# GMe Forum 2012

## Abstracts of the Invited Presentations

Vienna University of Technology
March 29 and 30, 2012

Society for Micro- and Nanoelectronics
Vienna, 2012

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 29, 2012

| | |
|---|---|
| 10:00 – 10:30 | Welcome, Coffee |
| 10:30 – 11:00 | Opening |
| 11:00 – 12:00 | **Keynote:** E. MONROY (CEA/INAC Grenoble): *GaN Quantum Devices for Infrared Optoelectronics* |
| | ***Optoelectronics:*** |
| 12:00 – 12:45 | A.M. ANDREWS (TU Vienna): *InGaAs/GaAsSb Quantum Cascade Lasers* |
| 12:45 – 14:00 | Lunch Break |
| 14:00 – 14:45 | J. WÖLLENSTEIN (IMTEK Freiburg): *MEMS Based Thermal IR Emitters* |
| | ***Sensors:*** |
| 14:45 – 15:30 | E. PEINER (TU Braunschweig): *Cantilever Sensors for Micro- / Nanometrology* |
| 15:30 – 16:30 | Poster Session & Coffee Break |
| | ***Advanced Devices from New Materials:*** |
| 16:30 – 17:15 | C. OSTERMAIER (Infineon Villach): *Gallium Nitride Power Devices* |

## Friday, March 30, 2012

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|---|---|
| | ***Advanced Devices from New Materials:*** |
| 09:30 – 10:15 | F. SCHÄFFLER (JKU Linz): *Structural and Optical Properties of SiGe Structures* |
| | ***Technology and Reliability:*** |
| 10:15 – 11:00 | J. FAUL (Globalfoundries Dresden): *Advanced Technology Nodes for Foundry Applications* |
| 11:00 – 11:30 | Coffee Break |
| 11:30 – 12:15 | T. GRASSER (TU Vienna): *Reliability of Modern CMOS Devices* |
| 12:15 – 13:00 | M. SCHREMS (austriamicrosystems): *(3D) Sensor Integration and its Strategic Importance for Europe* |

# GaN Quantum Devices for Infrared Optoelectronics

**Eva Monroy**

*CEA-Grenoble, INAC / SP2M / NPSC, Grenoble, France*

Intersubband (ISB) devices rely on electronic transitions between quantum confined states, so that the desired wavelength of operation can be tuned via band engineering of semiconductor nanostructures. The capabilities of the ISB technology has been demonstrated in the mid-IR and far-IR spectral region using As-based materials like GaAs/AlGaAs and InGaAs/AlInAs-InP. The extension of ISB optoelectronics towards the near-infrared range is interesting for the development of ultrafast photonic devices for optical telecommunication networks, as well as for the implementation of a new variety of chemical and biological sensors. The GaN/Al(Ga)N system is an excellent candidate for this application thanks to the large conduction band offset (about 1.8 eV for GaN/AlN) and subpicosecond ISB relaxation time. In addition, the remote lateral valleys lie high in energy (> 2 eV above the Γ valley) which is key to achieve lasing action. In this talk, we will present the latest achievements in terms of growth and characterization of GaN/Al(Ga)N ISB devices (quantum cascade detectors, modulators, light emitters) operating in the near infrared.

On the other hand, there is an interest to push the operation of ISB nitride devices to longer wavelengths, in particular to the THz frequency range. The interest of this spectral region for applications like security screening, quality control or medical diagnostics has driven extensive efforts to develop optoelectronics components. In this field, the large GaN LO-phonon energy (about three times that one of GaAs) opens prospects for ISB lasers and detectors operating at room temperature, and at infrared wavelengths inaccessible to other III-V semiconductors due to Reststrahlen absorption. We have experimentally demonstrated that the mid-infrared domain can be covered by GaN/AlGaN with proper quantum well design, and step-quantum-well superlattices make it possible to reach the far infrared. However, the extension of this technology towards these longer wavelengths requires a reduction of the polarization-induced internal electric field intrinsic to nitride heterostructures, which sets new material and design challenges.

