Seminar

# Aktuelle Entwicklungen der Mikroelektronik

(Current Developments of Microelectronics)

# Abstracts

Bad Hofgastein/Salzburg
3. – 6. März 1999

Mittwoch, 3. März 1999 – Donnerstag, 4. März 1999
Themenkreis: HF-Systeme

Donnerstag, 4. März 1999 – Freitag, 5. März 1999
Themenkreis: Optoelektronik

Freitag, 5. März 1999 – Samstag, 6. März 1999
Themenkreis: HF-Bauelemente

# HF-Systeme

Mittwoch, 3. März 1999 – Donnerstag, 4. März 1999

## Mittwoch, 3. März 1999 – Donnerstag, 4. März 1999
## HF-Systeme

| Mi., 3.3.1999 | |
|---|---|
| 17:00 – 18:00 | Karl-Reinhard SCHÖN, Siemens München<br>*HF-Technologie- und Schaltungskonzepte für Mobilfunkanwendungen* |
| 18:00 – 19:00 | Franco MALOBERTI, Pavia University<br>*High Speed Data Converters and New Telecommunication Needs* |
| 19:00 – 19:15 | Pause |
| 19:15 – 20:15 | Erich PFAFFELMAYER, Frequentis Nachrichtentechnik Ges.m.b.H., Wien<br>*Sicherheitsrelevante Systeme in der Flugsicherung* |
| Do., 4.3.1999 | |
| 09:00 – 09:30 | Nikolaus KERÖ, TU Wien,<br>*ASIC-Design-Zentren an österreichischen Universitäten*<br>*(A Survey of ASIC Design Centers at Austrian Universities)* |
| 09:30 – 10:00 | Hartwig W. THIM, Johannes Kepler Universität Linz<br>*MMIC-Forschung und -Entwicklung an österreichischen Universitäten*<br>*(A Ka-Band Detector Diode with High Sensitivity)* |
| 10:00 – 10:30 | Kaffee |
| 10:30 – 10:50 | Hans LEOPOLD et al., TU Graz<br>*Ein Zeit-zu-Spannungs-Umsetzer für genaue Laufzeitmessungen*<br>*(A Time-to-Voltage Converter for Accurate Measurements of Travel Time)* |
| 10:50 – 11:10 | Christoph FÜRBÖCK et al., TU Wien<br>*Laserprobing zur internen Charakterisierung von IG-Bipolar-Transistoren*<br>*(Internal Characterization of IGBTs Using the Backside Laserprobing Technique)* |
| 11:10 – 11:30 | Rainer FASCHING et al., TU Wien<br>*Eine neue Technologie für den Zusammenbau von ASICs and MEMS*<br>*(A Novel Technology for the Assembling of ASIC´s and MEMS)* |

# HF-Technologie- und Schaltungskonzepte für Mobilfunkanwendungen

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Mobile radio communication is of rapidly increasing importance. Production numbers of mobile phones double within two years. New fields of application arise like RKE (remote keyless entry) or LPS (local positioning system, i.e. ID tags). Size and weight of the devices decline together with prices.

To get this, strong requirements must be fulfilled by semiconductor technologies and software algorithms.

In the following I will focus on technology and circuit design aspects.

Reducing device size and costs needs primarily higher integration. This can be done in two ways.

The first way is to take as many external discretes like inductors, capacitances, varactors, and resistors as possible into the IC's, i.e. to realize fully integrated VCO's. For that the semiconductor technologies must be able to realize these devices with sufficiently high performance. Since integrated devices basically have larger tolerances, higher temperature or voltage coefficients than optimized discrete elements, the performance of the active devices has to be increased to compensate this disadvantage. On the other hand, much effort has to be made to improve the properties of passive device, in particular the integrated inductors.

The second way is to combine more IC's on one chip. This can be done by integrating a complete RF front-end with receiver, transmitter and synthesizer, including LNA, first power stage, and voltage regulator on the same silicon. In a next step, RF part and analog baseband circuitry can be put together. The final solution is the integration of the complete system on a single chip. New system and circuit architectures are needed to reach these goals.

This trend to higher integration corresponds to the roadmap of technologies. In leading-edge applications GaAs is the best, often the sole choice, but the most expensive, too. In standard products like handies or cordless phones the main part of RF functions is realized in silicon bipolar or high-performance bicmos technologies, and in low-end applications pure cmos technologies are starting up, with a up to now unknown potential for more critical applications.

# High Speed Data Converters and New Telecommunication Needs

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Present trends in telecommunications are pushing the border of digital conversion towards the transmit and receive terminals. This leads to ever higher demands on data converter specifications, namely speed and resolution. Moreover, many applications require continuous reductions in power consumption. Market requirements are favoring research on high speed data converters. In turn, the results achieved lead to new architectural solutions which create new needs. This paper discusses this virtuous process and presents recent solutions for solving the key design problems. Two examples of new architectures that leads to demanding specifications for data converters are the “software radio” and the smart antenna. In cellular communications digital services need to be supported with different formats and protocols. The software radio technique avoids the problem of complex front-end interfaces: a high speed A/D converter digitizes the entire band with all the embedded channels. The DSP implements the appropriate software to properly process the received signal. The advantage with respect to conventional down-converting is that many channels are translated into the digital domain simultaneously. However, proper speed, resolution and, more importantly, spurious-free dynamic range (SFDR) must be assured. Increased use of portable telephones requires increasing the capacity of a given cell. The smart antenna approach provides a suitable answer to this problem by reducing interference with a pseudo-spatial-division multiple access. A proper implementation of this approach requires wide band conversion and the successive digital adaptive beamforming processing. Other examples can be discussed but the ones given above are sufficient to outline the importance of the issue.

High speed of operation can be achieved with advanced modern technologies. Submicron CMOS and advanced BiCMOS permit bandwidth in the order of GHz. Therefore, speed is an issue that has been satisfactorily addressed by advances in technology. In contrast, accuracy depends on the physical and practical limits associated with circuit implementation. When more than 10 bits are required the only way to get rid of inaccuracy is to use calibration. For data converters we use on-line and off-line techniques. Moreover, various calibration algorithms have been proposed for answering specific design needs. The second part of this presentation discusses high speed data conversion needs and possible digital correction techniques. One issue that will be discussed in detail concerns the design of input buffers whose performance often affects the effectiveness of calibration approaches.

# Sicherheitsrelevante Systeme in der Flugsicherung

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Die Firma FREQUENTIS beschäftigt sich insbesondere mit Sprachvermittlungssystemen für die Flugsicherung. Das Wort Flugsicherung schließt bereits das Wort Sicherheit ein. Es geht hier insbesondere um Ausfallssicherheit. Unter diesem Blickwinkel ist der nachfolgende Beitrag zu sehen.

Das Thema Flugsicherung schließt die Kontrolle des zivilen und militärischen Luftraums ein. Es geht dabei um Systeme für die Überwachung und Lenkung des Flugverkehrs. Neben den Radarsystemen und der Radardatenverarbeitung, Flugplandaten, Instrumenten- etc. Landesystemen steht die Sprachvermittlung an oberster Stelle. Die Sprachvermittlung ist deshalb von so hoher Bedeutung, da es derzeit letztlich das einzige Kommunikationsmittel ist, das international und flächendeckend verfügbar ist, um zwischen dem Boden und dem Flugzeug zu kommunizieren. Ohne Anweisungen über Funk helfen auch die besten anderen Managementsysteme dem Lotsen nichts, wenn er keine Anweisungen an die Piloten geben kann.

## Welche Sprachvermittlungssysteme sind nun nötig?

Zum einen Teil handelt es sich um Ground/Ground Systeme, die zur Kommunikation der Fluglotsen im Zentrum untereinander beziehungsweise zwischen den einzelnen Kontrollzentralen und den Towereinrichtungen auf den Flugplätzen dienen.

Neben diesen Ground/Ground Verbindungen ist aber insbesondere dem Air/Ground System hohe Bedeutung beigemessen. Es geht hier um spezielle Funkvermittlungssysteme, die die Sprachvermittlung zwischen den Fluglotsen und den Piloten bzw. zwischen Luftfahrzeugen, die unterschiedliche Frequenzen benutzen, herstellen. Eng verbunden mit diesen Air/Ground-Kommunikationssystemen sind auch Remote Control Systeme, die die landesweite Nutzung von Sende/Empfangsanlagen durch eine zentrale Flugverkehrskontrollzentrale ermöglichen.

## Systemarchitekturen

Die Systemarchitekturen sind von der hohen Anforderung an die Systemverfügbarkeit geprägt. In den meisten Fällen handelt es sich dabei um nachrichtentechnische Systeme, die auf einer sternförmigen Struktur, einer busartigen Verbindung oder auf Ringstrukturen fußen. Hier werden die verschiedenen Systeme auf ihre Vor- und Nachteile untersucht und verglichen.

