When a large number of atoms condense into a fluid or solid, behaviors emerge that are only indirectly related to the physics of the individual atoms. Superconductivity is one such emergent behavior, which could not be anticipated from even a detailed study of an isolated atom. The goal of condensed matter physics is not only to measure and explain such emergent phenomena but also to manipulate these properties to produce the novel effects we desire. This allows us to both investigate fundamental physics and to develop commercially important applications.

A student in condensed matter physics must have a thorough understanding of both the microscopic quantum mechanics that underlies the system and the classical macroscopic theories of mechanics, electromagnetism, and statistical mechanics that describe its large scale behavior. This broad background enables students to go on to careers in academia, government labs, and industry.

A primary focus of our group is the study of highly confined electron systems in artificially structured semiconductors. We cover all aspects of these systems from fundamental theory to device fabrication. This group operates as part of the Center for Semiconductor Physics in Nanostructures (C-SPIN) one of the National Science Foundation’s few Materials Research, Science and Engineering Centers. C-SPIN is a multi-million dollar, interdisciplinary research collaboration between scientists at the University of Oklahoma and the University of Arkansas. We have theoretical and experimental efforts in nano-scale semiconductor devices, spin transport in semiconductors and high-speed transistors. In addition to semiconductor studies, the group also has research efforts in self-assembled monolayers, molecular plasmonics, nanoparticles, and lithium ion conducting polymers. Some of this work is performed in conjunction with researchers in the Departments of Chemistry and Biochemistry, Electrical & Computer Engineering, and Chemical, Biological, & Materials Engineering.

The majority of our experimental research takes place in the department’s state-of-the-art laboratories. Our well equipped facilities include: a dual-chamber molecular beam epitaxy (MBE) system for the growth of III-V and IV-VI semiconductors; several scanning tunneling and atomic force microscopes for high resolution imaging and patterning of atomic surfaces; a cleanroom for optical lithography and semiconductor processing; a thin-film laboratory for routine vapor deposition; low temperature (<20 mK) and high magnetic field (15 T) facilities for optical and electrical studies; optical microscopes for single nanoparticle spectroscopy; a grazing angle infrared spectrometer for molecular spectroscopy of monolayers; and picosecond pulsed laser systems for our polymer studies. Scanning electron and transmission electron microscopes are available in the Samuel Roberts Noble Electron Microscopy Laboratory and are routinely used by our students for their research.

Theoretical work is aided by numerous workstations. This work concentrates on electron-electron interaction effects, electronic band structure of the confined systems, and hot-electron transport & magneto-transport in confined electron systems.

The faculty in condensed matter physics share appointments in the engineering physics program. The engineering physicist provides the link between the pure scientist and the engineer by applying fundamental scientific theories to the solution of technological problems. As the miniaturization of transistors, lasers, and memory elements continues, an understanding of their operation increasingly requires knowledge of the underlying physics.
I am interested in surface physics at the nanometer-scale in condensed systems. In practical terms, can I build an electronic device out of a single molecule? Insight into critical technological problems, such as molecular-scale electronics, molecular light-emitting diodes, and light harvesting systems, relies on understanding fundamental physical processes at the nanometer scale. When a single molecule is placed between two electrodes, what is its electrical conductivity? How does light modify the molecule's electrical properties?

My focus is to understand the electronic and the optoelectronic characteristics of individual molecules and functional nanometer-scale assemblies. The experimental approach is to combine the molecular-scale resolution of scanning probe techniques, such as scanning tunneling microscopy (STM) and atomic force microscopy (AFM), with optical spectroscopy.

We use self-assembled monolayers (SAMs) as a matrix platform in which other molecules can be tethered. SAMs have the advantage that they can be easily prepared under bench-top conditions and their molecular components can be readily imaged by STM. Our recent work has concentrated on developing methods for natural patterning of SAMs on the nanometer scale, including surface-structure directed chemistry. We have a strong collaboration with Ron Halterman's synthetic organic group in chemistry to make the unique molecules used for our work. We have also developed flat gold nanoparticles (FGNPs) as plasmonic substrates for our STM studies. In addition to STM, my group also has developed capability in single nanoparticle spectroscopy for molecular plasmonics and in grazing angle-infrared spectroscopy for SAM characterization. Our group is also interested in developing novel scanning probe techniques.


