NCN Student Research Symposium 2008

May 27, 2008 (10 AM ~ 3:30 PM)
Burton D. Morgan Center for Entrepreneurship MRGN

AGENDA

Time	Speaker	Group	Title
10:00 - 10:15	**Joshua Small**	Prof. Peroulis	Measurements in RF MEMS
10:15 - 10:30	**A. Ehtesham Islam**	Prof. Alam	Trap Formation in CMOS Devices: Characterization, Modeling and Optimization
10:30 - 10:45	**Josh Smith**	Prof. Appenzeller	Silicon Nanowire Tunneling Field Effect Transistors for Low-Power Applications
10:45 - 11:00	**Rajib Rahman**	Prof. Klimeck	Quantum Control of Donor Qubits for a Scalable Quantum Computer Architecture
11:00 - 11:15	**Adina Scott**	Prof. Janes	*In-situ* Vibrational spectroscopy in metal-molecule-silicon devices
11:15 - 11:30	**Pradeep R. Nair**	Prof. Alam	Physics of Nanobiosensors
11:30 - 11:45	**Edward Kinzel**	Prof. Xu	
Lunch Break and Poster Session			
1:30 - 1:45	**Hao Shen**	Prof. Qi	Silicon photonics resonator: microring and its application
1:45 - 2:00	**Ya Zhou**	Prof. Strachan	Thermal Conduction in Metals by Molecular Dynamics
2:00 - 2:15	**Amani Salim**	Prof. Ziaie	Biomolecule Deposition Techniques for Biosensing
2:15 - 2:30	**Muhammad Usman**	Prof. Klimeck	Strain and Electronic Structure Study of Self-Assembled InAs/GaAs Quantum Dots using Multi-million Atomic Simulations --- $sp^3d^5s^*$ Tight Binding Approach
2:30 - 2:45	**Joolien Chee**	Prof. Peroulis	Geometry measurement of packaged MEMS devices
2:45 - 3:00	**Neophytos Neophytou**	Prof. Lundstrom	Nanowire transistors for future technology node transistor devices: Modeling of electronic structure properties
3:00 - 3:15	**Yanqing Wu**	Prof. Ye	III-V MOSFETs with ALD high-k dielectrics
3:15 - 3:30	**Ninad Pimparkar**	Prof. Alam	Device Optimization for Organic Photovoltaics with CNT Networks as Transparent Electrode

ABSTRACTS

Measurements in RF MEMS

Joshua Small (Prof. Peroulis group)

Abstract

Radio Frequency microelectromechanical systems (RF MEMS) is inherently multidisciplinary. Unlike solid state systems where the performance is dominated primarily by electronic mechanisms and geometrical configuration, the performance of MEMS must equally consider effects from several domains: electrical, mechanical, fluidic, chemical, and thermal to name a few. Consequently, it is difficult to exactly model and predict the behavior of these systems. Therefore, RF MEMS engineers depend strongly on properly executed experiments and careful measurement in order to improve devices as well as predict how a device will behave decades from now. This presentation overviews current techniques and experiments used to measure and understand the performance and reliability of RF MEMS.

Trap Formation in CMOS Devices: Characterization, Modeling and Optimization

Ahmad Ehtesham Islam (Prof. Alam group)

Abstract

This work focuses on developing physical principles and characterization techniques for time-dependent trap generation in existing CMOS transistors. We have particularly analyzed Negative Bias Temperature Instability (NBTI), which is one of the major CMOS reliability concerns in recent years. Through systematic analysis, we have developed the functional dependencies of NBTI over time, supply voltage, temperature, materials within the dielectric, and channel strain. Finally, all these understandings have allowed us to explore a truly exciting possibility of the design of a degradation-free transistor technology within CMOS architecture, a possibility – if demonstrated and adopted - may reshape how circuits are designed and evaluated.