## Safety

Der Begriff Safety wird vor allem im angloamerikanischen Raum bereits stark für all jene Untersuchungen und Betrachtungen verwendet, die sich mit Ausfallssicherheit beschäftigen. Umfangreiche Studien im Rahmen des Designs der Systeme und danach tragen dazu bei, daß

die zu entwickelnden Systeme von vornherein darauf ausgelegt sind, möglichst wenig Wirkung bei Teilausfällen zu verzeichnen.

Es geht hier um die Betrachtung, was passiert, wenn etwas passiert. Also insbesondere um die Störwirkwerte und das Ausfallsverhalten von Teilkomponenten. Hier sind Analogien zu den verschiedenen Betrachtungen im Bereich der Automobilindustrie durchaus vergleichbar.

## Zusammenfassung

Systeme in der Flugsicherung haben heute bereits einen hohen Verfügbarkeitsgrad. Hier geht es aber meistens um einzelne Systeme. Einzelne Systeme für die Sprachvermittlung und für die Datenverarbeitung. Diese Systeme sind strikt voneinander getrennt und werden auch von verschiedenen Herstellern erzeugt und von der Flugsicherungsbehörde dann normalerweise integriert.

Es besteht jedoch die klare Tendenz auch hier zu einer Sprachdatenintegration. Das soll vor allem Kosten bei Leitungsmieten aber auch bei der Wartung und Maintenance einsparen helfen. Hand in Hand geht da natürlich die Überlegung, was passiert mit der Ausfallssicherheit dieser Systeme. Das heißt, in Zukunft werden noch höher verfügbare Systeme mit Sprachdatenintegration auf Netzwerkbasis die Flugsicherung dominieren. Im Sinne eines Netzwerks können dann sicher einzelne Komponenten ausfallen, ohne daß das Gesamtsystem wirklich beeinträchtigt wird.

# A Survey of ASIC Design Centers at Austrian Universities

**N. Kerö**

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**Institute for Applied Electronics and Quantum Electronics**

Throughout the last years several groups at Austrian universities succeeded in establishing state-of-the-art ASIC design centers with the aid of regional, national, and European funding. These centers were by no means targeted to facilitate research and education activities alone. The direct support of Austrian enterprises – mainly but not exclusively small and medium sized companies – has been of equal importance to all groups. For the sake of clarification a brief historic summary will commence this survey. Subsequently all partners at the Vienna University of Technology, at the Graz University of Technology, and at the Linz University will introduced. After briefly describing the respective infrastructure we will cover the areas of interest and special competencies of every center. Finally the results of selected projects will be presented.

# A Ka-Band Detector Diode with High Sensitivity

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## Introduction

In millimeter-wave-systems suited for automotive applications Schottky-barrier diodes are used for detecting and mixing signals because of their high switching speed which results from the unipolar conduction mechanism. III-V semiconductors are the preferred materials because of their higher electron mobility. In this work the design and fabrication procedures of a matched zero bias $In_{0.38}Ga_{1-0.38}As$-Schottky detector diode for 35 GHz are described.

## InGaAs Diode

The voltage sensitivity of a detector diode is a function of the reverse saturation current. For optimum sensitivity this current has to be in the range of $10^{-6}$ A. To achieve this value with GaAs technology at zero bias – which is desirable to keep the circuit as simple as possible – the barrier height must be tailored to 0.22 – 0.25 eV by incorporating Indium. With increasing In content the energy gap of the semiconductor is lowered from 1.42 eV (GaAs) to 0.33 eV (InAs). With $In_{0.38}Ga_{0.62}As$ the desired barrier height of the Schottky contact can be adjusted. The diodes were fabricated using epitaxial layers of GaAs and InGaAs grown by metal organic vapor deposition (MOCVD) on GaAs substrates. Ni/GeAu/Ni/Au films were evaporated thermally respectively by e-beam and annealed to form ohmic contacts on n-type layers, Ti/Au and Cr/Au were evaporated and used for Schottky contacts. The ohmic contacts were recessed by wet chemical etching, and the connection to the Schottky contact on the top was led over an $SiO_2$ bridge. The etching of the $SiO_2$ was performed in a reactive ion etching (RIE) reactor. The patterns for the contact pads, the interconnections and the circuit were transferred to the substrate using e-beam lithography.

## Matching of Diode

For reduced bandwidths the sensitivity of 1 mV/µW was further improved by matching the impedance of the diode to the characteristic impedance of the transmission line. The equivalent circuit of the diode was deduced from network analyzer measurements. For the frequency range of 34 – 36 GHz a matching circuit consisting of a microstrip line terminated by a radial stub was designed and fabricated. With this design a sensitivity of 6 mV/µW was obtained.

## Conclusion

The described diode is used as a mixer in the receiving path of a Doppler-radar front-end. The signal is amplified with automatic gain control to achieve a sufficiently high signal level at the A/D converter. A digital signal processor (DSP) analyzes the sampled signal and calculates the target speed. With a corner reflector moving at constant speed an accuracy of 0.1% is possible.

# A Time-to-Voltage Converter for Accurate Measurements of Travel Time

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A circuit for highly accurate measurements of the velocity of sound in fluids has been developed at the Department of Electronics, Technical University Graz. Based on the principle of the delay locked loop (DLL), a control loop sets the period of an oscillator equal to the travel time needed by an acoustic pulse to travel through a known distance in a fluid. One of the major parts in that loop is the time-to-voltage converter. Compared to a standard phase locked loop (PLL) phase detector the demands for the circuit needed here are quit high, as the resolution should reach the range of picoseconds. In this paper a circuit will be presented which fulfils these demands. It has been proven to work in a range from +/-100 ns with a resolution of several picoseconds.

The first version of the converter was developed to be built with standard discrete components. But it is also well suited to be built into an integrated circuit, as the second part of the paper will show. The implementation in CMOS is currently under development at the department.

# Internal Characterization of IGBTs Using the Backside Laserprobing Technique

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[2] Physics of Electrotechnology, Munich University of Technology, D-80290 Munich, Germany

This work presents the time resolved internal characterization of Insulated Gate Bipolar Transistors (IGBTs) by Backside Laserprobing. Calibrated numerical device simulation is employed for investigating the effects of the sample preparation on the interpretation of the measurement results.

The Backside Laser Probing Technique makes use of the dependence of the refractive index of silicon on temperature (thermo-optical effect) and on carrier concentration (plasma-optical effect). The change of the refractive index is measured by detecting the phase change of an infrared laser beam, penetrating the device in vertical direction from the rear side. Interference with a reference beam leads to a time dependent detector signal of the form $\sin(2\Delta\omega t+\Delta\varphi(t))$, where $2\Delta\omega$ is the beat frequency of the heterodyne interferometer. The vertical IGBT has the collector contact on the rear side. Therefore the measurement technique requires to etch a window of 70 µm x 70 µm in size into the collector contact metallization. This window opening is done by a photolithographically structured etching in a two step process which does not affect the silicon. To suppress multiple-beam-interference within the silicon substrate, the window area is coated with an antireflection layer by a PECVD deposition process. For the quantitative evaluation of the experimental results, the device performance is simulated using a self-consistent electrothermal extension of the drift-diffusion model, as it is implemented in the general-purpose device simulator $\text{DESSIS}^{\text{ISE}}$.

The IGBT is operated under short circuit conditions. When only low collector-emitter voltages are applied, the contributions of temperature and carrier densities to the total phase shift of the probe beam are of the same order of magnitude. The two contributions can be distinguished by their different sign and different temporal behavior. The experimental data are compared to the results of the simulation. At high collector-emitter voltages, the thermal contribution becomes the dominant effect on the total phase shift. The constant power dissipation during a current pulse causes a linear rise of the phase shift. Assuming a linear temperature distribution along the beam path allows an approximate calculation of the surface temperature.

In conclusion the Backside Laserprobing technique appears as a powerful tool to study the temperature and carrier density dynamics in power devices under short circuit conditions.

# A Novel Technology for the Assembling of ASIC's and MEMS

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A miniaturized air bag sensor system with a complete novel connecting technology of the micro machined component and the ASIC part was developed, in order to allow a significant increase of the production yield and reliability in comparison with the currently used technologies by e.g. BOSCH or MOTOROLA.

This connecting technology, which is based on a soldering techniques, avoids the problems associated with the combination of the micro machining technology with the conventional semiconductor technology, by allowing a completely separated production of both components. Additionally, the required vacuum sealing of the micro mechanical component is performed. An ideal electrical shielding of the device as well as an electrical contact between the micro mechanical part and the ASIC unit are obtained simultaneously. Among others, one of the key solutions introduced with this technology is to form a metal solder ring onto the micro machined unit, which is very fragile and has a difficult surface topography. This is done using the float off technique in combination with a specially patterned double layer dry resist evaporation mask.

After successful technological development this device is ready for industrial pilot production now.

