Micro- and Nanostructure Research: Cleanroom Linz

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The research in the class 100 cleanroom facility of the "*Institut für Halbleiter-und Festkörperphysik*" of the Johannes Kepler Universität Linz depends essentially on the basic support given by the Society for Micro- and Nanoelectronics (GMe). In 2005 and 2006, the focus of the research carried out in Linz continued to be on semiconductor hetero- and nanostructures. The support by the GMe was vital for a number of research grants, in particular for the *Spezialforschungsbereich Infrared Optical Nanostructures*, the initiative *Nanostructured Surfaces and Interfaces* (NSI) and supported within the framework of the *Austrian Nanoinitiative* and a number of other FWF, FFF, and EU supported research efforts. Our work includes nanostructure growth using molecular beam epitaxy and metal organic vapor phase epitaxy, nanostructure fabrication based on several lithography and etching techniques, structural, electronic and optical characterization, fundamental investigations and modeling of physical properties, and finally the realization of novel optoelectronic nanostructure devices, like lasers and detectors. In the Christian-Doppler Laboratory, which is also hosted in our institute, simulation and fabrication of photonic crystals for various optical applications is being performed, and furthermore novel microfluidic devices are being investigated.

The funding of the activities in the cleanroom at the University of Linz which is jointly used by the semiconductor physics group, the solid state physics group, and by the Christian Doppler laboratory is of vital importance for our micro- and nanostructure research activities. This basic funding through the GMe allows for investigations which are made possible through additional funds coming from the FWF, the FFF, the Christian-Doppler society, the European Union as well as through cooperations with industrial groups as listed in the report.

The material basis of the work at our Institute is given by the epitaxial growth of Si/SiGe, IV-VI compounds, GaN based and organic hetero-and nanostructures using growth techniques like molecular beam epitaxy and metal organic chemical vapor phase deposition as well as hot wall epitaxy. In cooperation with the University of Lund, Sweden, the Institute is also involved in the growth of III-V compound nanowires, in particular on Si. The fundamental structural, electronic, optical and magnetic properties of nanostructures and semiconducting layers are studied using a large variety of characterization techniques. These range from advanced x-ray scattering techniques using synchrotron radiation, high-resolution electron microscopy, scanning force and scanning tunneling microscopy, optical spectroscopy, magnetic Squid investigations as well as low temperature magnetotransport measurements. The focus of research is to correlate the electronic properties of nanostructures with the fabrication processes and structural properties, taking advantage of the complementarity of information gained by the different techniques and modeling tools.

As far as device related studies are concerned, vertical microcavity lasers for the mid-infrared were realized based on broad band PbEuSe/BaF_2 broad band Bragg mirrors with cw emission up to 135K. With additional support from the company Infra-Tec dual band PbTe/BaF_2 Bragg mirrors with broad stop bands grown by MBE on Si (111) sub-

strates were realized, which offer applications for sensing in the spectral range of the two atmospheric windows in the infrared. For the mid-infrared also narrow-band lead-salt based photodetectors as well as solution-processible nanocrystal photodetectors were realized, the latter ones with so far unparalleled properties. Based on colloidal nanocrystals waveguides were fabricated and optical gain studies were performed. In collaboration with Konarka, a technique for the structuring of organic semiconductors was developed based on optical lithography and oxygen etching. Within the Christian Doppler Laboratory vertical taper structures for a fiber to chip coupler were fabricated and analyzed.

In collaboration with Electronic Vision a technique for preparing microfluidic devices in a special resist (Su 8) was developed based on a low temperature wafer bonding process, which turned out to be a viable MEMS fabrication technique.

The successful MOCVD growth of GaN and Fe doped GaN was made possible by careful in-situ investigations based on optical ellipsometry and in-situ x-ray diffraction studies which led to a superior control of growth rates. Hall effect, photoluminescence in GaN:Fe and GaFeN:Mg layers were performed, the magnetic properties of these materials were investigated as a function of the co-doping, with Mg using SQUID magnetometry, magnetic resonance, electron spin resonance, having spintronic applications in mind. In the magnetic semiconductor system GeMnTe, grown by MBE in Linz, carrier-mediated ferromagnetism with Curie temperatures exceeding 200 K could be found.

