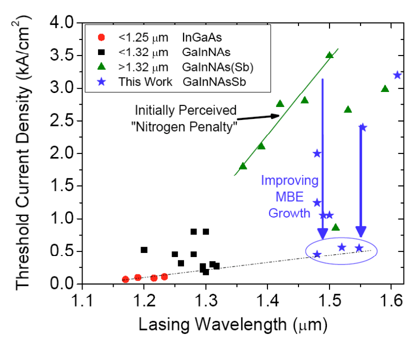
James S. Harris

James and Ellenor Chesebrough Professor in the School of Engineering, Professor of Electrical Engineering, Applied Physics and Materials Science
B.S. (1964), M.S. (1965), and Ph.D. (1969) Stanford University. Prof. Harris' current research interests are in the physics and application of new artificially structured materials and nanofabrication techniques for new electronic and optoelectronic devices and quantum computing. He has over 850 publications, 18 issued US patents and has supervised over 95 Ph.D. students in these areas. He received a Senior Humboldt Research Prize in 1998, the 2000 IEEE Morris M. Liebmann Memorial Award, the International Symposium on Compound Semiconductor Welker Medal, IEEE Third Millennium Medal and International MBE Conference 2008 MBE Innovator Award. He is a Fellow of the IEEE, Optical Society of America and the American Physical Society.
Personal homepage: **http://www-ee.stanford.edu/~harris**

KEYWORDS: molecular beam epitaxy, MBE, semiconductor lasers, VCSELs, tunable lasers, optical MEMS, detectors, modulators, quantum well structures, GaAs, GaNAs, GaInNAs, optical interconnects, mode locked lasers, non-linear optics, optically patterned GaAs, micro-fluorimeter, index-of-refraction sensor, lab-on-a-chip, photonic crystal nanofabrication, single electron devices, Spintronics, spin polarized electrons, dilute magnetic semiconductors
Group homepage: http://snow.stanford.edu/

CURRENT MAJOR PROJECTS:

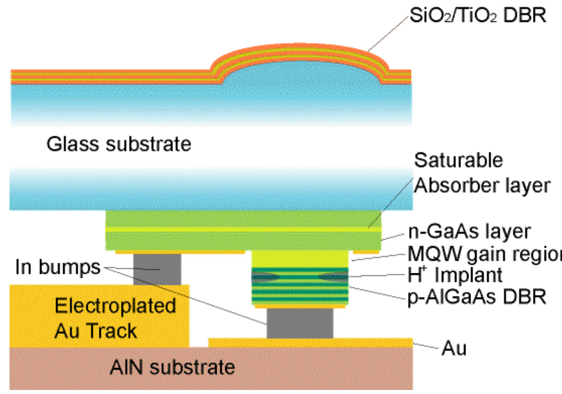
Long Wavelength Communications Lasers on GaAs
Principal Investigator: James S. Harris



Our work has focused on developing GaInNAsSb on GaAs where we have realized the lowest threshold current 1.55μm edge-emitting lasers and the first monolithic 1.55μm VCSELs. GaInNAsSb is a metastable material with many challenges to realize the longer wavelengths, but the tremendous advantages of producing long wavelength devices on GaAs where excellent DBR mirror technology exists and the potential to integrate photonic crystal waveguides and resonators will enable integration of more functional photonic integrated circuits, arrays of much lower cost, 2-D lasers and modulators which can be easily coupled into fiber or utilized in free space architectures and offer great architectural diversity. Edge emitting lasers from these alloys also offer much greater opportunity to realize very high power semiconductor laser pumps for Raman amplifiers and semiconductor optical amplifiers to open up the entire 1.3-1.6μm low loss fiber region as well as provide resonant pumps for very high power, high efficiency solid-state lasers. We achieved very low threshold current density of 373 A/cm^2 for 1.55um edge-emitting lasers and the first GaAs-based monolithic VCSEL at 1.53um.
URL: http://www-snow.stanford.edu/~hpbae/
URL: http://www-snow.stanford.edu/~tsarmie/
URL: http://www-snow.stanford.edu/~mgobet/

MARCO Interconnect Focus Center: Interconnections for Gigascale Integration

Co-Principal Investigators: Simon Wong, David Miller, Krishna Saraswat and James Harris



The focus of the Center is a broad, multi-disciplinary approach to investigate Interconnections for Gigascale Integration. The focus of the Miller/Harris portion is development of monolithically integrated GaAs/Si and GaInNAs devices for high speed optically based clocking and signal propagation. Novel, integrated laser structures are being investigated to produce 40-100GHz repetition rate, femtosecond pulses for timing and synchronized broadband sources for wavelength division multiplexing in dense optical interconnects.