Silicon Nanowire Tunneling Field Effect Transistors for Low-Power Applications

Josh Smith (Prof. Appenzeller group)

Abstract

While device dimensions have scaled aggressively over the last few decades, gate voltage has reached a fundamental limit, requiring a minimum of 60mV to change the current through a device by one order of magnitude at room temperature. This has led to a substantial increase in the power consumption of circuits. Lowering the voltage to circumvent this issue in conventional circuits requires a sacrifice in on-state performance as the overdrive must be decreased, which adversely impacts switching. A tunneling architecture with an n-i-p doping profile has been shown to decrease the inverse subthreshold slope well below the fundamental limit of 60mV/dec, owing to the use of one-dimensional channel materials and a doping scheme that permits a non-equilibrium Fermi distribution of the carriers involved in current transport. This allows for both high on-state performance and lower power consumption. While this device structure has been successfully demonstrated in carbon nanotubes, it has not been widely explored in Si. Widespread implementation coupled with its relatively well understood properties make Si a strong candidate for further scaling the voltage requirements using this tunneling concept; however, several experimental obstacles must be overcome to realize this goal. Currently, efforts are aimed at creating intimate contacts to Si nanowires that compliment

the needed doping profile through formation of Er and Pt silicide source/drain contacts, which serve to minimize interface traps and support the n-i-p bandstructure.

Quantum Control of Donor Qubits for a Scalable Quantum Computer Architecture

Rajib Rahman (Prof. Klimeck group)

Abstract

The Phosphorus donor based quantum computer architecture in Silicon has attracted immense attention since Bruce Kane's seminal proposal in 1998 due to its promise of scalability and coherence. The Kane qubit encodes quantum information in the nuclear spin of a Phosphorus impurity, and utilizes hyperfine interaction, Stark and Zeeman effects, as well as exchange interactions to perform qubit operations. Here, we investiagte electric field control (Stark effect) of various quantum mechanical properties of a single donor qubit, and resolve previous discrepancies between theory and experiment. The orbital Stark shift of a single donor close to an oxide interface is also investigated with respect to experiments. In addition, spin-orbit Stark effect as well as hyperfine map of donor wave functions is presented. The results help in detailed understanding of donor Physics which is essential for practical realization of donor qubits.

In-situ vibrational spectroscopy in metal-molecule-silicon devices

Adina Scott (Prof. Janes group)

Abstract

Recently there has been significant interest in incorporating molecular monolayers in electronic devices for sensing, nanoelectronic, energy conversion, and biological applications. Device properties can be modulated using surface chemistry, leading to flexible fabrication schemes and new system functionalities. It is desirable to develop solid-state molecular devices on silicon such as metal-molecule-silicon (MMS) devices, since the processing infrastructure and physical insights that have been developed for traditional integrated circuits can be utilized for such hybrid devices. Key challenges for realizing this technology are the development of fabrication methods that preserve molecular layer integrity and in-situ characterization techniques to probe molecular properties in completed device structures. We present a study of two complimentary vibrational spectroscopic techniques applied to MMS devices. Inelastic electron tunneling spectroscopy (IETS) is a method that probes the influence of vibronic modes on transport through a tunnel barrier. P-polarized backside reflection-absorption infrared spectroscopy (pb-RAIRS) is an optical spectroscopic technique that probes buried interfaces. By combining these two *in-situ* spectroscopic techniques to probe MMS systems, we gain a clearer understanding of the structural properties of the buried molecular layers.

Physics of Nanobiosensors

Pradeep R. Nair (Prof. Alam group)

Abstract

Biotechnology and bio-sensing are often mentioned as the next frontier of electronics that could rival semiconductor industrys broad and revolutionary impact on society. Since any disease is a signature of either a genetic defect or broken signaling pathways that occur far in advance of any overt signature detected by classical sensors, one of the grand challenges of modern bio-sensing is to find cost-effective, reliable, fast methods for gene sequencing (as an ultimate Finger-print of ones biological make-up and possibly early intervention for genetic anomaly) and the detection/identification of the irreducible and emergent protein network for application in

proteomics and system biology. Modern bio-sensors based on nanoscale electrical devices (e.g., Silicon Nanowires, Carbon Nanotubes, etc.) promise highly sensitive, dynamic, label-free, detection of bio-molecules unmatched by existing classical techniques.