In the SiGe system growth studies were focused on the realization of perfect two-dimensional lattices of SiGe islands on prepatterned Si substrates, as well as on the growth of Si islands on Ge substrates. A combination of structural characterization and photoluminescence studies was used to investigate the electron-hole recombination channels of electron-hole pairs in strained Si and SiGe islands, for which quite elaborate band-structure calculations including inhomogeneous strain fields were performed. In such structures also electron spin resonance experiments were performed and as compared to III-V compounds exceptionally long T_1 and T_2 times were observed. The transport properties of holes in undulated SiGe channels, grown on Si step-bunching templates, were studied in detail.

The study of IV-VI compound nanostructures was continued leading again to important results. A study of the overgrowth of PbSe quantum dots by PbTe and PbEuTe was performed and the shape transitions of the PbSe islands were investigated in detail using scanning tunneling microscopy, giving insight in details of the capping process. The formation of PbTe quantum dots in a zinc-blende CdTe matrix was investigated by transmission electron microscopy, bright photoluminescence was observed from these dots which are formed on the basis of a mechanism barely exploited so far for nanostructure formation.

In the electric/electronic application field, devices such as quantum dot and single electron transistors were formed in the Si/SiGe and AlGaAs/GaAs material systems and investigated in the milli-Kelvin regime.

The fabricated structures from the Institute in Linz were supplied also to external research groups in the framework of long term international collaborations. On the other hand, also materials and structures including SiGe as well as GaAs/GaAlAs based structures are supplied for studies in Linz from outside groups, in particular from the Technical University Vienna, for further processing and analysis with techniques developed at our institute.

The research activities are embedded in several large research initiatives and project clusters such as the IRON special research program, the NIS Nanostructured Surface and Interface project cluster, as well as the SANDiE European network of excellence and several other EU funded research projects. The principal investigator of a National

Research Network entitled “Interface Controlled Functionalised Organic Films”, which is funded by the FWF, is based in our Institute. In the reporting period also the PLATON project within the Austrian Nanoinitiative, in cooperation with the Technical University of Vienna and several companies, was evaluated successfully and will start in 2007.

A detailed presentation of the investigations carried out, and of the device fabrication is given below, in the individual reports.

Research Activities

Material Growth and Analysis

Mid-Infrared Optoelectronics

Microfluidics

Magnetic Semiconductors

SiGe Nanostructures

IV-VI Compound Nanostructures

Quantum Devices and Single Electron Transistors

Project Information for 2005 and 2006

Project Manager

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Project Group

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Schäffler	Friedrich	University professor	
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Springholz	Gunther	Associate professor	
Sitter	Helmut	Associate professor	
Bonanni	Alberta	Assistant professor	
Heiss	Wolfgang	Assistant professor	
Fromherz	Thomas	Assistant professor	
Stangl	Julian	Assistant professor	
Binder	Fritz	Technician	
Bräuer	Stephan	Technician	
Fuchs	Othmar	Technician	
Jägermüller	Josef	Technician	
Nusko	Ekkehard	Electronics Engineer	
Teuchtmann	Michael	Technician	FWF
Vorhauer	Ernst	Electronics engineer	
Andreeva	Svetlana	Lab Technician	FWF
Halilovic	Alma	Lab Technician	
Hasenfuss	Christine	Lab Technician	CD Lab
Praus	Antonia	Lab Technician	1/2 position
Burgstaller	Elisabeth	Phys. Lab. Assistent	1/2 position
Firmberger	Johanna	Apprentice	
Hingerl	Kurt	Head of CD Lab	
Holy	Vaclav	Guest Researcher	Charles Univ. Prag
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Wolos	Agnieszka	Post Doc	FWF
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Azimi[2]	Hamed	Ph.D. student	CDG
Baumgartner	Eugen	Ph.D. student	FWF
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Gruber	Daniel	Ph.D. student	Uni Linz
Grydlik	Martyna	Ph.D. student	FWF
Hernández Sosa	Gerardo	Ph.D. student	Scholarship from Mexico
Holly	Roman	Ph.D. student	CDG
Kaufmann	Erich	Ph.D. student	FWF
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Lavchiev	Ventsislav	Ph.D. student	CDG
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Matei	Dan	Ph.D. student	FWF
Mundboth	Rajivshing	Ph.D. student	FWF (Jan. - June)
Navarro-Quezada	Andrea	Ph.D. student	Scholarship from Mexico
Novak	Jiri	Ph.D. student	EC (SHINE, only 1 month)
Pachinger	Dietmar	Ph.D. student	FWF
Pillwein	Georg	Ph.D. student	FWF
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Rehman-Khan	Aaliya	Ph.D. student	ÖAD
Roither	Jürgen	Ph.D. student	FWF
Schmidegg	Klaus	Ph.D. student	EU ISCE-MOCVD, FWF
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Simma	Matthias	Ph.D. student	FWF
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[1] From April 2006 on
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Aynul	Islam	Diploma student	
Bergmair	Michael	Diploma student	
Bergmair	Iris	Diploma student	
Brehm	Moritz	Diploma student	
Eibelhuber	Martin	Diploma student	
Groiss	Heiko	Diploma student	
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Publications in Reviewed Journals

