

2014 NSF REU in Condensed Matter and Interdisciplinary Materials

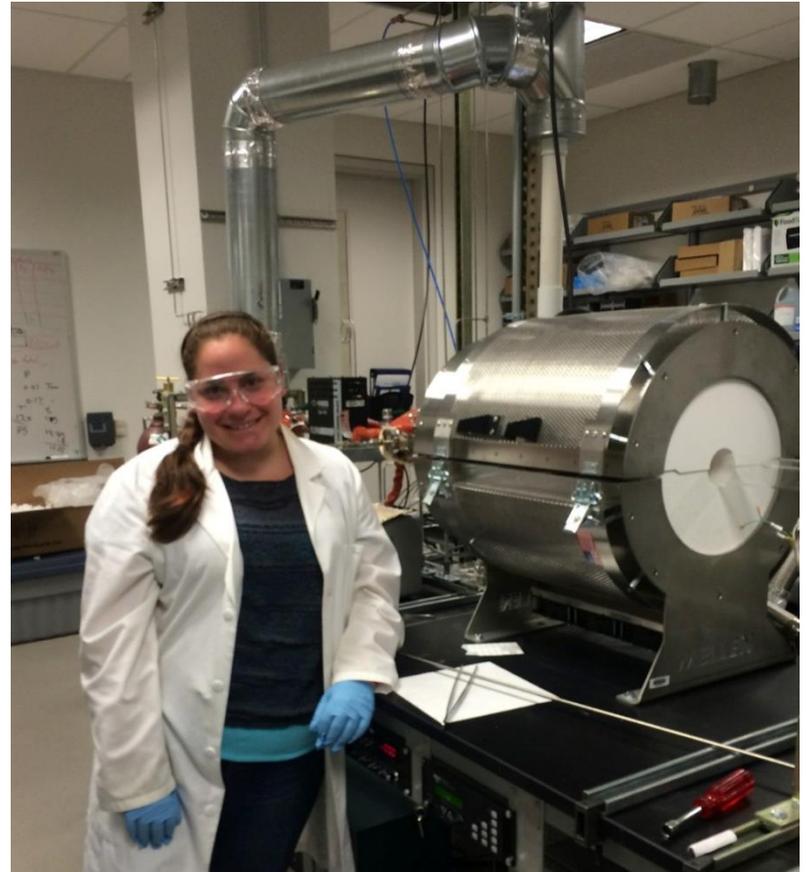
Growth of Two-dimensional hexagonal-Boron Nitride (h-BN) on Copper Foil

Gayle Geschwind, Department of Physics, Stony Brook University

Amin Azizi, Nasim Alem, Department of Materials Science and Engineering, Materials Research Institute, and Center for Two Dimensional and Layered Materials, The Pennsylvania State University

Hexagonal-boron nitride has a structure similar to graphene, but with alternating boron and nitrogen atoms instead of carbon. h-BN has many applications, including being an excellent dielectric and lubricant. It can also be used as a substrate on which to grow other materials for device applications. Previously, a reliable method for producing monolayer h-BN has been elusive.

This summer, I worked on perfecting the process of growing h-BN using low pressure chemical vapor deposition (LPCVD) and was able to hone in on the ideal conditions to grow h-BN. I also was able to transfer the material to TEM grids and analyze the samples using both transmission electron microscopy and scanning electron microscopy. This project has introduced me to working in a lab setting and helped me solidify my plans to go to graduate school after finishing my undergraduate studies. It's also given me a chance to explore materials science, a subject with which I've had little experience.



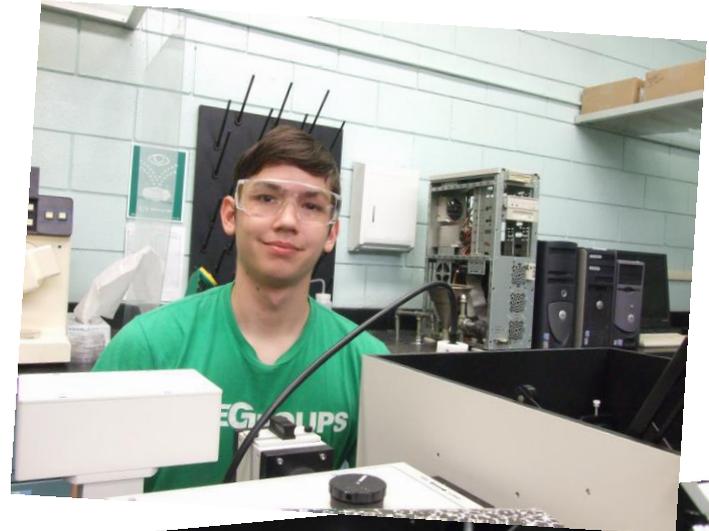
Fluorescence Quenching in Conjugated Polymer and Block Copolymer Solutions

Matthew Taw, Department of Physics, Union University

Dr. Youngmin Lee, Dr. Enrique Gomez, Department of Chemical Engineering, Penn State University

Many efforts are focused on producing cleaner, more efficient, and longer lasting energy sources. Solar energy appears to be an ideal energy source, as the sun provides an incredible amount of clean energy to the earth every day; it is just a matter of harvesting that energy. Organic photovoltaics are much cheaper, cleaner, and more versatile than silicon solar cells; however, they are very inefficient. The goal of this project is to examine charge transfer in conjugated block copolymers utilized in photovoltaic devices. Specifically, the work is focused on quantifying the fluorescence quenching of block copolymers in solution to study intramolecular exciton dissociation.

As a result, we were able to quantify the degree of quenching in a series of model polymers with increasing acceptor units. This experience has taught me how to interact with other scientists in a professional manner and given me an understanding of how to operate in a research environment. In future research opportunities I feel the relationships and skills I have developed at Penn State will be invaluable.