URL: http://www-snow.stanford.edu/~raldaz/

MARCO Materials, Structures and Devices and Focus Research Center

Co-Principal Investigators: Krishna Saraswat, K. J. Cho, Hongije Dai, Robert Dutton, James Harris, Paul McIntyre, Jim Plummer

Control over spins in the solid-state has the potential to provide a foundation for a new class of devices forming the basis for spintronics and quantum information technologies. The research focus is on electronic and nuclear spins in semiconductor nanostructures as a medium for the manipulation and storage of both classical and quantum information. We are investigating spin-engineered semiconductor nanostructures that exploit the coherent electronic spin dynamics in semiconductors and quantum structures to provide a foundation to build new spin based electronic devices and system architectures.

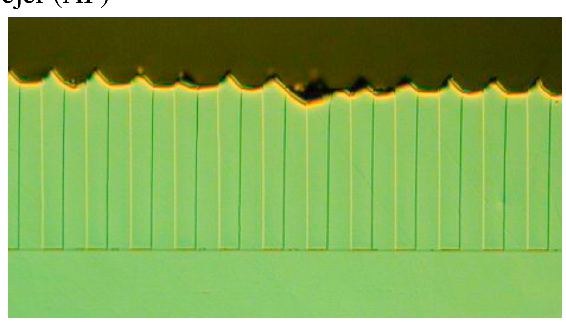
URL: http://www-snow.stanford.edu/~rwang/

URL: http://www-snow.stanford.edu/~ligao/

Non-linear Optics and Orientation Patterned GaAs and GaP

Principal Investigator: James S. Harris and Martin M. Fejer (AP)

The focus of this project is to develop artificially structured materials with simultaneously enhanced non-linear optical properties and a periodic modulation of the sign of the non-linear coefficient which provides phase match to optical signals of different frequency. This project has two primary foci; one for waveguide devices that can be integrated into optical networks for a variety of non-linear functions, such as all optical channel switching, and the second for thick bulk-patterned materials for high power laser generation in the mid-IR and Terahertz regions where there are no available compact solid state or semiconductor laser sources.



Side profile of bulk-patterned structure

URL: http://snow.stanford.edu/~angiel/

Spin Based Electronic Devices

Principal Investigator: James S. Harris and Stuart Parkin (IBM)

The focus of this program is to develop new device concepts utilizing the spin of electrons rather than charge for current. The immediate focus is developing injection of spin polarized electrons into GaAs using ferromagnetic metal Schottky barriers and to detect spin polarized electrons using recombination from quantum wells or quantum dots. The longer range interest is to investigate coherence lifetimes, storage and manipulation of spin polarized electrons for a variety of new electron devices and as potential application to quantum computing.

URL: **http://www-snow.stanford.edu/~rwang/**

URL: http://www-snow.stanford.edu/~ligao/

Nanofabrication and Single Electron Devices

Principal Investigator: James S. Harris

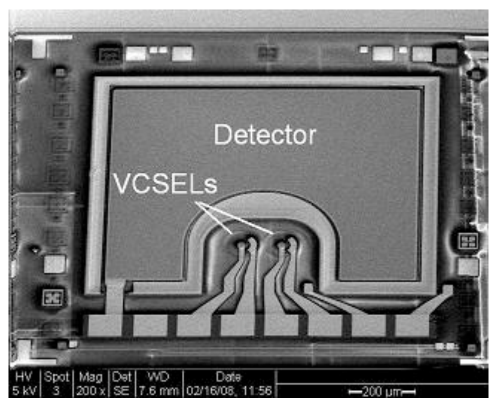
The focus of this program is development of nanofabrication technologies that combine with molecular beam epitaxy to produce two and three dimensionally confined structures to investigate the potential for electron devices based upon a single or few electrons. The project includes both processing intensive approaches using e-beam lithography and reactive ion etching or selective oxidation using the atomic force microscope (AFM) to define very precise patterns, or MBE growth based techniques to produce self assembled quantum dots or wires

URL: http://www-snow.stanford.edu/~shimbo/set.html

Development of integrated optical bio-sensors and fluorescent molecular imaging probes for continuous real-time monitoring of stem cells in living subjects

Principal Investigators: James S. Harris, Sanjiv Sam Gambhir (Departments of Radiology and Bioengineering), and Ofer Levi (University of Toronto)

We are fabricating miniaturized, integrated VCSEL/detector fluorescence sensors for live tissue imaging in unanesthetized mice. Major challenges of this project include fabricating detectors with extremely low dark current and sufficiently blocking laser excitation background from the detector. This project also involves the simulation and modeling of light interaction with live tissue. The devices will ultimately be implanted in freely moving mice to study tumor growth and cancer stem cell dynamics. This is a collaborative project with the School of Medicine.