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1. G. Bauer, Structural investigations of self-assembled SiGe/Si islands, 4th International Conference on Quantum Dots, May 1-5, 2006, Chamonix-Mont Blanc, France.

2. G. Bauer, “Structural Characterization of SiGe islands based on x-ray scattering diffraction techniques”, International Conference on Epitaxial Growth of Semiconductor Nanostructures, Bonassola, Italien, 17.09. – 21.09.2006
3. G. Bauer, “2D- and 3D-ordered islands: Initial stages of growth and structural characterization”, Workshop on Positioning of Single Nanostructures, Freudenstadt, Germany, 01.11. – 03.11.2006.
4. Friedrich Schäffler, Perspective of MBE-grown SiGe quantum structures, 14th International Conference on Molecular Beam Epitaxy (MBE 2006), 3-8 September 2006, Tokyo, Japan.
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12. G. Springholz, Photonic Structures and Devices for the Mid-Infrared Spectral Region, Colloquium at the Montanuniversität Leoben, 20.6.2006.
13. G. Springholz, Epitaxial Hetero- and Nanostructures: Properties and Applications, Colloquium at the University of Vienna, 9.6.2006.
14. J. Stangl, B. Mandl, E. Wintersberger, R.T. Lechner, C. Mocuta, W. Seifert, G.Bauer, X-ray diffraction from semiconductor nanostructures, 9th International Conference on X-ray and Neutron Scattering (SXNS 9), Taipei, Taiwan, 16.-20.07.2006
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29. G. Bauer, “20 Jahre Wahlfachgruppe Werkstoffe der Elektronik” (Seminarvortrag), Montanuniversität Leoben, 17.06.2006.
30. G. Bauer, “Growth and characterization of 2- and 3-dimensionally ordered quantum dots”, 7th International Conference on New Phenomena in Mesoscopic

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   Electro-optic memory effect at 1.54 μm Si:Er light-emitting diodes (Poster)
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   Ferromagnetic behavior of GaN:Fe and (Ga,Fe)N:Mg below and above the Fe solubility limit
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28th International Conference on the Physics of Semiconductors, 24.-28.07.2006, Vienna, Austria

10. A. Wolos, W. Jantsch, K. Dybko, Z. Wilamowski, Cz. Skierbiszewski
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13. C. Simbrunner
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137. "Circular Photonic Crystals" 1st International Workshop on photonic Crystals, Mashad, invited, September 2005, Kurt Hingerl

138. "Curvilinear and Circular Photonic Crystals" Gesellschaft für Mikroelektronik, invited, March 2005, Kurt Hingerl

139. "Curvilinear and Circular Photonic Crystals" Invited talk, Kurt Hingerl, XVth Int. Conf. on Material Research, August 2005, Cancun

140. "Fabrication of a silicon vertical taper structure connecting fibers to high index waveguides using KOH anisotropic etching", R. Holly and K. Hingerl, Micro and Nano-Engineering Conference, MNE 2005, September 2005, Vienna

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142. "Finite Difference Time Domain Simulations of Photonic Crystals" 1st International Workshop on photonic Crystals, Mashad, invited, September 2005, Javad Zarbakhsh

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Patents

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2. “Speicherelement für eine optische Signalausgabe”, D. I. Kryzhkov, W. Jantsch, B.A. Andreev, T. Gregorkiewicz, Z. F. Krasilnik, V.P. Kuznetsov, Patentanmelding 3A A 99/2006 am 20. Jänner 2006
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Diploma Theses

Finished in 2005:

