2008 WVNano NSF REU Site
Multifunctional Nanomaterials Project Descriptions

Nanophotonics: Design, Fabrication, and Characterization of Photonic Crystals

Main faculty supervisors and other involved faculty:

Jeremy Dawson (Electrical Engineering/Physics) (Advisor 1), *Larry Hornak* (Electrical Engineering) (Advisor 2), *Andrew Cao* (Electrical Engineering), *Dimitris Korakakis* (Electrical Engineering), *Aaron Timperman* (Chemistry)

Goals of the project (for up to 2 students for the summer)

1. Model & design 1-D and 2-D photonic crystal structures
2. Implement fabrication processes for photonic crystal formation
3. Integrate photonic crystals with microfluidic structures for analyte delivery
4. Develop testing apparatus and experimental procedures
5. Characterize the geometry and optical characteristics of the structure

Project description

Photonic crystals are exciting new structures revolutionizing the way we build devices to control the motion of light. Photonic crystals are designed structures that can control the propagation of light in ways not possible in naturally formed materials. We will use state of the art computer aided design tools to design photonic crystals that will specially designed defects capable of guiding and storing light of specific wavelengths. These structures will be used as building blocks to assemble integrated chip-level systems able to optically detect chemical and biological agents, improve the efficiency of LED-based lighting, and many other applications. We will design and fabricate photonic crystals in silicon, gallium nitride, and other materials using nanofabrication technologies.

Experimental/theoretical skills that participants will acquire

- Introduction to optical simulation tools for photonic crystal functional modeling and design
- Use of electron-beam lithography for photonic crystal patterning
- Understanding of integrated fabrication techniques; use of clean room and basic processing for photonic crystal fabrication
- Introduction to microfluidic system operation and fabrication
- Understanding and use of Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM) for imaging the photonic crystal structure on the micrometer and nanometer scales
- Knowledge of optical engineering and optical characterization of photonic crystals

Location of the project

Home/office location: Electrical Engineering
Optical modeling, design, and characterization: Electrical Engineering
E-beam writing: Physics
Imaging: Engineering and Physics
Microfluidic integration: Chemistry

Large-Area Nanoscale array patterns Fabricated by Nanosphere Lithography

Main faculty supervisor and other involved faculty

Nick Wu (Aerospace and Mechanical Engineering)

Goals of the project (for the summer)

To utilize self-assembly template lithography with nanofabrication techniques to develop nano-patterns that have potential applications in in photonic devices, optoelectronic devices, biosensors, catalysts and high-density magnetic recording devices.

Project description

Large-area-ordered two dimensional (2D) nanostructures have extensive applications in photonic devices, biosensors, catalysts and high-density magnetic recording devices. The future sucess of 2D nanostrustrutures depends on the availability of facile patterning methods that can scale up at low cost. Commomly used patterning techniques such as photolithography, electron beam lithography, and focused ion beam (FIB) lithography have limitations for the fabrication of 2D nanostructures. It is very difficult for the photolithography method to generate the features less than 100 nm. The e-beam and FIB techniques are limited by their low throughput in creating large area nanoscale patterns. Patterning with the self-assembled materials as the templates, such as nanosphere lithography pioneered by Deckman and Van Duyne, is an inexpensive, simple, high-throughput alternative routine for creating periodic nanostructures. In the present work, we will introduced a simple method to overcome the above drawbacks and obtained a large-area (~cm^2) well-ordered nanodot arrays.

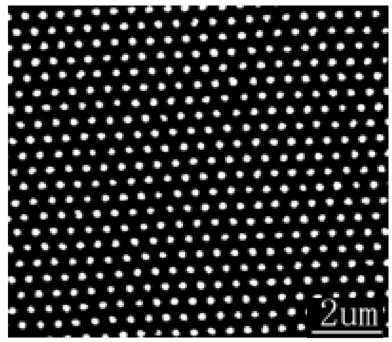


Figure 1 gold dot array pattern [6], by Nick Wu

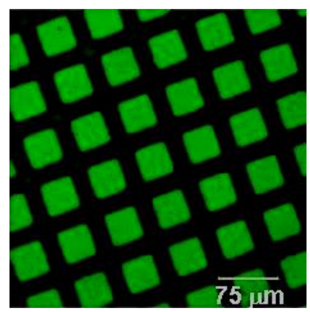


Figure 2 fluorescent imaging of protein array pattern, by Nick Wu

Experimental/theoretical skills that participant will acquire

The participant will be able to fabricate large-area ordered arrays of 2D structures and characterize them via scanning probe and electron microscopy.

