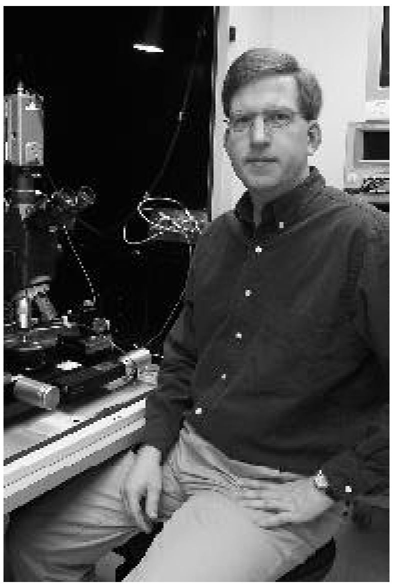
Nanotechnology

Nanotechnology has become the buzzword in the high tech world. But what is it and how does it relate to everyday life? It's the ability to manipulate matter at the nanometer-scale to realize new or enhanced properties not achievable in a macroscopic world. Nanotechnology impacts virtually all science and engineering disciplines from semiconductors to biology and medicine. This is the future of the 21st century, and here at The Ohio State University, the Department of Electrical Engineering is at the forefront of these technological innovations. Professors Paul Berger, Len Brillson, and Steve Ringel each lead groups investigating critical areas of nanotechnology: nanoelectronics, nanostructures and electrical materials on a nanoscale.

the dawning of a nanonosized world



The emphasis on nanotechnology has primarily arisen from the microelectronics industry's never-ending quest to reduce transistor size and increase circuit and system level sophistication. Early microprocessors used transistors whose critical dimensions were on the order of a micron, compared to about 0.13 microns today. Nanotechnology investigates matter at one to two orders of magnitude smaller than a Pentium-4 microprocessor and now crosses many sectors of the high technology industry. The National Nanotechnology Initiative is fueling this exploration by providing Federal funding to researchers across the country, including faculty within the Electrical Engineering Department's Solid State Electronics and Photonics Area.

Nanoelectronics deals with electrical switches that are beyond current CMOS-based microcircuitry and which begin to operate at the single electron regime, beyond the needs targeted by the Semiconductor Industry Association (SIA). Professor Paul R. Berger's Nanoelectronics and Optoelectronics Laboratory (NOEL) is meeting this challenge head-on by investigating nanoelectronics based upon quantum dot (QD) transistors. The National Science Foundation's (NSF) Nanoscale Science and Engineering (NSE) Program sponsors research in this area, and a $1.6M award was made to Ohio State (Lead: Berger) for "Self-Aligned and Self-Limited Quantum Dot Nanoswitches." Dr. Berger received the highest rated Nanoscale Interdisciplinary Research Team (NIRT) award given nationally by NSF in the area of "Structures and Phenomena: Electronic, Magnetic and Optoelectronic." To address these issues, an interdisciplinary team of researchers who are actively involved in nanoelectronics, specifically addressing growth, fabrication, characterization, circuits and modeling, have been assembled. An important aspect of the NIRT team Dr. Berger leads is its collaborative nature. It involves Researchers from four universities, the Naval Research and the Air Force Research Laboratories as well as Professor Michael Mills, OSU Materials Science and Engineering, and the Center for Materials Research based in the OSU Physics Department. This NIRT project will demonstrate the validity of nanoscale computing based upon QD by developing a process technology to fashion QDs of a predictable size, shape and placement, suitable for mass production and which can be readily contacted by external circuitry. Furthermore, this proposed approach greatly relaxes the lithographic tolerances needed to achieve 1-4 nanometer diameter QDs for room temperature switching. The interdisciplinary nature of the work involving electrical engineering, materials science, physics and computer science makes this an excellent educational topic for the training of future scientists. This proposed novel process for the formation of QD based switching elements is an enabling technology which can be applied to a variety of circuit architectures, including (i) single-electron tunneling (SET) transistors, (ii) resonant tunneling diode (RTD) based circuitry, (iii) quantum-dot cellular automata (QCA), and quantum computing in general.

Nanostructures consisting of various compound semiconductor heterojunctions, quantum wells, superlattices and embedded multi-atom clusters are being investigated in Professor Steven A. Ringel's Electronic Materials and Devices Laboratory (EMDL). These nanostructures are being synthesized using Molecular Beam Epitaxy (MBE), the cornerstone experimental technique within EMDL's state-of-the-art Semiconductor Epitaxy and Analysis Laboratory (SEAL). Several programs investigate the application of nanostructures both to improving the performance of optoelectronic devices such as laser diodes and solar cells for space power applications, as well as exploiting the unique properties of nano-engineered semiconductors to develop devices that may revolutionize various areas of semiconductor device application. These include quantum dot solar cells which hold great promise to convert the sun's energy into electricity twice as efficiently as the best performing solar cells available today, quantum dot laser diodes and other optoelectronic devices that can operate at speeds, efficiencies and wavelengths not currently

attainable by conventional means, and the synthesis of nanocomposite electronic materials that utilize so-called "low temperature" grown (LTG) III-V compound semiconductors whose unique optical and electronic properties are already enabling new classes of optical and electronic devices that complement existing technology. Many of these nano-engineered materials are being pushed to the next level already, by exploring the means to integrate these novel properties and devices with silicon device technology. Institutions supporting these activities include the Army Research Office, NASA, the National Science Foundation, the Office of Naval Research, the National Renewable Energy Laboratory, and several private companies.