Directed assembly of partially etched nanowires (PENs) in electrical fields to form lattice structures

Kimberly Guzmán Betancourt, Department of Chemistry, University of Puerto Rico at Cayey
Sarah J. Boehm, Christine D. Keating, Department of Chemistry, Penn State University

The study of nanowires has increased in the recent years given their physical, electrical, and optical properties, which make them an important target for new technologies. The ability to assemble these nanowires into large, ordered arrays with unique and interesting structures can further expand applications such as solar cells, photonics, and electronic devices. Therefore, the purpose of this research was to design different types of PENs to probe their specific interactions and the assembly structures formed within an electrical field. Studying the assembly mechanisms and particle behavior will allow new structures to be created so that future researchers can fabricate highly efficient devices for desired applications.



This summer I designed and fabricated different PENs using the electrochemical deposition technique, followed by silica coating and selective etching with nitric acid, producing hollow, solvent filled segments. Directed assemblies of the PENs were performed using electrodes fabricated using photolithography and metal deposition techniques. Optical microscopy was used to view the assemblies *in situ* and to characterize them based on the nanowire behavior and their array formations. Our results show that the effect of the field on the particles depends on the size of the nanowires and the amount of gold that is in them. For example, the wires with more gold experienced the dielectrophoretic force of the field and were able to form lattice structures at lower field conditions. The experience of working in a research laboratory and spending time with graduate students was useful to improve my communication skills and learn what graduate school was like. Working on a research project allowed me to acquire more knowledge, learn new techniques and review or improve the techniques I already knew.

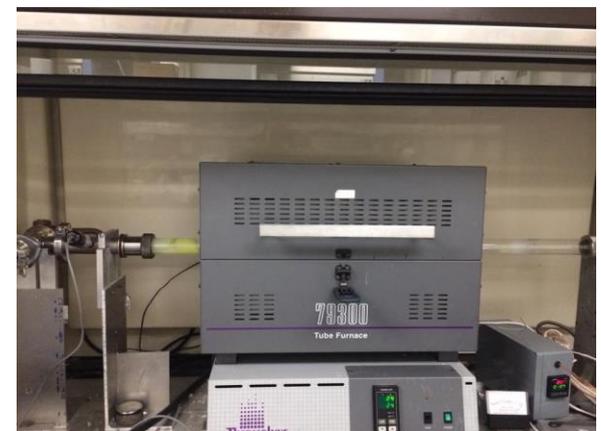
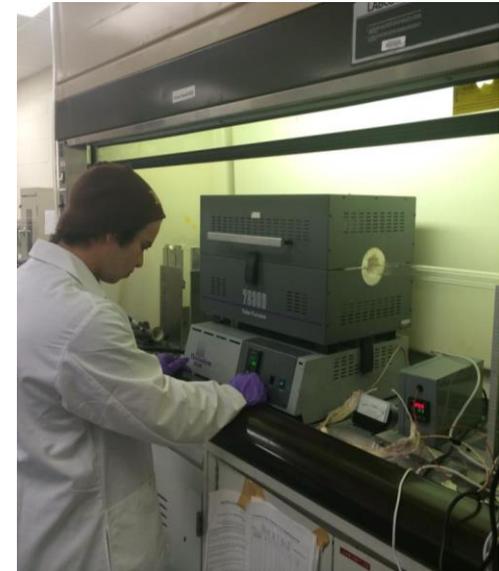
Controlled synthesis and characterization of MoS₂/WS₂ heterostructured 2D materials

Pablo I. Sepúlveda Medina, Physics Applied to Electronics , University of Puerto Rico
Kazunori Fujisawa, Bartolomeu Cruz Viana, Ana Laura Elias
and Mauricio Terrones

Department of Physics, Penn State University

Single layer of TMD, such as MoS₂ and WS₂ are materials of interest mainly due to their electronic properties when compare to graphene and boron nitride. Heterstructure structure such as Mo_xW_{1-x}S₂ can provide tunable properties depending on the ratio of the composition. With fully understanding of this materials there is opportunity for improvement in the field of electronics such as optoelectronics.

To achieve a successful synthesis of material that have heterstructures I help on the synthesis of Mo_xW_{1-x}S₂ thin films using PVD substrates with different configurations and ratios of MoO₃ and WO₃ using low pressure vapor deposition under an inert atmosphere. Raman spectroscopy, Photoluminescence (PL) measurements and transmission electron microscopy (TEM) the techniques we performed to characterize this material. After PL and TEM analysis we determine that the PL measurements were coming from interface interactions and not from the amount of layers in the material. This project has allow me to have experience with TMD materials the different approach for analyzing its structure, it's electrical properties and learned more about my self and what I need to improve to become a better scientist.



Determining the Normalizer of the Subperiodic Crystallographic Groups

**Pedro Valentín De Jesús, Department of Physics, University of Puerto Rico, Mayagüez Campus
Brian K. VanLeeuwen, Dr. Venkatraman Gopalan, Department of Material Sciences and Engineering, Penn State University**

The normalizer of a group is the set of transformations that transforms a group into itself. These groups are important tools for finding optimal packing of molecular crystals, determining the relationship between equivalent descriptions of crystal structures along with their respective structure factors making the comparison between them easier, also for reducing the parameter regions to be considered in a geometrical study and in defining equivalence relationships on the set of subgroups and supergroup of a crystallographic symmetry group. With affine normalizers, affine transformations are considered. With Euclidean normalizers, Euclidean transformations are considered. At the present, both normalizer groups have been found for the space groups of one, two and three dimensions.



