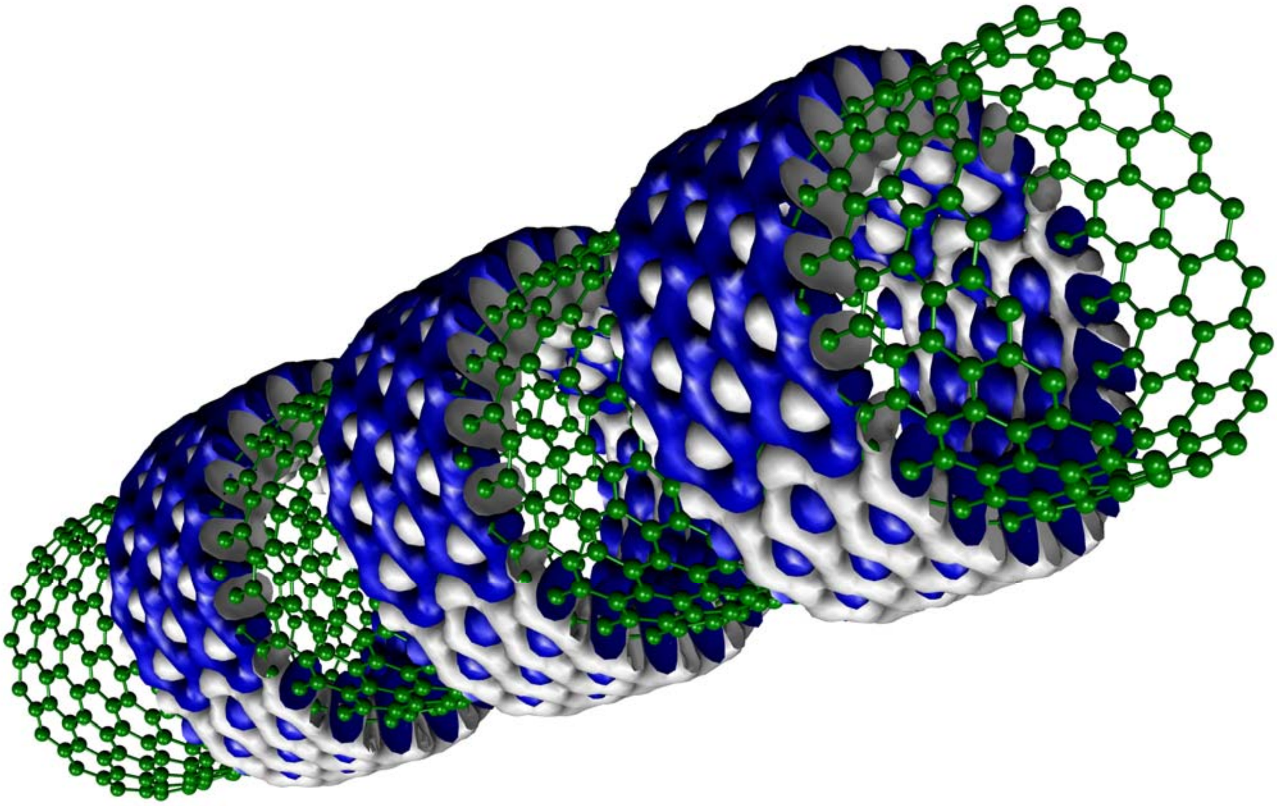
Technische Universität Berlin

Institute of Solid State Physics

Institut für Festkörperphysik

2003 - 2004



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Front Cover

Electronic wavefunction of a (19,0) carbon nanotube. Blue and white correspond to different signs of the wavefunction. The carbon atoms are shown in green. (From Carbon Nanotubes: Basic Concepts and Physical Principles, S. Reich, C. Thomsen, and J. Maultzsch, Wiley-VCH, Berlin, 2004)

Back cover

Some of the larger projects and agencies funding our work, 2003 – 2004.

(Layout: Dipl.-Phys. M. Geller)

CONTENTS

1. PREFACE

The Institute of Solid State Physics presents its eighth biannual progress report. Founded in 1974 the Institute is located since 1985 at its site in Hardenbergstraße next to the center of Berlin, where it disposes of spacious lecture halls, seminar rooms and state-of-the-art laboratories. Our scientific work is focussed on surface science, epitaxial growth of semiconductor hetero- and nanostructures, physics of nanostructures, novel materials research as well as physics and technology of nano-photonic devices and systems. In addition, development of nanoscopic measurement techniques, like cathodoluminescence, cross-section scanning tunneling microscopy, near field scanning optical microscopy, micro-photoluminescence, and micro-Raman are common subjects of the research activities of our four scientific departments.

The new "Center of NanoPhotonics" CNP at our institute was inaugurated by the Senator of Science of Berlin, Dr. Th. Flierl, and the TUB President, Prof. K. Kutzler, in June 2004. In clean rooms up to class 10 most modern optical lithography, dry etching, oxidation, insulator and metal deposition systems, and ellipsometers for processing wafers up to 6 inch diameter are concentrated. Novel devices like Quantum Dot Vertical Surface Emitting Lasers, QD Emitters, QD Semiconductor Optical Amplifiers, QD VECSELs, … are developed based on both narrow gap nanomaterials like InAs/GaAs or widegap materials like InGaN/GaN. Most modern education and research on devices and their technology can now be offered to our students and PhD candidates. In addition, the CNP will provide assistance to small and medium size companies and act as incubator for start-ups. Its staff is presently financed by 50 % via contracts. Consumables are covered by 100 % via contracts. We are particularly indebted to the government of the State of Berlin, represented by the Science Senator, Dr. Th. Flierl, deciding to cofinance our infrastructure via the European Fund of Regional Development EFRE, to the president of TUB, Prof. K. Kutzler, its former chancellor, W. Bröker, various departments of bmb+f, DLR and VDI-TZ for cofinancing the other part. Finally we would like to express our gratitude to the directors of Heinrich-Hertz-Institute, Prof. C. Baack and Prof. J. Hesse, the head of the technology department, Dr. U. Niggebrügge, and their staff for allowing us to train our researchers in advance, such that CNP could be planned and is now operated with experienced scientists.

The activities of the institute and the large number of students, PhD candidates and postdocs we employ depend now since a decade mostly on external financial resources. The funding from TUB and our state government in Berlin covers less than 20 % of cost of consumables and equipment. Our most important funding agency continues to be the German Research Foundation (DFG). It sponsors the Center of Excellence "Growth-Related Properties of Low-Dimensional Semiconductor Structures" (Sfb 296), hosted by the institute. Cooperation on nanostructure research with colleagues from four other institutions in Berlin (Humboldt Universität, Fritz-Haber-Institute, Max-Born-Institute, and Paul-Drude-Institute) continued to intensify. In addition, projects in the frame of Sfb 290 on "Thin Metallic Films" and other projects focussing on III-nitrides, on the microscopic mechanism of epitaxial growth and on high frequency photonics were funded by DFG.

Further important projects were financed by the Federal Ministry of Research and Technology (BMBF) within its KomLaser, synchrotron radiation and high-T_c superconductor programs and by the European Union, INTAS, NATO, the Volkswagen Foundation as well as the government of the State of Berlin in the frame work of its "Zukunftsfond". The bmb+f competence center CC NanOp (Nano-Optoelectronics), established in October 1998, presented in the last years a very effective and successful means for initiating important programs on nanomaterials and devices like Nanomat and Dotcom.

We are particularly proud of being initiator and member of the presently only EU 6th framework Center of Excellence in the field of semiconductor nanostructures SANDiE. Strong links to leading international optoelectronic and communication companies like Agilent, Aixtron, Bookham, Infineon, NL Nanosemiconductors, Sentech, Siemens have been established within the framework of the above mentioned and other bilateral programs. In addition, regional and national collaborations are of largest importance for the progress reported here. Interdisciplinary research projects evolved with some of our own start-ups like LayTec or Lumics and our first joint start-up with St. Petersburg's Ioffe-Institute, NL Nanosemiconductors, which had an excellent take-off.

Know-how was transferred, graduates were hired and joint development and research contracts were obtained in the areas of measurement technologies and photonic systems. In order to protect our intellectual property better than in the past and to have a better basis for cooperation with the industry, we also continued to file for patents.

We are very grateful to all our funding agencies and their administrators and cooperating industry for their continuous help and encouragement.

The scientific part of the present report will certainly provide sufficient evidence that funding we received carried excellent results. Particular appreciation of our scientific achievements was expressed by the bestowal of a number of important awards listed in part 2 of the report.

We continue to welcome Prof. Nicolai N. Ledentsov as a temporary faculty member at the institute. He received an appointment at TU Berlin in 2003 – 2004 as a DFG Mercator Professor and - as the first external member of the faculty - of our new "International Post Graduate School of Engineering and Advanced Technologies". Presently he is on a leave of absence to serve as VP of Research at NL Nanosemiconductors GmbH at TUB.

Scientific contacts with institutions at many different locations in Europe, Japan or USA continued to flourish. Especially strong collaborations were exercised to research institutions and universities in Barcelona, Belgrade, Cambridge, Minsk, Novosibirsk, St. Petersburg, Roma, Toulouse...

Physics is a science not bound to a country or to borders. This "discovery" led an increasing number of our students and scientists in the past to pursue their research at foreign universities. We would like to thank particularly their local hosts. We will further encourage our co-workers to combine the challenge of different cultures and languages with high productivity in their scientific work.

Additional and particularly large burdens were taken over by all of the faculty staff of the institute in order to serve TUB and the scientific community as members or chairmen of committees on the local, national and international scale e.g. within advisory or program committees.

The election of Prof. Christian Thomsen as Dean of the Faculty of Mathematics and Science in spring 2003 and his devotion should be particularly mentioned here.

Finally, the enthusiasm and the dedication of our collaborators at the institute should be honoured, being fundamental to our success. The key element for future progress of the institute continues to be their motivation to generate new ideas and to work hard.

This report will

- give an overview of the formal structure of the institute and list staff and students
- summarize our teaching activities in order to provide information on our involvement in the education of young students and scientists
- summarize the scientific activities of our research groups, including lists of the approximately 300 scientific papers we published or which have been accepted for publication within the past 24 months, and of the numerous invited lectures we gave.

Dieter Bimberg
Executive director
March 2005

2. PRIZES AND AWARDS

Particular appreciation of our scientific achievements was expressed by the bestowal of a number of important awards and prizes:

Prof. Dr. Dieter Bimberg	Member of the German Academy of Natural Scientists "Leopoldina", March 2004
Prof. Dr. Dieter Bimberg	Fellow of the American Physical Society, Washington, November 2004.
Prof. Dr. Rudolf Germer	High Speed Imaging Award Symposium on High-Speed Photography and Photonics, Japan, November 2003
Dr. Kolja Haberland	Carl-Ramsauer Preis for his outstanding doctoral thesis, Berlin, July 2003
Prof. Dr. Nicolai N. Ledentsov	Fellow of the Institute of Physics, London, November 2004.
Dipl. Phys. Thorsten Kettler	Doktoranden-Förderpreis of the Wilhelm and Else Heraeus Foundation, Passau, September 2004
Dipl.-Phys. Anatol Lochmann	Doktoranden-Förderpreis of the Wilhelm and Else Heraeus Foundation, Passau, September 2004
Dipl.-Phys. Oliver Schulz	Doktoranden-Förderpreis of the Wilhelm and Else Heraeus Foundation, Passau, September 2004
Dipl.-Phys. Robert Seguin	W.E. Heraeus-Prize 2004 for his excellent and timely diploma, Berlin, July 2004
Dipl.-Phys. Till Warming	W.E. Heraeus-Prize 2003 for his excellent and timely diploma, Berlin, July 2003

3. STRUCTURE AND STAFF OF THE INSTITUTE

3.1 Office of the executive director

Prof. Dr. phil. nat. Dieter Bimberg (executive director)
Prof. Dr. rer. nat. Mario Dähne (deputy executive director)
Prof. Dr. rer. nat. Wolfgang Richter (deputy executive director)
Prof. Dr. rer. nat. Christian Thomsen (deputy executive director)
Priv.-Doz. Dr. rer. nat. Axel Hoffmann (chief operation officer)
Ulrike Grupe (administrative assistant, until November 2004)
Ines Rudolph (administrative assistant, since December 2004)

3.2 Departments of the institute

Department I:	Prof. Dr. phil. nat. Dieter Bimberg
Department II:	Prof. Dr. rer. nat. Christian Thomsen Prof. em. Dr.-Ing. Dr. h.c. mult. Immanuel Broser
Department III:	Prof. Dr. rer. nat. Mario Dähne Prof. em. Dr.-Ing. Hans-Eckhart Gumlich
Department IV:	Prof. Dr. rer. nat. Wolfgang Richter Prof. Dr.-Ing. Jürgen Sahm (until 30.09.2004)

3.3 Center of NanoPhotonics

Executive director of the Center of NanoPhotonics
Prof. Dr. phil. nat. Dieter Bimberg

Chief technology officer
Priv.-Doz. Dr. Udo W. Pohl

Deputy chief technology officer
Dr. André Strittmatter

Technical staff
Dipl.-Krist. Kathrin Schatke (department I)
Ilona Gründler (department I)
Christof Maerker (until July 2004)
Dipl.-Ing. Bernhard Tierock (since September 2004)

The Center of NanoPhotonics supports the departments of the institute by growth, processing and analysis of materials and structures. Growth activities focus on low pressure metal organic chemical vapor deposition (MOCVD). Our processing facilities were significantly advanced in 2004 by a new center for NanoPhotonics with additional spacious clean rooms (class 10 – 1000). Equipment includes dry etching, plasma deposition and optical lithography.

MOCVD of In(Ga)As/GaAs quantum dots in the Stranski-Krastanow mode was precisely controlled in-situ using reflection anisotropy spectroscopy, showing 2D island growth prior to QD formation. For InAs/GaAs depositions near the critical value for elastic relaxation, formation of a novel multimodal ensemble was found with QDs of shell-like increasing sizes. Sb used as a surfactant was shown to improve interface perfection and to advance ripening. Stacked QDs were developed for gain media in GaAs-based edge and surface emitting lasers. A transparency current density of 139 A/cm^2 was achieved for lasers emitting at 1.24 µm. Edge emitters were processed into deeply etched narrow ridge two section devices showing hybrid and passive mode locking at frequencies of 20.2 and 50 GHz, respectively. In-situ reflectance was employed for VCSEL development; during growth of a microcavity, evolution and in-situ determination of the cavity resonance was proved. Latest surface emitting lasers accomplished room temperature operation with 1.5 mW cw output power.

3.4 Workshops

Chief operations officer

Priv.-Doz. Dr. Axel Hoffmann

3.4.1 Mechanical workshop

Werner Kaczmarek (head)
Jürgen Hoppe
Lothar Kroll
Rainer Noethen
Wolfgang Pieper

3.4.2 Electronic workshop

Norbert Lindner

3.4.3 Glasstechnical workshop

Norbert Zielinski (part-time)

3.5 Affiliated scientific units

3.5.1 Center of Excellence (Sfb 296) of the National Science Foundation DFG "Growth Correlated Properties of Low-Dimensional Semiconductor Structures"

Chairman

Prof. Dr. Dieter Bimberg

Vice chairmen

Prof. Dr. Andreas Knorr (TUB)

Prof. Dr. Roland Zimmermann (Humboldt University Berlin)

Prof. Dr. Thomas Elsässer (Max-Born-Institute)

Chief operations officer

Dipl.-Phys. Andrei Schliwa

Administrative assistant

Melanie Wübbold (until September 2004)

Ines Rudolph (October/November 2004)

3.5.2 National Competence Center on NanoOptoelectronics of the Federal Ministry of Education and Research (bmb+f)

Chairman

Prof. Dr. Dieter Bimberg

Vice chairmen

Prof. Dr. Alfred Forchel (Universität Würzburg)

Dr. Norbert Grote (Heinrich-Hertz-Institute, Berlin)

Dr. Klaus Schulz (Merge Optics GmbH, Berlin)

Dr. Jörg Kropp (Infineon Technologies GmbH, Berlin)

Chief operations officer

Dipl.-Phys. Matthias Kuntz

Deputy chief operations officer

Dipl.-Phys. Oliver Schulz

Administrative assistant

Jinan Tso

3.6 External and retired faculty members of the institute

Priv.-Doz. Dr. Norbert Ernst, Fritz-Haber-Institute

apl. Prof. Dr. Rudolf Germer, Fachhochschule der Deutschen Bundespost

apl. Prof.. Dr. Holger Grahn, Paul-Drude-Institute

apl. Prof. Dr. Karl Jacobi, Fritz-Haber-Institute, retired (since February 2003)

apl. Prof. Dr. Hans-Joachim Lewerenz, Hahn-Meitner-Institute

apl. Prof. Dr. Hansjörg Maletta, Hahn-Meitner-Institute

apl. Prof. Dr. Michael Meißner, Hahn-Meitner-Institute

Prof. Dr.-Ing. Horst Nelkowski, retired (deceased 08.08.2004)

Priv.-Doz. Dr. Harm-Hinrich Rotermund, Fritz-Haber-Institute

apl. Prof. Dr. Wolfgang Treimer, Technische Fachhochschule Berlin

Priv.-Doz. Dr. Thomas Zettler, Laytec GmbH

3.7 Adjunct and guest professors, Humboldt fellows

Prof. Dr. Alexander M. Bradshaw, executive director, Max-Planck-Institut für Plasmaphysik München

Dr. Vladimir Haisler, Russian Academy of Sciences Nowosibirsk, Guest Professor

Dr. Igor Krestnikov, Russian Academy of Sciences, St. Petersburg, Humboldt Fellow

Prof. Dr. Nicolai N. Ledentsov, Russian Academy of Sciences St. Petersburg, DFG Mercator-Professor

Dr. Uk-Hyun Lee, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea

Dr. Mikhail Maximov, Russian Academy of Sciences, St. Petersburg, Humboldt Fellow

Dr. Vitali A. Shchukin, Russian Academy of Sciences St. Petersburg, Humboldt Fellow

Prof. Dr. Michael Steiner, executive director, Hahn-Meitner-Institute, Berlin

4. FOREIGN GUESTS

Department I

Yong Seok Choi, Nanolaser Lab. Phys. Dept., Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea, 18.08. – 01.09.2003

Dr. Robin Fehse, National Microelectronic Center, Cork, Ireland, 22.11.2004

Prof. Dr. Pawel Hawrylak, Institute for Microstructural Sciences, National Research Council of Canada, Ottawa, Canada, 08.06. – 10.06.2004

Dr. Leonid Ya. Karachinsky, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 07.10.2004. – 20.12.2004

Natalia V. Kryzhanovskaya, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 31.07. – 15.09.2003 and 01.07. – 20.08.2004

Simon Lautier, Ecole Polytechnique de l'Université d'Orléans, France, 28.06. – 20.8.2004

Dr. Maria Lifchits, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 21.09.2004 – 14.12.2004

Dr. Daniel Livshits, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 20.08. – 14.09.2003

Dr. Felix Martinez, Universidad Politecnica de Cartagena, Spain, 01.10. – 30.11.2003

Dr. Innokenti I. Novikov, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 18.08. – 15.10.2003

Dr. Alexey Sakharov, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia. 08.09. – 15.09.2003, 01.10. – 11.10.2003

Dr. Ilia Soshnikov, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 10.04.2003 – 30.06.2003, 15.04.2004 – 13.07.2004

Dr. Andrei F. Tsatsul'nikov, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 10.07. – 17.07.2003

Dr. Alexander V. Uskov, National Microelectronic Center, Cork, Ireland, 01.07. – 03.07.2003 and 22.11.2004

Prof. Dr. Victor Ustinov, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 23.03. – 31.03.2003.

Department II

Prof. Dr. Wolfgang S. Bacsa, Laboratoire de Physique des Solides, Université Paul Sabatier, Toulouse, France, 04.07. – 09.07.2004

Dipl.-Phys. Ayman Bassil, Laboratoire de Physique des Solides, Université Paul Sabatier, Toulouse, France, 28.11. – 06.12.2004

Prof. Nikolaus Dietz, Georgia State University, Atlanta, USA, 15.12.2003 – 08.01.2004

Prof. Konstantin Gartsmann, Weizman Institute of Science, Electron Microscopy Unit, Rehovot, Israel, 12.07. – 16.07.2004

Prof. Alejandro Goñi, Institut de Ciència de Materials de Barcelona, Bellaterra, Spain, 27.09. – 04.10.2004

Dipl.-Phys. Eduardo Machado, ICMAB, Instituto de Cienca de materiales, Consejo, Barcelona, Spain, 20.11. – 28.11.2003

Prof. Dr. Sergey Maksimenko, Institute for Nuclear Problems, Belarus State University, Minsk, Belarus, 01.01. – 31.01.2003, 01.07. – 31.07.2003 and 01.04. – 30.04.2004

Prof. Gennadi Medvedkin, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, 27.04. – 13.07.2003

Dipl.-Phys. Bozidar Nikolic, Faculty of Physics, University of Belgrade, Serbia and Montenegro, 20.06. – 18.07.2004

Prof. Dr. Pablo Ordejón, ICMAB, Instituto de Cienca de materiales, Consejo, Barcelona, Spain, 02.12. – 06.12.2004

Dipl.-Phys. Pascal Puech, Laboratoire de Physique des Solides, Université Paul Sabatier, Toulouse, France, 04.07. – 09.07.2004

Dr. Stephanie Reich, University of Cambridge, Department of Engineering, Cambridge, U.K., 27.09. – 04.10.2004, 17.11. – 21.11.2004

Dr. Gregory Slepyan, Institute for Nuclear Problems, Belarus State University, Minsk, Belarus, 01.01. – 31.01.2003, 01.07. – 31.07.2003 und 01.04. – 30.04.2004

Department IV

Dr. Oliver Briot, Universität Monpellier II, France, 28.10. – 02.11.2004

Dr. Sandhya Chandola, Trinity College, Dublin, Ireland 01.01.2003 – 31.12.2004

Prof. Dr. Anatoli Chkrebtii, University of Ontaria, Canada, 04.04. – 30.04.2003, and 28.11. – 04.12.2004

Dr. Rüdiger Goldhahn, Universität Ilmenau, Germany, 07.12. – 09.12.2004

Prof. Dr. Matt Evans, University of Wisconsin – Eau Claire, USA, 19.03.2003

Prof. Dr. Randall Feenstra, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA, 19.07. – 23.7.2003

Giannis Fragakis, University of Athens, Greece,15.06. – 29.08.2003

Konstantinos Georgarakis, University of Athens, Greece, 03.01. – 14.01.2003

Prof. Dr. John Mc Gilp, Trinity College, Dublin, Ireland, 20. – 22.04.2004

Prof. Dr. Ola Hunderi, Norwegian University of Science and Technology, NTNU, Norway, 01.10. – 29.10.2004

Georgios Katsionis, University of Athens, Greece, 02.11. – 02.12.2004

Christos Livitsanos, University of Athens, Greece, 15.06. – 29.08.2003

Prof. Dr. Bernardo Mendoza, Centro de Investigaciones en Optics, Leon, Mexico, 12.06. – 03.08.2003

Dr. Dimitra Papadimitriou, University of Athens, Greece,
19.07. – 29.08.2003 and 08.02. – 29.02.2004 and 18.07. – 29.08.2004

Dr. Olivia Pulci, Università degli Studi di Roma II, Tor Vergata, Roma, Italy,
28.10. – 03.11.2003

Charilaos Tsarouchas, University of Athens, Greece, 02.11. – 02.12.2004

Kerstin Volz, Universität Marburg, Germany, 04.10. – 08.10.2004

4.1 Talks by Guests

Dr. Claus Ascheron	**Wissenschaftliches Präsentieren oder Wie man einen guten Vortrag hält** 02.04.2003 Springer Verlag, Heidelberg, Germany
Dr. Claus Ascheron	**Electronic Publishing** 21.01.2004 Springer Verlag, Heidelberg, Germany
Prof. Alexander L. Aseev	**Research activities at the Institute of Semiconductor Physics** 06.10.2004 Institute of Semiconductor Physics, Russian Academy of Sciences, Siberian Branch, Novosibirsk, Russia
Dr. Oliver Briot	**Growth and optical properties of a new challenging nitride semiconductor : Indium Nitride** 29.10.2004 University Monpellier II, France
Yong-Seok Choi	**Quantum dots for ultra-small photonic crystal nanolasers** 21.08.2003 Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea
Prof. Dr. Anatoli Chrebtii	**Temperature dependent linear optical response of bulk GaAs: Ab-Initio Theory Versus Experiment** 01.12.2004 University of Ontario, Canada
Dr. D. J. Chu	**Recent R + D activities on optoelectronic devices and materials in EOS/ITRI** 01.09.2004 Industrial Technology Research Institute ITRI, Hsinchu, Taiwan
Dr. Philipp Ebert	**Rastertunnelmikroskopie an Störstellen in Halbleitern** 24.04.2003 Forschungszentrum Jülich, Germany

Prof. Dr. Matt Evans	**Growth of metal dimers on Si (001)** 19.03.2003 University of Wisconsin – Eau Claire, USA
Prof. Dr. Randall Feenstra	**Surface structure of GaN and AIN films** 21.07.2003 Dept. of Physics, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
Dr. Robin Fehse	**Investigation of carrier recombination processes in GaInAs/GaAs-based lasers using low-temperature and high pressure techniques** 22.11.2004 National Microelectronic Research Center, Cork, Ireland
Prof. Dr. Achim Hartschuh	**High-resolution near-field Raman and fluorescence spectroscopy on individual single-walled carbon nanotubes** 21.06.2004 Universität Siegen, Germany
Prof. Dr. Pawel Hawrylak	**Quantum dots – laboratory for correlated electron systems** 09.06.2004 Institute for Microstructural Sciences, National Research Council of Canada, Ottawa
Prof. Dr. Hans J. Herrmann	**Dünenbewegung** 06.11.2003 ICA1 der Universität Stuttgart, Germany
Prof. Dr. Ola Hunderi	**A „new“ use of Mueller matrix ellipsometry: characterisation of a spatial light modulator** 28.10.2004 Universität Trondheim, Norway
Dr. Rüdiger Goldhahn	**Anisotropy of the dielectric function for Wurtzite InN** 08.12.2004 TU Ilmenau, Germany
Dr. Evgueni Kleimenov	**In situ XPS applied to vanadium oxides** 22.04.2004 Fritz-Haber-Institute, Berlin, Germany
Natalia Kryzhanovskaya	**Optical and structural properties of InAs quantum dots grown on thick InGaAs layer** 12.09.2003 A.F. Ioffe Physico-Technical Institute, RAS, St. Petersburg, Russia

Natalia Kryzhanovskaya	**Temperature stability of InAs quantum dots overgrown by AlAs/InAlAs layers** 19.08.2004 A.F. Ioffe Physico-Technical Institute, RAS, St. Petersburg, Russia
Prof. Nicolai N. Ledentsov	**The tilted cavity concept for edge- and surface-emitting lasers** 23.09.2004 A.F. Ioffe Physico-Technical Institute, RAS, St. Petersburg, Russia
Dr. Ernst Lenz	**Analyse von Kettenabständen in XSTM-Daten** 08.05.2003 Technische Universität Berlin, Germany
Dr. Maria Lifshits	**On onion-like quantum dots** 09.12.2004 A.F. Ioffe Physico-Technical Institute, RAS, St. Petersburg, Russia
Prof. Dr. Bernhard Keimer	**Magnetische Anregungen in Hochtemperatur-Supraleitern** 08.05.2003 Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany
Dr. Theophilos Maltezopoulos	**Wave function mapping on InAs quantum dots by scanning tunneling spectroscopy** 10.11.2003 Institute of Applied Physics, University of Hamburg, Germany
Dr. Ingo Manke	**Tomographie und Kleinwinkelstreuung** 17.06.2004 Hahn-Meitner-Institute, Berlin, Germany
Prof. Dr. Bernardo Mendoza	**Layer-by-layer analysis of spectroscopic optical surface probes for semiconductors** 02.07.2003 Centro de Investigaciones en Optics, Leon, Mexico
Dr. Jens-Oliver Müller	**On the microstructure and reactivity of Diesel engine soot** 28.10.2004 Fritz-Haber-Institute, Berlin, Germany
Dipl.-Phys. Bozidar Nikolić	**Jahn-Teller effect in diperiodic systems** 28.06.2004 University of Belgrade, Serbia and Montenegro

Dr. Innokenti Novikov	**Temperature characteristics of long wavelength quantum dot lasers** 10.10.2003 A.F. Ioffe Physico-Technical Institute, RAS, St. Petersburg, Russia
Dr. Thomas Pfeiffer	**Neueste Entwicklungen in der optischen Übertragungstechnik für den Zugangsbereich** 16.11.2004 Alcatel SEL, Stuttgart, Germany
Dipl.-Phys. Pascal Puech	**Discontinuous tangential stress in double-wall carbon nanotubes** 06.07.2004 Université Paul Sabatier, Toulouse, France
Dr. Armando Rastelli	**A close look into the epitaxial growth of self-assembled quantum dots** 22.04.2004 Max-Planck-Institut für Festkörperphysik, Stuttgart, Germany
Dr. Stephanie Reich	**Nanoröhrchen aus Kohlenstoff** 18.11.2004 University of Cambridge, UK
Dr. Stephanie Reich	**Exciton-exciton resonances in nanotubes** 19.11.2004 University of Cambridge, UK
Dr. Oliver Schuhmann	**Einfluss der Stickstoffkonzentration auf das Wachstum von InGaNAs-/GaAs-Quantenpunktsystemen** 03.02.2004 Infineon Technologies, München, Germany
Dr. Pablo O. Vaccaro	**Micro-origami: A method to make self-positioning micromachined components** 17.10.2003 ATR Adaptive Communications Research Laboratories, Kyoto, Japan
Dr. Alexander V. Uskov	**On pattern-effects-free operation of QD SOAs for high-speed applications** 02.07.2003 National Microelectronic Research Center, Cork, Ireland
Dr. Alexander V. Uskov	**Quantum dot semiconductor optical amplifiers: an analog of "plasma effect" contribution into the refractive index and the cross-phase-modulation without pattern effects** 22.11.2004 National Microelectronic Research Center, Cork, Ireland

5. PARTICIPATION IN COMMITTEES

5.1 Program and Advisory Committee

Dieter Bimberg

Member of Technical Committee of IEEE Nanotechnology Council, Arlington, VA, USA, 2003

Technical Program Committee, Intern. Symp. on Compound Semiconductors, San Diego, CA, USA, 2003