As the dimensions of semiconductors, insulators, and their contacts to metallic conductors shrink, many new electronic and optical phenomena present themselves. At the same time, the surfaces and interfaces of such structures become increasingly important at these small scales, often dominating the overall physical properties. Researchers can now take advantage of these nanoscale phenomena in order to construct new materials and structures with properties never before created in nature. The Electronic Materials and Nanostructures Laboratory (EMNL) headed by Professor Leonard J. Brillson is using leading edge experimental techniques to understand and control the properties of electronic materials on a nanoscale. This group has a broad research program in the structure and properties of electronic materials, emphasizing compound semiconductors for high speed microelectronic and optoelectronic device structures, wide band gap semiconductors for sensor and display applications, and thin film dielectrics for insulating gate structures. The EMNL group uses an array of state-of-the-art equipment to reveal properties of ultrathin films only a few monolayers thick used in tunneling magnetoresistance (TMR) devices, nanometer-thick two dimensional electron gas (2DEG) film structures based on piezoelectrically induced charge confinement for high electron mobility transistor (HEMT) structures, submicron grains and nanoscale grain boundaries of polycrystalline semiconductors used in varistors, charge rectification interfaces between metals and semiconductors fundamental to metal-semiconductor diodes, and heterointerfaces between semiconductors employed in next generation solar cells, infrared energy conversion, and ultrahigh frequency (GHz-THz) communications. This research demonstrated new ways to create sensors capable of responding to light, heat, pressure, and chemical environment – often at temperatures far beyond what current technologies can provide. Funding for this program comes from variety of sources including the National Science Foundation (individual, group, and major instrumentation grants), the Department of Energy, the Office of Naval Research, the Air Force Office of Scientific Research, NASA, and private industry sources. A number of highly competitive grant awards reflect national recognition for Ohio State's nanotechnology thrust in this arena. They include one of only a handful of National Science Foundation Major Research Instrumentation 2000 awards totaling more than $1.3 million over two years. This award to Professor Leonard Brillson enables the development of the SIMS/LEEN/MBE instrument to probe chemical and electronic structure of materials on a nanometer scale. Similarly, the cross-disciplinary Ohio State team of Professors Leonard Brillson (lead), Steven A. Ringel, John Wilkins (Physics), and Jonathan Pelz (Physics) received a 3-year NSF Focus Research Group (FRG) award for more than $960,000 to study the morphological, chemical and electronic properties of lattice-mismatched heterojunctions at the nanoscale. This work aims to find new ways to combine semiconductors with different crystal lattice dimensions by understanding the relationships between structural, atomic bonding, and electronic properties as these structures grow.


From r to l: Shawn Bradley, Phil Smith and Professor Leonard Brillson

Advances in the nanotechnology of electronic materials can make a major impact on both the state of Ohio and The Ohio State University. Five of the top twenty-five manufacturing employers residing in Ohio produce electrical equipment and electronics. The shrinking of electronics to the nanoscale will impact traditional automotive, aerospace, and consumer electronics not only in improved performance but also in creation of new markets. Nanoelectronics stands to give added value to commodity products from traditional Ohio industries by imbedding microscopic electronic sensors, computers, and communication devices into structural, power generating, and biomedical products. Ohio's initial investments in electronic materials have already reaped huge benefits. Funds for clean room, epitaxial growth, processing, and characterization facilities has provided extraordinary leverage, resulting in several millions of Federal research dollars annually flowing into electronic materials research at Ohio State alone from the National Science Foundation, the Department of Energy, and all of the Department of Defense agencies. The infrastructure developed over the past few years in electronic materials – in terms of state-of-the-art equipment, researchers, and laboratories – positions Ohio State and its collaborating Ohio institutions for even greater funding opportunities in nanotechnology. Formal cooperative research agreements now in place with the Air Force Research Laboratories and the NASA-Glenn Research Center provide further links between Ohio State, The Air Force Research Laboratory in Dayton, the Air Force Institute of Technology (AFIT), the University of Cincinnati, Ohio University, and Case Western University in key areas of advanced electronic nanotechnology that extend across Ohio. This research infrastructure can now provide value to a substantial number of new and current industrial partners.