# Optoelektronik

Donnerstag, 4. März 1999 – Freitag, 5. März 1999

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# Optoelektronik

| Do., 4.3.1999 | |
|---|---|
| 17:00 – 18:00 | Andreas ULLRICH, RIEGL Laser Measurement Systems GmbH, Horn<br>*3D-Laser-Entfernungsbildaufnahme* |
| 18:00 – 19:00 | Markus-Christian AMANN, Schottky-Institut, München<br>*Neueste Entwicklungen auf dem Gebiet der III-V Heterostrukturlaser (Recent Developments on III-V Heterostructure Laser Diodes)* |
| 19:00 – 19:15 | Pause |
| 19:15 – 20:15 | Hanno WACHERNIG, Mütek, Herrsching<br>*In-situ–Spurenüberwachung mit abstimmbaren MIR Diodenlasern* |
| Fr., 5.3.1999 | |
| 09:00 – 10:00 | Anton KÖCK, FH Wr. Neustadt<br>*Optoelektronik an österreichischen Universitäten* |
| 10:00 – 10:20 | Kaffee |
| 10:20 – 10:40 | Gunther SPRINGHOLZ et al., Johannes Kepler Universität Linz<br>*Herstellung von Bragg-Spiegeln für den mittleren Infrarot-Bereich mit hohem Wirkungsgrad aus IV-VI Halbleitern (Fabrication of Highly Efficient Mid-Infrared Bragg Mirrors from IV-VI Semiconductors)* |
| 10:40 – 11:00 | Peer O. KELLERMANN et al., TU Wien<br>*Adjustierbare oberflächenemittierende Single-Mode Laserdioden mit kontradirektionaler Oberflächenmoden-Kopplung (Wavelength Adjustable Surface Emitting Single Mode Laser Diodes with Contradirectional Surface Mode Coupling)* |
| 11:00 – 12:00 | Postersession<br>Poster:<br>A. BONANNI et al., Johannes Kepler Universität Linz<br>*Self-Assembling Mn-Based Nanostructures*<br>N. FINGER et al., TU Wien<br>*Analysis of Single-Mode Grating Coupled Twin Waveguide Laser Structures*<br>M. GRITSCH et al., TU Wien<br>*Investigation of Local Ions Distributions in Polymer Based Light Emitting Cells*<br>W. HEISS et al., Johannes Kepler Universität Linz<br>*ZnCdSe/ZnSe Quantum Wires by Epitaxy on Prepatterned GaAs Substrates*<br>L. HVOZDARA et al., TU Wien<br>*GaAs/AlGaAs Based Intersubband and Interminiband Mid-Infrared Emitters*<br>S. LANZERSTORFER et al., Johannes Kepler Universität Linz<br>*Light Generation by Er in Si Related Materials* |

| | |
|---|---|
| | T. MAIER et al., TU Wien<br>*GaAs VCSELs with Dielectric $Si_3N_4/SiO_2$ Mirrors*<br>S. MUSSER et al., TU Wien<br>*Determination of Trace Element Distribution in Cr Sputter Targets by 3-d SIMS*<br>W. SCHRENK et al., TU Wien<br>*GaAs/AlGaAs/InGaAs Bandgap Lasers — From DH Lasers to VCSELs*<br>J. ULRICH et al., TU Wien<br>*Far-Infrared Electroluminescence in Parabolic Quantum Wells* |

# 3D-Laser-Entfernungsbildaufnahme

**Andreas Ullrich**

**RIEGL Laser Measurement Systems GmbH, Horn**

Nowadays our world becomes more and more a digitized world in almost every aspect (speech, sound, imaging, communications, etc.). At present one major effort is to achieve more or less complete digital 3D representation of natural as well as man-made objects such as workpieces, art's works, buildings, complete scenes, or even whole landscapes.

Various methods for achieving 3D images have been developed, e.g., mechanical touch probes mounted on co-ordinate measuring machines (contouring), laser-based triangulation, 3D reconstruction from multiple images, and projection of light fringes.

3D imaging laser sensors based on the time-of-flight principle deliver high productivity and accuracy. 3D data acquisition is accomplished by fast line scanning based on angular deflection with a number of rotating reflective surfaces for one dimension. Rotating the whole scanning device or moving the whole scanner platform (e.g. by airplane, airship, helicopter, or by car) provides the second dimension.

This new tool provides a compelling alternative to traditional techniques by accurately measuring structures, even when they are inaccessible or in an unsafe area, due to the high measurement capability up to ranges of hundreds of meters to naturally reflecting objects.

3D laser imaging facilitates 3D data acquisition in a vast area of applications: 3D-imaging of buildings for architecture and preservation of cultural heritage (castles, ruins, relics of the past), reverse engineering (plant as-built records), scene acquisition for virtual reality modeling, acquisition of digital terrain models of residential areas, whole districts or even towns, including vegetation and structures, topographic mapping of quarries or open pit mines, cliff faces, and dimensional measurements of all kind of vehicles.

# Recent Developments on III-V Heterostructure Laser Diodes

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Recent advances in materials technology and device design now allow the fabrication of laser diodes from the mid IR to the UV spectral regions. This talk covers the essential progress on the technology of the III-V semiconductor materials such as nitride- and antimony-based compounds and quantum dot structures. Furthermore, the present status on advanced device concepts, such as vertical cavity surface emitting lasers (VCSELs), quantum cascade lasers, and wavelength-tunable longitudinal mode-stabilized lasers is reviewed. Finally, present efforts for a further improvement of laser diode performance and for an extension of the wavelength range are discussed.

# *In-situ*–Spurenüberwachung mit abstimmbaren MIR Diodenlasern

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**E-Mail: mir-pmx@cube.net**

Beim Vergleich der spektroskopischen Eigenschaften konventioneller MIR-Spektrometer und abstimmbarer Diodenlaser sind die Hauptunterschiede in der nachfolgenden Abbildung und der Tabelle zur Übersicht dargestellt:

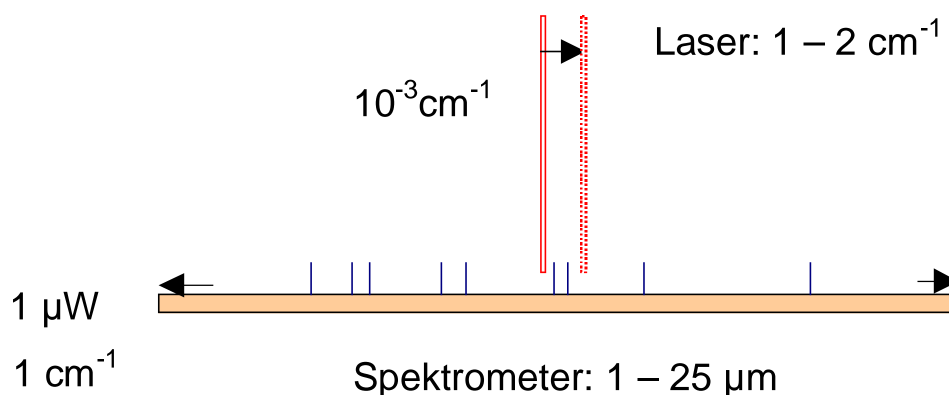


Fig. 1: Vergleich der Eigenschaften von konventionellen MIR-Spektrometern und Diodenlasern.

| Merkmal | Konvent. Spektrometer | Diodenlaser |
|---|---|---|
| Abstimmbarkeit | 1 – 25 µm | step-tunable 100 $cm^{-1}$, kont. abstimmbar 1 – 2 $cm^{-1}$ |
| Spektrale Helligkeit | 1 µW/ $cm^{-1}$ | 100 µW/$10^{-3}cm^{-1}$ |
| Strahlführung | eher divergent | Punktfokus / Parallelität |
| Schnelligkeit | msec | µsec |

Tabelle 1: Konventionelle MIR-Spektrometer und Diodenlaser.

Daraus folgt die unterschiedliche **Anwendung** und **Spezifikation** beider Techniken:

Während das konventionelle Spektrometer durch seine weite kontinuierliche Abstimmbarkeit mit einem Scan eine Menge von Molekülkomponenten erfaßt, reicht die geringe für die Spektroskopie nutzbare kontinuierliche Abstimmbarkeit des Lasers im allgemeinen nur für die Überwachung eines einzigen Zielanalyten. Ein Diodenlasersystem wird daher hauptsächlich als Monitoring-Methode eingesetzt. Wegen seiner spektralen Helligkeit, seiner Selektivität

und der exzellenten Strahlführungsqualitäten kommt der Diodenlaser bei der *in-situ* Spurenüberwachung zur Anwendung. Spuren deshalb, weil der Laser zur Detektion hoher Konzentrationen von Molekülen gegenüber konventionellen Techniken zu teuer kommt. Einfache Lasersysteme kosten 30.000 EURO pro Gaskomponente.

Im besonderen sind folgende Anwendungen für die Diodenlasersysteme in der Spurenanalytik aufzuführen: In den Plasmaanlagen für die Chemical Vapor Deposition (CVD) in der Halbleiterindustrie wird der Partialdruck der Gase und Radikale mit Hilfe der Diodenlaserspektroskopie gemessen. Weiters werden Molekülreaktionen, die in nsec oder langsamer ablaufen, in Gasen, in der Atmosphäre oder Stratosphäre untersucht. Bei der Untersuchung der luftchemischen Vorgänge bei der Bildung des Ozonlochs spielte der Diodenlaser eine große Rolle. Verbrennungsvorgänge können direkt am Ort des Geschehens studiert werden. Man mißt zum Beispiel die Konzentration von Ammoniak bei der Eindüsung von Urinstoff bei der Verbrennung. Man beobachtet die Gaskinetik im Motor und man mißt Temperaturen im Gasraum im Abstand von 0,1 msec.

