# GMe Forum 2005

## Abstracts of the Invited Presentations

Vienna University of Technology
March 17 and 18, 2005

Society for Micro- and Nanoelectronics
Vienna, 2005

Society for Micro- and Nanoelectronics
c/o Institute of Sensor and Actuator Systems
Vienna University of Technology
Gusshausstrasse 27–29/366
A-1040 Vienna, Austria

## Thursday, March 17, 2005

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|---|---|
| 10:00 – 10:30 | Welcome, Coffee |
| | ***Opening:*** |
| 10:30 – 11:00 | E. GORNIK (President of the GMe) |
| | P. SKALICKY (President of the Vienna University of Technology) |
| | ***Nanoelectromechanical Systems:*** |
| 11:00 – 11.45 | R. BLICK: *From Classical Mechanics to Quantum-Electro-Mechanics* |
| 11:45 – 12:30 | Ch. HIEROLD: *From MEMS to NEMS* |
| 12:30 – 14:00 | Lunch Break |
| | ***Micromachining with Femtosecond Lasers:*** |
| 14:00 – 14:45 | A. ISEMANN: *Micromachining with Femtosecond Lasers* |
| | ***Bioelectronics:*** |
| 14:45 – 15:30 | H.U. DODT: *Bioelectronics and Bioimaging - New Approaches for the Investigation of Brain Microcircuits* |
| 15:30 – 16:00 | Coffee Break |
| | ***Spintronics:*** |
| 16:00 – 16:45 | L. ALFF: *Spintronics: A New Spin for the World of Electronics* |
| | ***Carbon Nanotubes:*** |
| 16:45 – 17:30 | W. HÖNLEIN: *Carbon Nanotubes – A Successor to Silicon Technology?* |
| 17:30 – 17:45 | Break |
| | ***Evening Session:*** |
| 17:45 – 18:00 | E. GORNIK: *Presentation of the Activities of the GMe* |
| 18:00 – 19:00 | Panel Discussion: “*Who supports technology in Austria?*” |

## Friday, March 18, 2005

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|---|---|
| | ***Technology:*** |
| 09:00 – 09:45 | R. MINIXHOFER: *Semiconductor Process Simulation* |
| 09:45 – 10:30 | H. OKORN-SCHMIDT: *Using Extreme Sono-Effects to Improve on the Selectivity of Particle Removal to Microelectronic Structure Damage below 65 nm* |
| 10:30 – 11:00 | A. LUGSTEIN: *Focused Ion Beam Technology* |
| 11:00 – 11:30 | Coffee Break |
| | ***Quantum Devices:*** |
| 11:30 – 12:00 | T. MÜLLER: *Carrier Dynamics at Quantum Dots* |
| | ***Opto-Electronics:*** |
| 12:00 – 12:30 | K. HINGERL**:** *Photonic Crystals: Optical Materials for the 21st Century* |
| 12:30 – 13:00 | G. SPRINGHOLZ**:** *Lead-Salt Lasers* |
| | ***Sensors:*** |
| 13:00 – 13:30 | D. ROCHA: *Sensor Interface Electronics* |
| | ***Poster Exhibition:*** |
| 13:30 | Snacks and Poster Exhibition |

# From Classical Mechanics to Quantum-Electro-Mechanics

**Robert H. Blick**
**Laboratory for Molecular Scale Engineering**
**University of Wisconsin-Madison, Electrical & Computer Engineering**
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Classical Mechanics is what lies at the beginning of the physics curriculum as everyone will recall from numerous textbook questions. The transition to quantum mechanics is traditionally treated by looking into atomic and molecular physics. However, semiconductor processing techniques by now allow to build systems with a mechanical degree of freedom on the micron and nanometer scale. Hence, one can envision to machine systems for studying quantum electro mechanics (QEM).

In terms of applications such nano-electromechanical systems (NEMS) as compared to MEMS on the micron-scale are also found in sensor and communication components. Especially, in communication applications they are valuable additions as switching, filter, and mixer elements. The mechanical resonance frequencies for NEMS are now of the order of 1 – 2 GHz, which makes NEMS-circuits compatible with CMOS. In terms of sensor applications, I want to focus on mass sensing: NEMS implies not only microwave operating frequencies, but in addition NEMS possess extremely small masses. This inherent high sensitivity for mass sensing is of crucial importance for a number of areas such as the ever expanding field of proteomics.