An STM image sequence of progressively smaller areas of a flat gold nanoparticle (FGNP) with a decanethiol self-assembled monolayer (SAM) supported on indium-tin oxide (ITO) coated glass. The left image shows the hexagonal FGNP with its gold (111) terraces. Note the edges of the hexagon are aligned with the Au<110> crystallographic directions. The surrounding relatively rough area is the ITO coating on the substrate. The center image shows the Au(111) terraces and the SAM structural domain boundaries, which are also aligned along Au<110> directions. The right image resolves the individual molecules of decanethiol in the SAM.
My research interests center on the magneto-electronic properties of semiconductors. The work is focused on the lower-dimensional electron systems formed in synthetically created quantum wells and superlattices. Photonic transitions between quantum levels in the wells, and between magnetic levels induced by strong external magnetic fields, are studied using both a far-infrared, optically-pumped laser system as well as a Fourier transform infrared spectrometer. Our group’s goals include the determination of electron dispersion as well as relaxation processes.

We are especially interested in novel properties of quantum-well systems caused by band structure effects such as extreme non-parabolicity. Our work is made possible by the flexibility for designing quantum-well systems with the MBE system as part of the Center for Semiconductor Physics in Nanostructures (C-SPIN). Our experiments concentrate on the narrow-gap system InSb which, as a quantum-well material, shows much promise for infrared and laser devices. We have been able to determine the defining characteristics of the binding potentials for these quantum wells (gap mismatch and band offset). We have observed spin resonance in this system and, in asymmetric wells, evidence of spin splitting in zero magnetic field because of strong spin-orbit coupling. Spin-orbit effects are also responsible for spin-dependent anticrossing behavior which we recently observed in this system.

A recent study of the exciton spectrum in high magnetic fields has led to first results in understanding the holes in InSb quantum wells that subsequent cyclotron resonance experiments have confirmed.

A plot of the spectra for excitons (electron-hole pairs) in parabolic InSb quantum wells with different widths. The samples were grown at OU. The figure is labeled by the transition type, between heavy hole (HH) or light hole (LH) states to conduction band (CB) electron states.


My main research effort is in lithium ion conducting polymers in collaboration with Professor Frech in Chemistry. We are particularly interested in the interactions between the polymer and the ion conducting salt that can provide insight as to the mechanisms of Li ion diffusion. We are studying these properties by combining two newly available technologies, a state-of-the-art tunable pulsed laser system including an optical parametric oscillator (OPO), and a step-scan FTIR.

We are also studying ionic association and polymer configurations and coordinations as a function of salt concentration and temperature in order to understand the basic interactions in these systems. We have ongoing collaborations for novel polymer preparations with Dan Glatzhofer in chemistry, for modeling with Ralph Wheeler in chemistry, and with researchers at the University of St. Andrews, Scotland, and Uppsala University, Sweden, where I was on sabbatical in 1997-1998.


A plot of the IR spectrum of a lithium-ion conducting polymer sample. The ionic association of the trifolate anion affects peak position and intensity.
Nanotechnology, the fabrication and manipulation of structures on the nanometer scale, has lead to the observation of new physical behavior and the development of new technologies. My research involves the fabrication, characterization, and study of a wide variety of individual nanostructures and their arrays.

Materials of interest include: semiconductors, ferro-electrics and ferromagnets, superconductors and polymers through nanotubes. In particular, I am interested in well-ordered arrays of nanostructures because such arrays will show new collective properties in much the same way that crystals show new properties compared with the properties of the individual constituent atoms or molecules from which they are made.

Fabrication techniques used in my lab include: lithography involving electron and ion-beams as well as scanning probe microscopy, and deposition from thermal and electron-beam evaporation and sputtering through molecular beam epitaxy. Characterization involves various types of scanning probe microscopies, x-ray diffraction, optical techniques including, UV-Vis, photoluminescence, various infrared techniques; scanning electron microscopy (SEM) and conventional and high-resolution transmission electron microscopy (TEM). Collective behavior etc. are studied using low-temperature magneto-transport available at OU and magnetometry, terahertz spectroscopy, Brillouin scattering, low-temperature magnetic force microscopy, and other more exotic techniques available through National Labs and various collaborations.


Trained and raised as a solid state theorist, in the mid-1990’s I started to explore ways in which the computational tools used in research could expand and enliven courses for both graduate and undergraduate students. This lead to the study of new technologies for supporting learning and ways to help other faculty take advantage of these tools.

My work now focuses on efforts to enhance physics and astronomy education through web-based resources. I am director of the ComPADRE network of educational resource collections (http://www.compadre.org), a collaboration of the American Association of Physics Teachers, the American Physical Society, and the Society of Physics Students and part of the National Science Digital Library (http://nsdl.org). I am also the editor of the physics collection on MERLOT (http://www.merlot.org), a multi-discipline and multi-institutional organization promoting the scholarly use of multimedia educational resources.


I am interested in the physics of novel effects in mesoscopic systems. My recent work falls in three broad categories: submicron electronic devices, heat transport in carbon nanotubes and graphene nano-sheets, and two dimensional electron gasses.