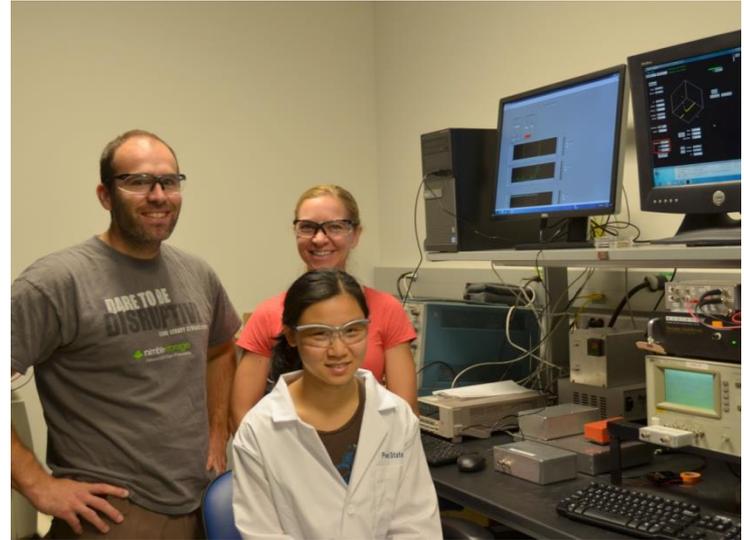
In this project, I helped to develop a computational method to find the affine and Euclidean normalizer of the subperiodic crystallographic groups and to make a notation for the Euclidean normalizers consistent with the International Tables of Crystallography.

Adjustable Optics for X-Ray Telescopes

Phoebe Yeoh, Department of Physics, Goucher College

Dr. Derek Wilke, Dr. Raegan Johnson, Dr. Susan Trolier-McKinstry, Department of Materials Science and Engineering, Penn State University

X-Ray Telescopes allow astronomers to better observe and further understand our universe and its origins. To advance the next generation of X-Ray telescopes, lightweight mirrors with precise, adjustable curvature must be developed. The Smithsonian Astrophysical Observatory, in collaboration with Dr. Susan Trolier-McKinstry's research group, has proposed to create such mirrors by coating flexible glass substrates with a thin film of lead zirconium titanate ($\text{Pb}(\text{Zr}_{1-x}\text{Ti}_x)\text{O}_3$ or PZT), a piezoelectric material.



During film crystallization, lead oxide tends to evaporate and create pores in the film that reduce its usable properties and lifetime. I attempted to minimize lead evaporation and improve the piezoelectric properties of the films by optimizing deposition pressure and exploring the effect of crystallizing films in Nitrogen. By depositing at 5 millitorr and crystallizing in oxygen, we were able to create a curved glass piece coated with piezoelectric PZT that had 100% electrical yield when tested.

I have learned many useful materials science topics and skills, experienced the challenges and thought processes that go into a research project, and enjoyed learning about the diverse projects being worked on by Dr. McKinstry's group. Next year, I hope to attend Penn State or another major research university for graduate studies in Materials Science and Engineering.

Multicomponent Chalcogenide Gradient Index Materials Research

Stephanie Pettit, Department of Physics, High Point University

Andrew Swisher, Alexij Pogrebnyakov, Dr. Theresa Mayer, Department of Electrical Engineering, Penn State University

•The goal of my project was to find a variation in index of refraction of a material through different treatments. By using the concept of gradient refractive index optics, by finding a way to change the index of refraction, lenses can be corrected as well as flattened.

•My research involved thermally annealing samples and using ellispometry to find indices of refraction, then use that data to find a change. I successfully found a change due to the formation of nanocrystals as shown through TEM images. This research has given me many skills and helped me learn more about optics than I had ever known.

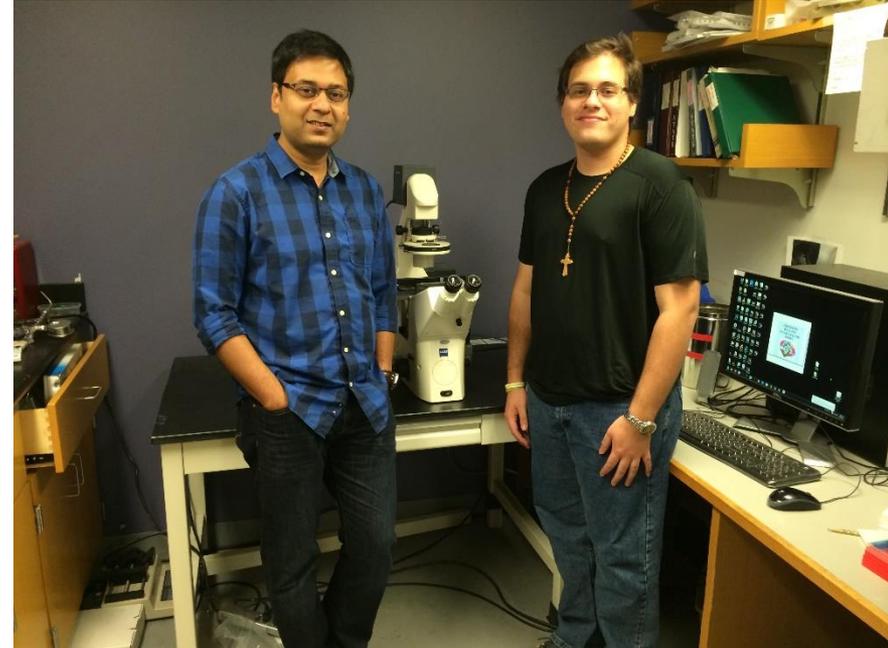


Swarming of Autonomous Micromotors Powered by Enzyme Catalysis

Wilfredo Méndez-Ortiz, Department of Industrial Biotechnology, University of Puerto Rico at Mayagüez
Dr. Krishna K. Dey, Dr. Ayusman Sen, Department of Chemistry, Penn State University

Research on self-powered micro- and nanomotors has recently been focused on molecules of active enzymes which show functional characteristics of both molecular motors and pumps, ways by which energy is manipulated at microscopic level. However, unlike inorganic motors, collective behavior and swarming of enzyme powered systems remains largely an open field for investigation.

In order to examine collective behavior of particles powered by enzymatic reaction, we functionalized microscopic polymer particles with enzymes and study their motion in the presence of substrates and various external/internal stimuli. We also configured such systems to observe predator-prey behavior among the swimmers, where groups of particles driven with different enzymes form an interaction cascade and display emergent dynamic patterns. This research experience granted me the opportunity to visualize and understand was expected of a student at a graduate level, and most importantly gave me the chance to learn about a different slope of science, which I wasn't as familiar with.