# InGaAs/GaAsSb Quantum Cascade Lasers

**Aaron Maxwell Andrews,**
**M. Nobile, Ch. Deutsch, H. Detz, T. Zederbauer, W. Schrenk, K. Unterrainer, and G. Strasser**

*Institute for Solid-State Electronics, Center for Micro- and Nanostructures, and Photonics Institute, Vienna University of Technology, 1040 Wien, Austria*

Quantum cascade lasers (QCLs) utilize intersubband (ISB) transitions to produce coherent light in the mid-infrared (MIR) and terahertz (THz) spectral regions, 3 – 300 µm. Each cascade cell is a sequence of quantum wells and barriers, engineering an upper and lower laser level, where electrons can relax in a radiative transition. The unipolar nature of the QCL allows great creativity and flexibility in the active region and waveguide design.

The InGaAs/GaAsSb material system, lattice-matched to InP, is an excellent candidate to replace the commonly used GaAs/AlGaAs material system for both MIR and THz lasers and detectors. This material system has the potential to improve ISB devices by the elimination of aluminum from the barriers, reducing the electron effective mass and Al-oxide from the exposed surfaces, therefore simplifying subsequent post processing and/or regrowth. The low effective mass for electrons leads to a spreading of the electron wave function and a higher optical matrix element and thus improved laser gain. The InP substrate is ideal for dielectric waveguiding in the MIR and for substrate lift off in THz double-metal waveguides.

We present recent progress in the design, growth, and fabrication of MIR and THz QCLs from the InGaAs/GaAsSb material system.

# MEMS Based Thermal IR Emitters

**Jürgen Wöllenstein**

*IMTEK - Institut für Mikrosystemtechnik, Freiburg, Germany*

A novel micromachined thermal emitter for fast transient temperature operation is presented. Compared to most commercially available thermal emitters, the one here presented is able to operate in a pulsed mode. This allows the use of lock-in techniques or pyrodetectors in the data acquisition without the use of an optical chopper for light modulation. Therefore, these types of thermal emitters are very important for small filter photometers. Several spider type hotplate concepts were studied in order to find a design with excellent mechanical stability and high thermal decoupling. The thermal emitters are fabricated using silicon on insulator (SOI) technology and KOH-etching. The emitters are heated with Pt-meanders. For temperature determination an additional Pt-structure is deposited onto the hotplates. The emitters are mounted in TO-5 housings using a ceramic adhesive and gold wire bonding. The used operation temperature is 750 °C. In pulsed operation it is important to have a large modulation depth in terms of thermal radiation intensity in the needed spectral range. The maximal reachable modulation depth ranges from ambient temperature to steady state temperature. A modulation frequency of 5 Hz still allows using nearly the maximum modulation depth.

# Cantilever Sensors for Micro-/Nanometrology

**Erwin Peiner**

*Institute of Semiconductor Technology, TU Braunschweig, University of Technology*

Micro- and nanoelectromechanical (M/NEMS) cantilever sensors have been rapidly emerging over the past two decades as the key components for various probing and sensing applications including scanning probe microscopy at atomic resolution and trace-level bio/chemical molecule detection. Meanwhile cantilevers were integrated in thousands of single elements as probes for data storage systems, e.g. IBM's "millipede" and as sensors, e.g., Caltech's high-density NEMS cantilever array of 6 million cantilevers per square cm.

While highest sensing resolution under stabilized clean room settings or even vacuum is often the motivation of ongoing research and development with cantilevers, the main focus of this contribution is on cantilever-based metrological tools and methods operated under the rough conditions of normal workplace environment. Self-sensing cantilevers with integrated probing tip will be described which have been designed for high-speed form and roughness evaluation of high-aspect-ratio micro-/nanoscale components and systems, e.g. diesel injector nozzle spray holes. Diamond-like carbon will be addressed as an inert, wear resistant MEMS material suitable for cantilevers and strain gauges. Cantilever force standards will be described for on-the-spot calibration of micro pipettes designed to apply mechanical micro-to-nanonewton forces to immobilized isolated mouse heart muscle cells and to convert their response into biochemical signals. Resonant operation of high-$Q$ silicon cantilevers will be described for phase transition detection in ultra-thin films. The shift of a cantilever's resonance frequency induced by the mass of nanoparticles attached to the cantilever's surface will be proposed as a method to monitor personal exposure to engineered airborne nanoparticles at workplaces. Silver sintering will be described for high-temperature-stable cantilever die attach. Construction, design, and fabrication of robust self-sensing cantilever sensors will be covered as well as performance test and evaluation regarding the users' target specifications.