“Mesoscopic” systems are those in between the regimes of classical and quantum physics, typically less than a micron across. Experimentalists can routinely fashion devices so small that the electrostatic energy of a single electron can control the flow of current, or in which electrons can travel coherently from one side of the device to the other. The theoretical challenges are to understand how the quantum mechanical effects in the microscopic device couple to macroscopic world of voltmeters and ammeters, and how to take advantage of the novel dynamics for new applications.

Heat transport in small devices and nano-composites is often not diffusive. In order to understand how energy flows through such systems we have to go beyond a Boltzmann equation approach and look at the dynamics of the electron and phonon modes. Careful control of material properties on the nanometer scale can enable us to design devices and materials with novel thermal and electrical properties.

My third area of interest the dynamics on electrons when they are confined to a two dimensional plane. This leads to a host of interesting topics including localization, behavior in a strong magnetic field, and the existence of electron “bubbles” called skyrmions.


My group studies quantum and spin transport of electrons in confined geometries. Two-dimensional confinement is achieved when the electrons reside in a thin layer of a low bandgap semiconductor sandwiched between layers of higher bandgap material. Additional confinement results from processing the semiconductor samples into wires or dots. These reduced dimensional systems have yielded some of the more interesting developments in condensed matter physics in the last two decades such as the quantum Hall effects and quantized conductance. As of late, a good deal of effort has been devoted to quantum and spin transport in these reduced dimensional systems. Quantum and spin transport occur when the sample dimensions are smaller than the electronic scattering and spin decoherence lengths. Not only do these studies aid in our understanding of fundamental physics, but they can also contribute to technological innovation through new devices which exploit quantum principles.

At the University of Oklahoma, we have access to a particularly interesting semiconductor system, InSb, grown by Prof. Santos’s group. This material has an extremely low electron effective mass resulting in high mobility and a very large Lande g factor and other spin effects. With tools available in our lithography facilities we can fabricate devices with submicron sized features, package them for our experiments and perform room temperature inspection and characterization. Our transport measurements are conducted at low temperatures (from 10K to 0.01K) and in high magnetic fields (up to 15 Tesla).

The figure shows a scanning electron microscope image of an InSb magnetic focusing device. In such a device an electron injected from the left entrance slit will be focused into the right hand slit under the influence of an appropriately tuned perpendicular magnetic field. Two focusing trajectories are shown: the solid trace for a low magnetic field; and the dotted trace corresponding to a higher magnetic field. Large spin-orbit effects in InSb based devices suggest that electrons with different spins may travel along different paths allowing for the intriguing possibility of spin-polarized currents.


My current work focuses on the use of video techniques to enhance physics instruction. Using 3-D computer animation, the Physics Video Project is producing a video series entitled “Understanding Modern Technology” to illustrate the application of the principles of physics to modern technology. Also in production is a companion series of Physics Video Clips designed to elucidate physical phenomena that evolve in time and thus are not readily illustrated in a static figure. The goal of the Physics Video Project is to enhance learning in introductory physics classes by illustrating the applications of physics and demonstrating concepts that students often have difficulty visualizing or understanding mathematically.

A continuing area of interest is the development of new techniques and instrumentation for use in such fields as materials characterization, non-destructive testing and energy conservation. A differential, constant-resistance anemometer developed for energy conservation has application in both analytical chemistry and geophysics.


The interests of my research group focus on the growth of narrow-gap semiconductors and device applications for these materials. We use molecular beam epitaxy to grow heterostructures based on InSb, InAs, and In$_x$Ga$_{1-x}$As. Because the bandgap of InSb is the smallest of all binary III-V compounds, two-dimensional electron systems in InSb quantum wells have a small effective mass, a large g-factor, and strong spin-orbit effects. The room-temperature mobility in these structures is higher than in quantum wells made of any other semiconductor. We are exploring ways to exploit this and other features in mesoscopic magnetoresistors, ballistic transport devices, and spin devices. These studies are being pursued in collaboration with Professor Murphy (magneto-transport), Professor Doezema (far infrared magneto-optics), and others. We also grow In$_x$Ga$_{1-x}$As/In$_x$Al$_{1-x}$As and InAs/GaSb/AlSb structures for electronic and photonic applications, respectively.

Since the operation of electronic devices depends on the quality of the heterostructure materials, my group makes use of materials analysis techniques including transmission electron microscopy, reflection high-energy electron diffraction, Auger electron spectroscopy, x-ray photoelectron spectroscopy, high-resolution x-ray diffraction, and scanning probe microscopy. Some of these materials studies are performed in collaboration with Professor Johnson’s group.

“A plot of the electron mobility in an InSb quantum well at 300K, as a function of the densities of threading dislocations (TD) and microtwins (MT). One goal of modern semiconductor research is to grow perfect layered structures with no defects, in order to achieve high mobility for electrons travelling through the structure.”