Program Committee, Workshop on "Growth, Electronic and Optical Properties of Low-dimensional Semiconductor Quantum Structures", and Session Chair on "Nano-Cavities and Coherent Excitations", Schloß Ringberg, Rottach-Egern, Germany, March 2003

Intern. Scientific Committee, Intern. Conf. on Materials for Advanced Technologies ICMAT, Singapore, July 2003

Intern. Advisory Committee, The 11th Intern. Conf. on Modulated Semiconductor Structures MSS11, Nara, Japan, July 2003

Intern. Advisory Board, Intern. Symp. on Clusters and Nano-Assemblies: Physical and Biological Systems, Richmond, VA, USA, November 2003

Intern. Advisory Committee, The 11th and 12th Intern. Symp. on Nanostructures: Physics & Technology, St. Petersburg, Russia, June 2003 and June 2004

Award Committee, The 11th and 12th Intern. Symp. on Nanostructures: Physics & Technology, St. Petersburg, Russia, June 2003 and June 2004

Program Committee, Photonics Europe, Semiconductor Lasers and Laser Dynamics, Strasbourg, France, 2004

Program Committee, Intern. Photonics Research Conference "Active and Compound Semiconductor Devices", San Francisco, CA, USA, 2004

Intern. Advisory Committee, 3rd Intern. Conf. on the Physics and Chemistry of Quantum Dots. QD 2004, Banff, Canada, May 2004

Intern. Advisory Committee, 3rd Intern. Conf. Computational Modeling and Simulation of Materials, Special Symp. on Modeling and Simulating Materials Nanoworld, Acireale, Sicily, Italy, May 2004

Intern. Advisory Committee, 27th Intern. Conf. on the Physics of Semiconductors (ICPS 27), Flagstaff, Arizona, USA, July 2004

Session Chair "Quantum Dots", 27th Intern. Conf. on the Physics of Semiconductors (ICPS 27), Flagstaff, Arizona, USA, July 2004

Intern. Advisory Board, Nano Conference 2004, St. Gallen, Switzerland, September 2004

Norbert Esser

International Advisory Committee of the International Conference on Spectroscopic Ellipsometry, Wien, Austria, 2003

Axel Hoffmann

National Advisory Committee of the Workshop for Solid State Physics, DPG Frühjahrstagung 2003, Dresden, Germany, March 2003

Intern. Advisory Committee, ICNS-5, The Fifth Int. Conf. on Nitride Semiconductors, Nara, Japan, May 2003

Program Committee, PLMCN 3, 3rd Conference on Physics of Light-Matter Coupling in Nanostructures Acireale, Sicily, Italy, October 2003

Program Committee of the Workshop for Solid State Physics, DPG Frühjahrstagung 2004, Regensburg, Germany, March 2004

Intern. Advisory Committee, PLMCN 4, IV. International Conference on Physics of Light-Matter Coupling in Nanostructures, St Petersburg, Russia, June/July, 2004

Intern. Advisory Committee, IWN 2004, International Workshop on Nitride Semiconductors, Pittsburgh, USA, July 2004

Intern. Advisory Committee, 27th International Conference on the Physics of Semiconductors (ICPS 27), Flagstaff, Arizona, USA, July 2004

Nicolai Ledentsov

Chair of Physics and Simulation of Optoelectronic Devices XI, Session 2 – Physics of Quantum Dot Lasers, SPIEs Conf. Photonics West, San José, California, USA, January 2003

Wolfgang Richter

Program Committee of the Optics of Surfaces and Interfaces Conference, OSI-V (2003), León, Guanajuato, Mexico

Program Committee of the European Workshop on Metal Organic Vapour Phase Epitaxy, EW MOVPE X (2003), Lecce, Italy

Program Committee of the 3rd International Conference on Spectroscopic Ellipsometry, ICSE-3 (2003), Vienna, Austria

Advisory Committee of the International Conference on Metal Organic Vapor Phase Epitaxy, ICMOVPE XII (2004), Lahalna, Hawaii, USA

Advisory Committee of the EPIOPTICS –8 (2004) Workshop, Erice, Italy

Christian Thomsen

Member of the Board of "Electronic Properties of Novel Materials", Kirchberg, Austria

5.2 Editorial duties / Boards of institutes and companies

Dieter Bimberg

Chairman of the Scientific Advisory Committee, NL Nanosemiconductor GmbH, Dortmund

Member of the Scientific Advisory Committee, PCB Ltd., Tel Aviv

Member of the Board of the International Postgraduate School of Engineering and Science, Berlin

Nicolai Ledentsov

Editorial Board of Semiconductors and Semiconductor Science and Technology

Wolfgang Richter

Member of the council of the Physikalische Gesellschaft zu Berlin e.V. (until Feb. 2004)

Member of the council of the Deutsche Physikalische Gesellschaft e.V. (until Dec. 2004)

Member of the working group "Solar Materials", Hahn-Meitner-Institute, Berlin

Member of the council of the ISI, Forschungszentrum (FZ) Jülich

Christian Thomsen

Editor physica status solidi

Scientific Advisory Board; Laser und Medizintechnik GmbH Berlin, LMTB

Scientific Advisory Board of the Max-Born-Institute Berlin

Member of the council of the Physikalische Gesellschaft zu Berlin e.V. (since March 2004)

6. EXTERNAL COLLABORATIONS

Department I

Universität Antwerpen, Belgium, Prof. J.T. Devreese, Prof. F. Peeters

National Technical University, Athens, Greece, Prof. Dr. Y. Raptis, Dr. A. Kontos

Universidad de Aveiro, Portugal, Prof. N. Sobolev

Humboldt Universität zu Berlin, Germany, Prof. O. Benson, Prof. F Henneberger, Prof. R. Köhler, Prof. Dr. W. Neumann Prof. M. von Ortenberg, Prof. R. Zimmermann

University of Cambridge, U.K., Prof. I. White, Dr. R. Penty

University of Cincinnati, Ohio, USA, Prof. Dr. H.-P. Wagner

Universität Dortmund, Germany, Prof. U. Woggon, Dr. P. Borri

National Institute of Standards and Technology, Gaithersburg, USA, Dr. M. Hanke

University of Glasgow, U.K., Prof. J. Marsh and Dr. C. Bryce

Universität Karlsruhe, Germany, Prof. D. Gerthsen

Denmark Technical University, Lyngby, Denmark, Prof. M.J. Hvam and Prof. D. Birkedal

Universität Leipzig, Germany, Prof. M. Grundmann

Katholieke Universiteit Leuven, The Netherlands, Prof. V. Moshchalkov, Dr. M. Hayne

Universität Magdeburg, Germany, Prof. J. Christen, Prof. A. Krost

University of Nottingham, U.K., Prof. L. Eaves, Dr. M. Henini

Universita di Roma „La Sapienza", Italy, A. Polimeni, M. Capizzi

Universität Linz, Austria, Prof. G. Bauer, Dr. A. Darhuber

Belarus State University Minsk, Belarus, Dr. M.V.P. Kalosha

University of Sheffield, U.K., Prof. M. Skolnick, Dr. D. Mowbray

University of Southern California, Los Angeles, USA, Prof. A. Madhukar

University of Surrey, U.K., Prof. O. Hess, Dr. E. Ehrig

University of Tokyo, Japan, Prof. Y. Arakawa

Yerevan State University, Armenia, Prof. A. Kirakosyan

Heinrich-Hertz-Institute, Berlin, Prof. C. Baack, Dr. N. Grote, Dr. B. Döldissen, Dr. U. Niggebrügge

Instituto de Microelectronica de Madrid, Spain, Dr. J.M. Garcia

A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, Prof. Zh.I. Alferov, Prof. N.T. Bagraev Prof. I. Ipatova, Prof. Dr. N.N. Ledentsov, Prof. V. Ustinov, Prof. S. Konnikov

Max-Born-Institute, Berlin, Germany, Prof. T. Elsässer

Max-Planck-Institut für Mikrostrukturforschung, Halle, Germany, Prof. U. Gösele, Dr. P. Werner, Dr. N. Zakharov

Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea, Prof. Y.H. Lee

Agilent Technologies, Ipswich, U.K., Dr. R. Harrel

Aixtron AG, Aachen, Germany, Dr. H. Jürgensen, Prof. M. Heuken

Bookham Technologies Ltd., Caswell, U.K., Dr. A. Robbins, Dr. M. Wale

CNRS-LPN, Marcoussis, France, Dr. J.-Y.Morzin

Infineon Technologies, München and Berlin, Germany, Dr. M. Schell, Dr. J. Kropp

JDS Uniphase, Eindhoven, The Netherlands, Dr. B. Verbeck

LayTec GmbH, Berlin, Germany. Priv.-Doz. Dr. Th. Zettler

Lumics GmbH, Berlin, Germany, Dr. N. Kirstaedter, Dr. K. Eberl

Merge Optics GmbH, Berlin, Germany, Dr. K. Schulz

NL Nanosemiconductors GmbH, Dortmund, Germany, Prof. Dr. N.N. Ledentsov

Osram Opto Semiconductors GmbH, Regensburg, Germany, Dr. N. Stath

Optoelectronics and Nonlinear Optics Laboratory, National University of Cork, Ireland, Prof. Dr. J. McInerney, Dr. G. Huyet

Optical Communication Research Group, University of Bristol, U.K., Prof. J. Rorison

PCB Ltd., Tel Aviv, Israel, Dr. D. Tseitlin

Sony Research Labs, Yokohama, Japan, Dr. A. Ishibashi

Toshiba, Cambridge, U.K., Dr. A. Shields

US Air Force College, Dayton, USA, Prof. J.A. Lott

U^2T Photonics GmbH, Berlin, Germany, Dipl.-Phys. A.Umbach

Department II

Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany, Dr. Siegmar Roth
Paul-Drude-Institute, Berlin, Germany, Prof. K. Ploog, Dr. H.T. Grahn
Instituto de Cienca de materiales, Consejo, Barcelona, Spain, Prof. Dr. Pablo Ordejón,
Instituto de Cienca de materiales, Consejo, Barcelona, Spain, Prof. Dr. Alejandro Goñi,
Ekatherinenburg, GUS, Dr. Ponosov
Université Montpellier, France, Prof. P. Bernier
University of Sofia, Bulgaria, Dr. Miroslav Abrashev
University of Belgrade, Serbia and Montenegro, Prof. Dr. Zoran Popović
University of Belgrade, Serbia and Montenegro, Prof. Dr. Milan Damnjanović
University of Valencia, Spain, Dr. Andres Cantarero
Laboratoire de Physique des Solides, Université Paul Sabatier, Toulouse, France, Prof. Dr. Wolfgang Bacsa
Centro Atomico, Bariloche, Argentinia, Prof. Dr. Alex Fainstein

RWTH Aachen, Germany, Prof. K. Heime
Universität Giessen, Germany, Prof. B.K. Meyer
Gesamthochschule Paderborn, Germany, Prof. K. Lischka
Walter Schottky Institut München, Germany, Prof. M. Stutzmann
Humboldt Universität zu Berlin, Germany, Prof. R. Zimmermann
Fraunhofer-Institut für Angewandte Festkörperphysik, Freiburg, Germany, Dr. F. Fuchs
Université Montpellier, France, Prof. P. Bernier
CNRS Université Montpellier, France, Prof. B. Gil
CNRS Université Grenoble, France, Dr. B. Daudin
Otto-von-Guericke Universität, Magdeburg, Germany, Prof. J. Christen
Technical University of St. Petersburg, Russia
Mie University, Japan, Prof. K. Hiramatsu
University of Exeter, U.K., Dr. A. Plaut
A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, Prof. Zh.I. Alferov
Belarus State University, Minsk, Belarus, Dr. M.V.P. Kalosha
Aixtron AG, Aachen, Germany, Prof. Dr. M. Heuken
Siemens AG, Erlangen, Germany, Dr. C. Fricke

Department III

Freie Universität Berlin, Germany, Prof. G. Kaindl
Fritz-Haber-Institute, Berlin, Germany, Prof. K. Horn, Prof. K. Jacobi, Prof. M. Scheffler
Forschungszentrum Jülich, Germany, Dr. P. Ebert

Hahn-Meitner-Institute, Berlin, Germany, Dr. R. Scheer
Humboldt Universität zu Berlin, Germany, Prof. R. Manzke
Infineon Technologies, Dr. L. Geelhaar
Technische Universität Dresden, Germany, Prof. C. Laubschat, Dr. S. Molodtsov
Universidad del País Vasco, San Sebastián, Spain, Prof. J.E. Ortega
University of Texas, Austin, USA, Prof. Ken Shih

Department IV
Carnegie Mellon University, Pittsburgh, USA, Prof. Dr. Randall M. Feenstra
Ferdinand-Braun-Institute, Berlin, Germany, Dr. Markus Weyers
Forschungszentrum Jülich, ISI, Germany, Prof. Dr. Heribert Wagner
Forschungszentrum Jülich, ISI, Germany, Prof. Dr. Hans Lüth
Friedrich-Schiller-Universität, Jena, Germany, Prof. Dr. Friedhelm Bechstedt
Freie Universität Berlin, Germany, Prof. Dr. Klaus Lüders, Prof. Dr. Klaus Baberschke
Hahn-Meitner-Institute, Berlin, Germany, Prof. Dr. Martha Ch. Lux-Steiner
International University Bremen, Germany, Prof. Dr. Veit Wagner
Max-Planck-Institute, Stuttgart, Germany, Prof. Manuel Cardona
National Technical University, Athens, Greece, Dr. A. Kontos, Prof. Dr. Liarokapis, Prof. Dr. D. Papadimitriou, Prof. Dr. Y. Raptis
Norges Tekniske Hogeskole, (NTNU), Trondheim, Norway, Prof. Ola Hunderi
Norwegian University of Science and Technology, Trondheim, Norway, Prof. B. O. Fimland
North Carolina State University, NCSU, Raleigh, USA, Prof. Dave Aspnes
Oliver Lodge Lab., Liverpool, U.K., Prof. Peter Weightman
Polish Academy of Science, Warsaw, Poland, Prof. Marian Herman
KFKI Research Institute Particle and Nuclear Physics of the Hungarian Academy of Sciences, Budapest, Hungary, Dr. D.L. Nagy
Sentech Instruments, Berlin, Dr. Albrecht Krüger
Sony Corp., Quantum Photon Delivery Lab., Yokohama, Japan, Dr. A. Ishibashi
Technische Universität Chemnitz, Germany, Prof. Dr. D.R.T. Zahn, Dr. H.-P. Wagner
Trinity College Dublin, Physics Dept., Ireland, Prof. John McGilp
Universität Bremen, Germany, Prof. Dr. D. Hommel
Universität Karlsruhe, Germany, Prof. Dr. D. Gerthsen, Dr. A. Rosenauer, Dr. D. Litvinov
Universität Magdeburg, Germany, Dr. J. Bläsing
Universität Würzburg, Physikalisches Institut, Germany, Prof. Dr. J. Geurts, Dr. A. Waag
University of Rome II, Italy, Prof. R. Del Sole, Prof. P. Chiaradia
University of Toronto, Canada, Prof. J. Sipe
University of Technology, Sydney, Australia, Prof. Tony Moon
University of Lecce, Italy, Prof. Dr. N. Lovergine, Dr. P. Prete

7. TEACHING

Lab Course in Methods of Applied Physics I and II
D. Bimberg

Lab Course in Advanced Experimental Physics
D. Bimberg, M. Dähne, W. Richter, C. Thomsen

Applied Physics I + II
D. Bimberg, R. Heitz, A. Hoffmann, M. Weyers

Seminar on Photonics: Materials, Devices, Systems
D. Bimberg, R. Heitz, A. Hoffmann, U.W. Pohl

Nanoepitaxy – Nanooptoelectronics
N.N. Ledentsov

Introduction to the Basics of Magnetic Resonance Spectroscopy
W. Gehlhoff

Macroscopic Quantum Phenomena in Solid State Physics
A. Hoffmann

Modern Methods of Solid State Physics
A. Hoffmann

Semiconductor Epitaxy
U. W. Pohl

Seminar on Photonics
D. Bimberg, U. W. Pohl

Current Nobel Prizes in Physics
U. W. Pohl

Lab Course in Advanced Experimental Physics
D. Bimberg, M. Dähne, W. Richter, C. Thomsen

Solid-State Physics I + II
W. Richter, N. Esser, N. Nickel

Exercises to Solid-State Physics I + II
W. Richter, P. Vogt

Advanced Lab. Course
W. Richter, N. Esser

Modern Concepts of Epitaxy
U. W. Pohl, J. Neugebauer

Seminar "Advances in Solid Surfaces"
N. Esser, W. Richter

Introduction to Physics for Engineering Students I +II
C. Thomsen

Introduction to Physics: Problem Solving for
Graduate and Advanced Diploma Students
C. Thomsen

Special Topics in Physics for Engineering Students
C. Thomsen

Special Topics in Semiconductor and Nanotube Research
C. Thomsen

Experimental Physics I + II
M. Dähne, H. Eisele

Advanced Experimental Physics II: Solid State Physics
M. Dähne, H. Eisele

Introduction to Physics I + II for Chemistry Students
N. Esser, I. Loa, M. Dähne, H. Eisele

Seminar on Surfaces, Interfaces and Nanostructures
M. Dähne, S. K. Becker, H. Eisele, K. Hodeck, A. Lenz, R. Timm

Student Seminar on Solid State Physics
D. Bimberg, M. Dähne, W. Richter, C. Thomsen

Experimental Surface Physics
N. Ernst

Physics of Organs of Perception
R. Germer

Physics of Electronic Devices
R. Germer

Ultrasonics and Phonons
R. Germer

X-ray and Neutron Optics
W. Treimer

X-ray Interferences and Applications I + II
W. Treimer

Electron Spectroscopy of Surfaces
K. Jacobi

Photo-Electro Chemical Solar Energy Conversion
H.-J. Lewerenz

Photovoltaic Solar Cells
H.-J. Lewerenz

Neutron Scattering (Statics and Dynamics of Magnetic Model Systems)
M. Steiner

Neutrons as an Efficient Tool to Investigate Condensed Matter
M. Steiner, K. Siemensmeyer

Structure and Dynamics of Disordered Solid State Systems
M. Meißner

Neutron Scattering and Dynamics of Condensed Matter
K. Siemensmeyer

8. PATENTS

Frei triggerbarer, jitterarmer Halbleiterlaser mit Selbstinjektion
PCT/DE03/03212
Dr. Dieter Huhse, Dr. Olaf Reimann, Prof. Dr. Dieter Bimberg

Contact structure for an electric II/VI semiconductor component and a method for the production of the same
US 6,673,641 B1
Dr. Matthias Straßburg, Dipl.-Phys. Oliver Schulz, Priv.-Doz. Dr. Udo W. Pohl, Prof. Dr. Dieter Bimberg

Verfahren zur Verbesserung der Effizienz von epitaktisch hergestellten Quantenpunkt-Halbleiterbauelementen
P118201DE/PCT
Dr. Roman Sellin, Prof. Dr. Nicolai N. Ledentsov, Prof. Dr. Dieter Bimberg

Elektrooptisches Sampling im Frequenzbereich mittels gesteuerter Phasenverschiebung
Anmeldung vom 17.03.2003
Dr. Dieter Huhse, Dr. Olaf Reimann, Prof. Dr. Dieter Bimberg

Messsystem zur Bestimmung der Übertragungseigenschaften von optischen und elektrooptischen Komponenten
Anmeldung vom 26.05.2003
Dr. Dieter Huhse, Dr. Olaf Reimann, Prof. Dr. Dieter Bimberg

Verfahren zur Epitaxie von (Indium, Aluminium, Gallium)-nitridschichten auf nicht-planaren Si-Substraten
Anmeldung vom 25.11.2004
Prof. Dr. Dieter Bimberg, Dr. André Strittmatter, Dipl.-Phys. Lars Reißmann

9. SCIENTIFIC ACTIVITIES

9.1 Department I

Prof. Dr. phil. nat. Dieter Bimberg

9.1.0 Staff

Secretary

Monika Michel (until October 2004)
Ulrike Grupe (since December 2004)

Technical staff

Jörg Döhring
Ilona Gründler
Dipl.-Ing. Bernd Ludwig
Dipl.-Krist. Kathrin Schatke

Permanent guest scientists

Prof. Dr. Jürgen Christen
Priv.-Doz. Dr. Armin Dadgar
Prof. Dr. Vladimir Haisler
Prof. Dr. Alois Krost
Prof. Dr. Nicolai N. Ledentsov
Dr. Uk-Hyun Lee (until September 2004)
Dr. Vitali A. Shchukin

Principal scientists

Prof. Dr. Wolfgang Gehlhoff
Priv.-Doz. Dr. Robert Heitz (deceased 10.06.2003)
Priv.-Doz. Dr. Udo Pohl
Dr. André Strittmatter

Senior scientists

Dr. Friedhelm Hopfer
Dr. Dieter Huhse (until 30.04.2004)
Dr. Christian Kapteyn (until 28.02.2003)
Dr. Olaf Reimann (until 30.09.2003)

PhD candidates (status of 31.12.2004 – thesis completed = c)

Dipl.-Phys. Sebastian Bognár (c)
Dipl.-Phys. Vadim Eisner
Dipl.-Phys. Gerrit Fiol
Dipl.-Phys. Martin Geller
Dipl.-Phys. Florian Guffarth (until 31.05.2004) (c)
MSc Ilia Kaiander
Dipl.-Phys. Thorsten Kettler
Dipl.-Phys. Matthias Kuntz
Dipl.-Phys. Matthias Lämmlin
Dipl.-Phys. Marc Anatol Lochmann
Dipl.-Phys. Alex Mutig
MSc Dongxun Ouyang (until 31.12.2003) (c)
Dipl.-Phys. Holger Pfitzenmaier (until 31.05.2003) (c)
Dipl.-Phys. Konstantin Pötschke
Dipl.-Phys. Holger Quast
Dipl.-Phys. Lars Reißmann
Dipl.-Phys. Christian Ribbat (until 31.01.2003) (c)
Dipl.-Phys. Sven Rodt
Dipl.-Phys. Andrei Schliwa
Dipl.-Phys. Oliver Schulz
Dipl.-Phys. Robert Seguin
Dipl.-Phys. Roman Sellin (until 31.10.2003) (c)
Dipl.-Phys. Erik Stock
Dipl.-Phys. Till Warming
Dipl.-Phys. Momme Winkelnkemper

Diploma and teacher students (status of 31.12.2004 – thesis completed = c)

Anja Brostowski
Andreas Marent
Christian Meuer
Alexander Paarmann (until 31.05.2004) (c)
Kristijan Posilovic
Cornelia Sing (until 11.07.2003) (c)
Carola Szewc
Witlef Wieczorek

9.1.1 Summary of activities

The activities of the department are grouped in five mutually connected research areas with complementary objectives:

- epitaxy of novel nano- and heterostructures,
- physics of nanostructures,
- nanophotonics,
- high frequency photonics, and
- paramagnetic and cyclotron resonance.

A major step in advancing our growth capability was the acquisition of a new planetary 3x2" Aixtron MOCVD reactor for the growth of InGaSbAs/GaAlAs quantum dot structures. Alternative, low-pressure MO sources like tertiarybutylarsine (TBA) are used to avoid the highly toxic AsH_3. An EpiRAS200 reflection anisotropy spectroscopy sensor is used for in-situ diagnostics, providing substantially improved growth control.

The long wavelength limit of luminescence from such close to defect-free QD-layers deposited on novel strain relaxing ternary layers like InGaAs or InGaP was shifted far beyond 1.3 µm. First alternative precursor triple-stack ridge-waveguide lasers are emitting at 1.24 µm with excellent cw characteristics, like a transparency current below 10 A/cm^2 per QD-layer and η_{int} = 91.4 %. A first attempt to grow surface emitting lasers with fully oxidised mirrors based on stacking of nine layers of QDs was successful. 1.4 mW pulsed output power, an external efficiency of 45 % and 85 µA threshold current at 1.1 µm for a 9 µm aperture are extremely promising results.

InGaN insertions in GaN layers grown on Si-substrates demonstrated zero dimensional behavior. Exciton and biexcitons with huge binding energies were identified. The long-wavelength limit of such insertions was shifted up to 550 nm. Control via RAS and spectroscopic in-situ reflectance proved to be essential for the growth of complex structures based on cubic or hexagonal substrates.

The formation of ultradense arrays of QDs and their stability against Ostwald ripening was investigated theoretically leading to the discovery of the importance of short-range elastic interactions and self-relaxation energies.

QD-based technologies represent the ultimate approach for single carrier memories: All energy levels are only twofold degenerate. Coulomb repulsion in the presence of a first carrier is so strong that the localisation of the second carrier is much smaller. For DRAMs the carrier life-time in a QDs must be in the 1 ms range. The RT electron lifetime in a InAs/GaAs QD is only a few ps. QDs based on type II materials like GaSb/GaAs, where the holes are bound and/or type I QDs with large band-gap barriers were demonstrated to present a way for reaching the goal.

In addition, spectral hole burning experiments on QD - p-i-n diodes demonstrate the other basic building block of read/write for single electrons in QD memories.

Based on our 8-band k•p single particle wave-functions exciton, biexciton, trions, states were calculated including exchange and correlation in a configuration interaction scheme. See binding energies of these few-particle states are strongly dot-geometry dependent. Correlation energy in turn depends mainly on the number of bound hole states in a QD. Thus, by varying the size of a QD, the biexciton can be either bound or unbound. Cathodoluminescence spectroscopy on very perfect onion-like multimodal InAs QD-distributions confirmed the theoretical predictions. CL-spectra of short wavelength QDs using a shadow mask technique demonstrated for the first time spectral diffusion and allowed again identification of binding and antibinding biexcitons in Wurtzite structures.

Comparative near-field and beam quality (M^2) experiments on narrow-stripe QW- and QD-lasers grown by MOCVD and MBE lead to the discovery of a hitherto unknown suppression of beam-filamentation in QD-lasers. As a consequence the brilliance of QD-lasers is by far superior to that of QW-lasers. Equally important is the discovery of perfect, long-time stable operation of narrow ridge lasers down to 1 µm ridge width etched through the active layer. 1 µm ridge width lasers have a round beam profile. One consequence of both discoveries is a decrease of cost of focussing optics in fiber-optic systems by one order of magnitude.

The wavelength range of QD-lasers grown by MBE on metamorphic substrates was extended to 1.5 µm. Output power of broad area devices reached beyond 4 W. CW-output power of narrow single-mode ridges was beyond 200 W.

For many applications at 1.3 µm light sources pulsed at GHz frequencies having ps pulse width are imperative. We demonstrated the first 10 Gb/sec open-eye operation of QD-lasers at bit error rates below 10^{-12} at 1300 nm. This discovery was based on joint development with NL Nanosemiconductors and U^2 T Photonics of high speed sources with cut-off frequencies beyond 7 GHz.

Passive and hybride mode-locking present approaches to construct optical clocks at still larger frequencies. We demonstrated passive mode-locking of QD-lasers at 1.3 µm in the frequency range of 5-50 GHz with Fourier-limited pulse widths of 3 ps and uncorrelated timing jitter below 1 ps.

Including results on strongly reduced optical feedback sensitivity of QD-lasers discovered in cooperation with UCC Cork, we can state that QD-lasers are now fit for replacing the previous generation of InP-based QW-lasers at the data- and telecom-wavelengths around 1.3 µm.

Theoretical and experimental work started on QD-amplifiers indicate similar advantages of QD-SOAs as compared to QW-based ones.

Test of high-speed electronic and optical devices in the >50 GHz range presents an enormous challenge. Cut-off frequencies of present sampling oscilloscopes is much too low. We developed an electro-optical sampling system based on ultra-low fs-jitter single mode 500 fs laser pulses at arbitrary repetition rates. The laser pulses were compressed using comb-like dispersion profile fibers. Operation up to 160 GHz in testing ultrafast p-i-n diodes was demonstrated.

The contribution of the dominant native defects to the optical absorption of the ternary II-IV-V_2 compound $ZnGeP_2$ is revealed by photo-EPR investigations in combination with the first ODMR experiments. In addition, native defects in $ZnSiP_2$ could be detected for the first time.

These intrinsic defects limit promising applications of these compounds for non-linear optical devices and play a decisive role by the formation of ferromagnetic states after doping of the compound with transition metals.

In synthetic diamonds the level positions of isolated Ni and Ni-related defect pairs were determined by photo-EPR. The studies show that the Ni defects exhibit a week electron-lattice interaction.