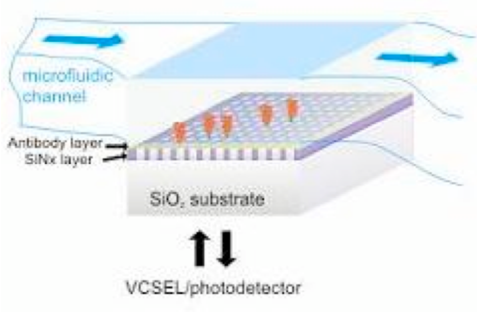
URL: **http://www-snow.stanford.edu/~tdo/**

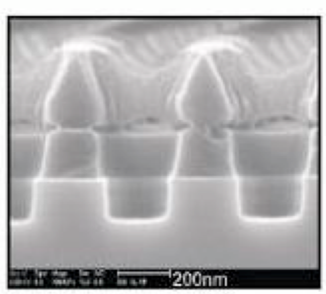
http://www-snow.stanford.edu/~levi

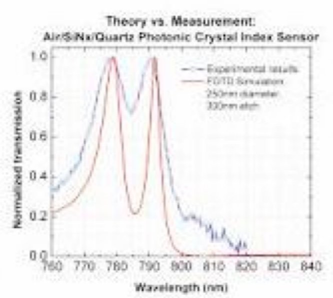
Miniaturized label-free optical sensors using photonic crystal guided resonances

Principal Investigators: James S. Harris, Shanhui Fan, Steven R. J. Brueck (University of New Mexico)

This project focuses on the design and development of a miniaturized, "label-free" optical sensor for a lab-on-a-chip. Applications include portable biomedical diagnostics, bio-defense, imaging, and environmental monitoring of gas or liquids. The sensor features a 2D photonic crystal slab (sub-







wavelength grating) that gives rise to a guided resonance when illuminated by normally-incident light. When molecules approach the photonic crystal slab surface, we can detect a shift in the resonance.

The all-dielectric device operates in the near-infrared transparency window for low absorption of water and hemoglobin, and is compatible with our integrated VCSEL/photodetector/filter. First-generation device results agree with 3D Finite Difference Time Domain simulations; present work includes the integration of microfluidic controls and the prototyping of new sensor architectures for increased sensitivity. We ultimately aim to combine multiple sensing mechanisms on one platform to provide rapid, correlated bio-analysis.

URL: http://www-snow.stanford.edu/~mmlee/

URL: http://www-snow.stanford.edu/~ethrush/bioproject/intro.htm
URL: http://snow.stanford.edu/~levi/biosensors.html
URL: http://www-snow.stanford.edu/~mmlee/
URL: http://www-snow.stanford.edu/~tdo/

Integrated Semiconductor Optical Sensors for Functional Brain Imaging
Principal Investigators: James S. Harris, Krishna V. Shenoy, Stephen J. Smith (Molecular & Cellular Physiology), and Ofer Levi (University of Toronto)
Our current research centers on the development of integrated optical sensors for functional brain imaging. Intensity changes in back-scattered light, called Intrinsic Optical Signals (IOS) track hemodynamic changes associated with neural activity. Current imaging systems typically employ benchtop equipment including lamps and CCD cameras to study anesthetized animals using visible wavelengths. Sensor integration using arrays of semiconductor sources and detectors operating in the near-infrared (670-850nm) will allow studies of freely behaving animals and the potential for long-term, minimally invasive neuroscience studies. Other possible applications include pharmaceutical evaluation and neural prosthetics. The neural prosthesis work is connected to a larger effort in Brain Machine Interface led by Dr. Shenoy at Stanford and in Neural Engineering led by Dr. Levi and collaborators at the University of Toronto. Current work involves modeling light propagation in neural tissue using MR derived 3-D rodent brain anatomy, measuring the optical properties of neural tissues, studying the characteristics of near-infrared IOS through skull, exploring ways to take advantage of structured illumination to improve performance, and characterization of low-frequency noise in VCSELs. Planned work includes design and fabrication of near-infrared integrated VCSEL/detector 1-D sensor arrays, and evaluation of these sensors side-by-side with CCD cameras