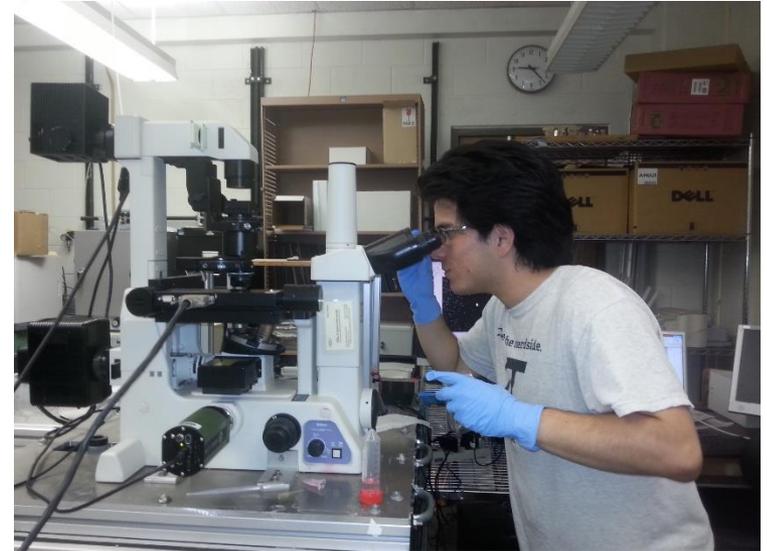


Hierarchical assembly of tracers using barium sulfate

William Weigand, Department of Physics, University of San Diego

Abhishek Kar, Darrell Velegol, Department of Chemical Engineering, Penn State University

Sparingly soluble salts such as calcium carbonate are capable of exhibiting diffusioosmotic pumping effects. These effects occur because of the difference in diffusion coefficients of the ions in produced in the dissolution of the salt. One application of these microparticles, which we call micropumps, involves directing the motion of bimetallic (Au-Pt) nanorods which use hydrogen peroxide as fuel. Unfortunately, calcium carbonate dissolves in a short period of time preventing its use in nanorod systems. My task for the summer was to find a synthesis route for the development of barium sulfate microparticles to see if they show the same pumping effects as calcium carbonate.



Using fluorescent microscopy, I was able to observe that barium sulfate does in fact show diffusioosmotic pumping effects. Interestingly, these micropumps also continue to pump in hydrogen peroxide and saline conditions making them leading candidates for directing nanorod motion. One important component of this project was tracking the tracer particles as they were pumped by the barium sulfate. The knowledge I gained from this research experience, such as synthesizing particles and using the tracking software, allows me to better understand the interconnectedness of the science community and gives me a broad set skills for use in future research.

Penn State MRSEC Summer Millennium Scholar Researchers

MOCVD and the Selective Growth of Mono-layered Tungsten Diselenide on Patterned Substrates

Aleksander Piasecki, Department of Chemical Engineering, Pennsylvania State University

Dr. Sarah Eichfeld, Lorraine Hossain, Matt Koehler, Yu-Chuan Lin, Dr. Joshua Robinson, Department of Materials Science and Engineering, Pennsylvania State University

Tungsten diselenide (WSe_2) synthesis is of particular interest for electronic and optoelectronic applications, specifically high efficiency transistors, LEDs, photo detectors and photo voltaics. This is due to its interesting properties including the transition from indirect to direct band gap at mono-layer thickness. Methods which exist for synthesis of this material are currently either not effective at producing a large continuous film of high quality or are not scalable for commercial use in industry. Our process holds promise for both of these concerns. Formation of this mono-layered material is currently being achieved through metal organic chemical vapor deposition (MOCVD) in the lab. This project involves the optimization of WSe_2 growth parameters including temperature, pressure, and Se:W ratio and understanding of WSe_2 nucleation. During the summer REU I learned about, and was trained on, the MOCVD growth process as well as the various characterization techniques we use for the samples (those being Raman Spectroscopy, Photo Luminescence, and Atomic Force Microscopy). I also was able to induce selective growth of the WSe_2 on a sapphire substrate which had been etched in a square pattern. The growth on WSe_2 centered exclusively in the etched trenches and did not grow at all on the un-etched part of the surface. While the exact reason this happened is not yet fully understood, we plan to spend more time investigating it and being able to repeat the result.



Throughout the summer I spent time growing samples on the MOCVD system, as well as characterizing these samples using the various techniques I mentioned above. I learned about lab safety and procedures as well as how frustrating (and rewarding) it can be to be involved in research. I connected with the members in my lab and advanced as a researcher to the point where my own side project, that of selective growth in patterned etches, holds high potential for eventually becoming a publication. I plan on continuing to work in this lab on the main project (optimization), as well as my own aforementioned side project of specific area growth induction, during the semester.

Creating Air-Stable Supported Lipid Bilayers by Attachment of Elastin-Like Polypeptides

**Blaise N. Pfaff, Departments of Biochemistry and Molecular Biology and Chemical Engineering,
The Pennsylvania State University**

**Matthew F. Poyton, Dr. Paul S. Cremer, Departments of Chemistry and Biochemistry and Molecular
Biology, The Pennsylvania State University**

Solid-supported lipid bilayers (SLBs) play a key role in the current surge in development of biosensors. Much like a canary in a cage, which miners would utilize to detect harmful gases before they were potent enough to harm the human, biosensors respond to toxic substances at much lower concentrations than people can detect. Such devices may potentially be deployed within a busy airport or subway station to protect from the growing risk of bioterrorism. SLBs are the foundation for many types of biosensors, so it is important to have a robust structure. However, bilayers typically do not possess the strength and stability required to withstand exposure to air; let alone endure transport, storage, and the necessary conditions of commercial use. One way to increase the air stability is to attach proteins or polymers to the bilayer. Although effective, these methods have not yet been optimized. We have covalently attached elastin-like polypeptides (ELPs) to the bilayer in order to create a hydrogel above the bilayer surface which should allow the bilayer to be air stable.