9.1.2 Books

Epitaxy of Nanostructures
V.A. Shchukin, N.N. Ledentsov, D. Bimberg
Springer-Verlag, June 2003, ISBN 3-540-67817-4

9.1.3 Publications

The abstracts of papers marked by* are reprinted in section 9.1.7

a) Novel Nano- and Heterostructures

1.* Alternative-precursor metalorganic chemical vapor deposition of self-organized InGaAs/GaAs quantum dots and quantum dot lasers
R.L. Sellin, I. Kaiander, D. Ouyang, T. Kettler, U.W. Pohl, D. Bimberg, N. Zakharov, P. Werner
Appl. Phys. Lett. **82**, 841 (2003)

2. At the beginning of the nano-composite era
V.A. Shchukin
Proc. 2003 Advanced Research Workshop Future Trends in Microelectronics: The Nano, the Giga, the Ultra, and the Bio, FTM (2003)

3. Atomic structure of InAs and InGaAs quantum dots studied by cross-sectional scanning tunneling microscopy
H. Eisele, A. Lenz, R. Timm, Ch. Hennig, M. Ternes, F. Heinrichsdorff, A. Krost, R. Sellin, U.W. Pohl, D. Bimberg, T. Wehnert, E. Steimetz, W. Richter, M. Dähne
Proc. 26th ICPS, IOP Publishing Conf. Ser. **171**, P 199 (2003)

4. Characteristics of deep levels associated with rhodium impurity in n-type GaAs
A. Majid, M. Zafar Iqbal, S. Haidar Khan, Akbar Ali, Nasim Zafar, A. Dadgar, D. Bimberg
J. Appl. Phys. **94**, 3115 (2003)

5. Control over the parameters of InAs-GaAs quantum dot arrays in the Stranski-Krastanov growth mode
N.A. Cherkashin, M.V. Maksimov, A.G. Makarov, V.A. Shchukin, V.M. Ustinov, N.V. Lukovskaya, Yu.G. Musikhin, G.E. Cirlin, N.A. Bert, Zh.I. Alferov, N.N. Ledentsov, D. Bimberg
Semiconductors **37**, 861 (2003)

6. **Controlled self-assembly of semiconductor quantum dots using shadow masks**
T. Schallenberg, T. Borzenko, G. Schmidt, M. Obert, G. Bacher, C. Schumacher, G. Karczewski, L.W. Molenkamp, S. Rodt, R. Heitz, D. Bimberg
Appl. Phys. Lett. **82**, 4349 (2003)

7. **Deep levels in rhodium-doped p-type MOCVD GaAs**
A. Majid, M. Zafar Iqbal, A. Dadgar, D. Bimberg
Physica B **340-342**, 362 (2003)

8.* **Direct evidence of nanoscale carrier localization in InGaN/GaN structures grown on Si substrates**
I.L. Krestnikov, M. Strassburg, A. Strittmatter, N.N. Ledentsov, J. Christen, A. Hoffmann, D. Bimberg
Jpn. J. Appl. Phys. **42**, L 1057 (2003)

9. **Electron localization by self-assembled GaSb/GaAs quantum dots**
R.N. Pereira, W. Gehlhoff, A.J. Neves, N.A. Sobolev, L. Rino, H. Kanda
Appl. Phys. Lett. **82**, 4355 (2003)

10. **Evidence of quantum dots in "quantum well" InGaN/GaN structures**
I.L. Krestnikov, A. Strittmatter, A.V. Sakharov, W.V. Lundin, A.F. Tsatsul'nikov, Yu.G. Musikhin, D. Gerthsen, N.N. Ledentsov, A. Hoffmann, D. Bimberg
Proc. 26th ICPS, IOP Publishing Conf. Ser. **171**, H 163 (2003)

11. **Gallium-nitride-based devices on silicon**
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9.1.4 Invited talks

D. Bimberg

Quantum dot based devices: From dreams to reality
Workshop on Growth, Electronic and Optical Properties of Low-dimensional Semiconductor Quantum Structures, Schloß Ringberg, Rottach-Egern, Germany, February 2003

D. Bimberg

Optische Technologien – Perspektiven für Forschung und Entwicklung
VDE-Forum Berlin "Optische Technologien – Perspektiven für Forschung und Technik", Berlin, Germany, March 2003

D. Bimberg

Looking at the inside of quantum dots: HRTEM versus XSTM
Microscopy of Semiconducting Materials III Conf., Churchill College, Cambridge, UK, April 2003

D. Bimberg

Auf dem Weg zu den kleinsten Dingen – Nanos für das Jahrhundert der Photonik
Vortrag in der Urania Berlin, Germany, April 2003

D. Bimberg

Quantum dots for lasers, amplifiers and photonic systems
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D. Bimberg

Quantum dot photonics: from lasers to networks
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D. Bimberg

Quantum dot photonic devices for lightware communications
Intern. Symp. on Compound Semiconductors, San Diego, CA, USA, August 2003

D. Bimberg

Quantum dots for lasers, amplifiers and computers
Physikalisches Kolloquium, Universität Hamburg, Germany, October 2003

D. Bimberg

Quantum dots for lasers, amplifiers and computers
Physikalisches Kolloquium, Universität Magdeburg, Germany, October 2003

D. Bimberg

Quantum dot photonic devices for lightware communications
Intern. Symp. on Quantum dots and Photonic Crystals, University of Tokyo, Japan, November 2003

D. Bimberg

Quantum dots for lasers, amplifiers and computing
5th Pacific Rim Conf. on Lasers and Electro-Optics, Taipei, Taiwan, December 2003

D. Bimberg	**Quantum dots for lasers, amplifiers and computers** The 3rd Intern. Workshop on Optoelectronics, The Barbara and Norman Seiden Optoelectronics Center, Technion, Haifa, Israel, March 2004
D. Bimberg	**Auf dem Weg zu den kleinsten Dingen – Nanos für das Jahrhundert der Photonik und Medizin** 125 Jahre TU Berlin, Festwochenveranstaltung, Berlin, Germany, May 2004
D. Bimberg	**Onion-like growth of and inverted many-particle energies in quantum dots** E-MRS 2004 Spring Meeting, Strasbourg, France, May 2004
D. Bimberg	**Added value of governmental funding and established networks for start-ups** 7th Intern. Conf. on Nanostructures Materials NANO 2004, Wiesbaden, Germany, June 2004
D. Bimberg	**Quantum dot nanostructures: Paradigm changes in semiconductor physics** 20th General Conf. of the Condensed Matter Division of the European Physical Society, Prague, Czech Republic, July 2004
D. Bimberg	**Forschungsstandort Europa: Rahmenbedingungen für eine wettbewerbsfähige Forschung aus der Sicht des Forschungsalltags** Expertengespräch, Europäische Forschungsförderung, Akademie der Konrad-Adenauer-Stiftung, Berlin, Germany, September 2004
D. Bimberg	**Modellierung der elektronischen Eigenschaften von Nanostrukturen** Fakultätskolloquium, TU Berlin, Germany, November 2004
D. Bimberg	**Quantum dot lasers: Novel sources for picosecond high frequency pulses** 5th Intern. Conf. on Low Dimensional Structures and Devices 2004, Cancun, Mexico, December 2004
W. Gehlhoff	**Properties of intrinsic and impurity-related defects in $ZnGeP_2$ and $ZnSiP_2$** Colloquium at the Institute for Materials Research, Tohokyo University, Sendai, Japan, March 2003
W. Gehlhoff	**EPR studies of intrinsic and Mn-related defects in the II-IV-V_2 semiconductors $ZnGeP_2$ and $ZnSiP_2$** Symp. "Chalcopyrite-based Magnetic Semiconductors and Point Defect", TUAT (Tokyo University Agriculture and Technology) ", Tokyo, Japan, March 2003

W. Gehlhoff

EPR- und Photo-EPR Untersuchungen von Eigendefekten und Mn-korrelierten Störstellen in den II-IV-V_2 Halbleitern $ZnGeP_2$ und $ZnSiP_2$
Seminarvortrag am Hahn-Meitner-Institute, Berlin, Germany, May 2003

W. Gehlhoff

Defekte in II-IV-V_2 Chalkopyrit-Halbleitern
Seminar „Neue Materialien“ am Institut für Festkörperphysik, Otto-von Guericke-Universität, Magdeburg, Germany, June 2003

W. Gehlhoff

Charakterisierung von Fremd- und Eigendefekten in II-IV-V_2 Chalkopyrit-Halbleitern
Physikalisches Kolloquium im Institut für Festkörperphysik der Friedrich-Schiller-Universität Jena, Germany, November 2003

W. Gehlhoff

The inequivalence of the two Mn-on-Zn Sites and the formation of Mn-Mn Pairs in $ZnGeP_2$
14th International Conference on Ternary and Multinary Compounds (ITCMC-14), Denver, USA, September 2004

W. Gehlhoff

Magnetic resonance methods as a tool for the investigation of point defects in semiconductors
Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, USA, October 2004

W. Gehlhoff

EPR studies of intrinsic and impurity-related defects in II-IV-V_2 compounds: $ZnGeP_2$ and $ZnSiP_2$
Georgia State University, Department of Physics and Astronomy, Atlanta, USA, October 2004

F. Guffarth

Many-particle effects in self-organized quantum dots
13th Intern. Winterschool on New Developments in Solid State Physics, Mauterndorf, Austria, February 2004

R. Heitz

Few-particle states in self-organized quantum dots
Workshop on Growth, Electronic and Optical Properties of Low-dimensional Semiconductor Quantum Structures, Schloß Ringberg, Rottach-Egern, Germany, February 2003

R. Heitz

Biexciton spectroscopy in single semiconductor quantum dots
Deutsch-Japanisches Symposium, Berlin, March 2003

I.N. Kaiander

Long wavelength (> 1.24 µm) InGaAs/GaAs quantum dot laser grown by alternative precursor MOCVD
11th Intern. Symp. Nanostructures: Physics and Technology, St. Petersburg, Russia, June 2003

M. Kuntz	**High speed quantum dot lasers for novel photonic systems** Taiwan Intern. Conf. on Nano Science and Technology TICON 2004 National Tsing Hua University, Hsinchu, Taiwan, R.O.C., June 2004
M. Kuntz	**Quantum dot lasers for high frequency systems** Conf. on Laser Electro-Optics / Intern. Quantum Electronics Conf., San Francisco, CA, USA, June 2004
M. Kuntz	**Nanophotonik – Halbleiterstrukturen in der Kommunikations-technologie** Jour Fixe der Berliner Wissenschaftlichen Gesellschaft, Berlin, Germany, November 2004
N.N. Ledentsov	**Recent advances in long wavelength GaAs-based quantum dot lasers** SPIE's Intern. Symp. on Physics and Simulation of Optoelectronic Devices XI (Photonics West), San José, CA, USA, January 2003
N.N. Ledentsov	**Quantum dots and the next revolution in optoelectronics** Intel Developer Forum / Intel Academic Forum, ICC, Berlin, Germany, April 2003
N.N. Ledentsov	**Self-organizing semiconductor nanostructures** Science and Mankind Progress, Round Table "Nanostructures in Chemistry and Physics", Educational Center at the Ioffe Institute, St. Petersburg, Russia, June 2003
N.N. Ledentsov	**Semiconductor lasers beyond quantum dots** 2003 Advanced Research Workshop on Future Trends in Microelectronics: The Nano, the Giga, The Ultra and the Bio, FTM, Corsica, France, June 2003
N.N. Ledentsov	**Unique properties of quantum dot lasers** 3rd IEEE Conf. on Nanotechnology (IEEE-NANO), San Francisco, CA, USA, August 2003
N.N. Ledentsov	**Near-ideal InAs QDs on GaAs substrates for 1.3 – 1.5 µm laser applications** 20th Nordic Semiconductor Meeting, Tampere, Finland, August 2003
N.N. Ledentsov	**Tilted cavity laser** Emerging Technologies in Optical Sciences shaping the Future of Communication, ETOS 2004, University College Cork, Ireland, July 2004
N.N. Ledentsov	**Novel laser sources based on quantum dots** QEP, Quantum Electronics and Photonics Conference, Glasgow, UK, September 2004

U. W. Pohl	**Quantum dot lasers and amplifiers** MRS Fall Meeting, Boston,USA, December 2003
U. W. Pohl	**Stranski-Krastanow-Wachstum von InGaAs- und GaSb-Quantenpunkten** Seminar des Instituts für Physik, Humboldt-Universität zu Berlin, Germany, February 2004
H. Quast	**Optisches Messsystem zur Charakterisierung von Höchstfrequenzbauelementen** Physikalisches Kolloquium, Universität Frankfurt, Germany, December 2003
A. Schliwa	**Strain effects in single and stacked quantum dots** Workshop on Growth, Electronic and Optical Properties of Low-dimensional Semiconductor Quantum Structures, Schloss Ringberg, Rottach-Egern, Germany, February 2003
A. Schliwa	**Structure dependent few-particle effects in quantum dots** Intern. Workshop on Computational Approaches toward the Electronic Properties of Quantum Dots, Chicago, USA, September 2003
A. Schliwa	**Correlation of structural and optical properties of self-organized quantum dots** SPIE's Intern. Symp. on Quantum Dots, Nanoparticles, and Nanoclusters (Photonics West), San José, CA, USA, January 2004
A. Schliwa	**Elektronische Eigenschaften von Quantenpunkten** Physikalisches Kolloquium, Universität Hamburg, Germany, July 2004
R. Sellin	**Quantum dot photonic devices for lightware communications** Crest & Qnn '03 Joint Intern. Workshop, Nara, Japan, July 2003
R. Sellin	**High power single and multimode quantum dot lasers with superior beam profile** SPIE's Novel In-Plane Semiconductor Lasers III (Photonics West), San José, CA, USA, January 2004
R. Sellin	**Quantum dots for lasers and amplifiers** Deutsch-Chinesischer Workshop der DFG und der Chinese National Science Foundation, Institute of Semiconductors, Beijing, China, March 2004
V.A. Shchukin	**Epitaxial semiconductor nanoworlds: Breakthrough in physics and applications** The 5th RIES-Hokudai Symposium Advanced Nanoscience, Hokkaido University, Sapporo, Japan, December 2003

A. Strittmatter	**Benefits of optical in-situ measurements for the MOCVD of III-Nitrides** Workshop “Nitride Growth and Applications”, Institute of Electronic Materials Technology, Warsaw, Poland, September 2003

9.1.5 PhD theses

Sellin, Roman	**Metalorganic chemical vapor deposition of high-performance GaAs-based quantum-dot lasers** 02.07.2003
Pfitzenmaier, Holger	**MSM-Photodetektoren: Implementierung neuer Technologien und Realisierung des Wanderwellenkonzepts** 24.07.2003
Guffarth, Florian	**Elektronische Eigenschaften von In(Ga)As/GaAs Quantenpunkten** 21.10.2003
Ouyang, Dongxun	**Characterization of lasers based on self-organized In(Ga)As quantum dots** 22.12.2003
Hopfer, Friedhelm	**Oberflächenemittierende Quantenpunktlaser: Design, Technologie und Charakterisierung** 07.12.2004

9.1.6 Diploma theses

Pötschke, Konstantin	**Antimon-basierte Quantenpunkte** 07.02.2003
Warming, Till	**Spektrales Lochbrennen durch resonante Anregung selbstorganisierter Quantenpunkte** 13.03.2003
Zimmermann, Dennis	**Femtosekundenpulserzeugung mittels nichtlinearer optischer Effekte** 14.08.2003
Seguin, Robert	**Untersuchung einzelner InGaN/GaN und In(Ga)As/GaAs Quantenpunkte mittels Kathodolumineszenzspektroskopie** 27.01.2004
Stock, Erik	**Kapazitätsspektroskopie an selbstorganisierten Quantenpunkten** 24.04.2004
Mutig, Alex	**Entwicklung von oberflächenemittierenden Lasern** 03.05.2004
Paarmann, Alexander	**Phononenstreuung und thermische Umverteilungsprozesse in Quantenpunktensembles** 21.05.2004
Winkelnkemper, Momme	**Elektronische Eigenschaften niederdimenisonaler Halbleiterstrukturen mit Wurtzitstruktur** 17.08.2004
Fiol, Gerrit	**Dynamisches Verhalten von Quantenpunktlasern** 02.11.2004

9.1.7 Abstracts of selected papers of department I

1. *Appl. Phys. Lett.* ***82*** *(2003), 841*

Alternative-precursor metalorganic chemical vapor deposition of self-organized InGaAs/GaAs quantum dots and quantum-dot lasers

R. L. Sellin, I. Kaiander, D. Ouyang, T. Kettler, U. W. Pohl, and D. Bimberg
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Metalorganic chemical vapor deposition of laser diodes based on triple stacks of self-organized $In_xGa_{1-x}As$/GaAs quantum dots (QDs) as active medium using the alternative precursor tertiarybutylarsine (TBAs) is reported. Epitaxy of monodispersed QDs using TBAs is demonstrated. Due to the high cracking efficiency of TBAs at low temperatures, the crucial growth parameters V/III ratio and temperature can be tuned almost independently. Ridge-waveguide QD lasers show a transparency current of 29.7 A/cm^2 - equivalent to 9.9 A/cm^2 per QD layer - an internal quantum efficiency of 91.4%, and an internal optical loss of 2.2 cm^{-1}.

8. *Jpn. J. Appl. Phys.* ***42*** *(2003), L 1057*

Direct Evidence of Nanoscale Carrier Localization in InGaN/GaN Structures Grown on Si Substrates

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InGaN insertions in a GaN matrix provide efficient lateral carrier localization on a nanoscale level as established by nonresonant and resonant time-resolved photoluminescence studies. In the case of resonant excitation the line width is defined by the excitation laser pulse only, while the decay characteristic remains the same as that in the case of nonresonant excitation. No spectral shift of the resonant photoluminescence peak which could be caused by reducing the piezoelectric screening of nonequilibrium carriers was found. This demonstrates that only one electron-hole pair may be generated in a compositional domain, which must have a strong localization and wide energy spacing.

21. *Phys. Rev. Lett.* ***90*** *(2003), 076102-1*

Metastability of Ultradense Arrays of Quantum Dots

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T. P. Munt and D. E. Jesson
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We present a linear stability analysis of ultradense arrays of coherently strained islands against Ostwald ripening. Surprisingly, short-range elastic interactions are found to overcome the destabilizing contribution of surface energy, leading to a metastable array of quantum dots. Simulations of Ostwald ripening kinetics directly verify the existence of this metastable regime and confirm the nature of the most unstable mode for subcritical island coverage.

32. *J. Cryst. Growth* ***272*** *(2004), 154*

Alternative precursor growth of quantum dot-based VCSELs and edge emitters for near infrared wavelengths

I.N. Kaiander*, F. Hopfer, T. Kettler, U.W. Pohl, D. Bimberg
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Growth of up to 10 stacks of longwavelength InGaAs quantum dots (QDs) for laser applications is demonstrated, using metalorganic chemical vapor deposition (MOCVD) with exclusively non-hydride precursors. Lasing at 1240 nm is achieved at room temperature using two different types of QDs, namely InGaAs QDs deposited on GaAs, and InAs QDs deposited on thin InGaAs templates. Both kinds of QDs were overgrown with InGaAs quantum wells in order to increase the emission wavelength. Defect-reducing in situ annealing to improve luminescence and laser properties of the QDs was successfully realized. Based on InGaAs QDs, we fabricated an electrically driven vertical-cavity surface-emitting laser. This is, to our knowledge, the first electrically driven QD-VCSEL grown by MOCVD presently attaining a maximum output power of 0.7mW at 1.1 μm.

36. *Phys. Rev. B* ***70*** *(2004), 85416*

Elastic interaction and self-relaxation energies of coherently strained conical islands

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Projection force density methods, based on the surface Green's function approach, are employed to obtain analytical expressions for the elastic interaction and self-relaxation energies of coherently strained conical islands. These results are used to evaluate the island chemical potential as the basis for coarsening models and a stability analysis of elastically interacting quantum dot arrays.

37. *Phys. Rev. Lett.* ***92*** *(2004), 166104-1*

Hierarchical Self-Assembly of GaAs/AlGaAs Quantum Dots

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A novel structure containing *self-assembled,* unstrained GaAs quantum dots is obtained by combining solid-source molecular beam epitaxy and atomic-layer precise *in situ* etching. Photoluminescence (PL) spectroscopy reveals light emission with very narrow inhomogeneous broadening and clearly resolved excited states at high excitation intensity. The dot morphology is determined by scanning probe microscopy and, combined with single band and eight-band $k \cdot p$ theory calculations, is used to interpret PL and single-dot spectra with no adjustable structural parameter.

38. *Appl. Phys. Lett.* ***84*** *(2004), 963*

In situ area-controlled self-ordering of InAs nanostructures

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Real-time control of self-organized growth of InAs nanostructures has been achieved by employing epitaxial stationary shadow masks in a molecular-beam-epitaxy process. The method is based on the surface diffusion of group-III adatoms governed by the group-V surface concentration. Lateral control is achieved by the geometry of the mask and the incidence angles of the molecular beams. We apply the method to self-organized growth of nanoscale InAs quantum structures at the edge of the incidence region of the arsenic beam. The high quality of the *in situ* fabricated nanostructures is confirmed by bright cathodoluminescence of InAs quantum wire embedded in GaAs barriers.

44. *J. Cryst. Growth* ***272*** *(2004), 76*

Optimization of GaN MOVPE growth on patterned Si substrates using spectroscopic in situ reflectance

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In real-time monitoring of III-Nitride growth on patterned and masked substrates by spectroscopic reflectance, a characteristic interference pattern generated by the superposition of wave-fronts reflected at different μm-sized structures at the sample surface is measured. Up to now this time- and wavelength-dependent pattern was used only for empirical fingerprint-evaluation of III-Nitride growth processes which employ patterning or masking for bulk defect reduction. In this paper, we report on the analysis of real-time spectroscopic reflectance data measured in the range 1.65–4.5eV during the epitaxial growth of GaN layers on structured Si(1/1/1) substrates. The successful implementation of a two-dimensional interference model into conventional thin-film analysis algorithms enables the quantitative analysis of characteristic vertical and lateral growth rates and overgrowth mechanisms involved. The new method is applied to optimize III-Nitride growth processes on patterned silicon substrates used for subsequent III-Nitride device growth.

45. *J. Cryst. Growth* ***272*** *(2004), 143*

Real-time control of quantum dot laser growth using reflectance anisotropy spectroscopy

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Reflectance and reflectance anisotropy spectroscopy (RAS) were used to control in-situ the complex MOCVD growth process of both InGaAs/GaAs quantum dots (QDs) and lasers with such QDs in the active region. Spectra and transients yield online information on details of quantum dot and cavity formation, like InGaAs monolayer deposition prior to QD formation and evolution of the cavity resonance. The data were used to develop laser devices including the first electrically driven vertical cavity surface emitting QD laser (QD VCSEL) grown by using MOCVD.

61. *Phys. Stat. Sol. (b)* ***237*** *(2003), 308*

Exciton–LO-phonon coupling in self-organized InAs/GaAs quantum dots

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The exciton–LO-phonon interaction in self-organized quantum dots is investigated emphasizing the impact of realistic structural properties. The possibility to engineer the local charge density via the shape and composition profile of such strained quantum dots provides an unique opportunity to optimise the electronic and optical properties of a semiconductor nanostructure. Size-selective luminescence, resonant Raman scattering, and time-resolved luminescence experiments provide insight into the exciton–LO-phonon and exciton-photon couplings in self-organized quantum dots. The impact of the structural details is analyzed based on eight-band $\boldsymbol{k} \cdot \boldsymbol{p}$ model calculations.

64. *Phys. Stat. Sol. (b)* ***238*** *(2003), 258*

Hole storage in GaSb/GaAs quantum dots for memory devices

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The hole confinement of self-organized GaSb/GaAs quantum dots embedded in n+p-diodes is investigated experimentally by admittance spectroscopy. The highest thermal activation energy obtained, 400 meV, refers to only weakly charged quantum dots. Detailed bias-dependent investigations allow to study state- filling and Coulomb charging effects. State filling lowers the activation energy down to 150 meV in quantum dots charged with the maximum number of about 15 holes. The observed thermal activation barrier for GaSb/GaAs quantum dots is about twice as high as for structurally comparable InAs/GaAs quantum dots.

65. *Phys. Rev. B* ***67*** *(2003), 235327*

Lateral carrier transfer in $Cd_xZn_{1-x}Se/ZnS_ySe_{1-y}$ quantum dot layers

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Lateral carrier transfer is investigated for single $Cd_xZn_{1-x}Se/ZnS_ySe_{1-y}$ quantum dots (QD's) in a high-density ensemble by time-resolved spectroscopy. Following nonresonant excitation a significant probability of independent capture of electrons and holes in separate QD's is observed. The subsequent lateral migration of carriers between adjacent QD's leads to a slow decay component of the exciton ground-state luminescence. At low temperatures the lateral carrier transfer is restricted to phonon-assisted inter-QD tunneling, resulting in migration times of the order of several nanoseconds. The role of independent carrier capture is suppressed at high excitation densities or increased temperatures, enabling thermally activated migration.

71. *Appl. Phys. Lett.* ***82*** *(2003), 1941*

Radiation hardness of InGaAs/GaAs quantum dots

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The interaction between point defects in the matrix and excitons localized in self-organized InGaAs/GaAs quantum dots is investigated for structures irradiated by protons. The exciton ground state is demonstrated to be unaffected by radiation doses up to 10^{14} p/cm^2. The close proximity of radiation-induced defects leads to a strong nonmonotonous temperature dependence of the luminescence yield: Carriers are lost via tunneling from excited quantum dot states to irradiation-induced defects below ~100 K, whereas at higher temperatures, carriers escape to the barrier and are captured by defects.

73. *Phys. Rev. B* ***68*** *(2003), 35331*

Repulsive exciton-exciton interaction in quantum dots

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Biexcitons localized in single InAs/GaAs quantum dots (QD's) are investigated by cathodoluminescence, demonstrating an anticorrelation of the biexciton binding energy and the exciton transition energy. The binding energy decreases with increasing transition energy changing its sign at about 1.24 eV. The ''binding'' to ''antibinding'' transition is attributed to three-dimensional confinement, quenching correlation, and exchange and causing local charge separation. Model calculations of the biexciton in truncated InAs/GaAs QD's demonstrate the observed trend to result from the decreasing number of localized excited states with decreasing QD size. The interaction with resonant states in the wetting layer is found to be negligible.

74. *Appl. Phys. Lett.* ***83*** *(2003), 3668*

Self-induced transparency in InGaAs quantum-dot waveguides

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We report the experimental observation and the theoretical modeling of self-induced-transparency signatures such as nonlinear transmission, pulse retardation and reshaping, for subpicosecond pulse propagation in a 2-mm-long InGaAs quantum-dot ridge waveguide in resonance with the excitonic ground-state transition at 10 K. The measurements were obtained by using a cross-correlation frequency-resolved optical gating technique which allows us to retrieve the field amplitude of the propagating pulses.

76. *Proc. The 11th Intern. Symp. Nanostructures: Physics & Technology (2003), 356*

Spectral hole burning in the absorption spectrum of self-organized InAs/GaAs quantum dots

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We present a photocurrent study of a p-i-n GaAs diode incorporating InAs self-organized quantum dots (QDs) in the intrinsic region. In two-color experiments the possibility to burn a spectral hole in the QDs absorption spectrum by means of resonant excitation of the dot states is demonstrated.

84. *Appl. Phys. Lett.* ***84*** *(2004), 4023*

Multi-excitonic complexes in single InGaN quantum dots

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Cathodoluminescence spectra employing a shadow mask technique of InGaN layers grown by metalorganic chemical vapor deposition on Si(111) substrates are reported. Sharp lines originating from InGaN quantum dots are observed. Temperature dependent measurements reveal thermally induced carrier redistribution between the quantum dots. Spectral diffusion is observed and was used as a tool to correlate up to three lines that originate from the same quantum dot. Variation of excitation density leads to identification of exciton and biexciton. Binding and anti-binding complexes are discovered.

95. *Appl. Phys. Lett.* ***82*** *(2003), 952*

Complete suppression of filamentation and superior beam quality in quantum-dot lasers

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Comparative near-field and beam-quality (M^2) measurements on narrow stripe quantum-dot (QD) and quantum-well (QW) lasers of identical structure, both emitting at 1100 nm, are presented. Intrinsic suppression of filamentation in the QD lasers is observed. QD lasers emitting at 1300 nm again show no filamentation. For a 6-μm-stripe, QW laser, M^2 increases from 2.6 to 6.1 with output power increasing from 5 to 60 mW and with increasing stripe width (20 mW, 3→10 μm, M^2 =2.6→4.7). In the QD lasers, filamentation is suppressed up to 8 μm (1100 nm) and 9 μm (1300 nm) stripe width and no dependence on output power is observed.

99. *Electr. Lett.* ***39*** *(2003), 1126*

High performance quantum dot lasers on GaAs substrates operating in 1.5 μm range

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Stacked InAs/lnGaAs quantum dots are used as an active media of metamorphic InGaAs-InGaAlAs lasers grown on GaAs substrates by molecular beam epitaxy. High quantum efficiency (η_I > 60%) and low internal losses (α<3-4 cm^{-1}) are realised. The transparency current density per single QD layer is estimated as ~70 A/cm^2 and the characteristic temperature is 60 K (20-85°C). The emission wavelength exceeds 1.51 μm at temperatures above 60°C.

108. *Proc. The 11th Intern. Symp. Nanostructures: Physics & Technology (2003), 1*

Quantum dot photonics: from lasers to networks

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InAs-GaAs-based Quantum Dot Lasers emitting at 1140-60 nm useful as pump sources for Tm^{3+}-doped fibers for frequency up-conversion to 490 nm now reach output powers close to 12 W and show transparency current densities of 6 A/cm^2 per dot layer, η_{int} = 98% and α_i = 1.5 cm^{-1}. Continuous wave room-temperature output power of ~5 W for edge-emitters and of 1.2 mW for vertical-cavity surface-emitting lasers is realized for such devices operating at 1.3 μm. Long operation lifetimes and radiation hardness are manifested. Cut-off frequencies of up to 20 GHz and low α-factors are realized. No beam filamentation and strongly reduced sensitivity to optical feedback is observed for stripe widths up to at least 50 μm, making QD-lasers superior to QW-lasers for any system or network.
Quantum dot semiconductor optical amplifiers (QD SOAs) demonstrate gain recovery times of 120-140 fs, 4-7 times faster than bulk/QW SOAs, providing us with novel types of booster amplifiers and Mach-Zehnder interferometers. These breakthroughs became possible due to systematic development of self-organized growth technologies.

116. *Appl. Phys. Lett.* ***84*** *(2004), 2992*

1.24 μm InGaAs/GaAs quantum dot laser grown by metalorganic chemical vapor deposition using tertiarybutylarsine

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Metalorganic chemical vapor deposition of GaAs-based laser diodes, using self-organized InGaAs quantum dots (QDs), emitting at >1.24 μm is demonstrated. The environment-friendly alternative precursor tertiarybutylarsine is used as a substitute for arsenic hydride. The active region contains ten closely stacked InGaAs QD layers embedded in a GaAs matrix. Lasing emission at such long wavelengths was achieved by overgrowing the $In_{0.65}Ga_{0.35}As$ QDs with a thin $In_{0.2}Ga_{0.8}As$ film. The application of an *in situ* annealing step leading to the evaporation of plastically relaxed defect clusters is shown to be decisive for the laser performance. A transparency current density of 7.2 A/cm^2 per QD layer and an internal quantum efficiency of 75% were achieved at room temperature.

122. *Appl. Phys. Lett.* ***84*** *(2004), 1650*

Dynamic filamentation and beam quality of quantum-dot lasers

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We present a comparative study of numerical simulations and experiments on the spatiotemporal dynamics and emission characteristics of quantum-well and quantum-dot lasers of identical structure. They show that, in the quantum-dot laser, the strong localization of carrier inversion and the small amplitude–phase coupling enable a significant improvement of beam quality compared to quantum-well lasers of identical geometry. Near-field profiles and beam quality (M^2) parameters calculated on the basis of time-dependent effective Maxwell–Bloch equations into which the physical properties of the active media are included via space-dependent material parameters, effective time constants, and matrix elements are fully confirmed by experimental measurements. Together they indicate that, in the quantum-dot laser, the strong localization of carrier inversion and the small amplitude–phase coupling enable a significant improvement of beam quality compared with quantum-well lasers of identical geometry.