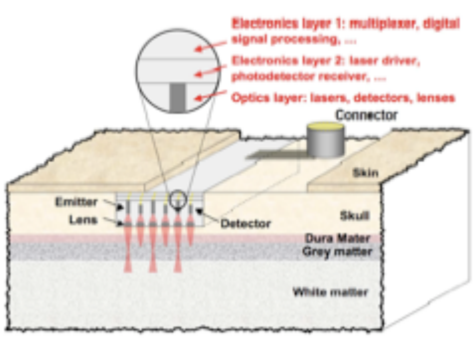
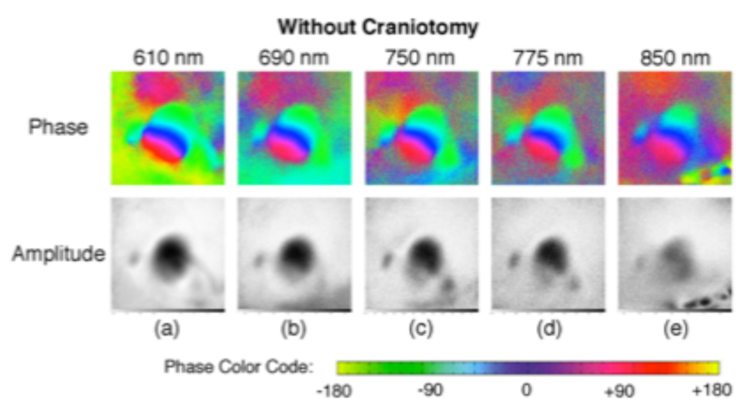


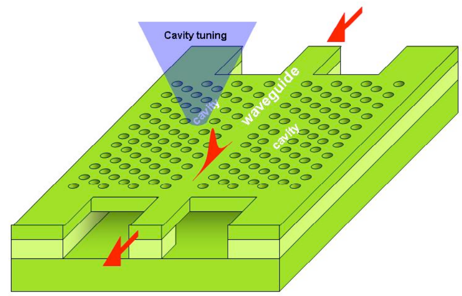
Illustration of sensor embedded into skull in IOS imaging in rodents.



IOS image of mouse visual cortex

URL: http://www-snow.stanford.edu/~tdo
http://www-snow.stanford.edu/~levi
http://www-snow.stanford.edu/~leet

Stopping light
Principal Investigators: James S. Harris, Shanhui Fan, Martin M. Fejer (AP)
The focus of this project is to develop photonic crystal based devices for stopping light all-optically. Dynamic resonator system has been used to accommodate the light pulse, compress the bandwidth and correspondingly drastically slow down the propagation speed of light. As a result of this all-optical manipulation, it has profound implication for coherent store of light pulse and ultimate control of light. Current work focuses on the e-beam lithography and etching fabrication process.

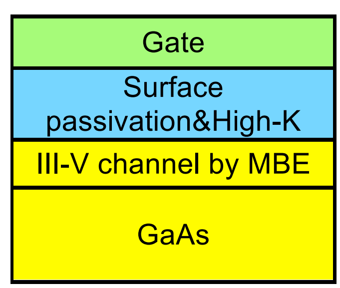


URL: http://www-snow.stanford.edu/~yjhuo/
URL: http://www-snow.stanford.edu/~panjun/

Ge/SiGe Quantum-Confined Stark Effect Modulators on Silicon
Co-Principal Investigators: James Harris and David Miller
The focus of this project is to provide optical modulator on silicon for high-speed communication and interconnects with CMOS-compatible fabrication. The growth and optical characterization of Ge/SiGe quantum wells on silicon substrates are being investigated to exploit its strong quantum confined Stark effect for electroabsorption modulator in long wavelength regime. The modulator and detector array based on this approach will enable all-group-IV photonics integrated with electronics.