Location of the project

Engineering Sciences Building

Detection of Lactate by Nanowire-Based Electrochemical Biosensor

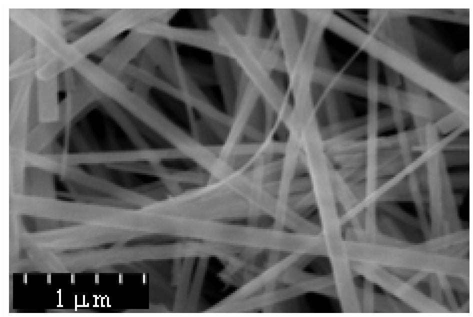
Main faculty supervisor and other involved faculty

Nick Wu (Aerospace and Mechanical Engineering)

Goals of the project (for the summer)

Construct a nanowire-based biosensor and test the sensing performance of the sensor.

Project description



Dispersed titanate nanowires

Enzyme immobilization is critical to the performance of amperometric biosensors because, for the majority of enzymes, their active sites are insulated by the protein matrix of the enzyme, thus blocking the direct electron transfer between the active sites and the electrode. To solve this problem, chemical mediators are usually employed to transduce enzyme activity into an electrical signal. The mediator regenerates the enzyme and itself by exchanging electrons with the enzyme and with the electrode. An alternate strategy for promoting direct electron transfer is to employ nanoparticles that can penetrate the insulting protein matrix, allowing the direct contact between the nanoparticles and the active sites. In the present work, we use titanate nanowires (TNWs) as electron mediators in a lactate biosensor, which transduce enzyme activity via direct electron transfer. TNWs are attractive in immobilization of enzymes in electrochemical biosensors due to their high surface area, chemical inertness, biocompatible, and other excellent properties. Our experiments will provide a base for development of sensitive, rapid and inexpensive lactate biosensors that should find extensive applications in environmental monitoring, food processing, clinical diagnostics, and medical research.

Experimental/theoretical skills that participant will acquire

Participant will learn to fabricate titanate nanowires, characterize their structure using electron microscopy, perform biomolecular attachment to the TNWs, and measure their electrical conducting properties.

Location of the project

Engineering Sciences Building

Magnetoelectronic Properties of Magnetic Alloys

Main faculty supervisor and other involved faculty

Sergei Urazhdin (Physics) (Advisor), David Lederman (Physics).

Goals of the project (for the summer)

Magnetoelectronic devices find important applications in computer memory and sensors. Development of smaller, more efficient and sensitive devices will rely on the progress in understanding and developing new ferromagnetic/antiferromagnetic alloys and structures with advanced electronic and magnetic properties. The goal of the project will be to determine how the magnetic and electronic properties of magnetic alloys can be tuned by changing their composition.

Project description

This project will consist of i) setting up a variable temperature magnetoelectronic measurement system for testing of magnetic alloys, ii) depositing epitaxial magnetic thin film heterostructures by high vacuum sputtering process, iii) determination of properties with magnetoelectronic measurements, x-ray scattering, and atomic force microscopy.

Experimental/theoretical skills that participant will acquire

Setting up experimental measurement, developing programs for computer-based data acquisition, high-vacuum deposition of thin films, low noise cryogenic measurements.

Location of the project

Physics (101 Hodges Hall).

Controlling DNA Conformation – The Effect of C8-Purine Modification on the B/Z and the ss DNA/Quadruplex DNA Equilibrium

Main faculty supervisor and other involved faculty

Peter Gannett (Basic Pharmaceutical Sciences) (Advisor), James Lewis (Physics), David Lederman (Physics)

Goals of the project (for the summer)

To utilize the self-assembly template lithography with electrochemical techniques to fabricate nano-patterns that have potential applications in in photonic devices, optoelectronic device, biosensors, catalysts and high-density magnetic recording devices.