Despite significant interest and almost monthly reports of groundbreaking experimental results in leading journals by researchers all over the world, the elements that dictate response of a nanoscale biosensor has remained -- until recently -- poorly understood. Here we describe how the elementary use of fractal geometry of diffusion, percolative transport in random networks, electrolyte screening-limited response, etc. are finally allowing us to establish the performance potential of such sensors. Indeed, our models provide a coherent theoretical interpretation for wide variety of puzzling experimental data that have so far defied intuitive explanation and have important implications for the design and optimization of nanoscale biosensors.

Silicon photonics resonator: microring and its application

Hao Shen (Prof. Qi group)

Abstract

Silicon photonics is developed rapidly now in laser, modulator, switching and filter areas. Here we introduce an ultra compact, high Q filter named microring resonator on silicon on insulator wafer. The system level application of this device in radio frequency arbitraty waveform generation has also been demonstrated.

Thermal Conduction in Metals by Molecular Dynamics

Ya Zhou (Prof. Strachan group)

Abstract

We use non-equilibrium molecular dynamics (MD) to characterize lattice thermal conduction of Al nanostructures and the role of interfaces in metallic nanocomposites. We calculate the lattice thermal conductivity of pure Al samples as well as the overall thermal conductivity and interfacial thermal resistivity (ITR) in Al/Al* (where Al* differs from Al only in its mass) and Al/Ni nanolaminate composites. Simple, additive models in terms of individual component thermal conductivity and ITR are developed to provide good estimates of the overall thermal behavior of the nanocomposites. The ITR of the nanocomposites is observed to be dependent on the direction of the heat flux, which is the first molecular level characterization of such thermal diode behavior in a realistic three dimensional material. We also perform mesodynamics simulations, based on new equations of motion, to describe the thermal role of implicit degrees of freedom in molecular crystals and electrons in metals.

Biomolecule Deposition Techniques for Biosensing

Amani Salim (Prof. Ziaie group)

Abstract

Developments in microelectromechanical systems (MEMS) since the late 1980s have resulted in the batch fabrication of devices such as cantilevers and resonators, which essentially operated using principles of surface stress and microbalance. MEMS have many favorable advantages including ease of integration with electronics for increased sensitivity, comparatively cheap batch fabrication, and the ability for various detection modes. Among the many challenges in cantilever and resonator devices for biosensing applications, is the need for reproducibility in measurements of one device or from one device to another especially in the case of parallel sensing as opposed to traditional sequential sensing. The use of surface chemistries that avoid the nonspecific bindings are important for the reproducibility of measurements and device regeneration. Furthermore, the development of batch patterning techniques to immobilized biomolecules such as antibodies, on the cantilevers/resonators sensing pads which avoid nonspecific binding and breakage of fragile platforms is highly desirable. The techniques for biomolecule (i.e. enzymes, antibodies, proteins) depositions on microfabricated devices such as cantilevers, have not been widely explored, and the common practices have been limited to simply bathing the sensor devices in the biomolecule solution. Biomolecule denaturation during deposition, the inability to control accurately the amount of deposited biomolecules, the unavailability for commercial spotting device, low resolution of patterns produced, and extensive fabrication involved for biomolecule patterning, are some of the drawbacks of the existing biomolecule deposition techniques for cantilever and microresonators based devices. This literature analysis addresses these issues, by first analyzing the specific chemistries that was used to reduce nonspecific bindings. Secondly, analysis is made of the current methods used for biomolecule deposition in MEMS-based devices with focus on cantilever-based ones, and existing biomolecule deposition/patterning techniques. Thirdly, the ability of hydrogel material for controlled and biomolecule delivery on the sensing platforms is introduced. Finally, a biomolecule deposition technique is proposed based on the above stated, and urgent requirements. The proposed solutions are mainly based on improving the microcontact printing technique due to its simplicity and parallel patterning ability. The solution is carried out, by incorporating hydrogels instead of the conventional PDMS material. The intrinsic structural and chemical favorable properties of hydrogels for biomolecule patterning will be briefly discussed. The proposed new technique will take advantage of the material property of hydrogels, most importantly its minimal fabrication requirements and simple construction, while at the same time providing solutions to the technical challenges in biomolecule deposition on cantilever and resonator biosensing platforms.