Silicon Based Coherent Photonic Sources
Co-Principal Investigators: James S. Harris, Jelena Vuckovic
The focus of this project is to produce an electrically pumped, silicon based laser. There are two major thrusts, a) to create SiGe based quantum well and/or quantum dot active regions in which the material is either direct or nearly direct bandgap and b) Si based photonic crystal cavities with ultra-high Q to eliminate any photonic states for spontaneous emission and enable stimulated emission into the single allowed state of the photonic crystal cavity.
URL: http://www-snow.stanford.edu/~yjhuo/

III-V CMOS Devices
Co-Principal Investigators: James Harris, Paul McIntyre
The focus of this research is to analyze the interface between III-V compound semiconductors and high-k gate oxide and fabricate III-V MOS FET using them. Since some compound semiconductor such as InGaAs, GaAs or InSb showed relatively higher electron mobility than Si, we want to improve device performance by using high mobility channel layer grown by MBE. Optional surface treatments are tried to reduce interface defects before ALD high-k deposition.



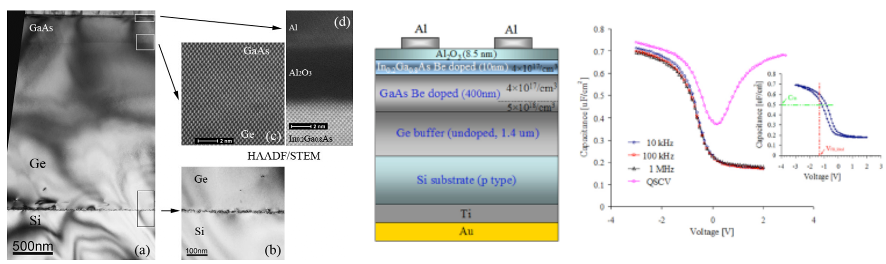
URL: http://snowboard.stanford.edu/~dhchoi

Nano-aperture VSELSs for Near Field Imaging and Storage
Co-Principal Investigators: James Harris, Bert Hesselink
The focus of this research project is to develop high-intensity nano-aperture VCSELs for ultrahigh-resolution near-field imaging and ultrahigh-density near-field optical data storage. We have demonstrated record-high intensity nano-aperture VCSELs with sub-100nm near-field spot sizes using ridge nano-apertures including bowtie, C, H and I-shaped apertures. The next step is to develop the application of these high-intensity nano-aperture VCSELs for near-field imaging and optical data storage.
URL: http://www-snow.stanford.edu/~zlrao/

Affiliated Ph.D. Students:

Hopil Bae
Admitted to Ph.D. Candidacy: 2002-2003
Research: Growth and fabrication of GaInNAs(Sb)/GaAs lasers. More specifically, the development of this new materials system to produce high power ridge-waveguide edge emitting lasers and very low cost vertical-cavity surface-emitting lasers (VCSELs). Additional work focuses on annealing and characterization of these films by photoluminescence.
URL: http://www-snow.stanford.edu/~hpbae

Donghun Choi
Admitted to Ph. D. Candidacy: 2004-2005
Research: Fabrication of the III-V FET using GaAs/Ge/Si growth on Silicon wafer.
The purpose of this project is to improve the device performance by using III-V materials that show high carrier mobility. In addition, this III-V structure will be grown on virtual GaAs wafer that is grown on Ge buffer of Si wafer by MBE. The Ge buffer layer is grown on Si wafer by CVD. This project includes the surface states passivation and interface analysis for high-k materials deposition on III-V materials for the gate oxide**.**

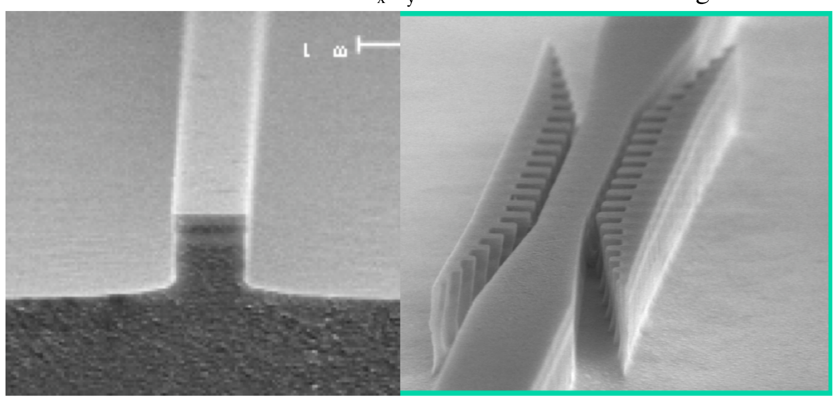


Li Gao
Admitted to Ph.D. Candidacy: 2004
Research: Spin angular momentum transfer, spin torque
Study the physics of current induced switching magnetization in magnetic nanostructures, which is expected to be used in future MRAM.