Finally, I will stress the importance of quantum effects analyzed with NEMS. Prominent examples being the interaction of single electrons and single phonon modes and the observation of the Casimir force in such mechanical resonators. Similarly, the mechanical degree of freedom on the nanometer scale can also be used to shuttle single electrons at radio frequencies in a non-stochastic manner. As an outlook, I will present first results on tubular shaped NEMS with an integrated low-dimensional electron gas. Such a topology can induce a geometrical confinement potential for electrons, which can be added to the electro-magnetically induced confinement.

# MEMS and NEMS

**Christopher Hierold**
**Mikro- und Nanosysteme, ETH Zurich**
**Tannenstrasse 3, CH-8092 Zurich, Switzerland**

The presentation is about the impact of scaling on the system performance of mechanical inertia sensors and first activities towards nano mechanical sensors. Permanent cost pressure will result in continuous efforts to integrate more functions into further miniaturized systems. As a consequence microsystems (MEMS) may also incorporate functional nano devices such as carbon nanotubes in the future. Therefore an overview of recent activities for the application of carbon nanotubes with a focus on mechanical sensors is given.

# Micromachining with Femtosecond Lasers

**A. Isemann**
**Femtolasers Produktions GmbH, 1100 Vienna, Austria**

Laser sources have been used for machining for some time now. With conventional continuously emitting or long pulsed laser sources in the nanosecond regime, however, limited precision in the range of some micrometers is possible. The heat deposited in the material during the absorption also makes the machining of delicate materials impossible. The shockwaves associated with the absorption of the pulse may also cause damage.

The mechanism of the ablation changes drastically when going from the nanosecond to the femtosecond pulse duration regime. Some background of the mechanism of the essentially cold ablation is given, explaining how the fascinating precise results have become possible. The difference in the mechanism for metals and dielectrics will be explained. Since with short pulses, less energy is needed for ablation than with long pulses, also the shock waves are reduced.

Among other things, shape memory alloys, delicate polymers and structured thin films will be shown as well as results from two photon polymerization

Also, using ultrashort pulses, it has become possible to create structure sizes below the diffraction limit of the beam, which is in the range of one micrometer for a laser operating in the near infrared region. By operating the laser close to the ablation threshold, only the central part of the beam initiates ablation, which is thus below the diffraction limit.

Machined samples will be shown providing some insight into possibilities of processing with ultrashort pulses.

Up to now, amplified femtosecond laser systems were necessary to do micro machining. A roadmap of possible developments is laid out and discussed. A new category of oscillator is introduced filling the gap of conventional oscillators and amplified systems to address the needs of micromachining. First experimental results of machined samples with this oscillator will be shown.

# Bioelectronics and Bioimaging - New Approaches for the Investigation of Brain Microcircuits

**H.-U. Dodt**
**Max-Planck-Institute of Psychiatry, D-80804 Munich, Germany**

Bioelectronics and bioimaging are new approaches for the investigation of the brain and its microcircuits. They complement each other, as bioelectronics investigates the function, whereas bioimaging is mainly concerned with the morphology of the brain. For the study of neuronal microcircuits, neurons in rather opaque brain slices have to be visualized. This allows the recording of the electrical potentials of these neurons with microelectrodes. The development of the necessary optical techniques will be described. By using these techniques, electrophysiological phenomena, which may be the basis of information storage in the brain, could be studied. A new approach for nonlinear correlation analysis revealed unknown synchronization phenomena between nerve cells, which can lead to the generation of epilepsy.

The wiring of neurons in neuronal networks could be investigated by laser stimulation of single neurons. We found that the connectivity in neuronal networks is dependent on external information input. To visualize neurons in the intact brain we started to inject quantum dots into nerve cells and detect them by their fluorescence. This approach offers new perspectives for the visualization of neurons in the intact brain.

A technique was developed to visualize brain microcircuits in 3-D with high resolution which renders fixed mouse brains by chemical means completely transparent. The method was combined with a new kind of microscopy. With this combination the neuronal network could be visualized with cellular resolution.

The results from these different approaches should help to understand the microcircuits of the brain and may ultimately allow the implementation of the underlying principles in technical solutions.