126. *Semicond. Sci. Technol.* ***19*** *(2004), L43*

Impact of the mesa etching profiles on the spectral hole burning effects in quantum dot lasers

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We investigated the impact of mesa etching profiles on the emission spectra of In(Ga)As quantum dot ridge waveguide lasers grown by metal-organic chemical vapour deposition. The mesa etching was terminated: (i) well before the waveguide, (ii) directly at the waveguide, (iii) after the waveguide forming tilted sidewalls and (iv) after the waveguide forming vertical sidewalls. We found a dramatic impact of the etching profiles on the spectral intensity modulation of the longitudinal modes. The spectral hole burning effect due to the Fabry–Pérot cavity resonances causes strong modulation of the lasing spectrum, if the etching profile is terminated at the waveguide, or when the mesa sidewalls are tilted. In addition, deep-etched-through mesas with vertical sidewalls demonstrate extra spectral features induced by the high *Q*-factor modes originating due to the total internal reflection at the vertical sidewalls. In contrast, no intensity modulation is found in the shallow mesa devices, due to the weak effective refractive index step. The present results indicate extended opportunities for the emission spectrum control characteristic of quantum dot lasers.

129. *Phys. Stat. Sol. (a)* ***201*** *(2004), 345*

Quantum dot semiconductor lasers with optical feedback

G. Huyet [1 *], D. O'Brian [1], S. P. Hegarty [1], J. G. McInerney [1], A. V. Uskov [2], D. Bimberg [3], C. Ribbat [3], V. M. Ustinov [4], A. E. Zhukov [4], S. S. Mikhrin [4], A. R. Kovsh [4], J. K. White [5], K. Hinzer [5], A. J. SpringThorpe [6]

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We analyse the sensitivity of quantum dot semiconductor lasers to optical feedback. While bulk and quantum well semiconductor lasers are usually extremely unstable when submitted to back reflection, quantum dot semiconductor lasers exhibit a reduced sensitivity. Using a rate equation approach, we show that this behaviour is the result of a relatively low but nonzero line-width enhancement factor and strongly damped relaxation oscillations.

131. *Technical Digest Optical Fiber Communication Conference and Exposition OFC* **1,** *343 (2003)*

Above 100 GHz Performance of Waveguide Integrated Photodiodes Measured by Electro-optical Sampling

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An excellent linear power and phase response up to frequencies of 160 GHz is demonstrated on ultrafast waveguide integrated photodetectors, by means of the electro-optical sampling method.

132. *Proc. 29th European Conf. on Optical Com. ECOC (2003), 1034*

Femtosecond pulsecompression using a comb-like dispersion profiled fiber (CDPF)

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Femtosecond compression of pulses with complex shape and phase using a CDPF is presented. Compression of already linear compensated pulses by a factor of 21 leading to a FWHM of 538 fs (autocorrelation) is shown.

135. *Proc. The 16th Annual Meeting of the IEEE, The Lasers and Optics Society, LEOS 2003* ***2**, (2003) 712*

Low jitter single mode laser source for arbitrary repetition rates

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[3]School of Science, Taiyuan University of Technology, P. R. China

A modified injection seeding set-up is used to generate low jitter single mode laser pulses from a gain-switched Fabry-Perot laser diode at arbitrary repetition rates. Detailed investigations on the jitter are presented.

137. *Appl. Phys. Lett.* ***85** (2004), 843*

35 GHz mode-locking of 1.3 µm quantum dot lasers

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35 GHz passive mode-locking of 1.3 µm (InGa)As/GaAs quantum dot lasers is reported. Hybrid mode-locking was achieved at frequencies up to 20 GHz. The minimum pulse width of the Fourier-limited pulses was 7 ps with a peak power of 6 mW. Low uncorrelated timing jitter below 1 ps was found in cross correlation experiments. High-frequency operation of the lasers was eased by a ridge waveguide design that includes etching through the active layer.

140. *NJP (New Journal of Physics)* ***6*** *(2004), 181*

Direct Modulation and Mode Locking of 1.3 µm Quantum Dot Lasers

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We report 7 GHz cut-off frequency, 2.5 Gb/s and 5 Gb/s eye pattern measurements upon direct modulation of 1.3 µm quantum dot lasers grown without incorporating phosphorus in the layers. Passive mode-locking is achieved from very low frequencies up to 50 GHz, hybrid mode-locking is achieved up to 20 GHz. The minimum pulse width of the Fourier-limited pulses at 50 GHz is 3 ps, with an uncorrelated timing jitter below 1 ps. The lasers are optimized for high frequency operation by a ridge waveguide design that includes etching through the active layer and ridge widths down to 1 µm. The far field shape for 1 µm is close to circular with a remaining asymmetry of 1.2.

143. *J. Quantum Electronics* ***40*** *(2004), 1423*

Linewidth enhancement factor in InGaAs quantum-dot amplifiers

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We report systematic measurements of the linewidth enhancement factor (LEF) in an electrically pumped InGaAs quantum-dot (QD) amplifier in the temperature range from 50 K to room temperature. At injection currents below transparency, the value of the linewidth enhancement factor of the ground-state interband (excitonic) transition is between 0.4 and 1, and increases with increasing carrier density. Additionally, we investigate the spectral dependence of the LEF by tuning the wavelength of our optical probe from below resonance with the ground state of the QDs up to resonance with the first optically active excited-state transition. We find a decrease of the LEF with increasing photon energy at all investigated temperatures.

147. *IEEE Photonics Techn. Lett.* ***16*** *(2004), 1265*

On Ultrafast Optical Switching Based on Quantum-Dot Semiconductor Optical Amplifiers in Nonlinear Interferometers

A. V. Uskov[1], E. P. O'Reilly[1], R. J. Manning[1], R. P. Webb[1], D. Cotter[1], M. Laemmlin[2], N.N. Ledentsov[2], and D. Bimberg[2]
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It is shown that interferometers containing quantum-dot semiconductor optical amplifiers can be effective for ultrafast cross-phase modulation and digital signal processing with low dependence on the specific random data pattern.

153. *Physica B **340-342** (2003), 1078*

Electron-dipole resonance of impurity centres embedded in silicon microcavities

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We present the findings of high efficient light absorption by self-assembled quantum well embedded in silicon microcavity that exhibits a distributed feedback identified by the FIR transmission spectra. The excitonic normal-mode coupling is found to result in high efficient bound exciton photoluminescence in the range of the Rabi splitting. The localisation of this exciton at an iron–boron pair is shown to cause giant exchange splitting created by strong sp–d mixing in the absence of the external magnetic field, which is revealed by the angular dependencies of photoluminescence spectra that are evidence of the electron-dipole resonance of the trigonal Fe_i^+ -B_s^- pairs.

155. *Material Science in Semiconductor Processing **6** (2003), 379*

EPR studies of native and impurity-related defects in II-IV-V_2 semiconductors

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Magnetic resonance studies of native defects in Zinc germanium diphosphide ($ZnGeP_2$) and their energy level positions in the band gap are reviewed and first results on defects in $ZnSiP_2$ are presented. The contribution of the dominant native defects to the optical absorption of $ZnGeP_2$ crystals is revealed by photo-EPR investigation in combination with the first ODMR-experiments. The EPR results published for Mn and Fe in the II-IV-V_2 chalcopyrites are summarized. The observation of some new Mn centers and the first experimental detection of antiferromagnetic Mn-Mn coupled pairs in $ZnGeP_2$ are presented. In addition, new results concerning Mn-induced local changes of the free parameter x_f of the chalcopyrite structure at the impurity site are discussed.

159. *J. Phys. Condens. Matter* **15** *(2003), 2493*

Photoexcitation electron paramagnetic resonance studies on nickel-related defects in diamond

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Measurements of the electron paramagnetic resonance (EPR) upon photoexcitation are reported on Ni defects in diamonds grown with Nicontaining solvent/catalysts. The temperature dependence of the W8 EPR spectrum photoquenching shows that the relaxation of substitutional Ni^{-}_{s} upon electron ionization is very small, corroborating the interpretation that the previously reported photoinduced effects with thresholds at 2.5 and 3.0 eV correspond to two complementary photoionization transitions involving Ni_s. Photoinduced behaviour of the NIRIM1 EPR centre favours the interstitial Ni^{+}_{i} model for this defect and suggests that the $Ni_i^{0/+}$ level is located at 1.98±0.03 eV below the conduction band. In N-doped diamond, Ni_i is more likely to appear in the neutral state, undetectable by EPR, whereas at substitutional sites Ni^{-}_{s} is revealed. Observation of a strong AB2 EPR signal photoquenching and simultaneous detection of different spectral dependencies of the EPR intensity for other defects determine an electron photoionization energy of 1.67±0.03 eV for the AB2. The implications of the obtained data for the identification of the AB defects' structure are discussed. Our study shows that Ni defects exhibit a weak electron–lattice interaction. The importance of the stronger spin–orbit coupling in these centres as compared to other defects in diamond is discussed. Assuming direct intercentre charge transfer from N_s, a theoretical description of the photoionization kinetics is proposed to explain the observed photoresponse of Ni defects.

160. *J. Phys. Chem. Sol.* ***64*** *(2003), 1923*

Structure and energy level of native defects in as-grown and electron-irradiated zinc germanium diphosphide studied by EPR and photo-EPR

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The properties of defects in as-grown p-type zinc germanium disphosphide ($ZnGeP_2$) and the influence of electron irradiation and annealing on the defect behavior were studied by means of electron paramagnetic resonance (EPR) and photo-EPR. Besides the well-known three native defects (V_{Zn}, V_P, Ge_{Zn}), an S=1/2 EPR spectrum with an isotropic g=2.0123 and resolved hyperfine splitting from four equivalent I=1/2 neighbors is observed in electron-irradiated $ZnGeP_2$. This spectrum is tentatively assigned to the isolated Ge vacancy. Photo-EPR and annealing treatments show that the high-energy electron irradiation-induced changes in the EPR intensities of the zinc and phosphorus vacancies are caused by the Fermi level shift towards the conduction band. Annealing of the electron-irradiated samples induces a shift of the Fermi level back to its original position, accompanied by an increase of the EPR signal associated with the V^-_{Zn} and a proportional increase of the EPR signal assigned to the V^0_P under illumination ($\lambda < 1$ eV) as well as generation of a new defect. The results indicate that the EPR spectra originally assigned to the isolated V^-_{Zn} and V^0_P are in fact associated defects and the new defect is probably the isolated phosphorus vacancy V_{Pi}.

9.2. Department II

Prof. Dr. rer. nat. Christian Thomsen
Prof. Dr.-Ing. Dr. h.c. mult. Immanuel Broser (see p. 107 ff.)

9.2.a Department IIa

Prof. Dr. rer. nat. Christian Thomsen

9.2a.0 Staff

Secretary
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Dr. Paula Giudici
Dr. Janina Maultzsch
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PhD candidates
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Dipl.-Phys. Uwe Kuhlmann (until 30.06.2003)
Dipl.-Phys. Christian Kristukat
Dipl.-Phys. María Machón
Dipl.-Phys. Harald Scheel
Dipl.-Phys. Hagen Telg

Diploma students (status of 31.12.2004 – thesis completed = c)
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Dirk Heinrich (c)
Marcel Mohr
Michael Stoll (c)
Hagen Telg (c)

9.2a.1 Summary of activities

The activity of this group is centered around optical spectroscopy of carbon nanotubes, wide and narrow-gap semiconductors nanostructures, 2D electron gases, quantum dots, superconductor-semiconductor-hybrid structures, ferrofluids, and high-T_c superconductors.

Emphasis in the work on **carbon nanotubes** was put on the understanding of chirality-dependent properties of these tubes. In 2004 we were successful in assigning ~ 60 different chiral indices to nanotubes in solution. We are now focussing on the physical properties of specific chirality nanotubes, e.g., the metallic or the semiconducting ones. Our second focus in this area was on double-resonant excitation in graphite and nanotubes. Recent highlights were the full derivation of the double-resonance process and the calculation of relative Raman cross sections and their comparison to experiment. We collaborate on *ab initio* work with P. Ordejón in Spain and on group theoretical work with M. Damnjanović in Belgrade.

In the **nanostructure**-related project of the Sonderforschungsbereich 296 investigations focused on Raman and fir-spectroscopy of quantum dots and their luminescence properties under pressure. A further research topic was the electrochemical doping of carbon nanotubes and the determination of the graphite phonon dispersion relation with inelastic x-ray scattering using the synchrotron source in Grenoble.

We continued our studies on wide-gap semiconductors with studies of binary and ternary **group-III nitrides** as a part of a special focus program of the DFG (Schwerpunktprogramm Nitride). Our ability to spatially resolve physical and structural properties allowed us to contribute significantly to the strain and luminescence characterisation of macroscopic samples. Finite-element calculations contributed to the consistent explanation of our results.

The behavior of oxygen atoms in the $YBa_2Cu_3O_{7-\delta}$ superconductor family when excited with visible light was investigated with Raman spectroscopy, high-resolution x-ray radiation and Monte Carlo simulations. We have developed a consistent picture of the involved physical processes and are able to connect the optical to transport properties in these fascinating materials.

Work continued on the electrical measurements of superconductor-semiconductor hybrids. Highly mobile two-dimensional electron gases were covered with PbIn, a superconductor below ~8 K. We then studied electrically the drag of the electron gas (Eddy currents) on the flux flow in the superconductor.

Based on predictions by density-functional calculations of a spin-polarized phase in higher subbands of a 2D electron gas in a single quantum well, we searched for such a phase in photoluminescence and inelastic light scattering. A sharp emission was observed and behaves under the influence of a magnetic field as predicted confirming the formation of spin polarized domains in the excited subband. We believe that we observed such a phase also in the inelastic scattering spectra.

Our work on surfacted ferrofluids continues. In this period we covered mostly the behavior of ion-stabilized ferrofluids in an applied magnetic field. These fluids - aside from physics research - are of interest for medical applications.

Most recently we started to investigate Si nanowires as a promising material concept for optoelectronics. Our work includes both theoretical and experimental methods.

9.2a.2 Publications

The abstracts of papers marked by * are reprinted in section 9.2a.7.

1.* **Spin-phonon coupling in the high pressure phase of the low-dimensional spin compound $(VO)_2P_2O_7$**
U. Kuhlmann, C. Thomsen, A.V. Prokofiev, F. Büllesfeld, E. Uhrig, M. Anton, C. Gross, and W. Assmus
phys. stat. sol. (a) **196,** 185-188 (2003).

2. **Double-resonant Raman scattering in single-wall carbon nanotubes**
J. Maultzsch, S. Reich, and C. Thomsen
Proceedings of the 26th International Conference on the Physics of Semiconductors (ICPS 26), Edinburgh, 29 July-2 August 2002, eds, A.R. Long, J.H. Davis, Institute of Physics Publishing **171**, Bristol, 2003, D209.

3. **Transport measurements on magnetically coupled superconductor 2-D-electron-gas hybrides**
H. Scheel, A.R. Goñi, C. Kristukat, C. Thomsen, and K. Eberl
Proceedings of the 26th International Conference on the Physics of Semiconductors (ICPS 26), Edinburgh, 29 July-2 August 2002, eds, A.R. Long, J.H. Davis, Institute of Physics Publishing **171**, Bristol, 2003, D125.

4. **Exchange-driven instability and spin polarization of the two-dimensional electron gas**
P. Giudici, A.R. Goñi, U. Haboek, C. Thomsen, K. Eberl, F.A. Reboredo, and C.R. Proetto
Proceedings of the 26th International Conference on the Physics of Semiconductors (ICPS 26), Edinburgh, 29 July-2 August 2002, eds, A.R. Long, J.H. Davis, Institute of Physics Publishing **171**, Bristol, 2003, H63.

5. **Pressure dependence of photoluminescence spectra of self-assembled InAs/GaAs quantum dots**
F.J. Manjón, A.R. Goñi, K. Syassen, F. Heinrichsdorf, and C. Thomsen
phys. stat. sol. (b) **235**, 496 (2003).

6.* **High-pressure photoluminescence spectra of the electronic stucture of InP/GaP quantum dots**
C. Kristukat, A.R. Goñi, F. Hatami, S. Dreßler, W.T. Masselink, and C. Thomsen
phys. stat. sol. (b) **235**, 412 (2003).

7.* **Elastic properties and pressure-induced phase transitions of single-walled carbon nanotubes**
S. Reich, C. Thomsen, and P. Ordejón
phys. stat. sol. (b) **235**, 354 (2003).

8. **Raman study of photoinduced chain-oxygen ordering in $RBa_2Cu_3O_{7-\delta}$**
S. Bahrs, A.R. Goñi, B. Maiorov, G. Nieva, A. Fainstein, and C. Thomsen
IEEE Transactions on Applied Superconductivity **13** (2), 3192-3195 (2003).

9.* **Magnetic excitations in $SrCu_2O_3$: a Raman scattering study**
A. Gößling, U. Kuhlmann, C. Thomsen, A. Löffert, C. Gross, and W. Assmus
Phys. Rev. B **67**, 052403 (2003).

10.* Lattice dynamics in GaN and AlN probed with first- and second-order Raman spectroscopy
U. Haboeck, H. Siegle, A. Hoffmann, and C. Thomsen
phys. stat. sol. (c) **0**, 1710-1731 (2003).

11. Properties of the nitrogen acceptor in ZnO
Martin Straßburg, U. Haboeck, A. Kaschner, Matthias Straßburg, A. Rodina, A. Hoffmann, C. Thomsen, A. Zeuner, H.R. Alves, D.M. Hoffmann, and B.K. Meyer
Proceedings of the 26th International Conference on the Physics of Semiconductors (ICPS 26), Edinburgh, 29 July-2 August 2002, eds, A.R. Long, J.H. Davis, Institute of Physics Publishing **171**, Bristol, 2003), P45.

12.* Electronic structure of self-assembled InP/GaP quantum dots from high-pressure photoluminescence
A.R. Goñi, C. Kristukat, F. Hatami, S. Dreßler, W.T. Masselink, and C. Thomsen
Phys. Rev. B **67**, 075306 (2003).

13.* Electronic and Raman measurements on single-walled carbon nanotubes
M. Stoll, P.M. Rafailov, W. Frenzl, and C. Thomsen
Chem. Phys. Lett. **375**, 625 (2003).

14.* High-energy phonon branches of an individual metallic carbon nanotube
J. Maultzsch, S. Reich, U. Schlecht, and C. Thomsen
Phys. Rev. Lett. **91**, 087402 (2003).

15. The radial breathing mode frequency in double-walled carbon nanotubes
E. Dobardžić, J. Maultzsch, I. Milošević, C. Thomsen, and M. Damnjanović
phys. stat. sol. (b) **237**, R7 (2003).

16. Vibrational properties of double-walled carbon nanotubes
J. Maultzsch, S. Reich, R.R. Bacsa, E. Dobardžić, M. Damnjanović, and C. Thomsen
Molecular nanostructures, eds. H. Kuzmany, J. Fink, M. Mehring, S. Roth, AIP Conference Proceedings **685**, (Melville), New York, 2003) p. 324-327.

17. *Ab initio* studies of electron-phonon coupling in single-walled nanotubes
M. Machón, S. Reich, J.M. Pruneda, C. Thomsen, and P. Ordejón
ibid., p. 427-430.

18. Double-resonant Raman scattering in an individual carbon nanotube
C. Thomsen, J. Maultzsch, and S. Reich
ibid., p. 225-229.

19.* Resonance and high-pressure Raman studies on carbon peapods
P.M. Rafailov, C. Thomsen, and H. Kataura
Phys. Rev. B **68**, 193411 (2003).

20. Stress analysis of $Al_xGa_{1-x}N$ films with microcracks
D. Rudloff, T. Riemann, J. Christen, Q.K.K. Liu, A. Kaschner, A. Hoffmann, C. Thomsen, K. Vogeler, M. Diesselberg, S. Einfeldt, and D. Hommel
Appl. Phys. Lett. **82**, 367 (2003).

21. Magnetic field effects on the exchange instability of the 2D electron gas
P. Giudici, A. R. Goñi, C. Thomsen, and K. Eberl
Physica E **22**, 438-441 (2003).

22.* The strength of the radial-breathing mode in single-walled carbon nanotubes
M. Machón, S. Reich, J. Maultzsch, P. Ordejón, and C. Thomsen
Phys. Rev. B **71**, 035416 (2005).

23. Excited-state carrier lifetime in single-walled carbon nanotubes
S. Reich, M. Dworzak, A. Hoffmann, C. Thomsen, and M.S. Strano
Phys. Rev. B **71**, 033402 (2004).

24.* Evidence of spontaneous spin polarization in the two-dimensional electron gas
A. R. Goñi, P. Giudici, F.A. Reboredo, C.R. Proetto, C. Thomsen, and K. Eberl
Phys. Rev. B **70**, 195331 (2004).

25. Raman scattering in carbon nanotubes
C. Thomsen
Proceedings SPIE **5219**, San Diego, USA 1.8.-5.8.2003, pp. 45-50 (2003).

26. Raman study of magnetic field effects on surfacted an ionic ferrofluids
J.E. Weber, A.R. Goñi, and C. Thomsen
J. Magn. Magn. Mat. **277**, 96-100 (2004).

27. Optical micro-characterization of group III-nitrides: correlation of structural, electronic and optical properties
J. Christen, T. Riemann, F. Bertram, D. Rudloff, P. Fischer, A. Kaschner, U. Haboeck, A. Hoffmann, and C. Thomsen
phys. stat. sol. (c) **0**, 1795-1815 (2003).

28.* Phonon dispersion in graphite
J. Maultzsch, S. Reich, C. Thomsen, H. Requardt, and P. Ordejón
Phys. Rev. Lett. **92**, 075501 (2004).

29.* Carbon Nanotubes: Basic Concepts and Physical Properties
S. Reich, C. Thomsen, and J. Maultzsch
(WILEY-VCH, Berlin, 2004) 224 pages.

30.* Light-induced oxygen-ordering dynamics in (Y,Pr)$Ba_2Cu_3O_{6.7}$: A Raman spectroscopy and Monte Carlo study
S. Bahrs, A.R. Goñi, C. Thomsen, B. Maiorov, G. Nieva, and A. Fainstein
Phys. Rev. B **70**, 014512 (2004).

31. Local vibrational modes and compensation effects in Mg-doped GaN
A. Hoffmann, A. Kaschner, and C. Thomsen
phys. stat. sol. (c) **0**, 1783-1794 (2003).

32.* Focus Issue on Carbon Nanotubes
guest editors: C. Thomsen and H. Kataura
New Journal of Physics, 2003 and 2004.

33. Photoluminescence of one-dimensional electron gases in cleaved-edge overgrowth quantum wires
C. Kristukat, A.R. Goñi, M. Bichler, W. Wegschneider, G. Absteiter, and C. Thomsen
phys. stat. sol. (b) **241**, pp 1041-1045 (2004).

34. Raman measurements on electrochemically doped single-walled carbon nanotubes
P.M. Rafailov, M. Stoll, J. Maultzsch, and C. Thomsen
Molecular nanostructures, eds. H. Kuzmany, J. Fink, M. Mehring, S. Roth, AIP Conference Proceedings **685**, (Melville), New York, 2003) p. 135-138.

35. Hexagonal diamond from single-walled carbon nanotubes
S. Reich, P. Ordejón, R. Wirth, J. Maultzsch, B. Wunder, H.J. Müller, C. Lathe, F. Schilling, U. Dettlaff-Weglikowska, S. Roth, and C. Thomsen
ibid., p. 164-168.

36.* Effects of the exchange instability on collective spin and charge excitations of the two-dimensional electron gas
P. Giudici, A.R. Goñi, C. Thomsen, P.G. Bolcatto, C.R. Proetto, and K. Eberl
Phys. Rev. B **70**, 235418 (2004).

37.* Raman spectroscopy of graphite
S. Reich and C. Thomsen
Philosophical Transactions: Mathematical, Physical and Engineering Sciences **362**, 2271-2288 (2004).

38.* Resonant Raman spectroscopy of nanotubes
C. Thomsen, S. Reich and J. Maultzsch
ibid., 2337-2359.

39. Raman spectroscopy with UV excitation on untwinned single crystals of $YBa_2Cu_3O_{7-\delta}$
S. Bahrs, S. Reich, A. Zwick, A.R. Goñi, W. Bacsa, G. Nieva, and C. Thomsen
phys. stat. sol. (b) **241**, No 12, R63-R66 (2004).

40.* Photoinduced chain-oxygen ordering in detwinned $YBa_2Cu_3O_{6.7}$ single crystals studied by reflectance-anisotropy spectroscopy
A. Bruchhausen, S. Bahrs, K. Fleischer, A.R. Goñi, A. Fainstein, G. Nieva, A.A. Aligia, W. Richter, and C. Thomsen
Phys. Rev. B **69**, 224508 (2004).

41. A resonant Raman study of the SWNTs under electrochemical doping
P.M. Rafailov, M. Stoll, J.Maultzsch, and C. Thomsen
Electronic Properties of Synthetic Nanostructures, eds. H. Kuzmany, J. Fink, M. Mehring, S. Roth, AIP Conference Proceedings **723**, (Melville, New York, 2004) p. 153.

42. The strength of the radial-breathing mode in single-walled carbon nanotubes
M. Machón, S. Reich, J. Maultzsch, P. Ordejón, and C. Thomsen
ibid., p. 381.

43. Phonon dispersion of graphite
J. Maultzsch, S. Reich, C. Thomsen, H. Requardt, and P. Ordejón
ibid., p. 397.

44. Raman excitation profiles for (n_1, n_2) assignment in carbon nanotubes
H. Telg, J. Maultzsch, S. Reich, F. Hennrich, and C. Thomsen
ibid., p. 330.

44. Strain determination in electrochemically doped single-walled carbon nanotubes via Raman spectroscopy
P.M. Rafailov, M. Stoll, and C. Thomsen
J. Phys. Chem. B **108**, 19241-19245 (2004).

46.* Double-resonant Raman scattering in graphite: interference effects, selection rules and phonon dispersion
J. Maultzsch, S. Reich, and C. Thomsen
Phys. Rev. B **70**, 155403 (2004).

47. Raman characterization of nitrogen doped multiwalled carbon nanotubes
S. Webster, J. Maultzsch, C. Thomsen, J. Liu, R. Czerw, M. Terrones. F. Adar, C. John, A. Withley, and D.L. Carrol
2003 Spring Meeting, Mat. Res. Soc. Symp. Proc. **772**, Nanotube-Based Devices, eds. Patrick Bernier, David Carroll, Gyu-Tae Kim, Siegmar Roth, M7.8.1

48.* Recombination dynamics in self-assembled InP/GaP quantum dots under high hydrostatic pressure
C. Kristukat, M. Dworzak, A.R. Goñi, P. Zimmer, F. Hatami, S. Dreßler, A. Hoffmann, W.T. Masselink, and C. Thomsen
phys. stat. sol. (b) **241**, 3263-3268 (2004).

49.* Chirality distribution and transition energies of carbon nanotubes
H. Telg, J. Maultzsch, S. Reich, F. Hennrich, and C. Thomsen
Phys. Rev. Lett. **90**, 177401 (2004).

50.* Effect of light on the reflectance anisotropy and chain-oxygen related Raman signal in untwinned, underdoped crystals of $YBa_2Cu_3O_{7-\delta}$
S. Bahrs, A. Bruchhausen, A.R. Goñi, G. Nieva, A. Fainstein, K. Fleischer, and C. Thomsen
J. Phys. Chem. Solids, submitted (Juli 2004).

51. Chirality assignments in carbon nanotubes based on resonant Raman scattering
C. Thomsen, H. Telg, J. Maultzsch, and S. Reich
phys. stat. Sol. (b), submitted (2004).

52.* Why is luminescence quenched in zigzag carbon nantotubes?
S. Reich, C. Thomsen, and J. Robertson
Phys. Rev. Lett., submitted (2004).

53. Raman spectroscopy on electrochemically doped carbon nanotubes
P.M. Rafailov and C. Thomsen
Journal of Optoelectronics and Advanced Materials, submitted (2004).

54. A Raman spectroscopic study of defects in $Bi_4Ge_3O_{12}$ crystals
P.M. Rafailov, T.I. Milenov, M.I. Veleva, C. Thomsen, and M.M. Gospodinov
Journal of Optoelectronics and Advanced Materials, submitted (2004).

55. High-energy vibrational modes in nitrogen-doped ZnO
U. Haboeck, A. Hoffmann, and C. Thomsen
phys. stat. sol. (b) **242**, R 21 (2005).

56.* Electronic band structure of high-index silicon nanowires
H. Scheel, S. Reich, and C. Thomsen
Phys. Rev. B, submitted (2004).

57. Ein Jahr für die Physik: Aufgabensammlung
C. Thomsen
(Wissenschaft & Technik Verlag, Berlin, 2004), 121 pages.

58. Magnetic field effects on the exchange instability of the 2D electron gas
P. Giudici, A.R. Goñi, C. Thomsen, and K. Eberl
Physica E **22**, 438-441 (2004).

59.* Raman scattering in picotubes
M. Machón, S. Reich, J. Maultzsch, R. Herges, and C. Thomsen
in preparation.

60. InP quantum dots embedded in GaP: optical properties and carrier dynamics
F. Hatami, W.T. Masselink, L. Schrottke, J.W. Tomm, V. Talalaev, C. Kristukat, and A.R. Goñi
Phys. Rev. B **67**, 085306 (2003).