Yangsi Ge
Admitted to Ph.D. Candidacy: 2004-2005
Research: Ge/SiGe Electro-Absorption Modulators.
Design, growth, and characterization of high speed Ge/SiGe quantum well QCSE modulators on Si substrates through direct SiGe buffers for long wavelength optical modulators. Further investigation of SiGe waveguide on Si and monolithic integration of modulator and photodetector on a single Si wafer for OEIC.

Mathilde Gobet
Admitted to Ph.D. Candidacy: 2005-2006
Research: Long wavelength Vertical Cavity Surface-Emitting Lasers on GaAs substrate
This work focuses on the simulation, fabrication and characterization of VCSELs at 1.55 μm with GaInNAsSb quantum wells. The aims of this project are to realize electrically pumped continuous wave VCSELs on GaAs at 1.55 μm, as well as VCSEL arrays for optical communications and wavelength division multiplexing applications. The first part of this project consists of improving the laser characteristics, namely by decreasing the threshold current and operating voltage to obtain CW operation, extending the wavelength to 1550 nm, as well as developing and optimizing new fabrication steps. The second part of this project involves the realization of high-speed devices with advanced fabrication techniques and the fabrication of multiple-wavelength VCSEL arrays with wavelength spacing on the order of 0.4 nm to use with DWDM technologies.

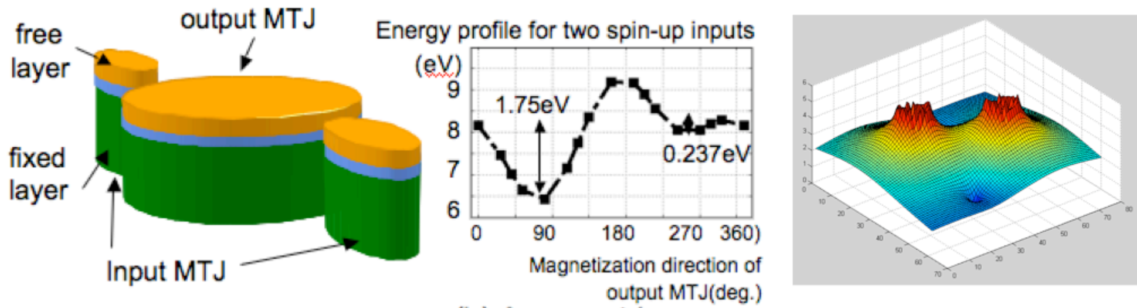
Yijie Huo
Admitted to Ph.D. Candidacy: 2004-2005
Research: Design, fabrication, and characterization of AlGaAs/Al_xO_y-based submicron waveguides and cavities for non-linear optical applications, such as all-optical frequency converter in optical fiber communication network and inter-/intra- chip optical connections. Characterization of photonic crystal micro-cavity and waveguide devices. Design, growth, and characterization of MBE-grown SiGe quantum wells devices for optical applications.



Meredith M. Lee
Admitted to Ph.D. Candidacy: 2005-2006
Research: Focuses on the development of miniaturized optical sensors designed for integrated "lab-on-a-chip" biomedical and bio-defense applications. Previous work demonstrated a fluorescence sensor with a monolithically integrated VCSEL, detector, and filter. Current work focuses on the design, simulation, fabrication, and characterization of an index-of-refraction sensor using guided resonances in 2D photonic crystal slabs. Such resonances offer design scalability, light coupling simplicity, and high sensitivity in a low-loss all-dielectric structure. Fabricated sensors demonstrate the potential for label-free monitoring of biochemical events such as virus binding. Ultimately, the fluorescence and index-of-refraction sensors can be combined on one platform with other detectors to provide portable, rapid, and correlated bio-analysis.
URL: http://snow.stanford.edu/~mmlee

Thomas T. Lee
Admitted to Ph.D. Candidacy: August 2004
Research: Integrated optical devices for minimally-invasive functional brain imaging.
Development of micro-fabricated optical sensors for long-term monitoring of brain activity in awake, freely-behaving animal subjects. Study of near-infrared intrinsic optical signals in rodent visual cortex. Modeling of optical propagation through cranial tissue and integration of GaAs-based photonics on Si. Applications include neuroscience research, drug discovery, and neural prostheses.
URL: http://www-snow.stanford.edu/~leet