# Spintronics: A New Spin for the World of Electronics

**Lambert Alff**
**Institute of Sensor and Actuator Systems, Applied Electronic Materials**
**Vienna University of Technology, A-1040 Vienna, Austria**

Electronic applications are based on the properties of electrons in solid bodies. While currently employed devices operate with the positive or negative charge of electrons, the spin of electrons has been neglected so far. The use of this purely quantum mechanical degree of freedom might be the next development of modern electronics: spintronics. What are the basic principles of spintronics, what are the advantages compared to conventional electronics? Which progress has already been made in the field, which problems are ahead? One focus of the talk will be the development of suited new materials for spintronics.

# Carbon Nanotubes - A Successor to Silicon Technology?

**W. Hoenlein, F. Kreupl, G.S. Duesberg, A.P. Graham, M. Liebau, W. Pamler, R. Seidel, E. Unger**
**Infineon Technologies AG, Corporate Research, D-81730 Munich, Germany**

Carbon nanotubes (CNTs) exhibit a number of interesting properties that make them viable candidates for applications in microelectronics. In particular, the availability of both metallic and semiconducting species for transistors and interconnects, respectively, means that the most important building blocks of microelectronics are accessible. However, silicon technology has set some definite conditions for large scale integration and manufacturing that have to be satisfied by any competing technology: Devices must be adequate for integration, a large number of devices must be fabricated at the same time, downscaling of lateral dimensions must be feasible, and modular processing must be possible at yields close to 100% for each individual processing step. In this paper state-of-the-art carbon nanotube production and placement procedures will be assessed with respect to these requirements. The first application result for interconnects will be presented that involves the replacement of metal via plugs between two conductive layers by carbon nanotubes. Likewise, semiconducting single-walled carbon nanotube field effect transistors will be compared to advanced silicon MOSFETs. The scaling of lateral dimensions is the most successful principle in microelectronics. We will also address the scalability of one dimensional CNT devices and show recent experimental results of very short CNTFETs. Finally, a stand alone CNT power device is presented that is produced with state-of-the-art deposition techniques and is capable of driving LEDs and small motors.

# Semiconductor Process Simulation

**Rainer Minixhofer**
**austriamicrosystems AG, A-8141 Unterpremstätten, Austria**

Semiconductor technology and industry has enormously advanced in the past decades. Starting from a plastic triangle, a slab of germanium, some gold foil and gold contacts (the first bipolar transistor in 1947), as of 2004 the typical transistor density per circuit is around 140 million transistors/$cm^2$ for micro processor applications, doubling every year.

Semiconductor industry is the main driving force for technology innovation and “New Economy” markets. The ongoing development of faster integrated circuits with higher device density has led to highly complex and sophisticated products which are widely accepted by the society. A modern integrated circuit cannot be developed without the massive use of computer aided design (CAD) in any step of the complex flow from the idea to the final product. This presentation concentrates on technology computer aided design (TCAD) and its use for the simulation of the semiconductor fabrication process flow.

Semiconductor process simulation aims to model the physical systems of single semiconductor fabrication steps and their sequence which form the overall process flow. This task implies the modeling of the single process steps with differential equations and solving them on mesh-grids, which represent a cross-section through the interesting area of the integrated circuit.

The final outcome is the topography of the overall structure (boundary of the cross-section consisting of different materials) and the doping distribution inside the semiconducting materials. This information can be used to model the electrical behavior of the structure in a subsequent device simulation step. Since the physical structure and the doping concentrations can be hardly obtained by experiments, process simulation gains even more value at nanometer scale process technologies.

This presentation aims to describe some aspects of the implementation of process simulators. Furthermore the benefits of process modeling are shown with a couple of examples.

# Using Extreme Sono-Effects to Improve on the Selectivity of Particle Removal to Microelectronic Structure Damage below 65 nm

**Harald F. Okorn-Schmidt et al.**
**SEZ Research Centers, A-9500 Villach, Austria**

Development work for the next generation of microelectronic devices, 65 and especially 45 nm, is under full steam, and major challenges for 32 nm and beyond are being tackled one-by-one by scientists and engineers working in pre-development, corporate and academic research centers. It seems that the red brick wall painted a couple years ago has become a little porous again as novel, sensitive substrates and materials finally find themselves being implemented or are close to introduction in the manufacturing process, e.g. strained silicon, high-k dielectrics, new silicides or maybe even metal gates. The excitement related to this seemingly everlasting move towards the ultimate nano-structured device however should not let us forget to explore in detail and understand the added process complexity and especially the increased requirements for contamination control and surface preparation.