# Fabrication of Highly Efficient Mid-Infrared Bragg Mirrors from IV-VI Semiconductors

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Due to their favorable electronic band structure, the IV-VI semiconductors (lead salt compounds) have long dominated the field of mid- and far infrared diode lasers in the 3 – 30 µm spectral region. The inherent wavelength tunability of these lasers has made them an ideal tool for high resolution infrared spectroscopy applications for trace gas analysis and atmospheric pollution monitoring. Progresses in IV-VI molecular beam epitaxy and laser processing techniques have led to cw operation temperatures of up to 223 K [1], and to pulsed mode operation even at room temperature. However, the IV-VI lasers are facing increasing competition from the novel III-V quantum cascade lasers based on intersubband transitions [2]. Important limitations for the IV-VI lasers are the properties of the lead salt substrate materials, which are not available on a commercial basis and exhibit rather low thermal conductivities.

In the present work, we have for the explored the possibilities for fabrication of IV-VI based vertical cavity surface emitting lasers (VCSEL) for the 3 – 6 µm spectral region. Such structures, grown on readily available $BaF_2$ (111) substrates have a great potential for reducing threshold currents and increasing the operation temperatures, while avoiding some of the difficulties in present IV-VI laser technology. In our work, the Bragg mirrors, which are the crucial part of the VCSEL structures, consist of a multilayer stack of PbEuTe quarter-wavelenght layers with the variation in refractive index induced by alternating the Eu content in the layers. In the PbEuTe materials system, the refractive index decreases and the energy band gap increases with increasing Eu content, with little change in the lattice constant. Thus, by using PbEuTe layers with Eu composition alternating between 1 and 6 %, an almost lattice-matched structure with sufficient contrast in the refractive index can be made, while each layer is optically transparent for the emission wavelength of the active material, which is PbTe in our case. In order to achieve a precise control of the composition and thickness of each $\lambda/4$ layer, the 1 % PbEuTe layers were grown as a short period PbTe/PbEuTe ($x_{Eu}$ = 6 %) superlattice where the net Eu content was adjusted by the appropriate PbTe to PbEuTe thickness ratio. The design of the final layering structure was derived from theoretical calculations taking into account the measured optical constants of reference layers at 77 K. Several such Bragg mirrors were grown by MBE, and their structural perfection characterized by high-resolution x-ray diffraction, scanning electron, and atomic force microscopy). Due to the long wavelengths in the MIR region, for 20 or more $\lambda/4$ pairs the total thickness of the Bragg mirror already exceeds 10 µm, and the total number of layers is more than 2000. Nevertheless, optical measurements show an excellent agreement of the minimum in the transmission spectrum with the target 77 K emission wavelength of PbTe. Furthermore, the absolute value of the transmission at this wavelength is well below 1 %, which indicates a Bragg reflectivity above 99 % of our structures, which to the best of our knowledge for such a structure is by far the best value achieved so far in the mid-infrared regime.

[1] Z. Feit, M. McDonald, R. J. Woods, P. Mak, Appl. Phys. Lett. 68, 738 (1996).

[2] J. Faist, et al., Appl. Phys. Lett. 68, 3680 (1996).

# Wavelength Adjustable Surface Emitting Single Mode Laser Diodes with Contradirectional Surface Mode Coupling*

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The principle of these laser diodes is based on a coupling mechanism between the laser mode and the surface mode which exists in a semitransparent metal/dielectricum waveguide structure on top of the laser diode. Phase matching of the laser mode and the surface mode is achieved by a surface relief grating in the laser diode. The grating causes radiation losses of the laser mode, which are reduced significantly only in a narrow spectral range by the excitation and feed back process of the surface mode. The effective gain mechanism of this resonance leads to single mode emission. The emission wavelength can be adjusted in a simple way by changing the optical thickness of the waveguide on top of the laser diode (this shifts the dispersion relation of the surface mode and thus the spectral position of the resonance). Surface emission with low beam divergence is caused by the surface grating. The principle was realized with GaAs/AlGaAs- and GaInP/AlGaInP-laser structures.

The radiation and the longitudinal mode characteristics of the waveguide grating structures have been investigated numerically with an in-depth analysis based on the Floquet-Bloch theory. The numerical analysis shows that in case of contradirectional coupling between the laser mode and the surface mode the sidemode suppression of the emission wavelength is increased compared to the codirectional coupling mechanism (due to a narrower resonance). The contradirectional surface mode coupling has now been realized for the first time. The emission wavelength (680 nm) of the GaInP/AlGaInP-laser structures was decreased in steps of 0.2 nm in an interval of 2 nm by reducing the thickness of the waveguide on top of the laser diode. The sidemode suppression increased from 19 dB with codirectional to a value of 26 dB with contradirectional coupling. The beam divergence of the emission via the surface is $0.10° \times 10°$.

* This work is supported by the Gesellschaft für Mikroelektronik (GMe), the BMWV and the Volkswagen-Stiftung (Germany).

# Self-Assembling Mn-Based Nanostructures

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Self-assembling nanostructures are attracting considerable attention because of their potential applications in electronic and optoelectronic devices as e.g. single electron transistors and quantum dot lasers. CdTe-based semiconducting magnetic heterostructures (MH), both in the diluted semimagnetic (DMS) phase of $Cd_{1-x}Mn_xTe$ and in the digital (DMH) arrangement embedding MnTe magnetic layers, offer the unique opportunity of having electronic band structures which can considerably be tuned by the application of magnetic fields of moderate intensity. In addition, the introduction of magnetic clusters in a semiconducting matrix opens new perspectives for applications in spin-dependent switching devices and in storage technology. Puzzling morphologies of self-assembled islands, depending on the growth conditions and due to strain and stress effects and surface diffusion processes, could represent, when properly controlled, interesting new systems for electronic confinement in low dimensions. In addition, with the presence of magnetic elements, they could allow for the study of non-collinear magnetic structures' formation and of strain effects on magnetic phases. In the present work, we report on the fabrication, by means of molecular beam epitaxy (MBE), of pure Mn nanocrystallites on CdTe and then on the possibility to obtain regular islands with different morphologies during the subsequent deposition of semiconductor compounds. The processes are monitored *in situ* and in real time via reflectance difference spectroscopy (RDS), a non destructive optical technique suitable for MBE as well as for non-ultra-high-vacuum systems like chemical vapor deposition (CVD) reactors.

# Analysis of Single-Mode Grating Coupled Twin Waveguide Laser Structures*

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An analysis of semiconductor laser structures with adjustable single-mode emission based on a contradirectionally grating coupled twin-waveguide structure consisting of a semitransparent metal (or ITO) / low-index dielectric waveguide on top of a corrugated active laser waveguide is presented. A coupled mode theory, where the coupling and radiation coefficients are expressed in terms of field overlap integrals between the unperturbed mode field patterns and rigorously calculated on-resonant Floquet-fields, is applied to describe the optical fields of the laser resonators with a high degree of accuracy, although the modulation of the dielectric constant in the grating region is large. At resonance between the laser mode and the surface mode the grating-coupled radiation losses into the substrate show a sharp drop with a linewidth comparable to the longitudinal Fabry-Perot-mode spacing of the laser cavity, thus preferring a single longitudinal mode to lase. An intermodal discrimination of more than 20 $cm^{-1}$ and a moderate threshold gain of ~50 $cm^{-1}$ can be obtained. Since the resonance wavelength depends on the optical thickness of the surface waveguide, a simple post-processing adjustment of the emission wavelength by adapting the surface waveguide thickness is provided. The laser structures under consideration have a wide tuning range in excess of ~15 nm, which is only limited by the roll-off of the gain spectrum, and a wavelength reproducibility in the subnanometer regime. Due to these features this type of laser diodes is expected to be of high interest for wavelength division multiplexing applications.

* This work is supported by the Gesellschaft für Mikroelektronik (GMe), the BMWV and the Volkswagen-Stiftung (Germany).

# Investigation of Local Ions Distributions in Polymer Based Light Emitting Cells

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Secondary Ions Mass Spectrometry (SIMS) is a well established analytical technique for the investigation of multi-dimensional element distributions in nearly all kind of materials. It is characterized by its high detection power (down to sub-ppm), its unique capability of detecting all elements, by good depth resolution (5 – 10 nm), good lateral resolution (in scanning mode 0.2 µm), and by the possibility of gaining image data information.

Polymer based light emitting cells exhibit a great potential in developing blue light emitting diodes as well as tunable light emitting diodes. Furthermore, they are comparatively cheap to produce and promise to be part of future flat panel displays, but still a lot of research work is necessary until series production is possible.