Thus far, we have tested the ability of vesicles containing various percentages of the Glutaryl lipid (1%, 10%, 25%, 50%) attached to two different ELPs (KV₂F-32 and V₅-120) to form supported bilayers. Making a supported bilayer was only possible using the 1% Glutaryl lipid attached to KV₂F-32. This suggests that bilayer formation is affected by the density of protein as well as the protein's size and hydrophobicity. The next step is to cross-link the lysine residues of the KV₂F-32 ELP on the surface of the SLB in order to create a more protective hydrogel layer that resembles the extracellular matrix of real cells. This REU has given me the opportunity to begin to develop my skills as a researcher, and has introduced me to creating a hypothesis, performing experiments, and viewing failure as a stepping stone rather than a road block.



Chemotaxis in Enzyme Molecules

**David T. Heineman, Dr. Paul E. Lammert and Dr. Vincent H. Crespi
(mentor)**

Department of Physics, Pennsylvania State University

Recent research has indicated that it may be possible to direct the motion of enzyme particles. It has been observed that enzymes diffuse more quickly in the presence of a reactive substrate, and that the direction of these quickened diffusive movements may depend on spatial variations in the local concentration of the substrate in question. It has been hypothesized that enzyme molecules will actively move toward areas of greater substrate concentration, giving the appearance of an effective attractive interaction between enzyme molecules, towards a local maximum in the fuel concentration.

I have created a computational model in which enzyme diffusion rates increase as a result of the consumption of substrate. We are in the process of determining the effects of changing rates of diffusion on the motion of enzyme particles. Comparison of the experimental results and the results generated through this simulation should allow us to determine whether directed motion based on substrate concentration actually occurs. Through working on this project, my proficiency at computer programming has increased. I have also gained experience working with a professional lab group as well as insight into what types of research I am interested in pursuing.



Synthesis and Vibrational Properties of Hexagonal Graphene Islands

Nicolas Mesyngier¹, Simin Feng², Eduardo Cruz-Silva² and Mauricio Terrones^{2,3}

¹ Department of Engineering Science and Mechanics, Penn State University

² Department of Physics and Center for 2-Dimensional and Layered Materials, Penn State University

³ Department of Materials Science and Engineering and Department of Chemistry, Penn State University

Following the isolation of graphene in 2004, research efforts in this area have increased exponentially. The findings have revealed a rich field for basic sciences and practical applications. Graphene is synthesized on copper by chemical vapor deposition (CVD), and is generally a continuous layer of milli- to centi-meter size with many structural defects. We attempted to synthesize micrometer-sized hexagonal graphene islands with fewer defects. Previous reports about such islands had been obtained with low-pressure CVD methods, however, we found that by varying the synthesis parameters, graphene islands can be obtained with an atmospheric pressure CVD setup. Different spectroscopic and microscopy techniques have been applied to characterize the materials we synthesized. In addition, theoretical calculations using the density functional tight-binding formalism have been carried out to better understand monolayer graphene islands. We examined graphene to find the ground state of the material, its electronic structure, as well as the most stable doping configurations. The synthesized material will be used to fabricate hybrid graphene heterostructures with other 2-D materials.



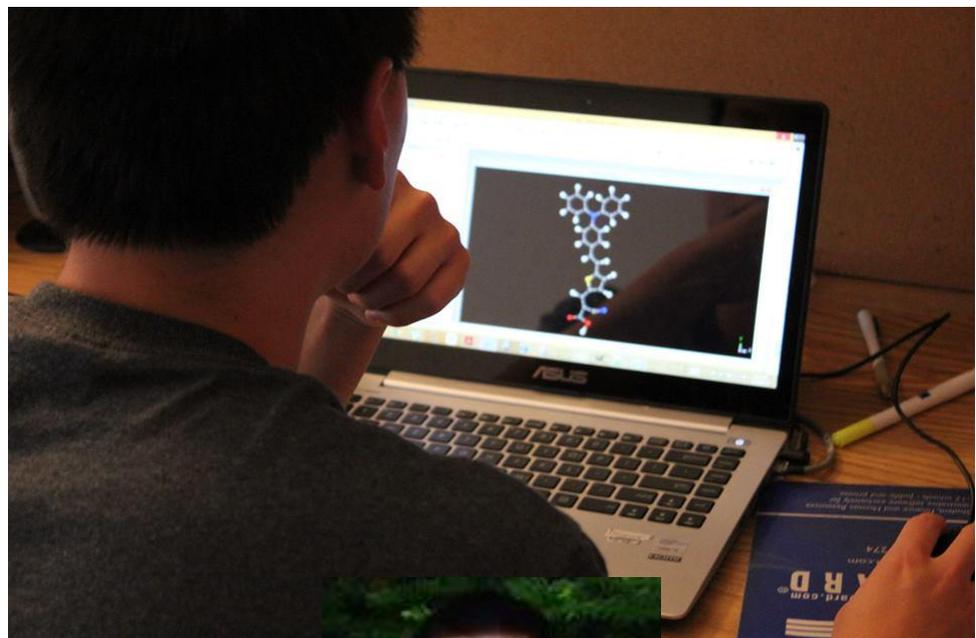
Predicting the Optical Properties of Metalloporphyrin Dyes From First Principles

Kevin Wang, Nicolas Poilvert,¹ and Ismaila Dabo²

¹Department of Mechanical Engineering, Penn State University,²Department of Materials Science and Engineering, Penn State University

At present, the most widely used dyes used in dye-sensitized solar cells are ruthenium-based complexes. These dyes have enabled the design of DSCs with 13% photoconversion efficiency. Recently, there has been much progress in the molecular engineering of ruthenium-free dyes to address problems of efficiency and cost. We studied the influence of transition-metal substitutions on the optical response of simple porphyrin molecules. While conventional Density Functional Theory approximations underestimate the onset of photoemission peaks to several eV's, our Koopman compliant functionals have reduced this error to a few tenths. These calculations provide valuable information to help and guide the design of more efficient porphyrin dyes.