In this presentation one major challenge microelectronic device manufacturers are facing will be especially highlighted: selective removal of nm sized particles without damage to equally or just slightly larger device structures. A novel approach to understand and improve on “physically assisted” chemical cleaning will be discussed.

# Focused Ion Beam Technology

**A. Lugstein, E. Bertagnolli**
**Institute of Solid State Electronics**
**Vienna University of Technology, A-1040 Vienna, Austria**

Nanoscale structuring opportunities are prerequisites for any nanoscale engineering. In particular, resist-less focused ion beam techniques are most suited for the combination of top-down structuring with selective bottom-up self-assembling techniques. To keep up with the trend of structures to shrink in dimensions, the response of ion induced material modifications will have to be controlled on a nanometer scale. A prerequisite thereof is a deep understanding of the ion beam interaction with the processed substrate material.

We demonstrate surface modifications caused by focused ion beam irradiation, addressing the primary mechanisms leading to material swelling, amorphization and preferential etching. In detail we have studied the impact of shrinking feature sizes on the sputter efficiency of focused ion beams for Si, InAs, GaAs, GaP, GaSb surfaces by in-situ FIB-SEM combined with XRD, AFM and high resolution AES. We completed these many-facetted experimental studies with the morphological study of the FIB exposed surface subjected to RTA by optical microscopy, AFM, and electrical measurements. Based on our experimental results, a sputter yield promoting self-focusing effect combined with a sputter rate increase at oblique angles, an opposing dose deficiency effect and material re-deposition for milling aspect ratios >1 are identified to be responsible for the complex sputter response of Si and GaAs.

Further we present a new approach for the generation of metallic nano patterns, which in contrast to conventional bottom up or top down processes is based on a subtractive self organization process relying on material decomposition induced by FIB exposure. Nanometer sized Ga droplets can be formed in a size and position controlled fashion on GaAs. The diameters of the dots range from 60 to 2000 nm. Two dimensional ordered arrays of embedded as well as freestanding Ga dots were fabricated by a site control technique relying on preformed craters and an irradiation mediated migration and agglomeration. The formation of these dots is discussed in terms of selective etching of arsenic due to the local energy injection by the gallium ions and further minimization of the excess free energy of the surfaces.

Further we have shown that FIB bombardment of InAs produces indium crystallites, and the size of the crystallites increases with ion dose and ranges from 80 nm to 1.5 μm. The influence of the ion dose, the beam energy, the sample temperature and the dose rate on the surface evolution has been investigated for further III/V compound semiconductors by atomic force microscopy, scanning electron microscopy, auger electron spectroscopy and X-ray diffraction measurements.

In summary, the surface topography resulting from FIB bombardment is being investigated for possible use in nano-technology applications. This technique, based on a subtractive self organization process, may lead to a new fabrication process for three dimensional metallic nanostructures.

# Carrier Dynamics in Quantum Dots

**T. Müller, F.F. Schrey, G. Fasching, G. Strasser, and K. Unterrainer**
**Institute for Photonics and Centre of Micro- and Nanostructures**
**Vienna University of Technology, A-1040 Vienna, Austria**

The dynamics of carriers in semiconductor quantum dots (QDs) has attracted much attention because of their physical interest and their important implications on the performance of novel optoelectronic devices. Most of the experiments have been performed by interband spectroscopy, where the signal reflects the combined electron-hole dynamics. In this contribution we report an interband pump-intraband probe experiment which is sensitive to the capture and relaxation of electrons only.

For the time-resolved measurements of the intraband transitions we use a mode-locked Ti:sapphire laser that delivers 12 fs pulses (780 nm wavelength). One part of the laser intensity serves as an interband pump to inject electrons and holes. The other part is used to generate tunable (70 – 155 meV) infrared probe pulses by phase-matched difference frequency mixing in a GaSe crystal [1].

After excitation the photoexcited electrons relax very fast into the InAs wetting layer, and from the IR absorption at different probe energies the QD level populations can be determined. From our measurements we find that the QD ground state e1 gets populated via the excited state e2 because the electrons leave e2 with the same time constant as they arrive in e1. The excitation density dependence of the capture time exhibits two regimes: At room-temperature it decreases from about 2.7 ps down to 1.5 ps with increasing excitation density above a certain threshold and it changes only slightly at low excitation densities. The high-power dependence can be explained by electron-electron scattering processes. When measuring the temperature-dependence of the capture time we find an increase to about 4.8 ps upon decreasing the temperature to 5 K. Possible explanations for the observed short capture times could be that electrons scatter between subsequent QD states via repeated emission of two LO-phonons [2]. Consequences for devices based on electronic interlevel transitions will be discussed.