The principle of such light emitting cells is that a polymer (e.g. conjugated polymer) serves as semiconductor which is doped electrochemically *in situ* to form a p-n joint. The system investigated has been developed at the Institute of Solid State Physics, Technical University of Graz, Austria, by S. Tasch. It consists of a glass substrate coated with a transparent electrode (100 nm of ITO), the polymer layer (120 nm of m-LPPP) doped with polyethylene oxide and $LiCF_3SO_3$, and as top electrode an evaporated layer of aluminum or gold. The p-n junction is formed when a voltage is applied by the reduction respectively oxidation of the polymer, polyethylene oxide serves as solvent to increase the mobility of the ions. As the p-n junction is formed in situ by the applied voltage, one would expect no difference depending on the polarity used initially, but light emission could only be reached when the base electrode (ITO) was set to negative potential. To investigate on this phenomenon, SIMS depth profiles have been made through the whole system. As the distribution of the $Li^+$ and the $CF_3SO_3^-$ ions both was of interest and only either positive or negative secondary ions can be detected within one depth profile, two different measurements using $Cs^+$ and $O_2^+$ primary ions respectively had to be performed on each sample and then the gained data had to be fit together. The results showed clearly that independent of the applied voltage a separation of the ionic species happens already during production of these elements, $Li^+$ ions diffuse into the ITO whereas $CF_3SO_3^-$ ions preferably enrich at the aluminum electrode.

# ZnCdSe/ZnSe Quantum Wires by Epitaxy on Prepatterned GaAs Substrates

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$Zn_{1-x}Cd_xSe/ZnSe$ quantum wells are relevant material systems for the fabrication of laser diodes emitting in the blue-green spectral range. For III-V semiconductors it has been demonstrated that the spike-like density of states in reduced dimensions yields much narrower and higher gain peak values as compared to quantum well lasers. Up to now, ZnCdSe/ZnSe nanostructures were fabricated by post molecular beam epitaxy (MBE) structuring and etching techniques. However, these nanostructures suffer by damage induced by the etching process, and the optical properties are dominated by nonradiative recombination and strain relaxation processes. For that reason, we investigate the possibility to realize quantum wires by MBE on patterned GaAs substrates, to achieve ”V-groove” or ”ridge” quantum wires.

As substrates we prepare (100) oriented GaAs submicrometer gratings by laser holography and subsequent preferential wet chemical etching. The etching gives trapezoidal shaped ridges, with (111) and (1-1-1) planes as side walls, embedded between 160 nm deep grooves. After etching, the top of the ridges and the bottom of the grooves are still (100) oriented. The growth rate for ZnSe and ZnCdSe depends strongly on the orientation of the substrate resulting in an anisotropic growth on our patterned substrates. This selective growth can be used to achieve carrier confinement by heterointerfaces not only in vertical but also in lateral direction. Depending on the chosen lateral dimensions of the substrate and on the thickness of the ZnSe buffer layer, quantum wires are achieved at the bottom of the grooves or on top of the ridges. Lateral confinement effects in these structures are evidenced by low temperature luminescence experiments, namely by strong optical anisotropies and by spectral blue and red shifts of the excitonic luminescence.

# GaAs/AlGaAs Based Intersubband and Interminiband Mid-Infrared Emitters

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Intraband optical transitions in the conduction band of GaAs/AlGaAs heterostructures are used to generate mid-infrared (5 – 15 µm) radiation. Bandstructure engineering and epitaxial growth techniques make it possible to tailor the emission wavelength of mid-IR light emitting diodes over a broad range. We report on the realization of these emitters, showing two different concepts. The principle of interminiband emitter is based on optical transitions across the minigap of a strong coupled superlattice. The other concept is using optical transitions between the discrete states in a system of coupled quantum wells. Emission, photovoltage and transmission spectra are presented. Self-consistent calculations of these structures are performed and compared to the experimental data. The structures are designed to achieve population inversion in different subbands of the conduction band. We intend to present the design of an AlGaAs/GaAs intersubband laser that is in progress.

Supported by: BRITE/EURAM III Project UNISEL; Gesellschaft für Mikroelektronik (GMe Austria); Fonds zur Förderung der wissenschaftlichen Forschung.

# Light Generation by Er in Si Related Materials

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One of the last unsolved principle problems in Si technology is the integration of compatible light sources as needed *e.g.* for optical communication within or between chips. Although there are different approaches followed worldwide there is no obvious solution so far. One of the most promising principles proposed is the light generation by intra-4f transitions in Er, which can be integrated in very different host crystals giving always the same characteristic sharp spectra and a temperature-independent emission wavelength of 1.54 μm.

The main problem with this approach was to achieve reasonable efficiency at room temperature. For pure Si as host material the luminescence efficiency is quenched already at temperatures well below 200 K, excluding a reasonable device performance. It turned out, however, that incorporation of large amounts of oxygen together with Er in Si alleviates this problem substantially. In this project, we investigate the mechanisms responsible for this effect. We show by comparison of high resolution spectra of Er in different host materials and excitation spectroscopy data that under specific preparation conditions $SiO_2$ clusters are formed in Si containing Er and in this environment the luminescence quenching sets in only well above room temperature. The disadvantage of these centers is, however, the very inefficient excitation by electron-hole pairs, responsible for light emission in conventional light emitting diodes or lasers. Instead, these centers can be excited by hot carriers injection in a reverse biased diode.

Using this type of excitation we achieve room temperature cw operation of erbium-doped silicon diodes under reverse bias condition with a maximum power of an estimated 0.1 mW, which may be sufficient already for some applications but not for long distance fiber optic communication. We indicate possibilities for further improvement.

# GaAs-VCSELs with Dielectric $Si_3N_4/SiO_2$ Mirrors

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We use plasma enhanced chemical vapor deposition (PECVD) to deposit $Si_3N_4$ and $SiO_2$ layers. The resulting amorphous layers are grown to form highly reflecting dielectric mirrors which are used as outcoupling mirrors in vertical cavity surface emitting lasers (VCSELs). Among the advantages of these mirrors are the reproducibly excellent optical quality, good adhesion properties, and high mechanical and thermal stability of the deposited films. We prepared VCSELs from an epitaxial wafer containing an n-doped AlAs/AlGaAs Bragg mirror and the active pn junction, using lateral wet oxidation of AlAs to define the current path into the active region. The relatively shallow depth of the active area from the semiconductor surface results in an almost planar surface and thus in a greatly simplified fabrication process. We present measurements of the laser characteristics demonstrating the high quality of the PECVD-deposited laser mirrors, with laser thresholds comparable to those of all-epitaxial VCSELs while gaining an increased flexibility in the laser preparation.

This work is supported by the BMWV.

# Determination of Trace Element Distribution in Cr Sputter Targets by 3-d SIMS

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TFT-LCD´s (thin film transistor liquid crystal displays) are thin, emit low radiation, have a high contrast ratio and full-color display capability. In many areas cathode ray tubes will be replaced by this kind of flat panel display.

All materials required for the production have to fulfill highest demands on purity and homogeneity. High purity chromium sputter targets are used for the production of the black-matrix and the color filters. The sputter targets are produced in two different powder metallurgical processes: during the hot isostatic pressing (HIP) process the raw material is encapsulated in steel containers and by applying high pressure and high temperature a homogenous and compact material is formed. In the sintering process the chromium powder is first compressed at room temperature and then heated to 2/3 of the melting temperature. In an additional step the material is rolled for compressing and shaping its final form.

Different chromium samples produced by these methods were characterized. Bulk analysis, carried out by GDMS (Glow Discharge MS), showed that sintered chromium has lower concentrations of impurities than HIPped chromium. For the production process is not only the overall concentration of trace elements important, but also their distribution. This is due the fact that impurities results in particle emission during sputtering. To determine the distribution of the trace elements 2-d and 3-d SIMS was applied. 2-d SIMS is a standard method for determination of lateral distributions of trace elements. 3-d SIMS can be seen as an extension, which combines the imaging capabilities of SIMS with depth profile analysis. This technique delivers the spatial distribution of trace elements in the ppm (part per million) range and is an important tool for the characterization of materials used in the semiconductor industry.

# GaAs/AlGaAs/InGaAs Bandgap Lasers — From DH Lasers to VCSELs*

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A solid source MBE system (MOD GEN II) is used for growth of AlGaAs materials for semiconductor lasers. This machine is equipped with a silicon cell for n doping, a carbon cell for p doping, and with an indium cell.

One project is the realization of grating coupled twin waveguide laser structures, where the two waveguides are the active laser waveguide and a passive waveguide formed by gold/SiO/SiN. The waveguides are coupled via a surface relief grating atop the semiconductor. These lasers allow postprocessing wavelength adjustment and high side mode suppression. The active zone consists of a strained InGaAs quantum well, and a ridge-waveguide is used for lateral optical confinement.

Another project is the realization of a laser interferometer which consists of a VCSEL (vertical cavity surface emitting laser) and a detector integrated on one chip. At the beginning, Bragg mirrors consisting of GaAs and AlAs layers were grown and characterized by reflection measurement and layer thickness measured by scanning tunneling electron microscope. First VCSELs with an AlGaAs/AlAs Bragg mirror and GaAs as active zone were grown. The top dielectric Bragg mirror of these lasers is made of SiO/SiN in a PECVD (plasma enhanced chemical vapor deposition) system.