# Gallium Nitride Power Devices – Next Generation of Energy Efficiency

**Clemens Ostermaier**

*Infineon Technologies Austria AG*

For the last two decades, significant and rapid advances in the growth and technology of III-N related semiconductors have yielded exciting performance for optical and electronic devices. Laser diodes from green to ultra-violet and light-emitting diodes based on gallium nitride and related wide band materials are already in mass production. Electron devices have shown outstanding results by high electron mobility transistors (HEMTs) utilizing the strong polarization from the group III-nitride wurzite crystal structure. The excellent electronic properties such as high electric field strength due to the large bandgap, high saturation and overshoot electron velocity, and good thermal conductivity, make GaN-based transistors ideal for high power, high speed, and high temperature applications even in harsh environments. In order to improve the efficiency, circuit design and safety of today's power amplifiers and converters, HEMTs with high current density, low on-state resistance, high breakdown voltage, low capacitances, operation in enhancement mode (E-mode, normally-off), and reliable surface passivation to minimize electron trapping are highly desired.

We will discuss the basic concepts of GaN high electron mobility transistors in comparison to the existing silicon-based technologies and its relevance for power devices. Beside the apparent advantage in the $R_{DSon}$ for comparable breakdown voltages, GaN HEMTs benefit further from the high electron mobility in the channel reducing gate charges and hence switching losses. However, even though the GaN is winning in figure-of-merits, its industrialization has been strongly triggered by the implementation of III-N epitaxial layers directly grown on economical silicon substrate with the possibility to go even up to 12 inch wafer diameter. The column-like growth on this highly lattice-mismatched substrate however leads to defect densities in the order of $10^9$ $cm^{-2}$ causing strong impact on the device breakdown, leakage currents, and reliability. Beside the long-term stability issues which are often reported along with defect creation in the material, several short-term trapping mechanisms have been identified which drastically reduce the benefits of this material system. Trapping of charges on the surface above the horizontal drift region is known to cause a dynamic increase of the $R_{DSon}$ in dependence of the applied electric fields. In a similar manner, the imperfect interface between the gate insulator and the III-N material can cause static drifts of the gate threshold voltage. Thus high efforts have to be done in order to achieve the same level of quality, performance, reliability and manufacturability as of silicon-based devices and still exploit the full potential of the III-N material system.

# Structural and Optical Properties of SiGe Structures

**Friedrich Schäffler**

*Institut für Halbleiter- und Festkörperphysik, Johannes Kepler Universität Linz*

At around 2003 the so-called *power crisis of the Si chip industry* brought Moore's law very close to a halt. Then, Intel saved it by introducing SiGe into their devices as a Si-compatible material for strain engineering. The concomitant mobility enhancement allowed them to compensate for the inadequate gate oxide thickness, which had by then reached its scalability limit. With that step SiGe had reached main stream Si technology in a much broader sense than through the earlier introduction of the SiGe heterobipolar transistor in the 1990ies.

In this contribution the structural and optical properties of SiGe epilayers will be discussed, with special emphasis on seeded growth and self-organization. In this way, SiGe quantum dots are created, which are expected to have a wide application potential. Examples reach from strain-engineered field effect transistors (so-called Dot-FETs) to enhanced light emission caused by zero-dimensional carrier confinement. Alternative materials involving other group-IV elements (C, Sn) will be discussed as a potential way to create direct gap semiconductors compatible with standard Si technologies that might finally lead to an efficient, Si-based light source.

# Advanced Technology Nodes for Foundry Applications

**Jürgen Faul and Manfred Horstmann**

*Globalfoundries Dresden, Wilschdorfer Landstraße 101, D-01109 Dresden*

Leading edge foundries need to fulfill a wide range of customer needs and have to deliver state-of-the-art performance processes. Therefore, an innovative but flexible modular technology set up is essential. From a leading edge foundry perspective this presentation will show the most recent technology trends as well as an outlook towards 20 nm and beyond.