This project allowed me to learn about the techniques and thought process of computational work. With no solid foundation, I was able to learn the Linux language and run calculation. More rigorous in math and physics, this project gave me insight into what work is like in a theoretical, yet experimental fashion.



Physics Department
Undergraduate Researchers

STAR's Forward Electromagnetic Calorimeter (Forward Muon Solenoid's EMI9954 Phototubes) Alterations

Ting Gu, Department of Physics, Penn State University

Daniel Marshall, Dr. Steven F. Heppelmann, Department of Physics, Penn State University

700 phototubes were broken at RHIC and need to be replaced in the FMS detector. My group has got 700 used phototube detectors from the Fermi National Lab were too large to accommodate the phototubes used in the FMS detector. This project is carried out to modify these bases and produce 700 EMI9954 photomultipliers to be brought to the Brookhaven National Lab so that further particle physics research can be conducted. I use a lot of different skills to complete the physical modification of the phototube bases and after that I run a data acquisition system along with ROOT programming to test all of them.



I use soldering, wire trimming, drilling, sanding, coating and gluing to modify all these phototube bases. After the physical modification of each base is complete, we use a data acquisition system and ROOT to test and collect data from each base for proper function. The modified bases will be sent to the Brookhaven National Lab to further the research in particle motions. This project helped me realize what scientific research is like and how to conduct research. I also learned how to demonstrate my research to people.

Silicon doped single walled carbon nanotubes: Synthesis and characterization

**Santiago Tarragó, Departamento de Física y Matemáticas, Universidad Iberoamericana
Lakshmy Pulickal Rajukumar^{1,2}, Dr. Mauricio Terrones^{1,2,3}, ¹ Materials Science and Engineering
Department, ² Center for 2-Dimensional and Layered Materials, ³Department of Physics, Penn
State University**

Carbon Nanotubes show a wide range of extraordinary mechanical and electrical properties, which makes them interesting candidates for the fabrication of electronic nanodevices and reinforcement materials. Some of the challenges faced in this area are to control the diameter of single walled carbon nanotubes (SWNTs), and to tune their electronic properties to better suit different applications. One approach to achieve this control is chemical doping, in which a dopant atom replaces a carbon atom in the graphene sp^2 lattice that forms the nanotube.

During the summer I synthesized Si doped SWNTs, and helped characterize them using Raman spectroscopy and Transmission electron microscopy. I also helped test their field emission and electronic transport properties. I learned a lot about this field of research and how research is done in general, and this will help me make the decision of what to choose as a career path.



Growth and Characterization of Monolayer Transition Metal Dichalcogenides including MoS_2 and $\text{Mo}_x\text{W}_{1-x}\text{S}_2$

Michael T. Thee¹, Zhong Lin¹, Ana Laura Elías¹, Simin Feng¹, Chanjing Zhou², Kazunori Fujisawa¹, Néstor Perea-López¹, Humberto Terrones³, and Mauricio Terrones^{1,2,4}

¹*Department of Physics and Center for 2-Dimensional and Layered Materials,*

²*Department of Materials Science and Engineering,*

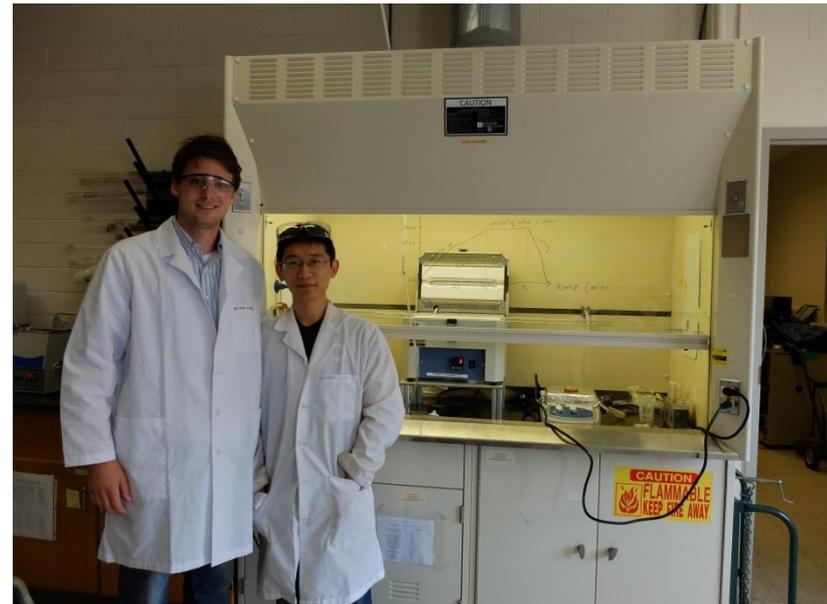
⁴*Department of Chemistry, The Pennsylvania State University.*

³*Department of Physics, Applied Physics and Astronomy, Rensselaer Polytechnic Institute*

During this summer 2014, I have been a part of a project involving the growth and characterization of two dimensional monolayer islands of transition metal dichalcogenides (TMDs), a semiconducting material complimentary to graphene.

The goal of this project is to develop an alternative method for the synthesis of monolayer TMDs: a simpler method at ambient pressure, lower temperature, shorter run time, no chemical reaction involved, and to increase the reproducibility. Another goal is to create monolayer alloyed TMDs with tunable band gaps. In a global context, research in the field of TMDs could give rise to advancements and applications in electronics and optoelectronics, possibly leading to extra sensitive photo sensors and flexible electronics.