* This work is supported by the Gesellschaft für Mikroelektronik (GMe)

# Far-Infrared Electroluminescence in Parabolic Quantum Wells

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We have measured the far-infrared emission from parabolically graded quantum wells driven by an in-plane electric field in the temperature range from 20 K to 240 K. The peak emission corresponds to the intersubband plasmon in the parabolic potential. Its photon energy (6.6 meV/9.8 meV) remains rather unaffected by temperature variations, the full width at half maximum ranges from 1 meV (T = 20 K) to 2 meV (T = 240 K). The reduction of emission efficiency with increasing temperature is attributed to the change in the non-radiative lifetime.

# HF-Bauelemente

Freitag, 5. März 1999 – Samstag, 6. März 1999

## Freitag, 5. März 1999 – Samstag, 6. März 1999
## HF-Bauelemente

| Fr., 5.3.1999 | |
|---|---|
| 17:00 – 18:00 | Hartmut PRESTING, Daimler-Chrysler Forschungsinstitut, Ulm<br>*Stand und Anwendungen von Si/SiGe-Hochfrequenz- und Optoelektronik-Bauelementen*<br>*(State and Applications of Si/SiGe High Frequency and Optoelectronic Devices)* |
| 18:00 – 19:00 | Andreas SCHÜPPEN, TEMIC, Heilbronn<br>*Stand der Prozeßentwicklung und Markteinführung des SiGe-HBT*<br>*(Silicon Germanium IC´s on the RF Market)* |
| 19:00 – 19:15 | Pause |
| 19:15 – 20:15 | Hartmut KAPUSTA, Siemens München<br>*GaAs-MMIC Design-Aspekte für Massenproduktion*<br>*(GaAs-MMIC Design Aspects for High Volume Production)* |
| Sa., 6.3.1999 | |
| 09:00 – 10:00 | Friedrich SCHÄFFLER, Johannes Kepler Universität Linz<br>*Hoch- und Höchstfrequenz-Bauelemententwicklung an österreichischen Universitäten*<br>*($Si/Si_{1-x-y}Ge_xC_y$ Heterostructures: A Ternary Material Base for High-Performance Si-Compatible Devices)* |
| 10:00 – 10:20 | Kaffee |
| 10:20 – 10:40 | K. WIESAUER et al., Johannes Kepler Universität Linz<br>*Nanolithographie für Halbleiter-Nanostrukturen unter Verwendung von Rasterkraftmikroskopie*<br>*(Fabrication of Semiconductor Nanostructures by Scanning Force Microscopy)* |
| 10:40 – 11:00 | Alois LUGSTEIN et al., TU Wien<br>*Fokussierte Ionenstrahlen, eine neue Technologie für die Mikrostrukturierung im Bereich unter 100 Nanometern*<br>*(Focused Ion Beam Technology – A New Approach for the Sub 100 nm Microfabrication Regime)* |
| 11:00 – 12:00 | Postersession<br>Poster:<br>R. HEER et al., TU Wien<br>*Enhanced Energy Resolution in Ballistic Electron Emission Microscopy Through InAs Base Layers*<br>C. RAUCH et al., TU Wien<br>*Onset of Scattering Induced Miniband Transport*<br>N. SANDERSFELD et al., Johannes Kepler Universität Linz<br>*Modulation Doped $Si/Si_{1-x}Ge_x$-Field-Effect Transistors*<br>C. SCHELLING et al., Johannes Kepler Universität Linz<br>*Growth Instabilities in Si Homoepitaxy*<br>Th. SCHWARZL et al., Johannes Kepler Universität Linz<br>*$CH_4/H_2$ Plasma Etching of IV-VI Semiconductors* |

| | |
|---|---|
| | H. SEYRINGER et al., Johannes Kepler Universität Linz<br>*Electron Beam Lithography of Nanostructures*<br>J. STANGL et al., Johannes Kepler Universität Linz<br>*Fast Growth Method for the Fabrication of Modulation Doped Si/SiGe Field Effect Transistors*<br>Y. ZHUANG et al., Johannes Kepler Universität Linz<br>*Si/SiGe Layers on Patterned Substrates for MODFET Applications* |

# State and Applications of Si/SiGe High Frequency and Optoelectronic Devices

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The turnover of microelectronic devices and circuits has been rapidly growing from \$ 45 billion in 1990 to \$ 77 billion in 1993 to about \$ 350 billion in the year 2000. Since silicon (Si) is the overwhelmingly dominating material in this market with an over 97% share there has been a great incentive to develop the silicon/germanium (SiGe) heterodevices due to their full compatibility with the widespread Si technology and due to their superior performance in the high frequency electronics market compared to conventional Si devices. Accessible market shares will depend on cost/performance advantages, therefore SiGe heterobipolar transistors (HBT's), SiGe hetero-fieldeffect transistors (HFET's), and SiGe heteroCMOS (HCMOS) circuits are very competitive devices which fit best into the respective Si markets. In addition, optoelectronic devices, such as Si/SiGe photodetectors for the telecommunication wavelength band in the near infrared (1.3 – 1.55 µm) regime as well as for thermography applications in the mid-IR (3 – 5 µm; 8 – 12 µm) band have been successfully demonstrated and can be seen as key components for low cost Si based photonic integrated circuits (IC). Superior performances for microelectronic devices have been demonstrated, such as high current gains (400 – 5000), ideal Gummel plots, high frequencies $f_t$ and $f_{max}$ (116 GHz and 160 GHz) low $F_{min}$ and 1/f noise figures for SiGe HBT's as well as high transconductances (500 mS/mm for n-type and 300 mS/mm for p-type devices) and frequencies ($f_t$ = 50 or 70 GHz for p- and n-type, $f_{max}$ = 120 GHz) for SiGe HFET's. Furthermore inverters and amplifiers, ECL ring oscillators, voltage controlled and dielectric ring oscillators (VCO's and DRO's) with low phase noise, digital to analog converters (DAC) have been realized from these devices.

Low cost, high performance SiGe IC's are best suitable for the high volume communication markets largely developing in the beginning of the next century, like mobile phones at 1 – 2 GHz, wireless local area networks (2.4 – 5.8 GHz), 10 – 14 GHz broadband satellite user terminals, and for cable and fiber transmission at 3 – 4 Gbits/sec. We will concentrate here on performances and market aspects for SiGe devices and give a comparison with III/V devices.

# Silicon Germanium IC´s on the RF Market

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TEMIC Semiconductors produces and sells now Silicon Germanium integrated circuits (SiGe IC´s).

The real HBT concept distinguished by a high doped base and a lower doped emitter originates from the Daimler Chrysler research center in Ulm and was successfully improved to a production technology in the last three years at TEMIC in Heilbronn. SiGe1 is a 50 GHz technology which is used for RF low noise amplifier and power amplifiers in mobile phones, e.g. DECT, GSM, DCS1800, CDMA, TDMA. In addition, gain blocks, dualband transceivers and mixer circuits for base stations are in the product portfolio.

The quality and the reproducibility of the technology were demonstrated by highlights as functioning 10k arrays over whole wafers and lots, by 0.5 W power HBTs revealing 72% PAE at 900 MHz and 64% at 1.8 GHz, a LNA at 5.8 GHz with a record noise figure of 1.6 dB and 26 dB associated gain, and a 2:1 multiplexer showing a clear eye diagram at 40 Gbit/s.

# GaAs-MMIC Design Aspects for High Volume Production

**Hartmut Kapusta**

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GaAs's image of being an expensive technology is no longer valid for high volume products. Minimizing chip area while maximizing reliability and yield as well as using low cost packages allows to produce components at costs competitive to alternative processes.

Tradeoffs between costs and performance influence the design and layout procedure, which will be demonstrated with circuit examples working between 0.8 and 77 GHz.

# $Si/Si_{1-x-y}Ge_xC_y$ Heterostructures: A Ternary Material Base for High-Performance Si-Compatible Devices

**Friedrich Schäffler,**

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

$Si_{1-x}Ge_x$ is the obvious choice for extending the physical properties of Si through the exploitation of heterostructures without sacrificing standard Si technologies. Most of the worldwide activities in that area were dedicated to the $Si/Si_{1-x}Ge_x$ heterobipolar transistor (HBT), which is now available commercially in integrated circuits that are expected to open fast growing high-frequency analog markets for Si-based electronics. Also, field effect transistors employing $Si_{1-x}Ge_x$ epilayers have demonstrated superior high frequency behavior on a lab level, with the performance gain of p-type transistors being even more promising than that of the complementary n-type FETs.