In the beginning of the talk GlobalFoundries and its technology portfolio is briefly introduced, followed by some general process technology trends. After that some details of current GlobalFoundries technology nodes in 32 and 28 nm ground rules follows. Focus here is the review of high-k metal gate and strained silicon process details and properties. Also, some key figures of the 28 nm technology platform are discussed in that part. Process tailoring to accommodate high performance and low standby power applications on one node is sketched.

At the end of the presentation an outlook on further device scaling is shown from a leading edge foundry´s perspective. To begin with recent transistor trends are discussed briefly, followed by some challenges of the 20 nm technology. For this node technology will be pushed to its limits. Therefore, upcoming nodes will require substantial innovations in both, technology and materials.

# Reliability of Modern CMOS Devices

**Tibor Grasser**

*Institute for Microelectronics, TU Wien*

As a consequence of the breath-taking developments in semiconductor device technology, the thickness of some material layers has been reduced down to a few atomic layers. This concerns in particular the insulating layer used in MOSFETs to exert electrostatic control over the channel via the gate. As such thin insulating layers give rise to large tunneling currents, which cause unacceptable power dissipation, various alternative oxide materials with larger permittivity have been recently introduced to replace the conventional $SiO_2$, allowing for physically thicker layers without loss of channel control. However, in terms of material quality, ease of fabrication, and quality of the channel/insulator interface, the material system $Si/SiO_2$ is unsurpassed, and any alternative material introduces a considerable amount of difficulties, both in terms of fabrication as well as in long term reliability. The consequence of the latter issue is insofar dramatic as not even the reliability of the traditional $Si/SiO_2$ system has been completely understood so far.

Since new technological options are introduced rapidly, it is impossible to explore their reliability performance on a similar level as it has been possible for the conventional $Si/SiO_2$ system. On the other hand, the trend to short product cycles will be more and more counterbalanced by the exponential growth of the costs involved in the fabrication facilities, resulting in the need for longer device lifetimes. Both issues cause reliability to be at the forefront of the concerns of semiconductor industry. The fundamental problem with reliability assessment is that it is economically impossible to simply operate a device or circuit for, say, 10 years to see if it remains functional. It is therefore inherently required to accelerate the degradation process by increasing the stress level. Then, this accelerated degradation has to be extrapolated back onto real operating conditions using some sort of model. Despite many decades of research, currently available reliability models are incomplete and contradictory and differ in their predictions quite often by orders of magnitude. However, miscalculated reliability margins can be disastrous, leading to product recalls and fatal accidents. Recent modeling progress in this field will be summarized with a particular focus on the elusive bias temperature instability.

# (3D) Sensor Integration and its Strategic Importance for Europe

**Martin Schrems**

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16% of the global economy depends from semiconductors and this trend will further increase in the future. Cost reduction, increasing functionality and performance of “smarter systems” continuously drive integration and miniaturization. Integration of sensors such as optical-, magnetic-, chemical- or MEMS into microelectronic systems to enable interaction of miniaturized systems with the environment has become a market reality based on recent advances in semiconductor design and manufacturing technologies. The more well-established path of systems integration is formation of “System on Chip” driven by CMOS scaling and the integration of add-on technology modules. 3D Heterogenous System Integration by stacking of chips using Through Silicon Vias and Wafer Level Packaging has emerged as an additional systems integration path. Based on practical examples from collaborative European R&D projects, market data and technology trends the presentation will try to highlight opportunities for Europe based on R&D strengths and that part of the semiconductor manufacturing sector that has so far remained in Europe. The inter-dependence of semiconductor manufacturing with circuit and systems design will be studied. Application examples for integrated microelectronic systems will include optical sensors enabling energy efficiency, magnetic sensors for motor control and robotics, automotive integrated systems for harsh environments, as well as sensors for industrial, medical and consumer applications including mobile handsets both at R&D and manufacturing stage. It will be found that systems knowledge is increasingly embedded into semiconductor manufacturing especially for Heterogenous Integration. Therefore the erosion of the EU semiconductor manufacturing base is an alarming trend, while existing EU R&D programs in combination with improved framework conditions offer an opportunity for the EU to maintain its microelectronics and thus its systems competence.