Project description

The well known molecular recognition and conformational properties of DNA makes it well suited for a variety of static structures such as 2-D arrays and 3-D objects. DNA has also been used for construction of tweezers, gears, motors, and other dynamic structures. Both static and dynamic uses of DNA in nanoscale systems/devices rely upon its behavior under various conditions. These properties can be controlled by selective modification of DNA which can expand the range of static and dynamic structures available for nanoscale systems. By modifying the guanine and adenine bases at the C8 position, we can alter the conformation preferences of DNA. Two significant alterations are the B/Z (Figure 1) and the ss DNA/quadruplex DNA equilibria (Figure 2). In the former case, the conversion of B to Z DNA results in a twisting motion as the B form is right-handed and the Z form is left-handed. In the latter case, the modification causes a single strand of DNA to fold to a quadra-helical or quadruplex structure, resulting in a large translational motion. We have observed these effects in short pieces of DNA and now want to know if a single modification will produce long-range effects or if the effects remain local, near the point of modification.

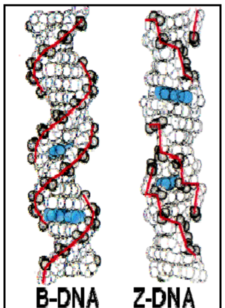


Figure 1. Right-handed B-DNA & Left-handed Z-DNA.

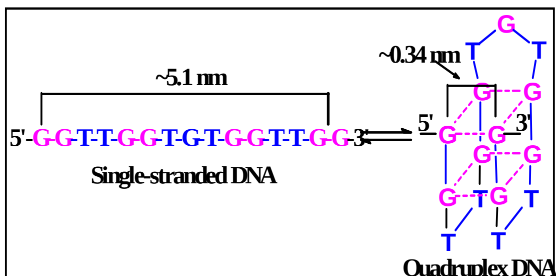


Figure 2. Equilibrium between single-stranded and the quadruplex form of DNA.

Experimental/theoretical skills that participant will acquire

1) Organic synthesis of the modified bases; 2) Preparation of DNA using automated DNA synthesis; 3) DNA Characterization by circular dichroism and nuclear magnetic resonance (NMR); 4) Computational methods for molecular modeling DNA

Location of the project

Physics (312 Hodges Hall) and Health Sciences Center (HSC, 1128 HSC-N).

Capillary Electrophoresis of Biological Molecules

Main faculty supervisor and other involved faculty

Lisa Holland (Chemistry)

Goals of the project (for the summer)

The goal is to introduce the student to a laboratory environment and encourage them to apply biology, chemistry, engineering, and physics coursework to a research project. The student will be encouraged to consider careers in research and will be mentored on the education and training necessary to pursue a career in research.

Project Description

The student will complete the four learning modules currently in use in the Holland lab. The purpose of the current modules is to make the technology behind efficient capillary separations available to other labs by providing instructions in the form of ***free eLearning modules.*** The success of our on-line real time distance learning project has established protocols and materials that support undergraduate research and expand cyber-infrastructure. Students engaged on this project will learn the analytical methodology and critique the current on-line materials in the process. After this orientation to the method, the student will improve these exercises by updating them with an extensive pre-laboratory with real-time electronic feedback to speed attainment of the learning outcome. This longer pre-lab exercise, which is completed outside of lab by the distant learner at her/his own pace, requires little or no equipment and can be amended for instruction at the high school level. The corresponding lab exercises which the student may also develop (for completion within in 3-hours) include: (1) Visualizing Triggered Physicochemical Changes of Supramolecular Phospholipid Assemblies, (2) A Demonstration of the Effects of Nonspecific Adsorption of biomolecules, (3) Bioactive Protein Separations and Denaturing Environments, (4) Isocratic and (5) Gradient Sieving of Carbohydrate Ladders, and (6) Build your Own Computer Triggered Magnetic Field Actuator. As before, the undergraduate level exercises will be submitted to the Analytical Sciences Digital Library for electronic publication.

Experimental/theoretical skills that participant will acquire

Record keeping, problem solving, critical thinking, hypothesis testing, gel electrophoresis, supramolecular assemblies, and nanotechnology.

Location of the project

Department of Chemistry (351 Chemistry Research Labs).