9.2a.3 Invited talks

Christian Thomsen — **Double resonant Raman scattering in an individual carbon nanotube**
XVII International Winterschool on Electronic Properties of Novel Materials, Kirchberg, Austria, March 2003

Christian Thomsen — **Raman scattering in carbon nanotubes**
SPIE Nanotubes and Nanowires, San Diego, USA, August 2003

Christian Thomsen — **Raman scattering in carbon nanotubes**
Fifth General Conference of the Balkan Physical Union, Vrjacka Banja, Serbia and Montenegro, August 2003

Christian Thomsen — **(n,m) chirality assignment based on resonant Raman scattering**
The 20th General Conference of the Condensed Matter Division European Physical Society, EPS, Prague, Czech Republic July 2004

Christian Thomsen — **Chirality assignment in single-walled carbon nanotubes**
XVI International Symposium on Condensed Matter Physics-SFKM 2004, Sokobanja, Serbia and Montenegro, September 2004

Christian Thomsen
Multimedia in der Lehrveranstaltung „Physik für Ingenieure“
Fakultätskolloquium, TU Berlin, Germany, November 2004

Christian Thomsen
Chiral-index assignment in single-walled nanotubes
MRS Fall Meeting (Materials Research Society), Boston, USA, November 2004

Christian Thomsen
Chirality assignment in carbon nanotubes based on resonant Raman scattering
SLAFES, XVII Latin American Symposium on Solid State Physics, Havanna, Cuba, December 2004

Sabine Bahrs
Photoinduced effects in undoped $YBa_2Cu_3O_{7-\delta}$ observed by Raman and reflectance anisotropy spectroscopy
Universität Hamburg, Institut für Angewandte Physik, Hamburg, Germany, October 2004

Sabine Bahrs
Illumination-induced effects in $YBa_2Cu_3O_{7-\delta}$ observed by RAS
AG-Seminar Prof. Richter, TU Berlin, Germany, January 2004

Paula Giudici
Many body effects in diluted 2DEG
XVII International Winterschool/Euroconference on Electronic Properties of Novel Materials, Kirchberg, Austria, March 2003

Paula Giudici
Dependence on well width of the exchange instability in diluted 2D Electron Gases
5th International Conference on low dimensional structures and devices, Cancun, Mexico, December 2004

Alejandro Goñi
Sobre ferromagnetismo en gases bidimensionales de electrones
Coloquio General de Fisica, Bariloche, Argentina, February 2003

Alejandro Goñi
On the electronics structure of quantum dots in external magnetic and stresss fields
the 2nd Euroconference on Quantum Optoelectronics for Nanotechnology (EQUONT-2), Toledo, Canada, June 2003

Alejandro Goñi
Magnetic Field Effects on the Exchange Instability of the 2D Electron Gas
15th International Conference on Electronic Properties of Two-Dimensional Systems, Narra, Japan, July 2003

Christian Kristukat
Recombination dynamics in self-assembled InP/GaP quantum dots under high pressure
International Conference High pressure semiconductor physics, Berkley, USA, August 2004

Maria Machón	**The strength of the radial-breathing mode in single-walled carbon nanotubes** International Workshop on Progress in Ab Initio Computational Methods for Condensed Matter, Gif/Yvette (Paris), France, January 2004
Janina Maultzsch	**Phonon dispersion of graphite by inelastic X-ray scattering** Fifth General Conference of the Balkan Physical Union, Vrnjacka Banja, Serbia and Montenegro, August 2003
Janina Maultzsch	**Phonon dispersion of graphite** XVIII International Winterschool/Euroconference on Electronic Properties of Novel Materials, Kirchberg, Austria, March 2004
Janina Maultzsch	**Vibrational properties of carbon nanotubes and graphite** Institut für Physikalische Chemie, Universität Siegen, Germany, June 2004
Janina Maultzsch	**Chirality-dependent electron-phonon coupling in carbon nanotubes** XVI International Symposium on Condensed Matter Physics-SFKM 2004, Sokobanja, Serbia and Montenegro, September 2004
Peter Rafailov	**Raman spectroscopy on electronichemically doped carbon nanotubes** 13th International School on Condensed Matter, Varna, Bulgarien, September 2004
Peter Rafailov	**A Raman spectroscopic study of defects in $Bi_4Ge_3O_{12}$ crystals** 13th International School on Condensed Matter, Varna, Bulgarien, September 2004
Stephanie Reich	**Hexagonal diamond from single-walled carbon nanotubes** XVII International Winterschool/Euroconference on Electronic Properties of Novel Materials, Kirchberg, Austria, March 2003

9.2a.4 Habilitation

Loa, Ingo	**Studies of structural, vibrational, and electronic properties of solids at high pressure** 31.01.2003

9.2a.5 PhD theses

Liu, Yuntao	**Polarized neutron reflectometry study of thin Fe films prepared on V(100)** 29.04.2004
Maultzsch, Janina	**Vibrational properties of carbon nanotubes and graphite** 15.06.2004
Hofmann, Stephan	**Low temperature growth of high aspect ratio nanostructures** 21.06.2004
Giudici, Paula	**On the spin instability and magnetic phases of the two-dimensional electron gas** 28.09.2004

9.2a.6 Diploma theses

Stoll, Michael	**Ramanstreuung an elektrochemisch dotierten Kohlenstoffnanotubes** 08.01.2004
Telg, Hagen	**Chirality assignment of single-walled carbon nanotubes from resonant Raman scattering** 30.09.2004
Heinrich, Dirk	**Ramanspektroskopie an ionenstabilisierten Ferrofluiden** 07.12.2004

9.2a.7 Abstracts of selected papers of department IIa

1. *phys. stat. sol. (a)* ***196****, 185–188 (2003)*

Spin–phonon coupling in the high pressure phase of the low-dimensional spin compound $(VO)_2P_2O_7$

U. Kuhlmann[1], C. Thomsen[1], A. V. Prokofiev[2], F. Büllesfeld[2], E. Uhrig[2], M. Anton[2], C. Gross[2], and W. Assmus[2]

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[2] *Physikalisches Institut, Universität Frankfurt, 60054 Frankfurt, Germany*

We examined single crystals of the high pressure phase of the alternating antiferromagnetic spin chain compound $(VO)_2P_2O_7$ by Raman scattering. Several phonons in the low-energy region around 200 cm^{-1} reveal a Fano line shape indicating a strong interaction with a background of elementary excitations. From the temperature behavior and the Raman selection rules we conclude a coupling of the phonons to the continuum of two magnon states of the alternating spin chains to be responsible for the observed line shapes.

6. *phys. stat. sol. (b)* ***235,*** *412 (2003)*

High-pressure photoluminescence study of the electronic structure of InP/GaP quantum dots

C. Kristukat[1], A. R. Goñi[1], F. Hatami[2], S. Dreßler[2], W. T. Masselink[2], and C. Thomsen[1]

[1]*Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany*

[2]*Department of Physics, Humboldt-Universität zu Berlin, Invalidenstr. 110, 10115 Berlin, Germany*

The electronic subband structure of self-assembled InP/GaP quantum dots (QDs) has been investigated by means of photoluminescence (PL) measurements as a function of hydrostatic pressure up to 8 GPa and temperature. At ambient pressure the PL emission of the sample arises from direct optical transitions between the lowest electron and hole Γ-point states confined in the QDs. At a very low pressure of about 0.15 GPa, the Γ–X conduction band crossover occurs, after which the PL emission of the dots becomes roughly 20 times weaker in intensity and its energy exhibits the slight redshift typical of indirect recombination processes from the conduction band X valleys. Our results indicate a type-I band alignment for the strained InP/GaP dot structure at low pressure and yield a value of 300 ± 30 meV for the valence-band offset.

7. *phys. stat. sol.* ***235**, 354 (2003)*

Elastic properties and pressure-induced phase transitions of single-walled carbon nanotubes

S. Reich[1], C. Thomsen[1], and P. Ordejón[2]
[1]*Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany*
[2]*Institut de Ciència de Materials de Barcelona (CSIC), Campus de la U.A.B. 08193 Bellaterra, Barcelona, Spain*

We studied the structure of single-walled carbon nanotubes under hydrostatic pressure by first-principles calculations. The circular tubes collapse at high pressure (7 GPa) to a phase with an elliptical cross-section. The elliptical structure leads to the formation of diamond-like bonds between the tubes at the point of strongest curvature. The bulk modulus of the circular, ambient-pressure phase that we found from our calculations is very similar to graphite (37 GPa). The interlinked phase also shows graphite-like behavior in the low- and high-pressure range: between 3.5 and 6.5 GPa its compressibility is very large. We compare our theoretical predicitions to X-ray scattering and piston–cylinder experiments.

9. *Phys. Rev. B* ***67**, 052403 (2003)*

Magnetic excitations in $SrCu_2O_3$: A Raman scattering study

A. Gößling, U. Kuhlmann, and C. Thomsen
Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, D-10623 Berlin, Germany

A. Löffert, C. Gross, and W. Assmus
Physikalisches Institut, J.W. Goethe-Universität, Robert-Mayer-Str. 2-4, -60054 Frankfurt a. M., Germany

We investigated temperature-dependent Raman spectra of the one-dimensional spin-ladder compound $SrCu_2O_3$. At low temperatures a two-magnon peak is identified at 3160±10 cm^{-1} and its temperature dependence analyzed in terms of a thermal-expansion model. We find that the two-magnon peak position must include a cyclic ring exchange of $J_{cycl}/J_{\perp}$=.09–0.25 with a coupling constant along the rungs of $J_{\perp}\approx$1215 cm^{-1} (1750 K) in order to be consistent with other experiments and theoretical results.

10. *phys. stat sol. (c) 0, 1710-1731 (2003)*

Lattice dynamics in GaN and AlN probed with first- and second-order Raman spectroscopy

U. Haboeck*, H. Siegle, A. Hoffmann, and C. Thomsen
Technische Universität Berlin, Institut für Festkörperphysik, Sekr. PN 5-4, Hardenbergstr. 36,D-10623 Berlin, Germany

We present a selection of our contributions to basic research on the lattice dynamical properties of group-III nitrides and their alloys. We used first-order Raman scattering to determine the zone-center phonons and their dependence on structural attributes such as stress, chemical composition, impurities, and doping. Results on the angular dispersion of the polar modes, strain distribution, coupled LO-phonon plasmon modes, multi-mode behavior in $Al_xGa_{1-x}N$, and the quantitative determination of the phase purity of cubic and hexagonal GaN are shown. Second-order Raman-scattering experiments on GaN and AlN provide information on the vibrational states throughout the entire Brillouin zone. Based on a comparison of experimental data and calculated phonon-dispersion curves we assigned the observed structures to particular phonon branches and points in the Brillouin zone. We also discuss the behavior of the optical modes under large hydrostatic pressure.

12. *Phys. Rev. B* ***67****, 075306 (2003)*

Electronic structure of self-assembled InP/GaP quantum dots from high-pressure photoluminescence

A. R. Goñi,[1] C. Kristukat,[1] F. Hatami,[2] S. Dreßler,[2] W. T. Masselink,[2] and C. Thomsen[1]
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[2]*Department of Physics, Humboldt-Universität zu Berlin, Invalidenstr. 110, 10115 Berlin, Germany*

The electronic structure of self-organized InP/GaP quantum dots (QDs) has been studied by means of photoluminescence (PL) measurements as a function of hydrostatic pressure up to 8 GPa, temperature, and laser excitation power. At ambient pressure the PL emission of the sample arises from *direct* optical transitions between the lowest electron and hole Γ-point states confined in the QD's. At a very low pressure of about 0.15 GPa, the Γ-*X* conduction-band crossover occurs, after which the PL emission of the dots becomes roughly 20 times weaker in intensity and its energy exhibits the slight redshift typical of indirect recombination processes from the conduction-band *X* valleys. Our results indicate a type-I band alignment for the strained InP/GaP dot structure at low pressure and yield a value of 300±30 meV for the valence-band offset. Upon further increase in pressure above 1.2 GPa we observe the quenching of the dot emission, which is taken as evidence for a type-I–type-II transition.

13. *Chem. Phys. Lett.* ***375,*** *625 (2003)*

Electrochemical and Raman measurements on single-walled carbon nanotubes

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Electrochemical measurements were performed on a carbon nanotube mat as a working electrode using different salt solutions. The gravimetric capacitance of the nanotube material was estimated and its effective surface area was determined in a purely electrochemical way. We also studied the Raman response upon electrochemical p-doping of carbon nanotubes. The frequency shifts and the Raman intensities of the radial breathing mode and the high-energy stretching-like mode were examined as a function of doping level.

14. *Phys. Rev. Lett.* ***91****, 087402 (2003)*

High-Energy Phonon Branches of an Individual Metallic Carbon Nanotube

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We present excitation-energy dependent Raman measurements between 2.05 and 2.41 eV on the same individual carbon nanotube. We find a change in the Raman frequencies of both the *D* mode (63 cm^{-1}/eV) and the high-energy modes. The observed frequencies of the modes at ≈1600 cm^{-1} as a function of laser-energy map the phonon dispersion relation of a metallic tube near the Γ point of the Brillouin zone. Our results prove the entire first-order Raman spectrum in single-wall carbon nanotubes to originate from double-resonant scattering. Moreover, we confirm experimentally the phonon softening in metallic tubes by a Peierls-like mechanism.

19. *Phys. Rev. B* ***68****, 193411 (2003)*

Resonance and high-pressure Raman studies on carbon peapods

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Raman spectra of C_{60} and C_{70} encapsulated in single-wall carbon nanotubes (so-called peapods) were measured at different excitation wavelengths in the range 458–568 nm and at hydrostatic pressure up to 9 GPa. We present the excitation profiles for some intense high-frequency peaks of C_{60} and C_{70} normalized to the scattering intensity of CaF_2. With some minor differences they resemble the corresponding optical absorption profiles of C_{60} and C_{70}. The results are discussed in terms of the electronic structure of the fullerenes and compared to their optical spectra in the solid state and solutions. Pressure slopes are obtained for the $A_g(2)$ mode of C_{60} peapods and the three modes at 1446, 1465, and 1476 cm^{-1} in C_{70} peapods. Abrupt changes in the slopes of these three lines are observed around 1.5 GPa.

22. *Phys. Rev. B* ***71****, 035416 (2005)*

The strength of the radial-breathing mode in single-walled carbon nanotubes

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We show by *ab initio* calculations that the electron-phonon coupling matrix element $M_{e\text{-}ph}$ of the radial breathing mode in single-walled carbon nanotubes depends strongly on tube chirality. For nanotubes of the same diameter the coupling strength $|M_{e\text{-}ph}|^2$ is up to one order of magnitude stronger for zig-zag than for armchair tubes. For (n_1,n_2) tubes $M_{e\text{-}ph}$ depends on the value of $(n_1 - n_2)$ mod 3, which allows to discriminate semiconducting nanotubes with similar diameter by their Raman scattering intensity. We show measured resonance Raman profiles of the radial breathing mode which support our theoretical predictions.

24. *Phys. Rev. B* ***70****, 195331 (2004)*

Evidence of spontaneous spin polarization in the two-dimensional electron gas

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Density-functional calculations using an exact exchange potential for a two-dimensional electron gas (2DEG) formed in a GaAs single quantum well predict the existence of a spin-polarized phase, when an excited subband becomes slightly populated. Direct experimental evidence is obtained from low-temperature and low-excitation power photoluminescence (PL) spectra, which display the sudden appearance of a sharp emission peak below the energy of the optical transition from the first excited electron subband upon its occupation. The behavior of this PL feature in magnetic fields applied in-plane as well as perpendicular to the 2DEG indicate the formation of spin-polarized domains in the excited subband with in-plane magnetization. The strong enhancement of exchange-vertex corrections observed in inelastic light scattering spectra by spin-density excitations of a slightly occupied first-excited subband also speaks for the appearance of magnetic ordering.

28. *Phys. Rev. Lett.* ***92****, 075501 (2004)*

Phonon dispersion in graphite

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We measured the dispersion of the graphite optical phonons in the in-plane Brillouin zone by inelastic x-ray scattering. The longitudinal and transverse optical branches cross along the Γ-*K* as well as the Γ-*M* direction. The dispersion of the optical phonons was, in general, stronger than expected from the literature. At the *K* point the transverse optical mode has a minimum and is only ≈70 cm^{-1} higher in frequency than the longitudinal mode. We show that first-principles calculations describe very well the vibrational properties of graphene once the long-range character of the dynamical matrix is taken into account.

29. *(WILEY-VCH, Berlin, 2004) 224 pages*

Carbon Nanotubes
Basic Concepts and Physical Properties

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C. Thomsen, *Technical University of Berlin, Germany*
J. Maultzsch, *Technical University of Berlin, Germany*

Carbon nanotubes are exceptionally interesting from a fundamental research point of view. Many concepts of one-dimensional physics have been verified experimentally such as electron and phonon confinement or the one-dimensional singularities in the density of states; other 1D signatures are still under debate, such as Luttinger-liquid behavior. Carbon nanotubes are chemically stable, mechanically very strong, and conduct electricity. For this reason, they open up new perspectives for various applications, such as nano-transistors in circuits, field-emission displays, artificial muscles, or added reinforcements in alloys. This text is an introduction to the physical concepts needed for investigating carbon nanotubes and other one-dimensional solid-state systems. Written for a wide scientific readership, each chapter consists of an instructive approach to the topic and sustainable ideas for solutions. The former is generally comprehensible for physicists and chemists, while the latter enable the reader to work towards the state of the art in that area. The book gives for the first time a combined theoretical and experimental description of topics like luminescence of carbon nanotubes, Raman scattering, or transport measurements. The theoretical concepts discussed range from the tight-binding approximation, which can be followed by pencil and paper, to first-principles simulations. We emphasize a comprehensive theoretical and experimental understanding of carbon nanotubes including

- general concepts for one-dimensional systems
- an introduction to the symmetry of nanotubes
- textbook models of nanotubes as narrow cylinders
- a combination of ab-initio calculations and experiments
- luminescence excitation spectroscopy linked to Raman spectroscopy
- an introduction to the 1D-transport properties of nanotubes
- effects of bundling on the electronic and vibrational properties and
- resonance Raman scattering in nanotubes.

30. *Phys. Rev. B* ***70****, 014512 (2004)*

Light-induced oxygen-ordering dynamics in $(Y,Pr)Ba_2Cu_3O_{6.7}$: A Raman spectroscopy and Monte Carlo study

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We investigated the time and temperature dependence of photobleaching effects in $RBa_2Cu_3O_{7-\delta}$ single crystals (R-Y,Pr) by Raman spectroscopy and Monte Carlo simulations based on the asymmetric nextnearest- neighbor Ising model. In a temperature range between 40 and 300 K the bleaching slows down on cooling, displaying a pronounced change in dynamics around 160 K for R=Y. To model this behavior we extended the Ising model by introducing a single energy barrier which impedes oxygen movement in the plane unless the oxygen atoms are excited by light. We obtain a time- and temperature-dependent development of superstructures under illumination with the fastest change at intermediate model temperatures. The chainfragment development in the simulation thus matches the experimental low-temperature dynamics of Raman photobleaching, providing further support for oxygen reordering in the chain plane being at the origin of Raman photobleaching and related effects.

32. *New Journal of Physics, 2003 and 2004*

Focus Issue on Cabon Nanotubes

guest editors: C. Thomsen and H. Kataura

The study of carbon nanotubes, since their discovery by Iijima in 1991, has become a full research field with significant contributions from all areas of research in solid-state and molecular physics and also from chemistry. This Focus Issue in *New Journal of Physics* reflects this active research, and presents articles detailing significant advances in the production of carbon nanotubes, the study of their mechanical and vibrational properties, electronic properties and optical transitions, and electrical and transport properties. Fundamental research, both theoretical and experimental, represents part of this progress. The potential applications of nanotubes will rely on the progress made in understanding their fundamental physics and chemistry, as presented here. We believe this Focus Issue will be an excellent guide for both beginners and experts in the research field of carbon nanotubes. It has been a great pleasure to edit the many excellent contributions from Europe, Japan, and the US, as well from a number of other countries, and to witness the remarkable effort put into the manuscripts by the contributors. We thank all the authors and referees involved in the process. In particular, we would like to express our gratitude to Alexander Bradshaw, who invited us put together this Focus Issue, and to Tim Smith and the *New Journal of Physics* staff for their extremely efficient handling of the manuscripts.

36. *Phys. Rev. B* ***70****, 235418 (2004)*

Effects of the exchange instability on collective spin and charge excitations of the two-dimensional electron gas

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We report inelastic light scattering measurements of the elementary excitations of a two-dimensional (2D) electron gas formed in a modulation-doped GaAs single quantum well, when the first excited conduction subband begins to be populated and the sudden renormalization of its energy occurs due to an exchange-driven instability of the 2D system. The Hartree and exchange-correlation terms of the Coulomb interaction, which can be precisely determined from the energies of the charge and spin-density excitations in light scattering spectra, exhibit abrupt changes upon filling of the excited subband. Density-functional calculations of the collective excitations within the time-dependent local spin-density approximation provide a simple explanation for the strong enhancement of the Hartree term observed in the experiment. In contrast, the sudden reduction of exchange-correlation vertex corrections at the instability are not well accounted for by the theory. We discuss this discrepancy and present its peculiar temperature dependence.

37. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* ***362****, 2271-2288 (2004)*

Raman spectroscopy of graphite

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We present a review of the Raman spectra of graphite from an experimental and theoretical point of view. The disorder-induced Raman bands in this material have been a puzzling Raman problem for almost 30 years. Double-resonant Raman scattering explains their origin as well as the excitation-energy dependence, the overtone spectrum and the di.erence between Stokes and anti-Stokes scattering. We develop the symmetry-imposed selection rules for double-resonant Raman scattering in graphite and point out misassignments in previously published works. An excellent agreement is found between the graphite phonon dispersion from double-resonant Raman scattering and other experimental methods.

38. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* ***362****, 2337-2359 (2004)*

Resonant Raman spectroscopy of nanotubes

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Single and double resonances in Raman scattering are introduced and six criteria for the observation and identifcation of double resonances stated. The experimental situation in carbon nanotubes is reviewed in view of these criteria. The evidence for the D mode and the high-energy mode is found to be overwhelming for a double resonance process to take place, whereas the nature of the radial breathing-mode Raman process remains undecided at this point. Consequences for the application of Raman scattering to the characterization of nanotubes are discussed.

40. *Phys. Rev. B* ***69****, 224508 (2004)*

Photoinduced chain-oxygen ordering in detwinned $YBa_2Cu_3O_{6.7}$ single crystals studied by reflectance-anisotropy spectroscopy

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We present a reflectance-anisotropy spectroscopy (RAS) investigation of photoexcitation and annealing effects in oxygen deficient detwinned $YBa_2Cu_3O_{6.7}$ single crystals. Well-resolved RAS spectral features are either bleached or enhanced on a time scale of hours upon laser illumination with polarization parallel to the Cu(1)-O(1) chains. These photoinduced effects recover with room temperature annealing in the dark. Based on previous ellipsometric studies and on cluster models for the oxygen Cu-O(1) chain-fragments we are able to assign the RAS peaks that depend on illumination to optical transitions involving copper atoms located either on short chain-fragments or in isolated $Cu\text{-}O(4)_2$ sites. This provides strong evidence that photoinduced chain-oxygen ordering is indeed at the origin of persistent photoconductivity and Raman vibrational mode bleaching in these materials.

46. *Phys. Rev. B* ***70****, 155403(2004)*

Double-resonant Raman scattering in graphite: Interference effects, selection rules, and phonon dispersion

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We present a comprehensive analysis of double-resonant Raman scattering in graphite and derive an analytical expression for the Raman cross section of the *D* mode in one dimension. The extension to two dimensions does not change the double-resonant phonon wave vectors. In the full integration of the Raman cross section, the contributions by phonons from exactly the *K* point cancel due to destructive interference. We calculate the *D* mode explicitly based on recent experimental data of the graphite phonon dispersion. Applying the selection rules, a mapping of additional disorder-induced and second-order Raman modes onto the Brillouin zone of graphite is obtained.

48. *phys. stat. sol. (b)* ***241****, 3263 (2004)*

Recombination dynamics in self-assembled InP/GaP quantum dots under high pressure

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We have investigated the recombination dynamics in self-assembled InP/GaP quantum dots by means of time-resolved photoluminescence measured at low temperatures between 2 and 100 K and high hydrostatic pressure up to 2 GPa. Due to the high-power levels for pulsed excitation, the quantum dot emission exhibits two components with typical decay times of 5 and 30 ns, corresponding to direct $\Gamma - \Gamma$ and $X - \Gamma$ interband recombination processes, respectively. These decay times appear to be independent of pressure. At a very low pressure of about 0.1 GPa the intensity of the dot emission drops abruptly relative to that of the wetting layer indicating a switching off of a carrier relaxation channel.

49. *Phys. Rev. Lett.* ***93****, 177401 (2004)*

Chirality distribution and transition energies of carbon nanotubes

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From resonant Raman scattering on isolated nanotubes we obtained the optical transition energies, the radial breathing mode frequency, and the Raman intensity of both metallic and semiconducting tubes.We unambiguously assigned the chiral index (n_1, n_2) of ≈ 50 nanotubes based solely on a thirdneighbor tight-binding Kataura plot and find $\omega_{RBM} = (214.4 \pm 2)$ cm^{-1} nm/d + (18.7 ± 2) cm^{-1}. In contrast to luminescence experiments we observe all chiralities including zigzag tubes. The Raman intensities have a systematic chiral-angle dependence confirming recent *ab initio* calculations.

50. J. Phys. Chem. Solids, submitted (2005)

Effect of light on the reflectance anisotropy and chain-oxygen related Raman signal in untwinned, underdoped crystals of $YBa_2Cu_3O_{7-\delta}$

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Recent studies of the optical anisotropy of a detwinned, underdoped $YBa_2Cu_3O_{7-\delta}$-crystal showed that illumination-induced change and recovery in the surface reflectance can be traced on a time scale of hours. This effect of light is also known from Raman bleaching and electrical transport and shares features of the oxygen reordering processes above room temperature. We report temperature-dependent studies of the optical anisotropy using Reflectance Anisotropy Spectroscopy and present time-dependent data for the optical transitions at 2.2 and 4.4 eV. We compare our results to Raman bleaching and discuss them within the picture of superstructure patterns and oxygen-defect reordering in underdoped $YBa_2Cu_3O_{7-\delta}$.

52. *Phys. Rev. Lett., submitted (2004)*

Why is luminescence quenched in zigzag carbon nantotubes?

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We show that the photoluminescence intensity of single-walled carbon nanotubes is much stronger in tubes with large chiral angles – armchair tubes – because excitation resonances make the luminescence of zigzag tubes intrinsically weak. Hence, armchair tubes do not grow preferentially with present growth techniques; they just have stronger luminescence. We suggest to use Raman scattering in resonance with the nanotube band gap as an unbiased tool to measure the abundance of tubes.

56. *Phys. Rev. B., submitted (2005)*

Electronic band structure of high-index silicon nanowires

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We calculated the electronic properties of high-index free-standing silicon nanowires. [112] nanowires are indirect semiconductors for diameters down to 0.8 nm; [110] wires have a direct band gap at the Γ-point, but the corresponding density of states is very small. Confinement arguments show that only [001] nanowires are expected to develop a direct gap with a large density of electronic states for diameters in the nm range. The magnitude of the gap depends strongly on the wire growth direction, which is due to the different effective confinement length and effective masses for the Γ*X*-derived silicon states. Correcting for the extension of the wavefunctions we find our calculated energies to agree with recent scanning tunneling experiments.

58. *Phys. Rev. B, submitted (2005)*

Raman scattering in picotubes

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The recently synthesized picotube molecule (also known as tetramer) is one of the most symmetrical hydrocarbons. Its close relation to the (4,4) nanotube opens the door to the chirality and diameter selective growth of carbon nanotubes by chemical means. We present a Raman study of picotube crystals. The spectrum is dominated by the graphite-like mode at about 1600 cm^{-1}. A group of lines at about 480 cm^{-1} possibly corresponds to radial-breathing-like modes. We derive the symmetry of the C-C vibrational modes and discuss the degree of interaction of the molecules in the crystal.

9.2.b Department IIb

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Patrick Zimmer

9.2b.1 Summary of activities

The main research activities concentrate on the optical properties of wide-band gap II-VI and III-V semiconductors with special emphasis on **ZnSe-, ZnO- and GaN-based structures**. The investigations are carried out on single crystals, epitaxially grown heterostructures and, especially, **low-dimensional structures like quantum wells and quantum dots**.

In the last years new activities were started like studies of the electro-optical effects in polymers, investigations of the energy transfer in organic light-emitting diodes and non-linear optics in chalcopyrites. Cooperations have been established with many research groups in Germany, France, Russia, Belarus, United Kingdom, Israel, USA and Japan. The essential physical topics include:

- excitonic polaritons and bound excitons in bulk crystals and excitonic complexes in low dimensional structures based on **InGaN, InGaAs and InGaAsN**,
- shallow and deep centers,
- recombination dynamics and non-radiative processes,
- non-linear optical effects of pure and doped wide-gap semiconductors,
- coherent dynamics,
- optical gain mechanisms,
- analysis of doping and dopant compensation mechanisms, and
- electro-optical effects in polymers.

Excitonic complexes, their excitation and relaxation mechanisms and the dynamics of these processes are in our center of interest. Knowledge about the energetic structure and relaxation mechanisms of free and bound excitons allows a precise analysis of defects created during growth and doping procedures. An important method to study such phenomena is the measurement of the DTS-signal using the two-color pump-and-probe ps-spectroscopy. These investigations are carried out in close cooperation with other groups aiming for the development and optimization of new optoelectronic devices like **blue light-emitting diodes and lasers**. Both wide-gap II-VI and III-V semiconductors are studied.

Our work on binary and ternary group-III nitrides has been concentrated to the experimental determination of basic band structure parameters of this as yet poorly known material. Many papers of the last two years have led to a complete understanding of the measured optical properties. A further focus has been on high-density effects, like **biexciton annihilation, exciton-exciton scattering or plasma creation,** which have been identified. Also, gain mechanisms in epitaxial group-III nitride layers and quantum wells were studied. All these investigations are of great interest for the development of blue emitting semiconductor laser diodes.

For GaN- and ZnO-based structures the problem of p-dopant compensation attracts a lot of interest. Intensive studies were dedicated to the behavior of donor-acceptor pair emissions of highly doped ZnO-layers. Our observation, that the broad luminescence band usually observed in highly doped material becomes much sharper at higher excitation levels, finally turning into the normal, low doping spectrum has triggered intensive investigations using optical spectroscopy as a function of intensity and temperature.

Currently, two different models for this effect are discussed, **in highly compensated specimens** the formation of **high electric fields** or the existence of an exponentially structured continuum of low lying donors or acceptors. Calculations have been performed to distinguish between the two different methods.

The study of **coherent processes** especially at localized excitations is a further issue in our research. Coherent lifetimes react very sensitively to defect structures and can thus help to optimize growth techniques for blue light-emitting devices. Four-wave mixing techniques could be applied to epitaxial layers of different II-VI compounds to receive non-linear quantum beats. We have shown that they originate either from zero-field split excited states of one complex or from interference between two different bound excitons. Coherent lifetimes of some hundred fs were observed.

The purpose of the Sfb 296 project headed by Axel Hoffmann and Christian Thomsen is to study the influence of the electron-phonon interaction in low-dimensional semiconductor systems. Here, our main focus is the investigation of the dynamical properties of excitonic states in II-VI and III-V quantum dots.

In cooperation with the Siemens AG experiments to measure the electro-optical coefficients of polymers and the electro-optical properties of **organic light-emitting diodes and bio-chip readers** were continued. The results are important to create new optical communication and signal processing systems on the basis of organic materials.