[1] T. Müller, R. Bratschitsch, G. Strasser, K. Unterrainer, Appl. Phys. Lett. 79, 2755 (2001).

[2] T. Müller, F.F. Schrey, G. Strasser, and K. Unterrainer, Appl. Phys. Lett., 83, 3572 (2003).

# Photonic Crystals: Optical Materials for the 21st Century

**Kurt Hingerl**
**Institute for Semiconductor and Solid State Physics,**
**Christian Doppler Laboratory for Surface Optics**
**Johannes Kepler University, A-4040 Linz, Austria**

Progress in photonics is closely connected to development of optical materials which allow controlling the flow of light. Photonic Crystals represent a novel class of materials which elevates the concept of steering of light to a new level: A spatially periodic varying index of refraction leads to the formation of a photonic bandstructure that may exhibit ranges of frequencies for which ordinary propagation of electromagnetic radiation is forbidden. As a consequence, these artificial materials profoundly influence the propagation characteristics of light as well as the radiation dynamics of optically active materials embedded in Photonic Crystals.

In this talk I will introduce the basic physical concepts of Photonic Crystals. This will be followed by a discussion of some of the most promising fabrication techniques of these materials. Based on this, I will give illustrative examples of both experimental and theoretical characterizations of Photonic Crystals. Finally, I will discuss selected applications of Photonic Crystals from the fields of integrated photonics and also highlight possibilities to localize light in nonperiodic systems. Especially it is shown that adhering to some restrictions in the acceptable lattice transformations one can achieve omni-directional photonic bandgaps for an entire sub-class of such structures. We demonstrate, designing an efficient arbitrary-angle waveguide bend, that curvilinear-lattice photonic crystals can be employed for the creation of original types of nano-photonic devices.

# Lead-Salt Lasers

**G. Springholz**
**Institute for Semiconductor and Solid State Physics**
**Johannes Kepler University, A-4040 Linz, Austria**

# Sensor Interface Electronics

**Daniel Rocha**
**Institute of Sensor and Actuator Systems**
**Vienna University of Technology, A-1040 Vienna, Austria**

The importance of tailored electronic readout circuits in biosensing applications has in the past often been neglected. In this contribution we demonstrate the relevance of the issue considering two practical examples involving closely coupled co-designs of micro- and nano-systems.

The first example involves the electronic read-out of signals in living cells. Cells communicate via ion-channels in cell membranes. These play crucial roles in physiology and pathophysiology as they are important drug targets. Microelectrode-based electrophysiological techniques which access the interior of a cell and can directly measure the minute currents through these channels have been employed in the past for the study of ion-channels. The most successful of these techniques and the current golden standard is the patch-clamp technique. The quality of the data produced by currently employed on-chip patch-clamp systems is however not yet high enough to resolve single ion-channel currents in a repeatable manner, this being even more so when envisioning the study of engineered bilipid membranes with singular implanted ion channels.

One of the most important features for high quality single ion-channel recordings is a good seal between the intra and extracellular measurement chambers. Any current path having a conductance comparable to a single ion channel's conductance (1 – 150 pS) would generate an excessive amount of noise and lead to it being impossible to discern the minute signal current flowing through the ion channel from the noise generated by the leakage conductance. We are currently working on improving the seal impedance by one order of magnitude when compared to traditional on-chip patch-clamp measurement setups so as to reach seal resistances in the order of 100 GΩ. The design is based on the employment of a biomimetic interface based on S-layer proteins. In the quest towards studying singular ion-channels artificially implanted into engineered patches having widths and lengths in the range of a few hundred nanometers, the need arises for optimal interfacing between the biosensor and the readout electronics. An amplifier designed for optimal noise performance in single-ion channel current measurements is presented here.

The second example relates to the label-free detection of biomolecules in immunological testing technology. Traditionally this technology has been mostly based on fluorescently labeled samples. The costs involved in labeling the biological samples are however significant and recent interest has arisen for label-free, electrical detection of the biochemical binding. Label-free capacitive affinity biosensors are based on the principle that the target molecules to be detected will bind to a thin receptor layer (e.g. antibodies) attached to an interdigitated electrode. Upon binding, changes in dielectrical properties of the medium in the immediate neighborhood of the electrode are detected by impedance spectroscopy.