Biomimetic Biomineralization of Nanoscale Inorganic Materials

Main faculty supervisor and other involved faculty

R. Lloyd Carroll (Chemistry)

Goals of the project (for the summer)

Students will:

- Grow calcium carbonate and other inorganic materials and characterize their growth and crystal structure by multiple techniques.
- Grow nanoscale rods of inorganic materials and characterize them by XRD and SEM.
- Construct a hydrogel-based diffusion-controlled reaction system for the controlled growth of inorganic materials.

Project Description

Living systems have had millennia to optimize the growth processes of biominerals for use as structural components in their systems. Molluscs and other invertebrates use calcium carbonates for protection in their external shells, diatoms and sponges build incredibly complex silica skeletons, and vertebrates have developed the mechanisms to incorporate phosphate-based minerals (such as hydroxyapatite) into bone, providing rigidity and strength. We have developed a controlled reaction system for the growth of nanoscale calcium carbonate. Our goal is to use this system to understand the biomineralization process and develop new nanoscale materials that have may have new useful properties. We would like to extend this work towards other interesting biomineralization products, including silica and phosphate minerals, as well as exploring new non-biogenic materials, such as semiconductors and metals. One approach is the use of a hydrogel-based diffusion system, modified with polyelectrolytes, to impart selective ion passage to the gel. The hydrogel will be used to control the interaction of reactive ions and force the precipitation reactions to occur at controlled rates on engineered surfaces. Growth processes of crystalline inorganic materials will be observed *in situ* using optical and confocal fluorescence microscopy. The crystals will be characterized by SEM and XRD to identify morphological and crystal structure. I n addition, we will use polycarbonate track-etched films as nanoscale growth chambers to confine the reaction and template the crystal to a rod shape. These materials may have many potential uses as biomedical materials, or components in nanoscale devices. The techniques that students learn will be applied to other, non-biotic materials, such as semiconductors and metals.

Experimental/theoretical skills that participant will acquire

Students will gain familiarity with wet chemical techniques, electron and optical microscopy techniques, and surface and structural characterization systems.

Location of the project

Experiments will be primarily carried out in facilities in the Chemistry Department (Chemistry Research Labs 550/556) and in the Physics Department (Hodges Hall, B-07).

Determination of the Role of Atomic Coordination on the Electronic Structure of Semiconducting Nanocrystals

Main faculty supervisor and other involved faculty

James P. Lewis (Physics)

Goals of the project (for the summer)

Determine the veracity of claims that atomic positions play a large role in the electronic properties of semiconducting nanocrystal systems.

Project Description

Within the last couple of decades it has been realized that semiconducting nanocrystals have optical and electronic properties that are unlike either bulk materials or molecules. These properties open up exciting new fields of research and development. It is believed that we will be able to use semiconducting nanocrystals in novel applications such as energy and lighting, disease detection, and solid state quantum computing. Nanocrystals composed of type II-VI semiconductors are especially exciting because of their relatively large band gap. As the nanocrystals grow smaller and become equal to or smaller than the exciton's Bohr radius the novel properties of the nanocrystals become more pronounced. For CdS nanocrystals this happens at a diameter of about 5 nm. A number of papers in the literature have stated that the atomic coordination of atoms in nanocrystals plays a big role in the electronic properties of nanocrystals. While this is most likely true, very little data has been published to back up these claims. Our group has recently written programs that will aid in showing if these claims are justified.

Experimental/theoretical skills that participant will acquire

This project is primarily computational in nature. The participant will become familiar with computational methods used to study model systems. The participant will also have the opportunity to work with supercomputers on campus and elsewhere.

Location of the project

Physics (Hodges Hall).

Investigation of Strained Nano-thin 3C-SiC Layers for Chemical Sensors

Main faculty supervisor and other involved faculty

Dimitris Korakakis (Electrical Engineering) (Advisor), Charter D. Stinespring (Chemical Engineering)

Goals of the project (for the summer)

Electrical characteristics of nano-thin 3C-SiC strained films on Si heterostructure will be evaluated under varying conditions. Gateless FET structure geometry will be employed. The results will be used to explain the effect of the environment on the surface states and the conduction mechanism to develop highly sensitive sensors.