9.2b.2 Publications

The abstracts of papers marked by* are reprinted in section 9.2.6

1. **Evidence of quantum dots in "quantum well" InGaN/GaN structures**
   I.L. Krestnikov, A. Strittmatter, A.V. Sakharov, W.V. Lundin, A.F. Tsatsul'nikov, Yu.G. Musikhin, D. Gerthsen, N.N. Ledentsov, A. Hoffmann, D. Bimberg
   Proceedings of 26^{th} Int. Conf. Phys. Semicond., Edinburgh 2002, Institute of Phys., Conf. Ser. **171**, A.R. Long and J.H. Davis (eds.), H 163 (2003)

2. **Properties of the nitrogen acceptor in ZnO**
   Martin Straßburg, U. Haboeck, A. Kaschner, Matthias Straßburg, A. Rodina, A. Hoffmann, C. Thomsen, A. Zeuner, H.R. Alves, D.M. Hofmann, B.K. Meyer
   Proceedings of 26^{th} Int. Conf. Phys. Semicond., Edinburgh 2002, Institute of Phys., Conf. Ser. **171**, A.R. Long and J.H. Davis (eds.), P 45 (2003)

3. **Local field effects in quantum optics of quantum dots**
   G. Ya Slepyan, S.A. Maksimenko, A. Hoffmann, D. Bimberg
   Proceedings of 26^{th} Int. Conf. Phys. Semicond., Edinburgh 2002, Institute of Phys., Conf. Ser. **171**, A.R. Long and J.H. Davis (eds.), D 154 (2003)

4. **Light-emitters fabricated on bulk GaN substrates: Challenges and achievements**
   Piotr Perlin, M. Leszczynki, P. Prystavko, R. Czernecki, G. Nowak, P. Wisniewski, L. Dmowski, H. Teisseyre, E. Litwin-Staszewska, T. Suski, I. Grzegory, S. Porowski, V.Yu. Ivanov, M. Godlewski, J. Holst, A. Hoffmann
   Mat. Res. Soc. Symp. Proc. **693**, 303 (2003)

5. **Growth and p-type doping of ZnSeTe on InP**
Matthias Strassburg, Martin Strassburg, O. Schulz, U.W. Pohl, A. Hoffmann, D. Bimberg, A.G. Kontos, Y.S. Raptis
J. Cryst. Growth **248**, 50 (2003)

6.* **Donor centers in Zinc Germanium Diphosphide produced by electron irradiation**
W. Gehlhoff, D. Azamat, A. Hoffmann
phys. stat. sol. (b) **235**, 151 (2003)

7. **Carrier dynamics in particle-irradiated InGaAs/GaAs quantum dots**
A. Cavaco, N.A. Sobolev, M.C. Carmo, F. Guffarth, H. Born, R. Heitz, A. Hoffmann, D. Bimberg
phys. stat. sol. (c) **0**, 1177 (2003)

8. **Radiation hardness of InGaAs/GaAs quantum dots**
F. Guffarth, R. Heitz, M. Geller, C. Kapteyn, H. Born, R. Sellin, A. Hoffmann, D. Bimberg, N.A. Sobolev, M.C. Carmo
Appl. Phys. Lett. **82**, 1941 (2003)

9. **Optical micro-characterization of group-III nitrides: Correlation of structural, electronic and optical properties**
J. Christen, T. Riemann, F. Bertram, D. Rudloff, P. Fischer. A. Kaschner, U. Haboeck, A. Hoffmann, C. Thomsen
phys. stat. sol. (c) **0**, 1795 (2003)

10.* **Local vibrational modes and compensation effects in Mg-doped GaN**
A. Hoffmann, A. Kaschner, C. Thomsen
phys. stat. sol. (c) **0**, 1783 (2003)

11. **Lattice dynamics in GaN and AlN probed with first- and second-order Raman spectroscopy**
U. Haboeck, H. Siegle, A. Hoffmann, C. Thomsen
phys. stat. sol. (c) **0**, 1710 (2003)

12.* **The origin of the photoluminescence Stokes shift in ternary group-III nitrides : Field effects and localization**
M. Straßburg, A. Hoffmann J. Holst, J. Christen, T. Riemann, F. Bertram, P. Fischer
phys. stat. sol. (c) **0**, 1835 (2003)

13. **Excitonic composites**
G.A. Slepyan, S.A. Maksimenko, A. Hoffmann, D. Bimberg
Advances in Electromagnetics of Complex Media and Metamaterials, S. Zouhdi et al. (eds.), Netherlands, p. 385-402 (2003)

14. **EPR studies of native and impurity defects in II-IV-V_2 semiconductors**
W. Gehlhoff, D. Azamat, A. Hoffmann
Mat. Sci. Semicond. Processing **6**, 379 (2003)

15.* **Exciton-phonon interactions and exciton dephasing in semiconductor quantum well heterostructures**
I.V. Bondarev, S.A. Maksimenko, G.Ya. Slepyan, I.L. Krestnikov, A. Hoffmann
Phys. Rev. B **68**, 73310 (2003)

16. **Direct evidence for nanoscale carrier localization in InGaN/GaN structures grown on Si substrates**
I.L. Krestnikov, M. Strassburg, A. Strittmatter, N.N. Ledentsov, A. Hoffmann, D. Bimberg, J. Christen
Jpn. J. Appl. Phys. **42**, L 1057 (2003)

17.* **Stress analysis of $Al_xGa_{1-x}N$ films with microcracks**
D. Rudloff, T. Riemann, J. Christen, Q.K.K. Liu, K. Vogeler, S. Einfeldt, D. Hommel, A. Kaschner, A. Hoffmann, C. Thomsen
Appl. Phys. Lett. **82**, 3678 (2003)

18.* **Inherent nature of localized states in highly-planar monolayer InAs/GaAsN pseudo-alloys**
I.L. Krestnikov, R. Heitz, N.N. Ledentsov, A. Hoffmann, A.M. Mintarov, T.H. Kosel, J.L. Merz, I.P. Shoshnikov, V.M. Ustinov
Appl. Phys. Lett. **83**, 3728 (2003)

19. **Lateral carrier transfer in Cd_xZnSe/ZnS_ySe_{1-y} quantum dot layers**
S. Rodt, V. Türck, R. Heitz, F. Guffarth, R. Engelhardt, U.W. Pohl, M. Strassburg, M. Dworzak, A. Hoffmann, D. Bimberg
Phys. Rev. B **67**, 235327 (2003)

20. **Exciton-phonon interactions and exciton pure dephasing in lens-shaped quantum dots**
I.V. Bondarev, S.A. Maksimenko, G.Ya. Slepyan, I.L. Krestnikov, A. Hoffmann
Materials Science & Engineering C **23**, 1107 (2003)

21.* **EPR and electrical studies of native point defects in $ZnSiP_2$ semiconductors**
W. Gehlhoff, D. Azamat, A. Krtschil, A. Hoffmann, A. Krost
Physica B **340-342**, 933 (2003)

22. **Optically detected magnetic resonance experiments on native defects in $ZnGeP_2$**
D.M. Hofmann, N.G. Romanov, W. Gehlhoff, D. Pfisterer, B.K. Meyer, D. Azamat, A. Hoffmann
Physica B **340-342**, 978 (2003)

23. **5th International Conference on Nitride Semiconductors (ICNS-5), Nara, Japan, 25-30 May 2003**
A. Hoffmann
phys. stat. sol. (a) **199**, 157 (2003)

24. **5th International Conference on Nitride Semiconductors (ICNS-5), Nara, Japan, 25-30 May 2003**
A. Hoffmann
phys. stat. sol. (b) **239**, 273 (2003)

25. **Structure and energy level of native defects in as-grown and electron-irradiated zinc germanium diphosphide studied by EPR and photo-EPR**
W. Gehlhoff, D. Azamat, A. Hoffmann, N. Dietz
J. of Physics and Chemistry of Solids **64**, 1923 (2003)

26. Exciton-phonon coupling of localized quasi-2D excitons in semiconductor quantum well heterostructures
I.V. Bondarev, S.A. Maksimenko, G.Ya. Slepyan, I.L. Krestnikov, A. Hoffmann
Physics, Chemistry and Application of Nanostructures, V.E. Borisenko, S.V. Gaponenko, and V.S. Gurin (eds.) World Scientific, Singapore, 302 (2003)

27.* Bound exciton and donor-acceptor pair recombination in ZnO
B.K. Meyer, H.R. Alves, D.M. Hofmann, W. Kriegeis, D. Foerster, F. Bertram, J. Christen, A. Hoffmann, M. Straßburg, M. Dworzak, U. Haboeck, A.V. Rodina
phys. stat. sol. (b) **241**, 231 (2004)

28. Magneto-optical properties of bound excitons in ZnO
A.V. Rodina, M. Straßburg, M. Dworzak, U. Haboeck, A. Hoffmann, A. Zeuner, H.R. Alves, D.M. Hofmann, B.K. Meyer
Phys. Rev. B **69**, 125206 (2004)

29. Identification of bound exciton complexes in ZnO
M. Strassburg, A. Rodina, M. Dworzak, U. Haboeck, I.L. Krestnikov, A. Hoffmann, O. Gelhausen, M.R. Phillips, H.R. Alves, A. Zeuner, D.M. Hofmann, B.K. Meyer
phys. stat. sol. (b) **241**, 607 (2004)

30. Multi-excitonic complexes in single InGaN quantum dots
R. Seguin, S. Rodt, A. Strittmatter, L. Reissmann, T. Bartel, A. Hoffmann, D. Bimberg, E. Hahn, D. Gerthsen
Appl. Phys. Lett. **84**, 4023 (2004)

31. Dissociation of H-related defect complexes in Mg-doped GaN
O. Gelhausen, M.R. Phillips, E.M. Goldys, T. Paskova, B. Monemar, M. Strassburg, A. Hoffmann
Phys. Rev. B. **69**, 125210 (2004)

32.* Doping-level-dependent optical properties of GaN : Mn
O. Gelhausen, E. Malguth, M.R. Phillips, E.M. Goldys, M. Strassburg, A. Hoffmann, T. Graf, M. Gjukic, M. Stutzmann
Appl. Phys. Lett. **84**, 4514 (2004)

33. Rabi oscillations in a semiconductor quantum dot: Influence of local fields
G.Ya. Slepyan, A. Magyarov, S.A. Maksimenko, A. Hoffmann, D. Bimberg
Phys. Rev. B **70**, 45320 (2004)

34.* Recombination dynamics of localized excitons in InGaN quantum dots
T. Bartel, M. Dworzak, M. Strassburg, A. Hoffmann, A. Strittmatter, D. Bimberg
Appl. Phys. Lett. **85**, 1946 (2004)

35. The growth and optical properties of large, high-quality AlN single crystals
M. Strassburg, J. Senawiratne, N. Dietz, U. Haboeck, A. Hoffmann, V. Noveski, R. Dalmau, R. Schlesser, Z. Sitar
J. of Appl. Phys. **96**, 5870 (2004)

36. Recombination dynamics in self-assembled InP/GaP quantum dots under high pressure
C. Kristukat, M. Dworzak, A.R. Goñi, P. Zimmer, F. Hatami, S. Dreßler, A. Hoffmann
High Pressure Conference, phys. stat. sol. (b) **241**, 3263 (2004)

37. Relaxation of energy and phase in self-organized In(Ga)As/GaAs quantum dots
M. Dworzak, P. Zimmer, H. Born, A. Hoffmann
Proc. 27^{th} Int. Conf. on the Physics of Semiconductors (Flagstaff, USA), AIP Journal (2004)

38. Redistribution of excitons localized in InGaN quantum dot structures
M. Dworzak, T. Bartel, M. Strassburg, A. Hoffmann, A. Strittmatter, D. Bimberg
Proc. 27^{th} Int. Conf. on the Physics of Semiconductors (Flagstaff, USA), AIP Journal (2004)

39. Growth of high quality AlN single crystals and their optical properties
M. Strassburg, J. Senawiratne, N. Dietz, U. Haboeck. A. Hoffmann, V. Noveski, R. Dalmau, R. Schlesser, Z. Sitar
Proc. 27^{th} Int. Conf. on the Physics of Semiconductors (Flagstaff, USA), AIP Journal (2004)

40. Electron Phonon interaction in InAsIGaAs quantum dots
A. Paarmann, F. Guffarth, T. Warming, A. Hoffmann, D. Bimberg
Proc. 27^{th} Int. Conf. on the Physics of Semiconductors (Flagstaff, USA), AIP Journal (2004)

41. Nitrogen doping in bulk and epitaxial ZnO
A. Zeuner, H. Alves, J. Sann, W. Kriegseis, C. Neumann, D.M. Hofmann, B.K. Meyer, A. Hoffmann, U. Haboeck, M. Straßburg, and A. Kaschner
phys. stat. sol. (c) **1**, 731 (2004)

42. Formation and dissociation of hydrogen-related defect centers in Mg-doped GaN
O. Gelhausen, M.R. Phillips, E.M. Goldys, T. Paskova, B. Monemar, M. Strassburg, A. Hoffmann
in “GaN and Related Alloys 2003”, H.M. Ng, M. Wraback, K. Hiramatsu, N. Grandjean (eds.); Mat. Res. Soc. Symp. Proc. **798**, pp. 497-502 (2004)

43. Optical properties of Mn-doped GaN
O. Gelhausen, E. Malguth, M.R. Phillips, E.M. Goldys, M. Strassburg, A. Hoffmann, T. Graf, M. Gjukic, and M. Stutzmann
in “GaN and Related Alloys 2003”, H.M. Ng, M. Wraback, K. Hiramatsu, N. Grandjean (eds.); Mat. Res. Soc. Symp. Proc. **798**, pp. 569-574 (2004)

44. Investigation of molecular co-doping for low ionization energy p-type centers in (Ga,Al)N
Z.C. Feng, A.M. Payne, D.N. Paul, D. Helm, I. Ferguson, J. Senawiratne, M. Strassburg, N. Dietz, Ch. Hums, A. Hoffmann
in “GaN and Related Alloys 2003”, H.M. Ng, M. Wraback, K. Hiramatsu, N. Grandjean (eds.); Mat. Res. Soc. Symp. Proc. **798**, pp. 545-550 (2004)

45. Valence band ordering and magneto-optical properties of free and bound excitons in ZnO
A.V. Rodina, M. Strassburg, M. Dworzak, U. Haboeck, A. Hoffmann, H.R. Alves, A. Zeuner, D.M. Hofmann, B.K. Meyer
in Zinc oxide- a material for micro- and optoelectronic applications,
N.H. Nickel and E. Terukov (eds.), Kluver Academic Publisher,
New York/Boston/Dordrecht/London/Moscow , p. 159 (2004)

46. Excitonic Rabi oscillations in a quantum dot: local field impact
G.Ya. Slepyan, S.A. Maksimenko, A.V. Magyarov, A. Hoffmann, D. Bimberg
Superlattices and Microstructures **36**, 773 (2004)

47.* Reconciliation of luminescence and Hall measurements on the ternary semiconductor $CuGeSe_2$
S. Siebentritt, I. Beckers, T. Riemann, J. Christen, M. Dworzak, and A. Hoffmann
Applied Physics Letters **86** (2005), 091909

48. Excited-state carrier lifetime in single-walled carbon nanotubes
S. Reich, M. Dworzak, A. Hoffmann, C. Thomsen, M.S. Strano
Phys. Rev. B **71**, 33402 (2005)

49.* High-energy vibrational modes in nitrogen-doped ZnO
U. Haboeck, A. Hoffmann, C. Thomsen, A. Zeuner, B.K. Meyer
phys. stat. sol. (b) **242**, R 21 (2005)

50. Site inequivalence for Mn_{2+} substitution on Zn sites in $ZnGeP_2$ and $ZnSiP_2$
W. Gehlhoff, D. Azamat, V.G. Voevodin, A. Hoffmann
phys. stat. sol. (b) **242**, R 14 (2005)

51. Raman photoluminescence and absorption studies on high quality AlN single crystals
J. Senawiratne, M. Strassburg. N. Dietz, U. Haboeck. A. Hoffmann, V. Noveski, R. Dalmau, R. Schlesser, Z. Sitar
phys. stat. sol. (c) **6**, xxx (2005)

52. ZnO - ein altes, neues Halbleitermaterial
C. Klingshirn, M. Grundmann, A. Hoffmann, B.K. Meyer, A. Waag
Physik Journal **5**, xxx (2005)

53. Local phonons in InAsIGaAs quantum dots
A. Paarmann, F. Guffarth, T. Warming, A. Hoffmann, D. Bimberg
Phys. Rev. B **xxx**, xxx (2005)

54. Development of dual MQW region LEDs for general illumination
D.B. Nicol, A. Asghar, M. Strassburg, M. Tran, M. Pan, H. Kang, I.T. Ferguson, M. Alevi, J. Senawiratne, Ch. Hums, N. Dietz, and A. Hoffmann
in “GaN and Related Alloys 2004”, Ch. Wetzel (ed.); Mat. Res. Soc. Symp. Proc. (2005)

55. Optical and structural investigations on Mn-ion states in MOCVD-grown $Ga_{1-x}Mn_xN$
M. Strassburg, J. Senawiratne, Ch. Hums, N. Dietz, M.H. Kane, A. Asghar, M. Alevli, A.M. Payne, I.T. Ferguson, C.R. Summers, U. Haboeck, A. Hoffmann, D. Azamat, W. Gehlhoff
in “GaN and Related Alloys 2004”, Ch. Wetzel (ed.); Mat. Res. Soc. Symp. Proc. (2005)

56. Strong-light matter coupling in a quantum dot: local field effects
G.Ya. Slepyan, A.V. Magyarov, S.A. Maksimenko, A. Hoffmann, and D. Bimberg
phys. stat. sol. (c) **2**, No.2, 850, (2005)

9.2b.3 Invited talks

Axel Hoffmann	**Optische und dynamische Eigenschaften von ZnO** Walter-Schottky-Institut, TU München, Germany, January 2003
Axel Hoffmann	**Excitons and phonons in GaN and ZnO** University of Sendai, Japan, May 2003
Axel Hoffmann	**Exciton localization effects in InGaAsN** University of Nagoya, Japan, May 2003
Axel Hoffmann	**Exciton dynamics in InGaAsN and InGaAs/GaAs quantum dots** Polytechnical University of Madrid, Spain, May 2003
Axel Hoffmann	**Optischer Gewinn in Nitridhalbleitern** Heraeus-Ferienschule, Magdeburg, Germany, August 2003
Axel Hoffmann	**Exzitonen and Polaritonen in Breitbandhalbleitern** Heraeus-Ferienschule, Magdeburg, Germany, September 2003
Axel Hoffmann	**ZnO- a promising semiconductor for application** EMRS Fall Meeting 2003, Warschau, Poland, September 2003
Axel Hoffmann	**Polaritons in ZnO and GaN** German-Polish Workshop on Physics and Technology of Nitride Semiconductors 2004, Berlin, Germany, March 2004
Axel Hoffmann	**Optical properties of InGaN quantum dots** E-MRS Spring Meeting, Strasbourg, France, May 2004
Axel Hoffmann	**Nitrides versus ZnO** XXXIII International School on the Physics of Semiconducting Compounds Physics, Jaszowiec, Poland, May, 2004
Axel Hoffmann	**Die Wiederentdeckung der Breitbandhalbleiter GaN und ZnO** 80. Birthday of Prof. I. Broser TU Berlin, Germany, June 2004
Axel Hoffmann	**Exciton dynamics in groupe-III nitride- and in InGaAs/GaAs - quantum dots** Australian National University, Canberra, Australia, September 2004
Axel Hoffmann	**Exciton dynamics in groupe-III nitride- and in InGaAs/GaAs - quantum dots** University of Technology, Sydney, Australia, September 2004
Axel Hoffmann	**Übergangsmetalle in Halbleitern mit großem Bandabstand als Anwendungspotential für die Spintronik** Universität Leipzig, Germany, November 2004

Axel Hoffmann	**Optische Untersuchungen an ZnO** Hahn-Meitner-Institute, Berlin, Germany, November 2004
Axel Hoffmann	**Optische und magnetische Eigenschaften von mit Übergangsmetallen dotierten Halbleiterstrukturen** Paul-Drude-Institute, Berlin, Germany, November 2004

9.2b.4 PhD theses

Born, Harald	**Rekombination und Relaxation in nulldimensionalen Strukturen** 11.08.2003
Gelhausen, Olaf	**Defect compensation mechanisms and transition metals in GaN** July 2004
Flissikowski, Timur	**Coherence properties of single self-assembled quantum dots** 16.11.2004
Meier, Ulrich	**Grenzflächenverhalten und Morphologie des ZnO/Si Heterokontaktes:Eine Photoemissionsstudie** 29.06.2004
Wagner, Jan-Martin	**Structure and Lattice Dynamics of GaN and AlN: Ab-Initio Investigations of Strained Polytypes and Superlattices** 14.10.2004

9.2b.5 Diploma theses

Bartel, Til	**Optische Eigenschaften lokalisierter Exzitonen in InGaN-Quanten-Strukturen** 27.04.2004
Hums, Christoph	**Optische Eigenschaften von InGaN-Heterostrukturen** 14.05.2004
Malguth, Enno	**Optische Eigenschaften von Übergangsmetallionen in GaN** 02.12.2004

9.2b.6 Abstracts of selected papers of department IIb

6. *Physica Status Solidi (b)* ***235*** *(2003), 151*

Donor centers in zinc germanium diphosphide produced by electron irradiation

W. Gehlhoff, D. Azamat, and A. Hoffmann
Institut für Festkörperphysik, Technische Universität Berlin, Germany

The properties of defects in p-type zinc germanium diphosphide ($ZnGeP_2$) were studied by means of electron paramagnetic resonance (EPR) and photo-EPR. Besides the well-known three native defects (VZn, VP, GeZn) an S = 1/2 EPR spectrum is observed in electron-irradiated $ZnGeP_2$ with an isotropic g = 2.0123 and resolved hyperfine splitting from four equivalent **I** = 1/2 neighbors. This spectrum is caused by a new center generated by the electron-irradiation and not by an existing center that is recharged as a result of the irradiation induced Fermi-level shift. It is tentatively assigned to the isolated Ge vacancy. Observation of the photoinduced recharging processes demonstrates that the location of the level Vge 3–/2– is at Eopt = (0.7 ± 0.06) eV. An annealing of the electron-irradiated samples causes a reverse shift of the Fermi level in direction to its original position and is accompanied with a reduction of an isotropic unstructured line at g = 2.003 caused by the irradiation damage.

10. *Physica Status Solidi (c) 0 (2003), 1783*

Local vibrational modes and compensation effects in Mg-doped GaN

A. Hoffmann, A. Kaschner, and C. Thomsen
Institut für Festkörperphysik, Technische Universität Berlin, Germany

The compensation and self-compensation effects in Mg-doped GaN is studied by low-temperature photoluminescence and Raman spectroscopy using a series of samples with different Mg concentrations. Strongly doped samples are found to be highly compensated in electrical measurement. The compensation mechanism is directly related to the incorporation of Mg leading to the additional formation of three different deep donor levels. Furthermore, hydrogen forms defect complexes with Mg and compensates the acceptor states. These complexes were observed as local vibrational modes in Raman spectra in the range of 2200 cm^{-1}. The direct incorporation of Mg can be controlled by local vibrational modes in the region of GaN host phonons. Investigating the intensity dependence of the different Mg–H complexes and the LVM of activated Mg the Raman spectra give a clear direct evidence of the degree of compensation and p-conductivity.

12. *Physica Status Solidi (c) 0 (2003), 1835*

The origin of the PL photoluminescence Stokes shift in ternary group-III nitrides: field effects and localization

M. Strassburg[1], A. Hoffmann[1], J. Holst[1], J. Christen[2], T. Riemann[2], F. Bertram[2], and P. Fischer[2]
[1] *Institut für Festkörperphysik, Technische Universität Berlin, Germany*
[2] *Institut für Experimentelle Physik, Otto-von-Guericke Universität Magdeburg, Germany*

We report on a systematic analysis of the localization and separation mechanisms of carriers and their coexistence in ternary group-III nitrides. AlGaN/GaN and InGaN/GaN multi-quantum-well (MQW) structures grown on sapphire substrate were investigated. Although the localization and separation mechanisms of carriers result in a similar behavior of the luminescence properties (e.g. both lead to blue shift of emission energy with increasing excitation density and vice versa a transient red shift after pulsed excitation), a clear distinction between these mechanisms is given by optical investigations with resonant and nonresonant excitation. Carrier separation due to a localization induced by internal electric fields described by the quantum-confined Stark-effect exist in all MQW structures and was found to be important in particular in the AlGaN/GaN MQWs. In general, the internal electric fields lead to a reduction of the luminescence efficiency. A fundamental localization mechanism, i.e. the localization in nm-scale islands of local minimum energy directly result from the spatial energy fluctuations due to disorder (e.g. alloy or QW thickness fluctuations). Especially at temperatures below 100 K, this mechanism dominates the carrier localization in the InGaN/GaN system. Evidence is given by the unique S-shape temperature dependence of peak energy and the existence of a mobility edge. Due to the localization of carriers in nm-scaled islands the overlap of its wavefunctions increases, which strongly increases the efficiency of the light output. This effect is significant weaker but still detectable in the AlGaN/GaN system.

15. *Physical Review B **68** (2003), 73310*

Exciton-phonon interactions and exciton dephasing in semiconductor quantum-well heterostructures

I. V. Bondarev, S. A. Maksimenko, and G. Ya. Slepyan
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I. L. Krestnikov and A. Hoffmann
Institut für Festkörperphysik, Technische Universität Berlin, Germany

We have investigated exciton-phonon coupling and related exciton dephasing processes in monolayer semiconductor heterostructures with localized quasi two-dimensional (2D) excitonic states. The calculated lateral size dependence of low-temperature Huang-Rhys factors indicates the enhancement of exciton-phonon coupling with decreasing the lateral size of the quasi-2D exciton localization area. This entails the increase of exciton dephasing. At low temperatures, the exciton absorption line exhibits an essentially non-Lorentzian asymmetric shape with the asymmetry increasing with the decrease of temperature and the lateral size of the quasi-2D exciton localization area.

17. *Appl. Phys. Lett.* ***82****, 3678 (2003)*

Stress analysis of $Al_{lx}Ga_{1-x}N$ films with microcracks

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Q. K. K. Liu
Abteilung Theoretische Physik, Hahn-Meitner-Institut Berlin, Germany
A. Kaschner, A. Hoffmann, and Ch. Thomsen
Institut für Festkörperphysik, Technische Universität Berlin, Germany
K. Vogeler, M. Diesselberg, S. Einfeldt, and D. Hommel
Institut für Festkörperphysik, Universität Bremen, Germany

Thick $Al_{lx}Ga_{1-x}N$ epilayer with microcracks grown by metalorganic vapor-phase epitaxy on a GaN buffer above a (0001) sapphire substrate was comprehensively characterized by spatially and spectrally resolved cathodoluminescence (CL) and micro-Raman (μ-Raman) spectroscopy. The variation of the CL line shift and the μ-Raman measurements between the microcracks are consistent with the interpretation that AlGaN is to a large extent stressed like a two dimensional film between the microcracks with nearly full relaxation close to the cracks. A satisfactory theoretical confirmation of this stress distribution was obtained by a three-dimensional finite-element application of the elasticity theory.

18. *Applied Physics Letters* ***83*** *(2003), 3728*

Inherent nature of localized states in highly planar monolayer InAs/GaAsN pseudo-alloys

I. L. Krestnikov, R. Heitz, N. N. Ledentsov, and A. Hoffmann
Institut für Festkörperphysik, Technische Universität Berlin, Germany
A. M. Mintairov, T. H. Kosel, and J. L. Merz
Department of Electrical Engineering, University of Notre Dame, Indiana
I. P. Soshnikov and V. M. Ustinov
A. F. Ioffe Physical-Technical Institute of Russian Academy of Sciences, St. Petersburg, Russia

We have studied the optical properties of pseudo-alloy monolayer InAs/GaAsN superlattices with highly planar interfaces. In spite of the two-dimensional growth mode, we found that the photoluminescence (PL) reveals strong exciton localization through the whole PL band, dominating the spectrum up to high excitation densities and observation temperatures. Pump-and-probe PL experiments provide the following time constants: (a) the exciton relaxation time to the ground states of the localization regions is found to be ~40–70 ps, depending on the photon energy, and (b) the time for depopulation of these localized states is between 2 and 4 ns.

21. *Physica B* ***340-342*** *(2003), 933*

EPR and electrical studies of native point defects in $ZnSiP_2$ semiconductors

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We present the first detection of native defects in $ZnSiP_2$. Similar to p-type $ZnGeP_2$, the EPR spectra of the zinc vacancy V_{Zn}^-, the phosphorus vacancy V_P^0, as well as of group IV anti-site Si_{Zn}^+(Ge_{Zn}^+) could be proved. The influence of the group IV-ions on the bonding behavior for the different lattice sites is reflected in the differences of the EPR parameters in both lattices. In both materials, V_P^0 could be observed only by photo-excitation, whereas the silicon anti-site Si_{Zn}^+ was detectable also in the dark contrary to Ge_{Zn}^+. This is connected with the shift of the Fermi level in the n-type $ZnSiP_2$ samples. In disagreement with the recharching model developed for the dominant native defects in $ZnGeP_2$ we could detect both Si_{Zn}^+ and V_{Zn}^- in the dark. This contradiction could be resolved by scanning surface potential microscopy measurements, which have shown that the Fermi level position laterally varies in these samples, realizing the paramagnetic states of both defects in different regions of the sample.

27. *Physica Status Solidi (b)* ***241*** *(2004), 231*

Bound exciton and donor–acceptor pair recombinations in ZnO

B. K. Meyer[1], H. Alves[1], D. M. Hofmann[1], W. Kriegseis[1], D. Forster[2], F. Bertram[2], J. Christen[2], A. Hoffmann[3], M. Straßburg[3], M. Dworzak[3], U. Haboeck[3], and A. V. Rodina[3,4]

[1] *I. Institut für Physik, Justus Liebig University Giessen, Germany*
[2] *Otto-von-Guericke University Magdeburg, Germany*
[3] *Institut für Festkörperphysik, Technische Universität Berlin, Germany*
[4] *A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia*

The optical properties of excitonic recombinations in bulk, n-type ZnO are investigated by photoluminescence (PL) and spatially resolved cathodoluminescence (CL) measurements. At liquid helium temperature in undoped crystals the neutral donor bound excitons dominate in the PL spectrum. Two electron satellite transitions (TES) of the donor bound excitons allow to determine the donor binding energies ranging from 46 to 73 meV. These results are in line with the temperature dependent Hall effect measurements. In the as-grown crystals a shallow donor with an activation energy of 30 meV controls the conductivity. Annealing annihilates this shallow donor which has a bound exciton recombination at 3.3628 eV. Correlated by magnetic resonance experiments we attribute this particular donor to hydrogen. The Al, Ga and In donor bound exciton recombinations are identified based on doping and diffusion experiments and using secondary ion mass spectroscopy. We give a special focus on the recombination around 3.333 eV, i.e. about 50 meV below the free exciton transition. From temperature dependent measurements one obtains a small thermal activation energy for the quenching of the luminescence of 10 ± 2 meV despite the large localization energy of 50 meV. Spatially resolved CL measurements show that the 3.333 eV lines are particularly strong at crystal irregularities and occur only at certain spots hence are not homogeneously distributed within the crystal contrary to the bound exciton recombinations. We attribute them to excitons bound to structural defects (Y-line defect) very common in II–VI semiconductors. For the bound exciton lines which seem to be correlated with Li and Na doping we offer a different interpretation. Li and Na do not introduce any shallow acceptor level in ZnO which otherwise should show up in donor–acceptor pair recombinations. Nitrogen creates a shallow acceptor level in ZnO. Donor–acceptor pair recombination with the 165 meV deep N-acceptor is found in nitrogen doped and implanted ZnO samples, respectively. In the best undoped samples excited rotational states of the donor bound excitons can be seen in low temperature PL measurements. At higher temperatures we also see the appearance of the excitons bound to the B-valence band, which are approximately 4.7 meV higher in energy.