I have been working with graduate student Zhong Lin on the synthesis of TMDs including MoS_2 and alloyed $\text{Mo}_x\text{W}_{1-x}\text{S}_2$. We successfully developed a new synthesis method for growing monolayer MoS_2 , meeting all of our project goals. The method we propose has also been extended to grow alloyed $\text{Mo}_x\text{W}_{1-x}\text{S}_2$ monolayers with a tunable band gap. This summer has been a sneak peak into the life of a graduate student. I have learned a lot during this program, including the stress involved, the pleasure that can come from successful experiments, and the importance of collaboration. This has prepared me to work in a materials science lab, and I am certain that this experience is an invaluable one.

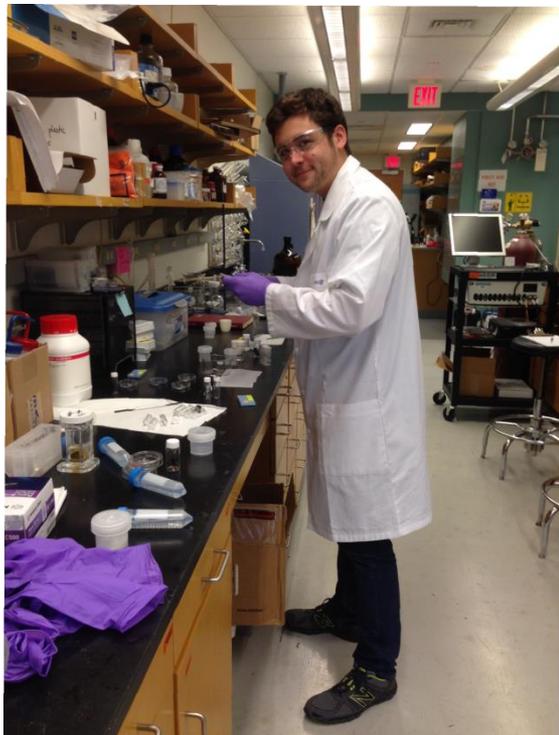


Zhong Lin and myself in front of our furnace

Synthesis of Tunable Size Silica Nanospheres & their Self Assembly into Superlattice Thin Films

Joseph M. Warren¹, Jennifer Dysart², and Dr. Thomas E. Mallouk²

¹Department of Physics, Penn State University; ²Department of Chemistry, Penn State University;



Highly monodisperse silica nanospheres are known to be valuable for colloidal templating due to their ability to self assemble into close-packed, ordered thin films via a facile evaporation method. These colloidal crystals can be infiltrated with other elements and etched away, leaving an artificial 3D metalattice. These metalattices have the potential to exhibit novel electronic, magnetic, and thermal properties as the order parameter of the lattice approaches the same length scale as many important physical phenomena.

My project was focused on trying to create a colloidal crystal film of silica nanospheres of two different sizes that packed into some sort of AB_x structure. The silica nanospheres were synthesized using a simple amino acid base-catalyzed reaction, and were regrown to larger sizes in multiple steps using the same method. The films are

created as the spheres self-assemble on silicon wafers through a simple evaporation method.

This project has helped to develop my research skills and introduced me to the graduate school environment. It also gave me a feel for the importance of interdisciplinary work in solving modern research problems.

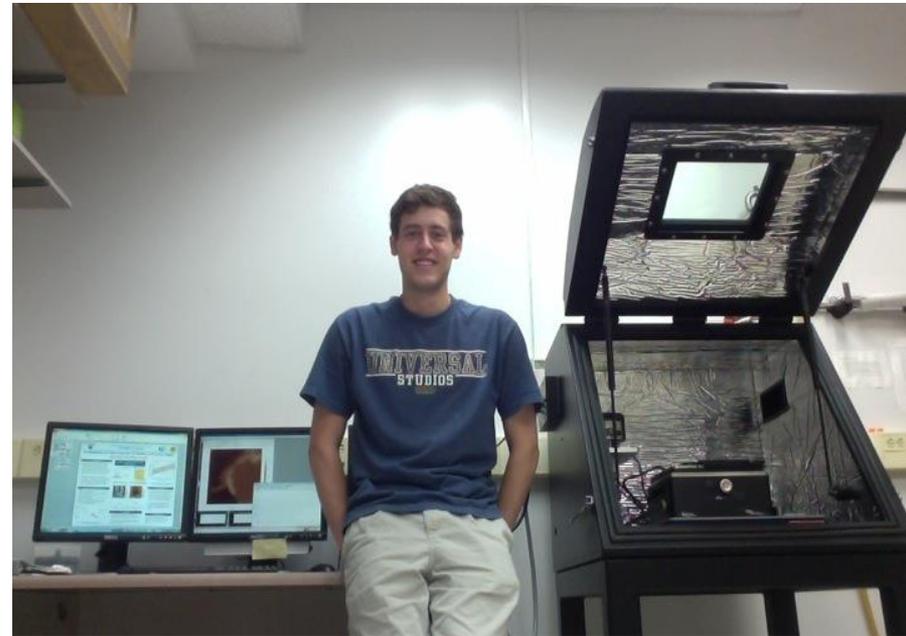
Investigating the Work Function Evolution of WS_xSe_{2-x} Alloys

Jacob Shevrin, Department of Physics, The Pennsylvania State University

Junjie Wang, Jun Zhu, Department of Physics, The Pennsylvania State University

Transition Metal Dichalcogenides are an important field of condensed matter research because they are two-dimensional layered materials with novel physical properties, including an indirect-to-direct gap transition in the monolayer limit, and a large valence band splitting due to strong spin-orbit interactions.

My main objective for this summer research project is to investigate the work function of varying compositions of these Sulfide-Selenide alloys, including the work function's dependence on the number of layers of the material. Accurate measurements of the work function of the materials can inform the choice of metal to use when making contacts and can also provide information regarding the band alignment in heterostructures made of dissimilar materials.



The professional development, communication practice, and independent research done in this summer research program has helped me feel more prepared and confident for graduate school and my career as a whole.