1. Matthias Wegscheider
   “Growth and Optical Characterisation of Nitride-based Diluted Magnetic Semiconductors”

Finished in 2006:

1. Moritz Brehm
   ”Photoluminescence investigation of SiGe and InAs1-xPx nanostructures”
2. Heiko Groiss
   ”Transmission electron microscopy of self-organized PbTe/CdTe nanocrystals”
3. Martyna Grydlik
   “Low temperature process for integrating Si based infrared photodetectors into optical resonators”
4. Thomas Hörmann
   “Modellrechnungen zum Metall-Isolator-Übergang in einer zweidimensionalen Silizium-Inversionsschicht in der Dipol-Streuungsnäherung”
5. Stefan Krimbacher
   “Funktionsweise der Solarzelle mit Betonung der didaktischen Aufbereitung”
6. Bernhard Mandl
   “Au-free growth of nanowires and their characterization”

7. Pichler Stefan
   "Nanokristall basierende elektrooptische Bauteile"
   (Supervisor: W. Heiss)

Current works:

1. Elisabeth Lausecker
   "Large-area high resolution microcontact printing"
2. Oliver Majovsky
   "p-Modulationsdotierung auf verkippten Si(001) Substraten"
3. Michael Niedermayr
   "Herstellung von Einzelelektronen-Transistoren auf der Basis von Nanokristallen"
4. Tomoyuki Suzuki
   "Quantum Dots Simulation with Finite Element Method"
5. Anzengruber Johannes
   "Optische Resonatoren für die Molekülspektroskopie"
   (Supervisor: W. Heiss)
6. Kirchschlager Raimund
   "Magnetooptische Eigenschaften von Eu-Chalcogeniden"
   (Supervisor: W. Heiss)
7. Eibelhuber Martin
   "Epitaktische BaF2/Bleisalz Heterostruktur-Bauteile für das mittlere Infrarote"
   Supervisor: W. Heiss)
8. Plochberger Birgit
   "Ba doped C60 layers for organic FET's"
   (Supervisor: H. Sitter)
9. Martin Quast
   "Transport phenomena in Fe-doped GaN"
   (Supervisor: A. Bonanni)

Doctor's Theses

Finished in 2005:

1. M.Sc. Jiri Novak
   "Untersuchung der strukturellen Eigenschaften von Quantenpunkten"
2. Dipl.Ing. Klaus Schmidegg
   "Growth and optical characterisation of GaN and its ternary compounds "
3. Dipl.Ing. Gernot Fattinger
   "Acoustic Wave Phenomena in Multilayered Thin Film Layer Stacks"

Finished in 2006:

1. DI Herbert Lichtenberger
   "Kinetic and strain-induced seof-organization of SiGe heterostructures"
2. M.Sc. Jiri Novak
   "Structural investigations of nano-islands using x-ray diffraction techniques"

Current works:

1. M.Sc. Laurel Abtin
   "STM investigation on self-assembled IV-VI semiconductor nanostructures"
2. Dipl.Ing. Thomas Berer
   "Electronic and spin properties of Si/SiGe heterostructures"
3. Dipl.Ing. Daniel Gruber
   "Substitutional Carbon in Si/SiGeC Heterostructures"
4. Dipl. Phys. Anke Hesse
   "Strukturelle Untersuchungen an Halbleiternanostrukturen"
5. M.Sc. Dmytro Lugovyy
   "Investigation of vertical and lateral ordering in self-organized PbSe quantum dot superlattices"
6. M.Sc. Dan G. Matei
   "Scanning tunneling microscopy invetsigations of self-assembled semiconductor nano-structures"
7. Dipl.Ing. Dietmar Pachinger
   "High Mobility Si/SiGe Heterostructures for spintronic Applications"
8. Dipl.Ing. Georg Pillwein
   "Elektrische Untersuchungen von Quanteneffekten an Nanostrukturen"
9. Dipl.Ing. Patrick Rauter
   "SiGe nanostructures for next generation infrared detectors"
10. M.Sc. Aaliya Rehman Khan
    "Growth and structural characterisation of Si/SiGe hetero- and nanostructures"
11. Dipl.Ing. Mathias Simma
    "Photoleitungsuntersuchungen an Quantenpunkten"
12. Dipl.Ing. Eugen Wintersberger
    "Röntgenbeugung und –reflexion an Si/SiGe/GaAs Hetero- und Nanostrukturen "
13. Dipl.Ing. Joachim Achleitner
    "Simulation magnetooptischer Effekte in EuTe"
    (Supervisor: W. Heiss)
14. Dipl. Ing. Eugen Baumgartner
    "Optoelectronic devices based on nanocrystals"
    (Supervisor: W. Heiss)
15. Dipl.Ing. Michaela Böberl
    "Electro-optical IV-VI devices for the mid-infrared"
    (Supervisor: W. Heiss)
16. Mag. Erich Kaufmann
    "Lateral emitting lead-salt microlasers"
    (Supervisor: W. Heiss)
17. M.Sc. Maksym Kovalenko
    "Synthesis and characterization of nanocrystals for the mid infrared"
    (Supervisor: W. Heiss)
18. Dipl.Ing. Hans Malissa
    "Spin properties of low-dimensional systems"
    (Supervisor: W. Jantsch)