32. *Applied Physics Letters* ***84*** *(2004), 4514*

Doping-level-dependent optical properties of GaN:Mn

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T. Graf, M. Gjukic, and M. Stutzmann
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The optical properties of molecular-beam-epitaxy-grown GaN with different Mn-doping levels ($5–23\times10^{19}$ cm^{-3}) were studied by cathodoluminescence (CL) and optical transmission spectroscopy. Transmission measurements at 2 K revealed an absorption peak at 1.414 ±0.002 eV, which was attributed to an internal $^5T_2 \rightarrow {}^5E$ transition of the neutral Mn_{31} state. The intensity of this Mn-related transmission peak was found to scale with the Mn_{31} concentration. The CL measurements showed that Mn-doping concentrations around 1020 cm23 reduced the near band edge emission intensity by around one order of magnitude. A complete quenching of the donor-acceptor-pair band at 3.27 eV and strong decrease of the yellow luminescence centered at 2.2 eV were attributed to a reduced concentration of VGa . In the infrared spectral range of 0.8–1.4 eV three broad, Mn-doping related CL emission bands centered at 1.0160.02, 1.0960.02, and 1.25 ±0.03 eV were observed. Their origin is attributed to deep donor complexes, which are generated as a result of the heavy Mn-doping.

34. *Applied Physics Letters* ***85*** *(2004), 1946*

Recombination dynamics of localized excitons in InGaN quantum dots

T. Bartel, M. Dworzak, M.Strassburg, A. Hoffmann, A. Strittmatter, and D. Bimberg
Institut für Festkörperphysik, Technische Universität Berlin, Germany

Indium-rich fluctuations in ultrathin InGaN layers act at low temperatures as a dense ensemble of quantum dots (QD). This leads to a complex potential landscape with localization sites of widely varying depth for excitons. We report on investigations of the recombination mechanisms of excitons localized in InGaN/GaN QD structures by time-resolved and spatially resolved photoluminescence (PL) measurements. The structures were grown by metalorganic chemical vapor deposition on Si (111) substrates. Sharp lines originating from single QDs could be observed. Their PL decays show monoexponential behavior. Similar transition energies have different time constants. Thus the well-known nonexponential PL decay of the QD ensemble is assigned to the summation of monoexponential decays originating from individual QDs with different exciton life-times.

47. *Applied Physics Letters* ***86*** *(2004), 091909*

Reconciliation of luminescence and Hall measurements on the ternary semiconductor $CuGaSe_2$

Susanne Siebentritt and Inge Beckers
Hahn-Meitner-Institut, Berlin, Germany
Till Riemann and Jürgen Christen
Otto-von-Guericke-Universität Magdeburg, Germany
Axel Hoffmann and Matthias Dworzak
Institut für Festkörperphysik, Technische Universität Berlin, Germany

Previous Hall and photoluminescence investigations on $CuGaSe_2$ yielded conflicting results: defect depths determined by luminescence are lower than the ionization energy found in electrical measurements. In this contribution, we present time and spatially resolved cathodoluminescence measurements that necessitate a new interpretation of the luminescence data, leading to a consistent model for luminescence and Hall data with three acceptors with ionization energies of 60, 100, and 150 meV. Luminescence decay times are long, in the range of 100 ns, indicating strong capture. Luminescence is spatially inhomogeneous, indicating inhomogeneous distribution of defects.

49. *Physica Status Solidi (b)* ***242*** *(2005), R 21*

High-energy vibrational modes in nitrogen-doped ZnO

U. Haboeck[1], A. Hoffmann[1], C. Thomsen[1], A. Zeuner[2], and B. K. Meyer[2]
[1] *Institut für Festkörperphysik, Technische Universität Berlin, Germany*
[2] *I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany*

We present results of Raman-scattering experiments on a series of nitrogen-doped ZnO epilayers grown by chemical vapor deposition. Nitrogen, a potential acceptor in ZnO, was introduced by the thermal decomposition of ammonia (NH_3). We found a structure consisting of at least four lines with frequencies of 2253, 2277, 2291, and 2304 cm^{-1}. They increase in intensity simultaneously with additional modes in the energy range of the host phonons: both scale with the nitrogen concentration in the samples. The origin of the high-energy structure is tentatively assigned to vibrations of lattice-bound nitrogen or complexes, composed of the constituents of the dopant NH_3.

9.3 Department III

Prof. Dr. rer. nat. Mario Dähne
Prof. Dr.-Ing. Hans-Eckhart Gumlich

9.3.0 Staff

Secretary
Angela Berner (part-time)

Technical staff
Gerhard Pruskil

PhD candidates and teaching assistants
Dr. Holger Eisele
Dipl.-Phys. Kai Hodeck
Dipl.-Phys. Rainer Timm

PhD candidates (status of 31.12.2004 – thesis completed = c)
Dipl.-Phys. Sebastian Becker (until 30.11.2004)
Dipl.-Phys. Andrea Lenz
Dipl.-Phys. Christian Preinesberger (until 31.03.2004)
Dipl.-Phys. Jan Grabowski (Nafög)

Diploma students (status of 31.12.2004 – thesis completed = c)
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Maximillian Assig
Mandy Baudach (c)
Olena Ivanova (c)
Jan Grabowski (c)
Christian Griesche
Tai-Yang Kim (c)
Hannelore Lünstroth (c)
Matthias Müller
Ferdinand Streicher (c)
Norman Tschirner

9.3.1 Summary of activities

The main research subject of the group of M. Dähne is the investigation of the structural, electronical and optical properties of semiconductor interfaces and nanostructures. In the experiments, special emphasis lies on the use of local probes, such as scanning-tunneling microscopy (STM) and spectroscopy (STS), cross-sectional scanning-tunneling microscopy (XSTM) and spectroscopy (XSTS), and scanning-nearfield optical microscopy (SNOM). Complementary information is obtained from photoelectron spectroscopy (PES) with synchrotron radiation at the Berlin storage ring BESSY. All experiments except SNOM are performed in ultra-high vacuum (UHV).

There are mainly three experimental setups:

1. an STM chamber with a preparation chamber containing LEED, sputter gun and effusion cells,
2. a chamber designed especially for XSTM experiments,
3. a SNOM setup, which works at temperatures down to 4 K.

For PES experiments, chambers from Prof. Kaindl at the Freie Universität Berlin and from Prof. Laubschat at the Technische Universität Dresden are used.

Recent results are listed in the following:

1. Atomic structure of quantum dots. In this project, the atomic structure, chemical composition and local electronic properties of semiconductor nanostructures, in particular quantum dots, are studied using XSTM. For this purpose, a cross-sectional (110) surface prepared *in*-situ by cleavage is studied by the STM tip. In experiments at InAs, InGaAs, InGaAsN, and GaSb quantum dots prepared at the departments I and IV, at the Fritz-Haber Institute, and at Infineon Technologies, the particular growth behavior was studied, with special emphasis on the shape, size, local stoichiometry and stacking behavior of the dots and on the electronic structure. For a quantitative analysis, the finite-element simulation of the strain relaxation, which was developed previously in our group, was extended in order to determine the local stoichiometry.

2. Optical properties of single quantum dots. The photoluminescence of individual InGaAs quantum dots, prepared in department I, was studied at temperatures between 4 K and 300 K using SNOM. The strong dependence of the Lorentzian linewidth of the spectral lines on temperature, which is related to thermally induced phonon interactions, was studied in detail. Furthermore, the development of biexcitons was studied when varying the excitation density.

3. Lanthanide silicide nanowires on Si(001). The self-organized formation of lanthanide silicide nanowires on Si(001), which was first observed in our group, was studied in detail using STM. The atomic structure of different nanowire types could be determined and structure models were developed based on the anisotropies of strain and substrate surface. Using ARPES at BESSY, the dispersion of the electronic states was studied, showing a strongly anisotropic metallicity of the nanowires.

9.3.2 Publications

The abstracts of papers marked by* are reprinted in section 9.3.5

1*. **Atomic structure of InAs and InGaAs quantum dots determined by cross-sectional scanning tunneling microscopy**
H. Eisele, A. Lenz, Ch. Hennig, R. Timm, M. Ternes, and M. Dähne
Journal of Crystal Growth ***248****, 322 (2003)*

2.* **Low budget UHV STM built by physics students for use in a laboratory exercise course**
S. K. Becker, J. Grabowski, T.-Y. Kim, L. Amsel, F. Bechtel, N. Tschirner, I. Mantouvalou, A. Lenz, R. Timm, K. Hodeck, F. Streicher, G. Pruskil, H. Eisele, and M. Dähne
Proceedings of 12th International Conference on Scanning Tunneling Microscopy/Spectroscopy and Related Techniques, *216 (2003)*

3.* **An STM Study of the 2×7 Dysprosium-Silicide Nanowire Superstructure on Si(001)**
C.Preinesberger, D. V. Vyalikh, S. L. Molodtsov, F. Schiller, G. Pruskil, S. K. Becker, C. Laubschat, and M. Dähne
Proceedings of 12th International Conference on Scanning Tunneling Microscopy/Spectroscopy and Related Techniques, 837 (2003)

4.* **Room-Temperature Observation of Standing Electron Waves on GaAs(110) at Surface Steps**
O. Flebbe, H. Eisele, R. Timm, and M. Dähne
Proceedings of 12th International Conference on Scanning Tunneling Microscopy/Spectroscopy and Related Techniques, *699 (2003)*

5.* **Multiline photoluminescence of single InGaAs quantum dots**
K. Hodeck, I. Manke, M. Geller, R. Heitz, F. Heinrichsdorff, A. Krost, D. Bimberg, H. Eisele, and M. Dähne
physica status solidi (c), **4**, *1209 (2003)*

6.* **Self-assembled structures of Dy silicides on Si(001) and Si(111) surfaces**
S.K. Becker, C. Preinesberger, I. Engelhardt, M. Wanke, S. Vandré, H. Eisele, and M. Dähne
Institute of Physics Conference Series, ***171****, D9 (2003)*

7.* **Atomic Structure of InAs and InGaAsQuantum Dots Studied by Cross-Sectional Scanning Tunneling Microscopy**
H. Eisele, A. Lenz, R. Timm, Ch. Hennig, M. Ternes, F. Heinrichsdorff, A. Krost, R. Sellin, U. W. Pohl, D. Bimberg, T. Wehnert, E. Steimetz, W. Richter, and M. Dähne
Institute of Physics Conference Series, ***171****, P199 (2003)*

8.* **Photoluminescence of individual InGaAs quantum dots**
K. Hodeck, I. Manke, M. Geller, J.L. Spithoven, J. Lorbacher, R. Heitz, F. Heinrichsdorff, A. Krost, D. Bimberg, and M. Dähne
Institute of Physics Conference Series, ***171****, P226 (2003)*

9.* Structure and intermixing of GaSb/GaAs quantum dots
R. Timm, H. Eisele, A. Lenz, S. K. Becker, J. Grabowski, T.-Y. Kim, L. Müller-Kirsch, K. Pötschke, U. W. Pohl, D. Bimberg, and M. Dähne
Applied Physics Letters, ***85****, 5890 (2004)*

10.* Nanovoids in InGaAs/GaAs quantum dots observed by cross-sectional scanning tunneling microscopy
A. Lenz, H. Eisele, R. Timm, S. K. Becker, R. L. Sellin, U. W. Pohl, D. Bimberg , and M. Dähne
Applied Physics Letters, ***85****, 3848 (2004)*

11. Queuing atoms: Self-Assembly of Silicide Nanowires
C.Preinesberger, D. V. Vyalikh, S. L. Molodtsov, F. Schiller, G. Pruskil, S. K. Becker, C. Laubschat, and M. Dähne
BESSY Highlights 2003, 22 (2004)

9.3.3 Invited talks

Eisele, Holger	**Atomic structure of quantum dots studied by cross-sectional scanning tunneling microscopy** Ringberg, February 2003
Eisele, Holger	**Looking at the Inside of Quantum Dots: HRTEM versus XSTM** Winter School, St. Petersburg, Russian Federation, March 2003
Dähne, Mario	**Seltenerdsiliziddrähte auf Si(001)** Physikalisches Colloquium, Dresden, April 2003
Eisele, Holger	**Looking at the Inside of Quantum Dots: HRTEM versus XSTM** MSM XIII, Cambridge, U. K., April 2003
Dähne, Mario	**Atomare Struktur und optische Eigenschaften von einzelnen InAs- und InGaAs-Quantenpunkten** Physikalisches Colloquium, Paderborn, July 2003
Becker, Sebastian	**GaAsN Basics und N-N Korrelationen** Ostseeseminar, Barth, September 2003
Dähne, Mario	**Atomare und elektronische Struktur von DySi auf Si(001)** Ostseeseminar, Barth, September 2003
Eisele, Holger	**GaAs und verwandte Halbleiter** Ostseeseminar, Barth, September 2003
Gumlich, H.-E.	**Zeitbegriff zwischen Physik und Philosophie** Ostseeseminar, Barth, September 2003

Hodeck, Kai	**Aktuelle Entwicklungen in der Rastertunnellumineszenz an Halbleiterstrukturen** Ostseeseminar, Barth, September 2003
Lünstroth, Hannelore	**Entstehung von ErSi auf Si(001)** Ostseeseminar, Barth, September 2003
Streicher, Ferdinand	**Einführung in die Physik und Elektronik von STM-Messungen** Ostseeseminar, Barth, September 2003
Timm, Rainer	**Bandanpassung imGaSb/GaAs-System** Ostseeseminar, Barth, September 2003
Dähne, Mario	**Selbstorganisierte Silizid-Nanodrähte auf Silizium** BESSY, Berlin, March 2004
Baudach, Mandy	**Untersuchung des Einflusses von Stickstoffbeimischungen in InAs/GaAs-Quantenpunkten mit Rastertunnelmikroskopie an Querschnittsflächen** DPG-Frühjahrstagung, Regensburg, March 2004
Grabowski, Jan	**Untersuchung von GaSb/GaAs-Quantenpunkten mit Rastertunnelmikroskopie** DPG-Frühjahrstagung, Regensburg, March 2004
Griesche, Christian	**Nahfeld-Photolumineszenz einzelner InGaAs-Quantenpunkte bei tiefen Temperaturen** DPG-Frühjahrstagung, Regensburg, March 2004
Kim, Tai-Yang	**Bau eines kostengünstigen UHV-STMs von Studierenden im Fortgeschrittenen-Praktikum** DPG-Frühjahrstagung, Regensburg, March 2004
Preinesberger, Christian	**Wachstum und elektronische Struktur von Seltenerdsilizid-Nanodrähten auf Si(001)-Vizinalflächen** DPG-Frühjahrstagung, Regensburg, March 2004
Streicher, Ferdinand	**Strukturuntersuchungen an dünnen InAs/GaAs-Schichten mittels Rastertunnelmikroskopie an Querschnittsflächen** DPG-Frühjahrstagung, Regensburg, March 2004
Timm, Rainer	**Atomic Structure and Type-II Band Alignment of GaSb Quantum Dots in GaAs Studied by Cross-Sectional Scanning Tunneling Microscopy** QD 2004, Banff, Alberta, Kanada, May 2004
Lenz, Andrea	**Bandanpassung imGaSb/GaAs-System** ICCG14, Grenoble, France, August 2004

Tschirner, Norbert	**LEED an Si(001) und Si(111)** Ostseeseminar, Zschorlau, September 2004
Hodeck, Kai	**Quantum Dot Single-Photon Sources** Ostseeseminar, Zschorlau, September 2004
Dähne, Mario	**Photoemissions-Spektroskopie bei BESSY II** Ostseeseminar, Zschorlau, September 2004
Ivanova, Olena	**STS an GaAs- und InAs-Dots** Ostseeseminar, Zschorlau, September 2004
Lenz, Andrea	**Forschungsstand InAs-Quantenpunkte** Ostseeseminar, Zschorlau, September 2004
Eisele, Holger	**Überblick Nitride** Ostseeseminar, Zschorlau, September 2004
Becker, Sebastian	**Lanthanide auf Si(001) und Si(111)** Ostseeseminar, Zschorlau, September 2004
Timm, Rainer	**FeldIonenMikroskopie und Spitzenpräparation** Ostseeseminar, Zschorlau, September 2004

9.3.4 Diploma theses

Lünstroth, Hannelore	**Struktur von Seltenerdsilizid-Nanodrähten auf Si(001)** Juni 2003
Grabowski, Jan	**Querschnittsrastertunnelmikroskopische Untersuchung von Antimon-haltigen GaAs-Halbleiternanostrukturen** April 2004
Streicher, Ferdinand	**Rastertunnelmikroskopie an Querschnittsflächen von InAs-GaAs-Halbleiter-Strukturen** April 2004
Baudach, Mandy	**Querschnitts-Rastertunnelmikroskopie an stickstoffhaltigen Gruppe-III-Arseniden** Juni 2004
Kim, Tai-Yang	**Querschnittsrastertunnelmikroskopische Untersuchung von InAs-GaAs-Quantenpunkten mit Sb-Beimischungen** Juni 2004
Ivanova, Olena	**Rastertunnelspektroskopie an Halbleiter-Nanostrukturen** Dezember 2004

9.3.5 Abstracts of selected papers of department III

1. *Journal of Crystal Growth* ***248****, 322 (2003)*

Atomic structure of InAs and InGaAs quantum dots determined by cross-sectional scanning tunneling microscopy

H. Eisele, A. Lenz, Ch. Hennig, R. Timm, M. Ternes, and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

In this work we present a comparative cross-sectional scanning tunneling microscopy study of different InAs and InGaAs quantum dot structures grown by metalorganic vapor phase epitaxy. The varying growth conditions lead to completely different spatial structures, as distinctive quantum dots, intermixed layers, and intermixed dots. Especially the overgrowth procedure and the arrangement of growth interruptions are responsible for segregation of the InAs material.

2. *Proceedings of 12th International Conference on Scanning Tunneling Microscopy/Spectroscopy and Related Techniques, 216 (2003)*

Low budget UHV STM built by physics students for use in a laboratory exercise course

S. K. Becker, J. Grabowski, T.-Y. Kim, L. Amsel, F. Bechtel, N. Tschirner, I. Mantouvalou, A. Lenz, R. Timm, K. Hodeck, F. Streicher, G. Pruskil, H. Eisele and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

Because of the limitation of the budget for laboratory courses, it is difficult to provide modern equipment for young students. In this work we show how students can build a state-of-theart UHV STM system on their own, with only a small budget and within a limited time period of three months.

3. *Proceedings of 12th International Conference on Scanning Tunneling Microscopy/Spectroscopy and Related Techniques, 837 (2003)*

An STM Study of the 2×7 Dysprosium-Silicide Nanowire Superstructure on Si(001)

C.Preinesberger, D. V. Vyalikh, S. L. Molodtsov, F. Schiller, G. Pruskil, S. K. Becker, C. Laubschat and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

We present a detailed STM study on the atomic structure and electronic properties of dysprosium–silicide nanowires, which can be formed on Si(001) by self assembly. Under ideal circumstances, these nanowires cover the whole silicon surface with a well-ordered 2×7 superstructure. Using voltage dependent STM we are able to develop an atomic structure model.

4. *Proceedings of 12th International Conference on Scanning Tunneling Microscopy/Spectroscopy and Related Techniques, 699 (2003)*

Room-Temperature Observation of Standing Electron Waves on GaAs(110) at Surface Steps)

O. Flebbe, H. Eisele, R. Timm, and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

Standing electron waves with a high coherence length were observed at steps of the GaAs(110) cleavage surface by scanning tunneling microscopy at room temperature. They are related to a two-dimensional electron gas in the GaAs conduction band caused by tip-induced band bending underneath a blunt tip. The simulated local density of states between two surface steps nicely describes the experimental corrugation. A self-consistent quantum-mechanical calculation of the potential variation demonstrates the dominant contribution of surface states with a high effective mass to the two-dimensional electron gas.

5. *physica status solidi (c),* ***4,*** *1209 (2003)*

Multiline photoluminescence of single InGaAs quantum dots

K. Hodeck, I. Manke, M. Geller, R. Heitz, F. Heinrichsdorff, A. Krost, D. Bimberg, H. Eisele, M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

Using scanning nearfield optical microscopy, the photoluminescence characteristics of individual InGaAs quantum dots is investigated. At low temperatures an ensemble of narrow lines is observed, caused by different carrier interactions within a quantum dot. A trion and a biexciton line can be identified in the ground-state region at low excitation power, showing much larger binding energies than previously reported for III-V quantum dots. This behavior can be explained by an inhomogeneous stoichiometry profile in InGaAs quantum dots.

6. *Institute of Physics Conference Series, **171**, D9 (2003)*

Self-assembled structures of Dy silicides on Si(001) and Si(111) surfaces

S.K. Becker, C. Preinesberger, I. Engelhardt, M. Wanke, S. Vandré, H. Eisele, and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

In this contribution we present an overview on the structural and electronic properties of self-assembled Dy silicide structures on silicon surfaces. High-resolution scanning tunneling microscopy images demonstrate the formation of nanowires and clusters on Si(001) and two-dimensional films with different surface reconstructions on Si(111). The latter were also investigated with photoemission spectroscopy, were a flat-band condition for low Dy silicide coverages is found.

7. *Institute of Physics Conference Series, **171**, P199 (2003)*

Atomic Structure of InAs and InGaAsQuantum Dots Studied by Cross-Sectional Scanning Tunneling Microscopy

H. Eisele, A. Lenz, R. Timm, Ch. Hennig, M. Ternes, F. Heinrichsdorff, A. Krost, R. Sellin, U. W. Pohl, D. Bimberg, T. Wehnert, E. Steimetz, W. Richter, and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

In this paper we present cross-sectional scanning tunneling microscopy measurements of different MOCVD and MOVPE grown quantum dot structures. Depending on the special growth parameters completely different spatial structures of the quantum dots are observed. Especially the insertion of growth interruptions and the overgrowth procedure determines the existence of segregation effects. Also the complete dissolution of already existent quantum dots during the overgrowth may occur.

8. *Institute of Physics Conference Series, **171**, P226 (2003)*

Photoluminescence of individual InGaAs quantum dots

K. Hodeck, I. Manke, M. Geller, J.L. Spithoven, J. Lorbacher, R. Heitz, F. Heinrichsdorff, A. Krost, D. Bimberg, and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

Using scanning nearfield optical microscopy, the photoluminescence characteristics of individual InGaAs quantum dots is investigated. A temperature-dependent linewidth broadening is observed, caused by phonon interactions with the quantum-dot hole states. The trion and the biexciton signals show much larger binding energies than previously reported. Photoluminescence images can show unusual ring-like emission profiles, which are explained by a tip-induced Stark effect.

9. *Applied Physics Letters, **85**, 5890 (2004)*

Structure and intermixing of GaSb/GaAs quantum dots

R. Timm, H. Eisele, A. Lenz, S. K. Becker, J. Grabowski, T.-Y. Kim, L. Müller-Kirsch, K. Pötschke, U. W. Pohl, D. Bimberg , and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

We present cross-sectional scanning tunneling microscopy results of GaSb quantum dots in GaAs, grown by metalorganic chemical vapor deposition. The size of the optically active quantum dots with base lengths of 4–8 nm and heights of about 2 nm is considerably smaller than previously published data obtained by other characterization methods. The local stoichiometry, obtained from atomically resolved images, shows a strong intermixing in the partly discontinuous wetting layer with an average GaSb content below 50%, while the GaSb content of the partly intermixed quantum dots is between 60% and 100%.

10. *Applied Physics Letters**, 85**, 3848 (2004)*

Nanovoids in InGaAs/GaAs quantum dots observed by cross-sectional scanning tunneling microscopy

A. Lenz, H. Eisele, R. Timm, S. K. Becker, R. L. Sellin, U. W. Pohl, D. Bimberg , and M. Dähne
Institut für Festkörperphysik, Technische Universität Berlin, Germany

We present cross-sectional scanning tunneling microscopy data of a type of InGaAs/GaAs quantum-dot structure characterized by a hollow center. This void structure develops during a long growth interruption applied after deposition of a quantum dot layer and a thin cap layer, resulting in an eruption of indium-rich material. Subsequent fast overgrowth does not fill the void completely. This growth behavior demonstrates limitations of current strategies to grow large quantum dots.

9.4 Department IV

Prof. Dr. rer. nat. Wolfgang Richter
Prof. Dr.-Ing. Jürgen Sahm from the Physics Teacher Education Department

9.4.0 Staff

Secretary
Claudia Hinrichs (part time)
Angela Berner (part time)

Technical staff
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Dr. Patrick Vogt
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Dipl.-Phys. Florian Poser
Dipl.-Phys. Bert Rähmer
Dipl.-Phys. Christian Kaspari

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Dipl.-Phys. Thalia Denizou (until 31.12.2003)
Dipl.-Phys. Massimo Drago
Dipl.-Phys. Theodor Herrmann (until 09.06.2004)
Dipl.-Phys. Kathy Lüdge (c) (until 14.11.2003)
Dipl. Phys. Katy Roodenko (until 31.12.2004)
Dipl.-Phys. Torsten Schmidtling (until 31.12.2004)
Dipl. Phys. Matthias Wahl (until 31.12.2004)
Dipl.-Phys. Stefan Weeke
Dipl.-Phys. Katrin Wilmers (until 15.01.2005)

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Girmay Dessalegn (c)
Robert Ehlert
Veit Hoffmann (c)
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Martin Leyer
Philipp Myrach
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Tobias Schenk (c)
Stefan Simon
Eugen Speiser (c)
Christoph Werner
Arno Wirsig (c)

9.4.1 Summary of activities

The work of the group centers around the formation of semiconductor interfaces. This includes the in-situ investigation of structural and electronic properties of surfaces and interfaces during their formation. Processes, which modify and form especially also nanostructured interfaces, in particular during the initial stages of growth are the goal of our work. Currently, epitaxial growth via MOVPE and MBE are the main techniques for interface formation. Heterointerfaces between III-V-semiconductors but also metal-semiconductor heterostructures have been considered. Large activities have been devoted to controlled preparation of well-defined III-V (nitrides) surfaces, surface passivation and modification by elemental adsorbates. Clean and adsorption modified metal surfaces were also studied by optical methods in the framework of the Sfb 290 and special attention has focused on magnetic layers Co, Ni.

The application of optical analytical techniques is strongly favored. This enables us to study surfaces and interfaces not only under UHV conditions but in gas phase environments (MOVPE, passivation, post-growth analysis) as well. Special attention was therefore paid to the technical development of the optical methods. This was especially Reflectance Anisotropy Spectroscopy, Spectroscopic Ellipsometry and Raman Scattering. To complement the optical information, mostly obtained in-situ, and to ease the theoretical interpretation, standard surface science analytical techniques (LEED, AES, STM, ARUPS and SXPS at BESSY) were utilized whenever possible, and last but not least STM in UHV and now also in MOVPE.

The MOVPE in-situ activities continued to deepen the understanding of the influence of doping on RAS signatures. With the help of a newly developed multi-channel RAS system, it is now possible to monitor carrier concentrations during growth in real time. Even a doping profile with <5nm resolution can be obtained. This multi-channel RAS detector also turned out be very useful for basic growth studies on the magnetic semiconductors (InP:Mn) or on the antimonides (InP-Sb, GaAs-Sb). The latter are studied in cooperation with the Ferdinand-Braun-Institute having HBT applications in mind, because antimony segregation is still a severe problem for device application.

The main focus of the MOVPE work in the last two years however, was on basic growth studies of nitride containing semiconductors, namely GaAs1-xNx (x<5%) and InN. The growth of InN ¾ which is characterized by a very narrow parameter window ¾ still needs a very careful optimization of the growth process. This is performed with the help of a special UV-sensitive in-situ MOVPE ellipsometer. Successful control and understanding of all steps during InN hetero-epitaxy has been reached. As a result smooth InN-layers on sapphire are obtained with mobilities close to the best reported values for MOVPE on sapphire. For GaAsN growth the main focus was on group V exchange reactions. RAS allowed to obtain clear insight into these reactions between Arsenic and Nitrogen.

The optical tools available allowed also for comparative studies of surfaces during MOVPE and those prepared under UHV conditions in MBE and MOMBE. Deeper insight into the mechanism of all three growth methods, differences and similarities in the surface processes could be elucidated. The understanding of the surface optical response and its correlation to the microscopic surface structure continued to be our goal. This understanding forms the basis for the successful application of our optical tools as surface science tools. For this purpose collaborations with theoretical groups are ongoing.

They concentrate on structurally well defined surfaces where optical experimental results are compared to the theoretical ones obtained either with Tight Binding calculations or more and more with the ab-initio (LDA-DFT, GW) calculations during the last years. The complementary information obtained from optical spectroscopy, STM and electron spectroscopic techniques such as photoemission is an essential help for understanding the complex atomic structures of clean and chemically modified surfaces. As such an example we could recently determine the structural aspects of the H-P-In-terminated InP(001) surface and thereby solve the controversial discussion in the literature.

This approach was also used to investigate the formation of ultrathin ferromagnetic layers (1nm - 50nm) like Co on GaAs and InGaP (001), a material combination possibly important for the promising spintronic devices. Our detailed studies on the initial growth and the interface formation demonstrate the important role of interface reactions during the deposition. They can only be hindered if a diffusion barrier like ErAs is introduced. With that a barrier growth of thin ferromagnetic Co films turned out to be possible. Interesting enough in the submonolayer deposition regime 1D nanowires were formed, which have scientific interest on their own.

Ongoing investigations concentrate also on the nitrides (InN) with the aim to find the best growth process (MBE, MOVPE) since InN is yet only very poorly understood in terms of surface formation and structure. An possibly even more important aspect of our investigations is the oxidation and deoxidation of InN, which is at present not really understood but is very important for first device applications (optoelectronic devices).