Despite the clear and demonstrated performance advantages, the peculiarities of the band alignment and the relatively large lattice mismatch of 4.2 % between Si and Ge impose certain restrictions regarding accessible band offsets and layer thicknesses. Part of these limitations may be overcome by adding carbon as a third group IV component to a $Si/Si_{1-x-y}Ge_xC_y$ heterosystem. A main purpose of C is strain adjustment, which becomes possible because of the smaller covalent bond length of carbon with respect to Si and the even larger Ge. Thus 1 % of C can compensate the lattice expansion of about 10 % of Ge in a $Si_{1-x-y}Ge_xC_y$ alloy, allowing strain adjustment in either direction with respect to the mandatory Si substrate. Another, on a short term probably even more important, feature of C in Si or SiGe is its very efficient suppression of transient diffusion of B upon subsequent ion implantation, which is a most undesirable effect especially with respect to HBT processing.

Obviously, $Si_{1-x-y}Ge_xC_y$ alloys are very attractive, but on the other hand, epitaxial growth is impeded by the almost negligible solid solubility of C in both Si and Ge, and by the existence of a stable SiC phase. Therefore, growth conditions have to be established which are far from thermal equilibrium, suppress SiC precipitation, and still maintain high crystal quality. We could demonstrate that these seemingly contradictory conditions can be met, at least up to C concentrations of about 2 %, which are sufficient for most of the envisaged applications.

This contribution aims toward a general introduction into the $Si/Si_{1-x-y}Ge_xC_y$ heterosystem, will summarize the state-of-the-art achieved in this unique material system, and will especially be focused on the envisaged applications.

# Fabrication of Semiconductor Nanostructures by Scanning Force Microscopy

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The fabrication of semiconductor nanostructures below 100 nm structure dimensions is a main issue for semiconductor processing technology. This regime is accessible only with advanced techniques such as UV or x-ray projection lithography or electron beam lithography. In this work we have developed a new technique for the fabrication of nanostructures which allows the combination of conventional photo resist technologies and optical lithography with scanning force microscopy (AFM) that allows an efficient fabrication of large as well as small scale structures.

For the AFM lithography step a very thin photo resist layer (10 nm thickness) is mechanically removed with the ultra sharp tip of a scanning force microscope. With a subsequent reactive ion etching the such produced pattern in the photoresist is transferred to the underlying sample surface. The use of a photoresist as mask for this nanolithography step allows a prepatterning of the sample with conventional optical lithography in order to efficiently produce the larger sized sample structures. With this two step lithography process we are able to produce nanostructures with lateral as well as vertical dimensions as small as 40 nm. The ultimate achievable resolution is mainly limited by the minimum thickness of the resist film that is required to ensure a sufficient pattern transfer during the reactive ion etching step. Further critical parameters of nanolithography process are the mechanical stability of the scanning force microscopy tip, the control of the interaction force during the resist modification process, and the compensation of the various nonlinearity of the AFM piezo scanners. The overall advantages of our technique are the relatively simple process implementation and the fact that it provides a comparatively low cost alternative to other nanolithographic techniques. On the other hand, the writing speed is rather limited due to the finite interaction time required for the mechanical modification of the photoresist and the limited maximal acceleration allowed for by the piezo scanners.

# Focused Ion Beam Technology – A New Approach for the Sub 100 nm Microfabrication Regime

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Focused ion beam (FIB) represents a versatile method for the analysis and modification of microelectronic high-performance circuits. Utilizing this attractive tool, spatially confined ultrafine structures can be written directly onto a substrate. Deposition of metal schemes or insulator patterns, a minimum feature size down to 25 nm and a nesting tolerance of 10 nm is in the reach of this technology. Composite materials can be selectively etched in reactive gas atmosphere achieving aspect ratios up to 10. Doping of semiconductors with Ga ions is possible in an energy range from 50 kV to 10 kV.

Using exemplary microelectronic devices, the analytical feasibilities of a Micrion 2500 FIB were exploited revealing an imaging resolution down to 10 nm. By ion milling and gas assisted etching multilayered structures could be made accessible for investigation. *In-situ* cross-sectional imaging allows quick evaluation and interpretation of process steps in a multilayered fabrication sequence. Experiments performed illustrate the potential of FIB for defect analysis of high-frequency circuits. Applications of FIB in quality control of devices and process control in fabrication are discussed.

Beyond the analytical capabilities, FIB allows the direct construction of microelectronic structures by a combination of both deposition and etching steps for metals and insulators. In this operation mode the modification of circuits in-situ on the chip was demonstrated. The wiring of an exemplary device was locally remodeled by first disconnecting the existing structure by ion milling and then redepositing metallic and dielectric material. This new 3-dimensional circuit fabricated by tungsten and $SiO_2$ deposition was reconnected with the existing structures to give a fully functional device.

Recent applications of FIB for semiconductor devices focus on an optimized MOSFET (FIB-MOS) using the localized beam to fabricate a unique, laterally tailored doping profile along the channel.

Concluding the presented material illustrates the potential of FIB for metrology and highly-resolved 3-dimensional imaging of complex multilayer structures. Spatially confined doping and metal deposition allow the improvement of high-frequency devices as well as fabrication of entirely new circuits.

# Enhanced Energy Resolution in Ballistic Electron Emission Microscopy through InAs Base Layers

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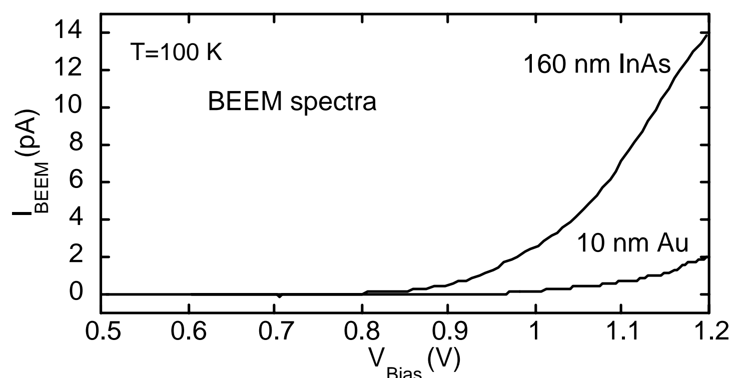
Ballistic Electron Emission Microscopy (BEEM) is a useful tool for probing surface and subsurface sample properties with high spatial resolution. To improve its spectroscopic sensitivity, it is important to optimize the ballistic electron current which is injected into the sample. In this work, we have replaced the commonly used metal base by a molecular beam epitaxy grown, n-doped, InAs layer on top of a GaAs sample. At low temperatures (T = 100 K), the attenuation length for ballistic electrons in the InAs base is in the order of 70 nm – 90 nm instead of 5 nm obtained on Au films, which means that the transmission is enhanced by one order of magnitude. In the spectra shown below, this is reflected by a much higher BEEM current achieved for a 160 nm InAs base compared to a 10 nm Au base.




The second major advantage of InAs, or, in general, semiconductor base layers, results from the low effective mass. Due to the large electron mass difference in Au and GaAs, parallel momentum conservation leads to considerable electron refraction at the Au-GaAs interface. As a consequence, the energetic distribution of the ballistic electron current is inverted beyond the interface and the corresponding energetic resolution is considerably decreased. For InAs-GaAs heterostructures, however, this is not the case, since the effective mass in InAs is smaller than in GaAs. Consequently, the energetic distribution of the ballistic electron current is focussed beyond the InAs-GaAs interface and the energetic resolution of the measurement is enhanced.

# Onset of Scattering Induced Miniband Transport

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The transition between coherent and incoherent transport in undoped GaAs/AlGaAs superlattices is observed. Hot electron spectroscopy is used to measure the superlattice transmittance at different bias conditions. For a short period superlattice the transmittance is found to be independent of the direction of the electric field. For a superlattice larger than the coherence length, the transmission becomes asymmetric and dependent on the electric field direction. The onset of scattering induced miniband transport is clearly evident. A coherence length of 150 nm, limited by surface roughness, and a scattering time of 1 ps are determined.

# Modulation Doped $Si/Si_{1-x}Ge_x$-Field-Effect Transistors

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Modulation doped $Si/Si_{1-x}Ge_x$ samples show high electron mobilities because of the motion of the carriers along a crystalline heterointerface and the absence of ionized impurities in the conduction channel. We present the methods and technologies that are applied at our institute to fabricate field-effect transistors on MBE-grown modulation doped $Si/Si_{1-x}Ge_x$ substrates. Ion implantation is used to form highly doped regions in the substrate; metal evaporation then realizes ohmic source and drain contacts on the implanted regions, and Schottky gates on unimplanted regions. In a following mesa process, reactive ion etching (RIE) is used to isolate the devices on the substrate laterally. The complete transistor process requires six lithographic steps. We employ optical contact lithography for structures down to 0.5 µm and electron-beam lithography for gate lengths <0.5 µm. By incorporation of a variety of test structures in our process, we are able to derive the essential device and process parameters after each technology step. For these characterizations we use an HP 4155 semiconductor parameter analyzer and an HP 4284 LCR meter in connection with an on-wafer prober.

# Growth Instabilities in Si Homoepitaxy

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Smooth Si buffers are required for subsequent overgrowth with quantum wells for superlattices and modulation doped transistor structures. However, to obtain ideally flat interfaces the occurrence of roughening and the driving forces behind it need to be identified. So far, it was generally believed that strain-driven step bunching provides a pathway for surface roughening. This approach is being intensively pursued by several groups that apply strained SiGe layers to investigate and enhance step bunching as templates for lateral ordering in self-organized growth. In contrast, our goal here is to produce interfaces as flat as possible to minimize interface roughness scattering of low-dimensional carriers.