Project Description

Silicon Carbide possesses a combination of properties that make it ideal for use in electronics. Its high values of electric breakdown field, melting point and saturated electron drift velocity have attracted the attention of the semiconductor community. Nano-thin 3C-SiC films have been grown on Si (100) by Gas Source Molecular Beam Epitaxy (GSMBE).These nano-films have been used in the fabrication of Metal-Semiconductor-Metal (MSM) devices formed from several metals such as Al, Cr and Pt. Under electrical characterization, these MSM devices have exhibited unique properties in that the dominant conduction path does not occur at the 3C-SiC/Si interface as previously reported, but within the entire 3C-SiC layer. Results obtained through chemical experimentation have indicated that conduction is largely dependent on the surface condition of the device. This suggests the possibility for nano-thin, surface-like, 3C-SiC films to be used in chemical sensors.

Experimental/theoretical skills that participant will acquire

The participant will acquire skills in several device fabrications such as photolithography, etching and sputtering and also performing I-V measurements in different conditions. Furthermore, the participants will be able to propose an empirical model for the current transport in the heterostructures designed based on strained nano-thin films and relate the experimental results to the theoretical band alignment of heterostructures.

Location of the project

Experimental work will be carried out in the Lane Department of Computer Science and Electrical Engineering.

Hybrid Microelectronic Actin-Myosin Motility Assay via Integrated Electric Field Addressing

Main faculty supervisor and other involved faculty

Parviz Famouri (Electrical Engineering) (Advisor), R. Lloyd Carroll (Chemistry), Lisa Holland (Chemistry)

Goals of the project (for the summer)

To fabricate electrode structures with biomolecular filaments and study their motility properties.

Project Description

The objective of this research is to fundamentally understand the governing mechanics of biological molecular transport mechanisms that can serve as a foundation for their direct use in integrated biomolecular systems or the development of nanoengineered systems that mimic these biological processes. The actin-myosin system represents a protein-based system being explored as basic building blocks for realization of linear biomolecular motor based on biological nanoscale transport phenomena. The approach is fundamental exploration of the interaction of electric fields localized on the micron scale with the nanoscale actin-myosin motility assay. Electric fields established with integrated electrode structures under the assayed surface will be used to experimentally characterize their effect on nanoscale linear biomolecular motor filament alignment, direction of motion, and assay ambient. Fluorescence techniques are used to optically observe actin motion in assay.

Experimental/theoretical skills that participant will acquire

The participant will learn how to isolate a purify biomolecules such as meromyosin and to fabricate electronic devices that produce localized electric fields on the biomolecules using lithographic techniques.

Location of the project

Experimental work will be carried out in the Lane Department of Computer Science and Electrical Engineering and the Chemistry Department.

Electronic Effects of Hydrogen Absorption on Magnetoelectronic Nanostructures

Main faculty supervisor and other involved faculty

David Lederman (Physics)

Goals of the project (for the summer)

To grow magnetic multilayers based on palladium ultra-thin layers and measure the effects of hydrogen absorption on their magnetic and electrical conductivity properties.

Project Description

Palladium is well known for absorbing hydrogen via a chemisorption process in which the H_2 molecule splits into two protons at the surface and which are subsequently absorbed into the lattice. While it is known that this changes the electrical and optical properties of Pd, it is not known whether the magnetic and electronic properties of thin layers of magnetic materials, such as Co, Fe, or Ni, immersed in a Pd matrix can be changed by hydrogen absorption. Nevertheless, in very small structures (less than 2 nm in thickness or diameter), electronic transfer due to the additional protons in the Pd matrix are expected to affect the electronic properties of the magnetic nanostructures. In this project, the REU student participant, in collaboration with a graduate student and the faculty advisor, will fabricate ultra thin magnetic layers in a Pd matrix and measure the magnetic and magnetoelectronic properties of the samples. In the long term, the knowledge acquired by this study may result in more efficient hydrogen sensors for fuel cell applications. This project is co-funded by the Department of Energy.

Experimental/theoretical skills that participant will acquire

The participant will learn how to fabricate thin films primarily via sputtering, measure their magnetic properties via vibrating sample magnetometry, and determine their electrical conductance as functions of magnetic field, hydrogen partial pressure, and temperature.

Location of the project

Experimental work will be carried out in the Department of Physics (Hodges Hall).