Strain and Electronic Structure Study of Self-Assembled InAs/GaAs Quantum Dots using Multi-million Atomic Simulations --- $sp^3d^5s^*$ Tight Binding Approach

Muhammad Usman (Prof. Klimeck group)

Abstract

Quantum dots (QDs) are solid-state semiconducting nano-structures that provide confinement of charge carriers (electrons, holes, excitons) in all three spatial dimensions resulting in localized wave functions and discrete energy. Self-assembled quantum dots (SADs), in the Stranski-Krastanov growth mode, nucleate spontaneously within a lattice mismatched material system (for example, InAs grown on GaAs substrate) under the influence of strain in certain physical conditions during molecular beam epitaxy (MBE). Such QDs grown by self-assembly are of particular importance in quantum optics (optical memories, laser applications etc) and quantum computing. We study the strain and electronic structure of such realistically scaled quantum dot systems using an atomistic approach. The strain is calculated using a VFF model and the electronic structure is calculated using $sp^3d^5s^*$ twenty band tight binding model.

Geometry measurement of packaged MEMS devices

Joolien Chee (Prof. Peroulis group)

Abstract

We have developed a novel method to measure planar geometry of packaged MEMS structures. This also allows us to observe changes in geometry of post-fabricated structures with their original layout dimensions. In this Electro-Micro Metrology Measurement Protocol (EMM MP) methodology, capacitance measurements of two or more closely spaced test structures with controlled layout differences are performed. Capacitance resolution of 60aF was achieved during measurement.

Nanowire transistors for future technology node transistor devices: Modeling of electronic structure properties

Neophytos Neophytou (Prof. Lundstrom group)

Abstract

As devices scale towards atomistic sizes, researches in silicon electronic device technology are investigating alternative structures and materials. As predicted by the International Roadmap for Semiconductors, (ITRS), structures will evolve from planar devices into devices that include 3D features, strong channel confinement, strain engineering, and gate all around placement for better electrostatic control on the channel. An alternative device that has been give large attention recently is nanowire (NW) transistors. In this talk, we give a brief description of modeling the electronic structure of NWs through atomistic models and explore their performance.

III-V MOSFETs with ALD high-k dielectrics

Yanqing Wu (Prof. Ye group)

Abstract

Our group's main efforts are on III-V MOSFETs with atomic layer deposited high-k dielectrics, with GaAs, InP, GaN, SiC and InGaAs acting as channel materials, and Al_2O_3,HfO_2, HfAlO as gate dielectrics. Detailed Capacitance-Voltage characteristics and transistor performance are studied. Important parameters like interface trap density and mobility are carefully and systematically evaluated.

Device Optimization for Organic Photovoltaics with CNT Networks as Transparent Electrode

Ninad Pimparkar (Prof. Alam group)

Abstract

Recently, there has been a lot of interest in flexible and high efficiency solar cells due to cost advantages of roll to roll printing. Traditionally, ITO (Indium Tin Oxide) or ZnO (Zinc Oxide) electrodes have been used as top contacts for solar cells because of their reasonable transparency and moderately low sheet resistance. However, these electrodes are not flexible and would undergo breakdown on bending of flexible substrates. Hence, several groups are working on various types of flexible electrodes which have better optical transparency as well as have high electrical conductivity. Among the various options, CNT (Carbon Nanotube) random networks have emerged as a viable alternative to ITO and ZnO, satisfying these constraints and indeed, several types of solar cells have been reported with CNT random networks as back contact. These experimental reports have so far not been complemented by meaningful modeling of CNT networks in solar cells for performance optimization of the solar cell device design. Here, for the first time we present comprehensive simulation results for organic excitonic solar cells with CNT networks as back contact that analyzes all elements of the solar-cell within an end-to-end theoretical framework.