We overgrew Si (001) wafers with well-defined miscuts of about 1° along the [100] or [110] directions with Si and SiGe layers. The surprising outcome of these experiments is that already homoepitaxial Si layers grown at very common temperatures (~500 °C) and rates (0,8 Å/s) tend to develop a distinct and very regular surface texture. This is reproduced by subsequently grown SiGe heteroepitaxial layers. We observe pronounced surface undulations running along the initial surface steps. They show a period of about 150 – 250 nm and are up to 15 Å high. The surface morphology strongly depends on miscut direction and growth temperature and is a kinetically induced: The homoepitaxial layers become smooth with a very small rms roughness of about 2 Å when deposited at high temperatures or upon post growth annealing. The length scales involved in the kinetic roughening are well within the mean free paths of carriers and thus might influence carrier mobilities in modulation doped structures. Thus, the newly discovered kinetic growth instabilities provide a means for systematic studies of the importance of interface roughness scattering in Si/SiGe heterostructures. In addition, our optimized growth/annealing conditions result in extremely smooth Si buffers, which now allow to distinguish between strain-induced and purely kinetic step bunching mechanisms.

# $CH_4/H_2$ Plasma Etching of IV-VI Semiconductors

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The narrow gap IV-VI semiconductor compounds have major importance for the fabrication of mid-infrared optoelectronic devices like lasers and detectors operating in the spectral range between 3 µm and 30 µm. In the fabrication of such devices lithographic patterning and etching are of crucial importance. Up to now only wet chemical etching has been used for the fabrication of buried IV-VI heterostructure lasers. For III-V and II-VI semiconductors, however, it has been shown that plasma etching is superior in several aspects as compared to wet chemical etching. In this work we demonstrate for the first time the feasibility of $CH_4/H_2$ plasma etching for the structurization of IV-VI semiconductors.

We find that the etch rate of several different IV-VI compounds shows a systematic decrease with increasing band gap which can be fitted with a power law dependence. A similar dependence is also valid for II-VI semiconductors. This suggests an equivalent etch reaction for IV-VI and II-VI semiconductors. The $CH_3$ radicals generated in the plasma are the etching components. However, they can also react to form a polymer deposit, so that deposition and etching are always competing processes. As a consequence, the etch rate depends strongly on the $CH_3$ content in the plasma. When Pb is substituted by other elements such as in ternary IV-VI alloys, the chemical reactions are altered. We find that the etch rate is strongly reduced and the power law dependence does not hold when Pb is partially replaced by Sn, Mn, or Eu. With detailed investigations of the etching behavior of the PbTe/$Pb_{1-x}Eu_xTe$ system which is one of the most important material combinations for IV-VI laser fabrication we demonstrate that with increasing methane concentration the etch depth of PbTe increases first but for a $CH_4$ content above 60 % decreases again. This behavior indicates that the etch rate increases with the $CH_3$ content as long as no polymerization takes place. For PbEuTe ($x_{Eu}$ = 1 %) a similar concentration dependence is observed. However, the etch rate is more than a factor of 3 lower than for pure PbTe and decreases drastically with increasing Eu content. In addition, the maximum etch rate shifts to lower $CH_4$ concentrations with increasing $x_{Eu}$. This could be caused either by polymer formation favored with increasing Eu content or by the formation of non-volatile Eu compounds. This interpretation is further confirmed by our time dependent etching experiments. While for PbTe the etch rate is nearly constant in time, the etch rate of PbEuTe decreases more and more rapidly with time with increasing Eu concentration. In fact, for $x_{Eu}$ = 6 % the etching stops completely after 60 min due to polymer or non-volatile Eu compound formation. This also demonstrates the very strong dependence of the etching rate on the Eu concentration. For identical etch conditions the etch depth decreases by a factor of 50 when $x_{Eu}$ is increased from 0 % to 6 %. Therefore, $CH_4/H_2$ plasma etching can be used as preferential etch to expose $Pb_{1-x}Eu_xTe$ heterojunctions.

# Electron Beam Lithography of Nanostructures

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We use a JEOL JSM 6400 scanning electron microscope at an accelerating voltage of 40 keV and polymethylmetacrylat (PMMA) resists with molecular weights between 50k and 900k a.u. for electron beam lithography of nanostructures on Si/SiGe heterostructures To create the masks and for exposure we use “Elphy Plus 1.233D” from Raith and “Nanolithography 2.0” which we have programmed by ourselves as supplement for “Elphy Plus”.

Here we report on three activities:

i) For Si/SiGe modulation-doped field-effect transistors, we fabricate Schottky gates by a lift-off technique with gate lengths $\leq 100$ nm. These gates are aligned between the implanted Source/Drain contacts via the mark recognition function implemented in the “Elphy Plus” system. Multiple resist layers are investigated for the fabrication of sub-micron gates with T- or $\Gamma$ cross sections for high frequency applications.

ii) By exposing arrays of boxes with a side length of less than 70 nm and by transferring them via reactive ion etching into a pre-structured Hall bar we produced antidots for magnetotransport investigations. Change in size and period of these antidots will provide information about the damaged area around the anti-dots caused by reactive ion etching. We want to use this information to optimize the etching process and increase the electron mobility in devices by decreasing the surface scattering.

iii) Oxide-patterned silicon substrates are used as a template for selective molecular beam epitaxy. By e-beam lithography arrays of windows less than 100 nm wide were transferred into a $SiO_2$ layer. These allow crystalline growth in the areas where the substrate is exposed, and polycrystalline deposition on the oxide covered areas. The latter can be removed selectively by etching the $SiO_2$-layer in diluted HF. By combining the prepatterned substrates with Stranski-Krastanov growth of Ge or SiGe layers, self-organized quantum dots can be arranged in a regular pattern for selective excitation or contacting. Also, the size of the windows affects the dot sizes.

# Fast Growth Method for the Fabrication of Modulation Doped Si/SiGe Field Effect Transistors

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For the realization of n-type Si-based hetero MODFET's, strained Si channels are required, which are usually grown on the top of thick relaxed SiGe buffer layers. To obtain low threading dislocation densities, these buffers are grown with a composition gradient, typically up to 30 % Ge content and a total thickness of about 3 to 5 µm. After a constant composition buffer, a 10 nm thick Si channel is deposited, followed by a SiGe spacer layer, the Sb-doped SiGe layer, and a Si cap layer. The growth of the thick SiGe buffer layers in an MBE or UHVCVD system is extremely time consuming, and thus not very well suited for industrial applications.

A new method has been recently developed which allows an increase of the growth rate by a factor of 10 to 50. i.e. 1 nm/s to 5 nm/s.[1] It is based on low energy DC plasma enhanced chemical vapor deposition, employing $SiH_4$ and $GeH_4$ and ion energies below 15 eV.

In order to determine the strain status of the Si channel, which is relevant for its electronic properties, the SiGe buffer layers were investigated by high resolution x-ray diffraction (HRXRD) and by secondary ion mass spectroscopy (SIMS). From the HRXRD reciprocal space maps the strain status of the SiGe buffer layers was determined as a function of the Ge content. Together with the SIMS data these measurements provide information on the depth dependence of the strain.

[1]C. Rosenblad, H.R. Deller, H. von Känel, Thin Solid Films 378, 11 (1998).

# Si/SiGe Layers on Patterned Substrates for MODFET Applications

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A route for possible applications of Si/SiGe layers in Si based heterostructure devices relies on the SiGe overgrowth on patterned Si substrates.[1]

In order to gain information on the applicability of such growth modes, we have studied arrays of square Si (001) pillars, oriented along <110> directions and of lateral dimensions ranging from 3 x 3 to 20 x 20 $\mu m^2$, which were anisotropically plasma-etched to a depth of 2 µm on (001) Si substrates. On these Si pillars, employing molecular beam epitaxy, a modulation doped Si/SiGe structure was deposited (100 nm Si, graded SiGe buffer region with Ge content varying from 5 to 25 % over 500nm, followed by a 200 nm thick uniform buffer layer). A 10 nm tensile-strained Si layer was followed by a 50 nm SiGe layer and a doped SiGe layer. The degree of relaxation in the SiGe layers was investigated both by micro-Raman spectroscopy as well as by x-ray techniques. Atomic force microscopy was used to study the top surface morphology. For lateral dimensions below 10 x 10$\mu m^2$, it turns out that there is a pronounced dependence of the strain relaxation on the lateral size of the structures, as evidenced experimentally as well as by theoretical calculations which will be presented. These results are important for choosing the proper lateral dimensions of typical SiGe based transistor structures grown on patterned Si substrates, in order to achieve a given strain status for the Si channel. With the lateral size one can thus tune the confinement energies for the two-dimensional electron gas in the Si channel.

[1]R. Hammond et al. Appl.Phys.Lett. 71, 2517 (1997)