Larkhoon Leem
Admitted to Ph.D. Candidacy: 2004-2005
Research: As an alternative logic device solution to spintronics transistor, Magnetic Coupled Spin-Torque Devices (MCSTD), an ensemble of lithographically patterned, interacting three magnetic tunnel junctions (MTJ) are investigated. The magnetizations of input MTJs are electrically oriented with spin-torque momentum. The magnetostatic stray fields from the input MTJs are sufficiently strong as to perturb the energy barrier height of the output MTJ. NAND, NOR operations and 400MHz ring oscillator are demonstrated in micromagnetics simulation. Research effort includes the fabrication of MCSTD, MCSTD+CMOS hybrid circuit for data retention flip-flops and multi-bit spin-torque transfer MRAM with MCSTD.



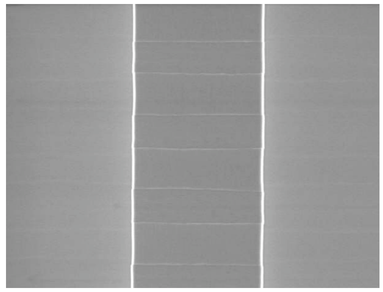
(a) Perspective view of MCSTD (b) Asymmetric energy barrier heights (c) Stray magnetic field from the input MTJs

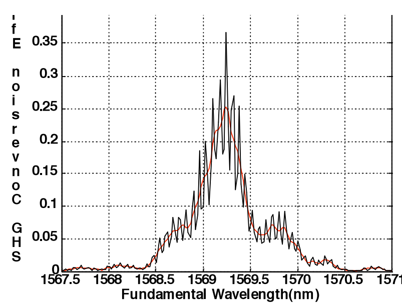
Paul Lim
Admitted to Ph.D. Candidacy: 1999-2000
Research: Investigations of the reliability physics of novel MOSFET devices through 1/f noise analysis. This research involves studying the 1/f noise characteristics of various MOSFETs like GePFETs, III-V FETs, CNTFETs, etc, and the correlations with the quality of the devices. Effects of strain on these devices are also studied.

Xiao Hann Lim
Admitted to Ph.D. Candidacy: 2005-2006
Research: Hybrid evanescently-coupled on-chip lasers for optical interconnects in silicon ICs.
This work involves the development of an evanescently-coupled on-chip semiconductor laser system that can be integrated with silicon ICs. By making waveguide structures from Si-based materials and integrating semiconductor lasers on a Si CMOS platform, this has the potential of moving towards the realization of an efficient silicon integrated photonics system. This is a design that uses the principle of evanescent waveguide coupling as an alternative to free-space or butt coupling, to connect the source (the semiconductor laser) to the waveguides on a silicon substrate. Previous students of the Harris group have come up with the idea of using ARROW (Anti-resonant reflective optical waveguides) and evanescent wave coupling in order to alleviate this problem of complexity in the external lens optics. Compared to free space direct coupling, the main benefits of evanescent coupling are more relaxed alignment tolerances, simpler packaging, higher immunity to catastrophic mirror damage and higher spectral purity.

Angie Lin
Admitted to Ph.D. Candidacy: 2005-2006
Research: Molecular beam epitaxy (MBE) growth of quasi-phase matched (QPM) III-V materials for nonlinear optical frequency mixing with applications in chemical gas sensing, airborne countermeasures and optical communications. This project includes growth of orientation patterned GaAs templates for both thick film growth by hydride vapor phase epitaxy and for the growth of AlGaAs nonlinear

waveguides. Another materials system being developed is orientation patterned GaP based on Si substrates. Materials characterization techniques include x-ray diffraction, atomic force microscopy, scanning electron microscopy, and transmission electron microscopy for determining crystal growth quality.





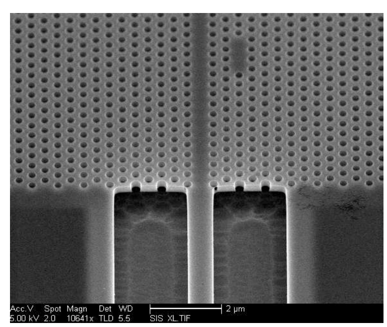
AlGaAs nonlinear waveguide fabricated on orientation-patterned GaAs template and second-harmonic generation efficiency

Hai Lin
Admitted to Ph.D. Candidacy: 2007-2008
Research: MBE growth and characterization of GeSn strained quantum wells in order to create light sources from group IV materials which could be used as part of optical interconnects in Si-based semiconductor devices. This project includes two main directions to get direct band gap group IV materials: one is to introduce 2% in-plane tensile strain to Ge; another is to form GeSn alloy. Characterization techniques include Atomic Force Microscopy, X-ray Diffraction, Secondary Electron Microscopy, Transmission Electron microscopy and Photoluminescence for determining materials' quality.