19. Dipl.Ing. Jürgen Roither
    "Light emitting nanodevices: Novel concepts and their realization"
    (Supervisor: W. Heiss)
20. Dipl.Ing. Clemens Simbrunner
    "MOCVD growth and In-situ characterization of ferromagnetic nitride semiconductors."
    (Supervisor: H. Sitter)
21. Dipl.Ing Walter Söllinger
    "Monte Carlo simulations of spin-related phenomena in magnetic semiconductor structures"
    (Supervisor: W. Heiss)
22. M.Sc. Andrea Navarro-Quezada
    "Magnetic nanostructures on nitride surfaces for spintronics applications"
    (Supervisor: A. Bonanni)
23. M.Sc. Gerardo Hernandez Sosa
    "Growth and Characterization of selforganised organic nanostructures"
    (Supervisor: H. Sitter)
24. Dipl.Ing Matthias Wegscheider
    "Optical characterization of transition metal doped ferromagnetic nitrides"
    (Supervisor: A. Bonanni)

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Industrial Cooperations

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5. Lumics GmbH, Berlin, Germany
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9. Siemens AG, Corporate Technology, Materials and Manufacturing, Innovative Electronics, D-91050 Erlangen, Deutschland, w4.siemens.de/ct/de
10. SENTECH Instruments GmbH, 12489 Berlin, Deutschland, www.sentech.com
11. ST Microelectronics, Crolles CEDEX, France, www.st.com
12. TeraView Ltd., Cambridge, UK;
13. Thales, Paris, France, www.thalesgroup.com
14. Toshiba Research Europe Ltd, Cambridge, UK;
15. Unaxis Balzers AG, Liechtenstein;
16. Unaxis (Balzers), Trübbach, Schweiz, www.unaxis.com

17. Upper Austrian Research GmbH, TECHCENTER Linz-Winterhafen, Hafenstrasse, 47-51, A-4020 Linz, www.uar.at
18. SOITEC, Crolles, France

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2. Charles University Prague, Czech Republic
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4. Experimentalphysik I, Universität Bayreuth, Germany
5. FOM-Institute for Plasma Physics, Rijnhuizen, The Netherlands.
6. Forschungszentrum Jülich, Deutschland
7. Heriott Watt University, Edinburgh
8. Inst. for Chemistry and Technology for organic materials, TU Graz
9. Inst. for computational solid state physics, Montanuniversität Leoben
10. Inst. for Physical Chemistry, University Chernivtsi, Ukraine
11. Inst. für Angewandte Physik, Univ. Linz
12. Inst. für Experimentalphysik I, Universität Bayreuth, Deutschland
13. Inst. für Experimentalphysik, Universität Graz, Graz, A
14. Inst. für Festkörperelektronik, TU Wien
15. Inst. für Festkörperphsik, TU Graz
16. Inst. für Festkörpertheorie und Theoretische Optik, Universität Jena, Germany
17. Inst. für Mikroelektronik, TU Wien
18. Inst. für Physik, Montanuniversität Leoben
19. Inst. für Physikalische Chemie, Universität Linz, A
20. Inst. of Physics, Polish Academy of Sciences, Warschau
21. Laboratorium für Festkörperphysik, Eidg. Technische Hochschule Zürich, Zürich
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31. Technical University Vienna
32. Thales Research and Technology, France
33. Universität Graz, Institut für Experimentalphysik

34. Universität Jena
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