Chemical Exfoliation of Thin Film Topological Insulators

Grant Smith, Department of Physics, Penn State University

Dr. Anthony Richardella, Prof. Nitin Samarth, Department of Physics, Penn State University

Bismuth selenide (Bi_2Se_3) is one of the most promising examples of a fascinating class of material known as “topological insulators.” Due to the fundamental symmetries that exist within the material, the surface electrons can inherently carry a spin polarized current – a property with potentially groundbreaking implications for the creation of “spintronic” devices. Since these properties can only be properly observed when the material is extremely thin, it is important to develop a technique to reliably produce thin films on arbitrary substrates from readily available films grown by molecular beam epitaxy (MBE).

This summer it was my responsibility to learn how to do this based on recently published material. I was able to show that it is possible to transfer films of bismuth selenide with lateral areas on the order of a cm^2 to arbitrary substrates with very little damage. With samples produced in this manner, many of the practical limitations that once slowed research into this material can be removed or significantly ameliorated – helping to take the focus off of sample production and applying it to better understanding the fundamental properties of this potentially important material



Studying the Use of Michel Electrons to Calibrate PINGU

Dylan D. Lutton, Department of Physics, Penn State University

Dr. João Pedro A. M. de André, Prof. Douglas F. Cowen, Department of Physics, Penn State University

The IceCube detector located in the South Pole was built in order to detect and better understand neutrinos. A proposed addition to this detector is the “Precision IceCube Next Generation Upgrade” (PINGU). It would specialize in detecting low energy neutrinos, and its main purpose is to determine the neutrino mass hierarchy. One idea is that it may be able to use Michel electrons to tag certain neutrino events as specifically muon neutrino events. Michel electrons are electrons created by muon decay, so if a muon neutrino is to interact in the detector and release a muon, and then soon after we detect a Michel electron we could tag that neutrino as a muon neutrino. To determine whether or not this is viable, tests are performed using a simulation of IceCube with the PINGU addition.



Using the simulation I performed various tests ranging from injecting large amounts of electrons, muons, or muon neutrinos into the detector system to gather general data, to placing $E = 0$ muons under a single detector to verify that muon decay works properly in our simulation. We determined how often we are able to detect light from Michel electrons within 50 meters of their creation (40% of the time), and how often we are able to reconstruct the endpoints of muons within 50 meters of their true location (80% of the time). These results let us know that this form of tagging is still a possibility, and the next steps involve figuring out how well we are able to reconstruct the distance from the muon endpoint to the hit in the detector from the Michel electron that it decayed into. So I will be continuing this project. It has been very illuminating to me in terms of how research is done, and in considering my future career path. It has also helped me to improve my programming skills, and given me a real interest in neutrino physics.

Superfluid Helium Flow in 1-Dimensional Limit

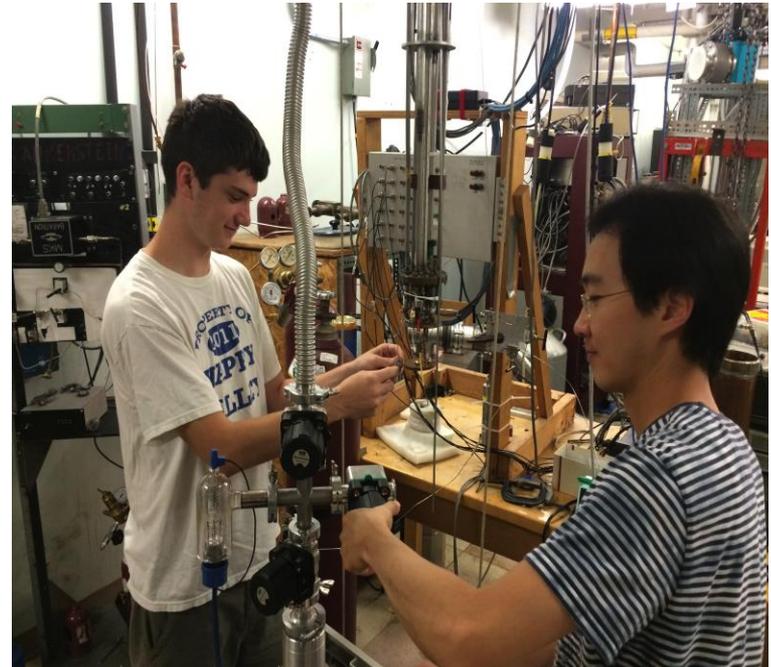
Clayton Harris, Department of Physics, Pennsylvania State University

Dr. Moses H. W. Chan, Department of Physics, Pennsylvania State University

Dr. Duk Y. Kim, Department of Physics, Pennsylvania State University

The goal of this experiment is to quantify the flow of superfluid helium on nano scales. Superfluid has been well studied in three and two dimensional systems but the behavior and ultimate breakdown of superfluidity through small capillaries is not well understood.

My work this summer has continued to refine our experiment and apparatus. Working with nanocapillaries with large aspect ratios has proved difficult, but we are overcoming these obstacles.



The Search for Excesses on the Auto-correlation Distribution of Ultra-high Energy Cosmic Rays

Alexander B. Thames, Department of Physics, The Pennsylvania State University
Dr. Miguel Mostafá, Department of Physics, The Pennsylvania State University

Ultra-high energy cosmic rays bombard Earth constantly from all directions. While the exact origins of these cosmic rays are still mysterious, it is possible to detect and analyze the succeeding secondary particles created when one crashes through the atmosphere. Uncovering any correlating evidence between the arrival direction of a cosmic ray and a possible galactic source in the same area could start to explain how these ultra-high energies are generated.



Using ROOT modeling software and a cosmic ray dataset collected with the Pierre Auger Observatory, I analyzed the zenith angles, declinations, and right ascensions of cosmic ray events from the dataset and from a simulated isotropic distribution. I then translated the incident information from these events into the distribution of cosmic ray pairs as a function of their angular separation, and contrasted that to the expected number of pairs from the isotropic distribution. This project has given me practical work experience with experimental and computation physics, and knowledge about myself as a researcher, for which I am very grateful.