Ofer Levi
Postdoctoral researcher, 2000-2007, Assistant Professor University of Toronto, 2007
Research: Nonlinear semiconductor devices for spectroscopy and optical networking, biomedical fluorescent sensors, integrated semiconductor based spectrometers, micro-optical systems.
URL: http://www-snow.stanford.edu/~levi

Thomas D. O'Sullivan
Admitted to Ph.D. Candidacy: 2006-2007
Research: Design, simulation, fabrication, and characterization of high-sensitivity, low-noise optical sensors and sensor arrays. Integrated VCSEL/filter/detector for biofluorescence and Raman sensing for /in vivo/ imaging and lab-on-a-chip applications. Design and development of bioluminescence-based instruments for genome characterization. Design and fabrication of microfluidic devices.
URL: http://www-snow.stanford.edu/~tdo/

Jun Pan
Admitted to Ph.D. Candidacy: 2004-2005
Research: Stopping light, photonic crystal micro-cavity and waveguide processing and their optical application. Fabrication of two dimensional photonic crystal slab in a silicon on insulator wafer. Study of photonic crystal cavity tuning, its loss and coupling with waveguide. Development of dynamic resonator system for all-optical buffer and coherent storage of light pulse.



Evan Robert Pickett
Admitted to Ph.D. Candidacy: 2003
Research: Characterization of dilute nitride GaAs-based semiconductor alloys and devices by high-resolution x-ray diffraction and transmission electron microscopy. Numerical simulations using TCAD-Sentaurus of solar cells, including III-V cells and novel, nanostructured thin film solar cells in the CuZnSnS and CuInGaSe materials systems.

Zhilong Rao
Graduated Ph.D. 2007
Research: Nano-apertured Vertical-Cavity Surface-Emitting Lasers for Ultrahigh-density Near-field Optical Data Storage**.** This work focuses on applying nano-apertures onto metal-coated emission facet of vertical cavity surface emitting lasers (VCSELs) and utilizing the near-field output spots from the nano-apertures for optical recording and readout. I demonstrated a unique C-shaped nano-aperture VCSEL with a small near-field spot siz and record-high near-field intensity, which is very promising to realize ultradense near-field optical data storage.
URL: http://www.stanford.edu/~zlrao

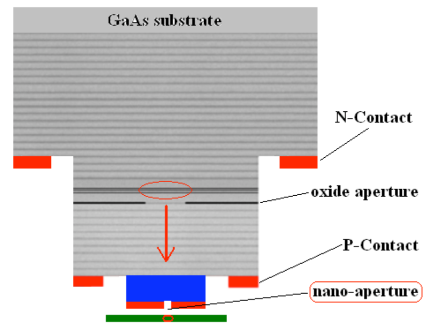


Illustration of Nano-apertured VCSEL

Tomás Sarmiento
Admitted to Ph.D. Candidacy: 2005-2006
Research: MBE growth, fabrication, and testing of edge-emitting GaInNAsSb/GaAs lasers. Investigate the use of different barriers to improve the temperature sensitivity of the lasers.

Barden Shimbo
Admitted to Ph.D. Candidacy: 1992-93
Research: Fabrication of single electron tunneling devices in thin metal films. Research focuses on the use of current-induced local oxidation (CILO) and atomic force microscope oxidation to form lateral oxide tunneling barriers. Recent work has concentrated on the characterization and modeling of low-temperature, gate-controlled transport through irregular arrays of metallic islands embedded in CILO-generated oxides.
URL: http://www-snow.stanford.edu/~shimbo/

Cheng-Han Yang
Admitted to Ph.D. Candidacy: 2005-2006
Research: The growth and characterization of thin film nitrides and oxides for spintronic materials and devices. The part of study involves the sputter deposition and magnetic properties of materials with very low magnetic anisotropy for application in magnetic tunnel junction devices (MTJs). The main research is focused on the properties of thermally evaporated magnesium oxide films and the controlled incorporation of defects into these films. Using oxide MBE growth techniques MgO thin films have been successfully doped by substantial amounts of nitrogen. By the particular post-annealing treatment, the ferromagnetism will be realized in MgO thin films.