direct bandgap (1.8 eV). I demonstrated a simple new technique for altering the optical and electrical properties of single layer MoS_2 by creating MoO_3 defects through an oxygen plasma treatment. This results and findings strengthen the understanding of fundamental physical properties of MoS_2, and demonstrate a new technique for engineering the bandgap and control the optical and electrical properties of atomically thin single layer MoS_2.

High-Performance Organic Field-Effect Transistors (OFETs) for Organic Electronics using Carbon-based Electrodes by Interfacial Engineering

The performance of organic field-effect transistors (OFETs) can be greatly limited by inefficient charge injection caused by the large interfacial barrier at the metal/organic semiconductor interface. In this project, I used state-of-art lithography techniques to enhance the performance of OFETs using electrodes made of carbon-based materials such as carbon nanotubes (CNTs) and graphene. To establish a fundamental understanding of the interface, I fabricated short-channel devices and carried out a low-temperature transport measurement to investigate how the alternative electrodes lowered the charge injection barrier. These experiments opened a new path for improving the performance of future nanoelectronic devices.

Carbon Nanotube Thin Film Transistors (CNT-TFTs) for Nanoelectronics

Because of exceptional electronic and mechanical properties of carbon nanotubes (CNTs), thin film transistors (TFTs) that are fabricated with CNTs have attracted a great deal of attention as they hold promise for use as components of next-generation flexible and transparent electronic devices such as sensors, and high frequency devices. The TFTs fabricated from a network of CNTs can be advantageous to individual nanotube devise as they provide more device-to-device homogeneity and cover large areas. In CNT-TFTs, a large number of nanotubes simultaneously contribute to the transportation of charge, which can significantly increase the output current. In this project, I developed an innovative way to improve the performance of short-channel solution-processed CNT-TFTs by controlling the longitudinal arrangement of semiconducting CNTs and metallic CNTs as semiconductors and source and drain electrodes. The low temperature transport measurement showed the lower Schottky barrier height. This work's findings suggest that CNT-TFT devices can be further improved through the use of metallic CNT electrodes.

The competitive proposal-submission and funding-application processes have taught me that excellent writing and communication skills are required. In addition, it is necessary to construct a feasible research plan, a timeline, and a budget, and to know how to use resources and reference tools to identify a broad range of funding opportunities. Thus, my experience will be instrumental in ensuring that I receive research funding in the future.

Future Research Plan

In the next five years, I plan to conduct further research to seek out and characterize novel low-dimensional nanomaterials, design high-performance devices, investigate fundamental charge-transport mechanisms, and build prototype applications to demonstrate next-generation technologies. A variety of factors that limit the performance of these devices must be addressed before they are released onto the market. To realize the highest-performing devices, it is paramount to identify these materials' fundamental properties and to develop appropriate processes and applications for them.

Below, I describe the initial research projects that I will use to build up a strong research program. Given recent funding-opportunity announcements, this program will provide great opportunities to receive funding from agencies such as the National Science Foundation (NSF), Department of Energy (DOE), and National Institutes of Health (NIH).

Charge-Transport Properties of 2D Nanomaterials

A unique aspect of 2D materials is that they can exist with the intrinsic electronic properties of materials such as metals, semimetals, semiconductors, and insulators; these properties are defined based on coordination chemistry. Among 2D materials, graphene (a semimetal) and MoS_2 (a semiconductor) have received significant attention. Although graphene has very high mobility, the lack of a bandgap in its electronic structure limits its applications in nanoelectronic and optoelectronic devices. On the other hand, MoS_2, as a member of the transition metal dichalcogenide family, offers a layer-dependent electronic bandgap. However, there is still a lack of understanding of (and control over) this compound's fundamental electronic properties. In this research project, I plan to develop bandgap engineering for 2D materials by controlling their electronic properties and investigating their charge-transport mechanism. This tunable bandgap enables these 2D materials to be more promising candidates for applications in field-effect transistors. In addition, as understanding charge-transport properties at the nanoscale and atomic scale has been challenging (due to the lack of experimental tools and techniques), I plan to work on controllably tuning the properties of 2D nanomaterials so as to develop a novel experimental platform for studying the charge transport of various nanomaterials. The insights that I obtain from this project will be valuable for developing bandgap engineering strategies for application in next-generation devices. I plan to submit this proposal to NSF ECCS.

Prototype Circuit Applications Using High-Performance Nanodevices

An electric circuit is made from electrical components such as transistors, resistors, capacitors, and diodes, which are interconnected in various ways. Transistors are the main building blocks of circuit applications, and billions of transistors can be used to form an integrated circuit. Several device parameters for the evaluation of transistor performance have been assessed for the initial testing of nanodevices. However, to successfully deliver basic circuit functionality, it is critical to build applications that reflect a circuit's functionality. This research can include both laboratory experiments and computational calculations and predictions based on the desired device geometry. I will demonstrate basic circuit functionality for use in high-performance nanodevices through various circuit applications (such as inverters and ring oscillators). In this project, I will investigate the effects that device configuration and process conditions have on transistor performance, and I will demonstrate circuit applications such as inverters and ring oscillators. This research will open up a path for prototype devices that will become commercially available in the near future. I plan to submit this proposal to NSF ECCS.

Flexible and Wearable Electronic Devices Using Carbon-based Electrodes

Flexible and wearable electronics is a rapidly growing research field due to its tremendous potential for applications such as flexible displays, flexible solar cell, wearable electronics, e-paper, and biomedical skin-like sensors. Carbon-based materials such as graphene and CNTs are promising candidates for flexible applications due to their high carrier mobility, optical transparency, and mechanical flexibility. However, the devices that use these materials on flexible substrates have yet to meet their potential in terms of performance. In addition, the well-developed methods for making conventional, silicon-based electronic devices are incompatible with most flexible materials due to the temperature-sensitive nature of plastic substrates. Flexible circuits require interconnections that are stretchable and bendable so as to remain intact when cycling through multiple instances of stretching and relaxation. As a result of these limitations, flexible electronic devices are limited to specific applications that do not require high performance. It is apparent that there is a need to improve the performance of flexible applications and related processes so as to rapidly and reliably manufacture flexible materials in a variety of configurations. Progress in the field of flexible electronics is expected to play a critical role in many important technologies, both emerging and established. In this project, I will continue to seek out new materials, develop new device architectures, and develop commercially feasible processing for making integrated electronic circuits that can be flexed, deformed, and bent. I plan to submit this research proposal to NSF ECCS and NIH R01/21.