The modification of semiconductor surfaces by organic molecules is a new and promising field for device development. There one has to understand first the bonding properties of molecules like cyclopentene and ethelene on the “standard” semiconductor surface Si(001). These studies are also extended towards the technologically important III-V(001) surfaces of GaAs and InP. First results give evidence that the interaction between the molecule and the surface is dominated by the surface dimers (their nature and chemical composition).

A number of apparative development works were also undertaken in the last two years and we could finally harvest the first results of our long ongoing work on the in-situ scanning probe microscope (STM) in MOVPE. Active cooling allows now for continuous operation up to 550°C, and even for short times (like buffer growth) operation at 600°C is possible. We succeeded in monitoring step-bunching at 550°C on GaAs. The resolution of these images was better than 20nm lateral and 2nm vertical. Therefore, even the resolution of mono-atomic steps seems possible, and the evolution of the topography during quantum dot growth in the MOVPE reactor can be measured.

Further apparative progress was a fast in-situ multi-channel ellipsometer with 1024 wavelengths and a time resolution of 100-300 ms and the worldwide first multi-channel RAS with eight channels and a time resolution <100 ms. The latter spectrometer have a signal to noise ratio comparable to a standard RAS systems and could be used also simultaneously with a conventional non-multichannel equipment. This is a big step towards a full real-time in-situ surface control.

Driven by the participation in an EU project we developed also a Raman scattering set up for in – situ studies in MOVPE. While initially monitoring of the MOVPE surface processes were the goal it evolved in the meantime as a project on anharmonic properties since Raman measurements above 1000 K became possible. New experimental results about lattice dynamical anharmonicities were obtained which will require new interpretations of the high temperature processes.

We are looking forward to put all these new experimental tools into full analytical use within our epitaxial growth equipment and surface preparation chambers.

9.4.2 Publications

The abstracts of papers marked by* are reprinted in section 9.4.6

1. **In-situ determination of interface roughness in MOVPE-grown visible VCSELs by reflectance spectroscopy**
K. Haberland, M. Zorn, A. Klein, A. Bhattacharya, M. Weyers, J.-T. Zettler and W. Richter
J. Crys. Growth 248, 194 (2003)

2.* **Sb-induced (1x1) reconstruction on Si(001)**
J. R. Power, O. Pulci, A. I. Shkrebtii, S. Galata, A. Astropekakis, K. Hinrichs, N. Esser, R. Del Sole, W. Richter
Phys. Rev. B **67**,115315 (2003)

3.* **Optical recognition of atomic steps on surfaces**
F. Baumberger, Th. Herrmann, A. Kara, S. Stolbov, N. Esser, TS. Rahman, J. Osterwalder, W. Richter, R. Greber
Phys. Rev. Letters **90** (19), 177402, 2003

4.* **Phonon- and Polarized Reflectance-Spectra from Si(111)-(4x1)In: Evidence for a charge-density-wave driven phase transition**
K. Fleischer, S. Chandola, N. Esser, W. Richter, and J. F. McGlip
Phys. Rev. B, **67** (23), 235318 (2003)

5. **Compositional Dependence of Raman Scattering and Photoluminescence Emission in $Cu_xGa_ySe_2$ Thin Films**
C. Xue, D. Papadimitriou, Y. S. Raptis, N. Esser, W. Richter, S. Siebentritt, M. Ch. Lux-Steiner
J. Appl. Phys. **94** (7), 4341, 2003

6.* **Model for the effects of surface disorder on reflectance anisotropy spectroscopy**
Bernardo S. Mendoza, Norbert Esser, Wolfgang Richter
Phys. Rev. B **67**, 165319 (2003)

7. **Control of Interfaces and Nanostructures in Epitaxial Growth**
W. Richter
Crystal Growth and Epitaxy, Publishing House,CUN PAN, Warszawa 2003

8. **Preparation of BeTe surface reconstructions by decapping and thermal treatment**
J.W. Wagner, V. Wagner, L. Hansen, G. Schmidt, J. Geurts,P. Vogt, N. Esser, W. Richter
Journ. of Appl. Phys. **93**, 1511, 2003

9.* **Surface Termination during GaN growth by Metal-organic Vapor Phase Epitaxy determined by Ellipsometry**
C. Cobet, T. Schmidtling, M. Drago, N. Wollschläger, N. Esser, W. Richter, R. M. Feenstra, T. U. Kampen
Journ. of Appl. Phys., **94** (10), 6997, (2003)

10.* **InP(001)-(2x1) surface: A hydrogen stabilized structure**
W.G. Schmidt, P.H. Hahn, F. Bechstedt, N. Esser, P. Vogt, A. Wange, W. Richter
Phys. Rev. Lett. **90**, 126101, (2003)

11.* **Spectroscopic ellipsometry during metalorganic vapor phase epitaxy of InN**
T. Schmidtling, M. Drago, U.W. Pohl, W. Richter
Journ. Crys. Growth **248**, 523 (2003)

12.* **Growth of spatially ordered InAs quantum dots on step-bunched vicinal GaAs(100) substrates**
F. Poser, A. Bhattacharya, S. Weeke, W. Richter
Journ. Crys. Growth **248**, 317 (2003)

13.* **In-situ Raman Spectroscopy on III-V semiconductors at high temperature in MOVPE**
E. Speiser, T. Schmidtling, K. Fleischer, N. Esser, W. Richter
phys. stat. sol. (c) **8**, 2949 (2003)

14. **Cobalt growth on InGaP(001)(2X4): Interface formation**
K. Lüdge, P. Vogt, W. Braun, W. Richter, N. Esser
J. Vac. Sci. Technol. B **21,** 1749 (2003)

15.* **Optical Reflectance Anisotropy of Al(110): experiment and ab-initio calculation**
Th. Herrmann, M. Gensch, M.J.G. Lee, A.I. Shkrebtii, N. Esser, W. Richter
Phys. Rev. B **69**, 165406 (2004)

16. **InN metalorganic vapour phase epitaxy and ellipsometric characterisation**
M. Drago, T. Schmidtling, U.W. Pohl, S. Peters, W. Richter
phys. stat. sol. (c) **0**, 7, 2842 (2003)

17. **Photoinduced reflectance anisotropy in detwinned $YBa_2Cu_3O_{6.7}$ single crystals**
A. Bruchhausen, A. Fainstein, G. Nieva, A.A. Aligia, S. Bahrs, A.R. Goñi, W. Richter, C. Thomsen, K. Fleischer
Phys. Rev. B **69**, 224508 (2004)

18. **Structure and Magnetic Properties of Ferromagnetic Ni Films on Cu(110)**
M. Wahl, Th. Herrmann, W. Richter and N. Esser,
phys. stat. sol. (c), (2003)

19.* **Influence of the reconstruction of GaAs(001) on the electro-opitcal bulk properties**
M. Pristovsek, S. Tsukamoto, B. Han, J.T. Zettler, W. Richter
Journ. Crys. Growth **248**, 254 (2003)

20.* GW calculations on surfaces: an application to the study of clean and Sb-covered Si(001)
O. Pulci, J. Power, A. Shkrebtii, W. Richter, R. DelSole
Computational Materials Science **30**, 98 (2004)

21.* Atomic Indium nanowires on Si(111): The (4x1)-(8x2)-phase transition studied with Reflectance Anisotropy Spectroscopy
K. Fleischer, S. Chandola, N. Esser, W. Richter, J.F. McGilp, W.G. Schmidt, S. Wang, W. Lu, J. Bernholc
Appl. Surf. Sci. **234**, 302 (2004)

22.* Structural Analysis by Reflectance Anisotropy Spectroscopy: As and Sb on GaAs(110)
O. Pulci, K. Fleischer, M. Pristovsek, S. Tsukamoto, R. DelSole, W. Richter
J. Phys.: Condens. Matter **16**, 4367 (2004)

23.* In-situ ellipsometry: Identification of surface terminations during GaN growth
C. Cobet, T. Schmidtling, M. Drago, N. Wollschläger, N. Esser, W. Richter
Phys. stat. sol. (c) **8,** 2938 (2003)

24. Metallic nanostructures on Co/GaAs(001)(4x2) surfaces
K. Lüdge, P. Vogt, W. Richter, B.-O. Fimland, W. Braun, N. Esser
J. Vac. Sci. Technol. B **22**, 2008 (2004)

25.* Optical anisotropy of Cs nanostructures on III-V(110) surfaces
K. Fleischer, G. Bussetti, C. Goletti, W. Richter, P. Chiaradia
J. Phys.: Condens. Matter **16**, 4353 (2004)

26.* Nitrogen-arsenic exchange processes and investigation of the nitrided GaAs surfaces in MOVPE
V. Hoffmann, F. Poser, C. Kaspari, S. Weeke, M. Pristovsek, W. Richter
Journal of Crystal Growth **272**, 30 (2004)

27. InN Growth and Annealing Investigations using in-situ Spectroscopic Ellipsometry
M. Drago, T. Schmidtling, C. Werner, M. Pristovsek, U.W. Pohl, W. Richter
Journal of Crystal Growth **272**, 87 (2004)

28. Optische Analyse des MOVPE Wachstums
W. Richter, E. Speiser, K. Fleischer, N. Esser, T. Schmidtling
Proceedings LOB 2004

29. Anisotropy of the dielectric function for wurtzite InN
R. Goldhahn, A.T. Winzer, V. Cimalla, O Ambacher, C. Cobet, W. Richter, N. Esser, J. Furthmüller, F. Bechstedt, H. Lu, W.J. Schaff
Superlattices and Microstructures **36**, 591(2004)

30. Optical Resonances of Indium Islands on GaAs(001) Observed by Reflectance Anisotropy Spectroscopy
N. Esser, A.M. Frisch, A. Röseler, S. Schintke, C. Goletti, B.O. Fimland,
Phys. Rev. B **67**, 125306 (2003)

31. Model for the Effects of Surface Disorder on Reflectance Anisotropy Spectroscopy
B.S. Mendoza, N. Esser, W. Richter
Phys. Rev. B **67**, 165319 (2003)

32. FTIR Synchrotron Ellipsometry for Studying the Anisotropy of Small Organic Samples
K. Hinrichs, M. Gensch, A. Röseler, E.H. Korte, K. Sahre, K.J. Eichhorn, N. Esser, Schade, Appl. Spectroscopy **57**, 1250 (2004)

33. Quality Control of Chalcopyrite Semiconductors by Raman Spectroscopic Techniques
C. Xue, D. Papadimitriou, N. Esser,
Proc. 5th Int. Symp. on Test and Measurement **5**, 3517 (2003)

34. In-situ Monitoring of Semiconductor Growth by Raman Spectroscopy
A.G. Kontos, K. Hinrichs, D. Papadimitriou, N. Esser,
Proc. 5th Int. Symp. on Test and Measurement **5**, 3517 (2003)

35. Optical Characterization of $Cu_xGa_ySe_2$-layers by Photoreflectance Spectroscopy
C. Xue, D. Papadimitriou, N. Esser,
Thin Solid Films **451-452**, 189 (2004)

36. Vacuum Ultraviolet Spectroscopic Ellipsometry Investigations of Guanine Layers on H-Passivated Si(111) Surfaces
S. D. Silaghi, M. Friedrich, R. Scholz, T. U. Kampen, C. Cobet, N. Esser, W. Richter, W. Braun, D. R. T. Zahn,
Thin Solid Films **455-456,** 505 (2004)

37. Micro-Raman Study of Orientation Effects of Cu_xSe-Crystallites on Cu-rich $CuGaSe_2$ Thin Films
C. Xue, D. Papadimitriou, Y.S. Raptis, W. Richter, N. Esser, S. Siebentritt, M.Ch. Lux-Steiner,
J. Appl. Phys. **96**, 1963 (2004)

38. Mapping of Gradient Composition CuxGaySe2 Film Properties using Raman and PL Spectroscopy
C. Xue, D. Papadimitriou, N. Esser
J. Phys. D: Appl. Phys. **37**, 2267 (2004)

39. Raman Scattering from Surface Phonons
W. Richter, N. Esser,
in Symposium Dedicated to the Memory of Professor Evangelos Anastassakis (1938-2000), Ed. M. Cardona, W. Richter, Y. S. Raptis, National Technical University of Athens, Athens 2004

40. IR- ellipsometric Study on Initial Stages of Oxide Growth on Si(001)
K. Hinrichs, M. Gensch, A. Röseler, N. Esser,
J. Phys. Condens. Matter **16,** 4335 (2004)

41. **Oxidation and Organic Molecule induced Changes of the Si Surface Optical Anisotropy: Ab initio Predictions**
W.G. Schmidt, F. Fuchs, A. Hermann, K. Seino, F. Bechstedt, R. Passmann, M. Wahl, M. Gensch, K. Hinrichs, N. Esser, S. Wang, W. Lu, J. Bernholc,
J. Phys.: Condens. Matter **16**, 4323 (2004)

42. **Infrared Ellipsometry for the Characterization of Electrochemically grafted Ultra Thin Organic Films**
M. Gensch, R. Hunger, A.G. Güell, K. Hinrichs, J. Rappich, U. Schade, W. Jägermann, N. Esser, E.H. Korte, and A. Röseler,
in preparation

43. **Ga-rich GaAs(001) surfaces observed by STM during high-temperature annealing in MBE**
M. Pristovsek, O. Akihiro, G.G. Bradford, G. Bell, O Takahisa, N. Koguchi
J. Crystal Growth 251, (2003) 46-50

44. **In situ scanning tunneling microscopy of InAs quantum dots on GaAs(001) during molecular beam epitaxial growth**
G.R. Bell, M. Pristovsek, S. Tsukamoto, B.G. Orr, Y. Arakawa, N. Koguchi
Surf. Sci. **544** (2003) 234-240

45. **Hydrogen local vibrational modes in zinc oxide**
K. Fleischer, N. Nickel
Physical Rev. Lett. **90** (2003) 1974

46. **Surface structure of $CuGaSe_2$ (001)**
Th. Deniozou, N. Esser, S. Siebentritt, P. Vogt, R. Hunger
Thin Solid Films, in print (2004)

47. **Gallium-rich reconstructions on GaAs(001)**
M. Pristovsek, S. Tsukamoto, A. Ohtake, N. Koguchi, B.G. Orr, W.G. Schmidt, J. Bernholc
Phys. Stat. Sol. B **240** (2003) 91-98

48. **In-situ study of GaAs growth mechanisms using tri-methyl gallium and tri-ethyl gallium precursors in MOVPE**
M. Pristovsek, M. Zorn, M. Weyers
J. Crystal Growth **262** (2004) 78-83

49. **Lateral short range ordering of step bunches in InGaAs/GaAs superlattices**
M. Hanke, M. Schmidbauer, R. Kühler, H. Kirmse, M. Pristovsek
J. Appl. Phys. **95** (4) (2004) 1736-1739

50. **In-situ study of low-temperature growth and Mn, Si, Sn doping of GaAs (001) in molecular beam epitaxy**
M. Pristovsek, S. Tsukamoto
J. Crystal Growth **265** (2004) 425-433

51. **Growth of strained GaAsSb layers on GaAs (001) in MOVPE**
M. Pristovsek, M. Zorn, U. Zeimer, M. Weyers
J. Crystal Growth (in print)

52. Molecule-Solid Interfaces Studied with Infrared Ellipsometry: Ultra-Thin Nitrobenzene Films
M. Gensch, K. Roodenko, R. Hunger, A.G.Güell, K. Hinrichs, J. Rappich, Th. Dittrich, U. Schade, N. Esser,
J. Vac. Science and Technol. B (2005) submitted

53. The $CuGaSe_2$-Surface: A (4x1)-Reconstruction
Th. Deniozou, S. Siebentritt, N. Esser,
Surface Science (2005) submitted

9.4.3 Invited talks

Richter, Wolfgang	**Raman scattering from semiconductors at high temperatures** University of Leon Optics of Surfaces and Interfaces, OSI V, Leon, Mexiko, May 2003
Richter, Wolfgang	**Real-time control of quantum dot laser growth by reflectance anisotropy spectroscopy** University of Lecce, EW MOVPE X, Lecce, Italy, June 2003
Richter, Wolfgang	**Kontrolle des Epitaktischen Wachstums von III-Nitriden mit spektroskopischer Ellipsometrie** 3rd Workshop Spectroscopic Ellipsometry, Stuttgart, Feb. 2004
Richter, Wolfgang	**Linear Optics as a Diagnostic Tool for Soft-Hard Matter Interfaces** INF Meeting, 2004, Genua, Italy, June 2004
Richter, Wolfgang	**Raman Scattering I + II,** Epioptics-8, Erice, Sicily, July 2004
Richter, Wolfgang	**Monitoring of epitaxial surface processes by linear optical spectroscopy** Workshop 2004 of the European Graduate College, Electron-Electron Interactions in Solids, Marburg, July 2004
Esser, Norbert	**Spectroscopic Ellipsometry for Characterization of Nitride layers: Bulk, Surface and Epitaxy** TU Ilmenau Kolloquium der Technischen Universität Ilmenau, Ilmenau, Jan. 2003
Esser, Norbert	**Spektroskopie an Grenzflächen: Grundlagen und Anwendungen** Institut für Spektrochemie und Angewandte Spektroskopie Berlin-Adlershof ISAS Kolloquium, Berlin, Feb. 2003
Esser, Norbert	**Vakuum-UV-Ellipsometrie an Nitriden und organischen Schichten** SENTECH Seminar Messung von dünnen Schichten, May 2003

Esser, Norbert	**Co/GaAs contacts for spintronics: Controlling the interface formation by ErAs interlayers** Max-Born-Institute Berlin Evaluierung des Strahlrohres bei BESSY, Berlin, June 2003
Esser, Norbert	**VUV Ellipsometry on III-Nitrides: Surface and Layer Structure ,** TU Wien Intern. Conf. On Spectroscopic Ellipsometry, Wien, Österreich, July 2003
Pristovsek , Markus	**Wachstum von GaAsSb und InGaAsSb-QW auf GaAs in der MOVPE** Universität Bremen Jahrestagung des Arbeitskreises III-V-Epitaxie der deutschen Gesellschaft für Kristallzucht und Kristallographie, Bremen, Dec. 2003
Pristovsek, Markus	**CxHy and MOVPE - when chemistry matters Hydrogen** TU Berlin, Universita Tor Vergata, Roma Adsorbates on surfaces probed by optics, Isola del Polvese, Italy, Sept. 2003
Vogt, Patrick	**Surface structure of III-P(001) surfaces and the influence of atomic Hydrogen** TU Berlin, Universita Tor Vergata, Roma Adsorbates on surfaces probed by optics, Isola del Polvese, Italy, Sept. 2003
Drago, Massimo	**Organometallic vapour phase epitaxy of InN monitored with in-situ spectroscopic ellipsometry** XXXIV Congresso Nazionale Roma 04, Italy, Sept. 2004
Fleischer, Karsten	**Cs nanowires on GaAs and InAs cleaved surfaces** National Institute for the Physics of Matter (INFM) INFMeeting 2003, Genua, Italy, June 2003
Fleischer, Karsten	**Metallic Nanowires -- Why and How** TU Berlin, Universita Tor Vergata, Roma Adsorbates on surfaces probed by optics, Isola del Polvese, Italy, Sept. 2003
Poser, Florian	**Geordnete Anlagerung von InAs Quantenpunkten an GaAs Makrostufen** Humboldt Universität Berlin Seminar, Berlin, Jan. 2003
Poser, Florian	**Recent MOVPE studies: a) InAs QD on stepbunched GaAs b) in-situ Raman c) InN dielectric function** Fritz-Haber-Institute (MPG) Workshop Schloß Ringberg, Rottach-Egern, Feb. 2003
Schmidtling, Torsten	**Surface and Bulk Properties of Wurtzite GaN** University of Rom Kolloquium, Rom, Italy, Jan. 2003

9.4.4 PhD theses

Kathy Lüdge	**Interface formation during epitaxial growth of Cobalt Layers on III-V semiconductors (001) surfaces** 17.10.2003
Michael Gensch	**Infrared ellipsometry for the investigation of interfacial layers and thin organic films on silicon** 17.12.2004

9.4.5 Diploma theses

Stefan Binkowski	**Ramanstreuung an Nitrid-Halbleiteroberflächen)** 29.03.2004
Markus Breusing	**Aufbau eines MOVPE-integrierten in-situ STM/AFM** 15.10.2004
Girmay Dessalegn	**Untersuchung von Oberflächenrauhigkeiten mit Rastersondenmikroskopie und Lichtstreuung** 28.10.2003
Veit Hoffmann	**Wachstumsmechanismen bei der Epitaxie von GaAsN auf GaAs** 25.3.2004
Regina Paßmann	**Struktur und vibronische Eigenschaften einfacher organischer Moleküle auf Siliziumoberfächen** 21.04.2004
Thomas Säuberlich	**Präparation und Oxidation von III-V-Halbleitern** 26.04.2004
Tobias Schenk	**Ellipsometrische Analyse von Nitridoberflächen** 17.10.2004
Eugen Speiser	**Raman-Streuung an Halbleitern bei ohen Temperaturen** 16.12.2003
Matthias Wahl	**Magnetoptische Eigenschaften epitaktischer 3-d-Metall-Schichten auf Metallsubstraten** 25.02.2003
Arno Wirsig	**Aufbau eines Ellipsometers zur schnellen spektralen in-situ Charakterisierung von MOVPE Prozessen** 05.05.2003

9.4.6 Abstracts of selected papers of department IV

2. *Phys. Rev. B* ***67****, 115315 (2003)*

Sb-induced (1×1) reconstruction on Si(001)

J. R. Power[1], O. Pulci[2], A. I. Shkrebtii[1,5], S. Galata[3], A. Astropekakis[4], K. Hinrichs[1], N. Esser[1], R. Del Sole[2], W. Richter[1]

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[2]*INFM, Department of Physics, University of Rome Tor Vergata, Roma, Italy*
[3]*Department of Physics, Aristotle University of Thessaloniki, Greece*
[4]*Department of Chemical Engineering, National Technical University of Athens, Greece*
[5]*Department of Physics, University of Toronto, Canada*

We combine low-energy electron diffraction and reflectance anisotropy spectroscopy (RAS) with *ab initio* calculations of the geometry, band structure, and optical anisotropy to investigate the adsorption of Sb on vicinal Si(001) (1×2). We focus, in particular, on the controversy concerning the Si(001)-(1×1)-Sb surface. On the basis of total-energy and band-structure calculations, we find that the Sb-undimerised model is unstable and metallic, while experimentally the (1×1) Sb shows no evidence of a Fermi edge. In contrast, the dimerised (2×1)-Sb and *c*(2×2)-Sb reconstructions are found to be semiconducting with a minimal difference in total energy. Furthermore, the RAS spectra calculated for both dimerised reconstructions show strong similarities to one another, and agree well with the experimental RAS data for the Sb-induced (1×1)-Sb surface, with a dominant feature centered at 3.7 eV. We report that these findings are compatible with the (1×1)-Sb surface comprising a mixture of the Sb-dimer-terminated (2×1)-Sb and *c*(2×2)-Sb structures.

3. *Phys. Rev. Lett.* ***90****, 177402 (2003)*

Optical Recognition of Atomic Steps on Surfaces

F. Baumberger[1], Th. Herrmann[2], A. Kara[3], S. Stolbov[3], N. Esser[2], TS. Rahman[3], J. Osterwalder[1], W. Richter[2], R. Greber[1]

[1]*Physik Institut der Universität Zürich, Switzerland*
[2]*Institut für Festkörperphysik der TU Berlin, Germany*
[3]*Department of Physics, Kansas State University, Manhattan, USA*

Visible and UV light spectra display striking differences in optical reflectivity for the two types of monatomic steps on copper (111) surfaces. Electronic structure calculations trace these differences to the specific contributions of $p_{\parallel}$ and $p_{|}$ local densities of states, parallel and perpendicular to the steps, of the distinctly coordinated corner atoms. The local origin of the spectral reflectance anisotropy is further corroborated by experiments on Cu(111) surfaces with varying step densities. Site specificity of the electronic structure of atoms in low coordinated sites on Cu(111) vicinals is thus revealed by reflectance anisotropy spectroscopy which can thereby detect step atom densities down to 10^{13} atoms/cm^2.

4. *Phys. Rev. B.* ***90****, 235318 (2003)*

Phonon and polarized reflectance spectra from Si(111)-(4×1)In: Evidence for a charge-density-wave driven phase transition

K. Fleischer[1], S. Chandola[2], N. Esser[1], W. Richter[1], and J. F. McGlip[2]
[1] *Institut für Festkörperphysik,Te chnische Universität Berlin, Germany*
[2]*Department of Physics, Trinity College, Dublin, Ireland*

The (4×1)" → (4×"2") phase transition of the In terminated Si(111) surface around 120 K has been investigated by optical spectroscopy. Characteristic surface phonon modes of the 4×1and4×"2" phases are observed with Raman spectroscopy. Reflectance anisotropy spectroscopy (RAS) reveals a splitting of a large feature in the optical anisotropy at 2 eV on formation of the low temperature phase. The changes in the RAS and Raman spectra are discussed within the framework of the conflicting models of the phase transition. Charge density wave formation driven by a Peierls transition is favored over transitions involving significant structural modifications.

6. *Phys. Rev. B* ***67****, 165319 (2003)*

Model for the effects of surface disorder on reflectance anisotropy spectroscopy

Bernardo S. Mendoza[1], N. Esser[2], W. Richter[2]
[1]*Centro de Investigaciones en Optica, A. C., León, Guanajuato, México*
[2]*Institut für Festkörperphysik, Technische Universität Berlin, Germany*

We present a simple model for surface disordering and study its consequences on reflectance anisotropy spectroscopy (RAS). Large unit cells are taken as a basis to introduce disorder by means of displacing the atoms from their equilibrium positions. Different displacement schemes are employed and ensemble averages are calculated in order to study the influence on the optical response. For reasons of computing time the semiempirical tight binding approach with an sp^3s^* basis is used to calculate the microscopic dielectric response of the surface, through which RAS is obtained. The well studied clean GaAs(110)(1×1) surface is used as an example. We find that the spectral RAS structures of GaAs(110)(1×1) follow a well defined behavior as a function of disorder and that a rather small number of surface atoms are needed only at equilibrium positions to produce already the RAS signal specific for the fully ordered surface reconstruction. This is a consequence of nearest neighbor interactions dominating the polarizability response and explains the fast dynamic response of RAS as compared to the diffraction methods which are limited by their large coherence length (low energy and reflection high energy electron diffraction).

9. *Journal of Appl. Physics* ***94****, 6997 (2003)*

Surface Termination during GaN growth by Metal-organic Vapor Phase Epitaxy determined by Ellipsometry

C. Cobet[1], T. Schmidtling[1], M. Drago[1], N. Wollschläger[1], N. Esser[1], W. Richter[1], R. M. Feenstra[2], T. U. Kampen[3]
[1]*Institut für Festkörperphysik, Technische Universität Berlin, Germany*
[2]*Department of Physics, Carnegie Mellon University, Pittsburgh, USA*
[3]*Institut für Physik, Technische Universität Chemnitz, Germany*

Spectroscopic ellipsometry is used to study GaN films during growth by metalorganic vapor phase epitaxy (MOVPE) in correlation to well known results of plasma-assisted molecular beam epitaxy (PAMBE). Results for the PAMBE reveal clear differences between growth under Ga-rich and N-rich conditions, which are attributed to the presence of a Ga bilayer on the surface (also seen with low energy electron diffraction) in the Ga-rich case. Results for MOVPE surfaces during growth or for surfaces which are stabilized under NH_3 are very similar to the N-rich PAMBE result. It is concluded that under normal growth conditions in MOVPE in contrast to PAMBE the surface is *not* terminated by a Ga bilayer.

10. *Phys. Rev. Lett.* ***90****, 126101 (2003)*

InP(001)-(2×1) Surface: A Hydrogen Stabilized Structure

W.G. Schmidt[1], P.H. Hahn[1], F. Bechstedt[1], N. Esser[2], P. Vogt[2], A. Wange[2], W. Richter[2]
[1]*Institut für Festkörpertheorie und Theoretische Optik, Friedrich-Schiller-Universität, Jena, Germany*
[2]*Institut für Festkörperphysik, Technische Universität Berlin, Germany*

The InP(001)(2×1) surface has been reported to consist of a semiconducting monolayer of buckled phosphorus dimers. This apparent violation of the electron counting principle was explained by effects of strong electron correlation. Combining *first-principles* calculations with reflectance anisotropy spectroscopy and LEED experiments, we find that the (2×1) reconstruction is not at all a clean surface: it is induced by hydrogen adsorbed in an alternating sequence on the buckled P dimers. Thus, the microscopic structure of the InP growth plane relevant to standard gas phase epitaxy conditions is resolved and shown to obey the electron counting rule.

11. *Journ. Crys. Growth* ***248****, 523 (2003)*

Spectroscopic ellipsometry during metalorganic vapor phase epitaxy of InN

T. Schmidtling, M. Drago, U. W. Pohl and W. Richter
Institut für Festkörperphysik, Technische, Universität Berlin, Germany

Metalorganic vapor phase epitaxy of indium nitride (InN) on sapphire was studied and optimized in situ by spectroscopic ellipsometry. Layers with smooth surface morphology were obtained on low-temperature nucleation layers on nitrided sapphire substrates using trimethylindium and ammonia at high V/III ratios above 30 000. Ellipsometry reveals a growth regime for InN below 550°C and best crystalline quality at 500°C. Improvement of the crystalline quality is achieved at lower growth temperatures. This tendency is confirmed by X-ray diffraction while still some residual mosaicity of the layers can be observed. The appearance of pronounced E_1 and A_2 Raman modes, obeying

12. *Journ. Crys. Growth* ***248****, 317 (2003)*

Growth of spatially ordered InAs quantum dots on step-bunched vicinal GaAs (1 0 0) substrates

F. Poser[1], A. Bhattacharya[2], S. Weeke[1], and W. Richter[1]
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[2]*Solid State Electronics Group, Tata Institute of Fundamental Research, Mumbai, India*

Spatially ordered growth of InAs quantum dots (QD) was demonstrated via metalorganic vapour phase epitaxy on step-bunched vicinal GaAs substrates. Regular terraces of step-bunched surfaces were achieved by growing on GaAs (1 0 0) substrates off-oriented 2°, 4° and 6° towards the <1 1 0> and <1 1 1> directions, thus serving as in situ templates for the growth of the QD layer. Multilayer stacks of strain-aligned QDs were successfully grown to improve the size homogeneity and therefore optoelectronic properties. Furthermore, the possibility of fabricating laterally ordered quantum wires (QWR) in the same manner was shown.

13. *phys. stat. sol. (c)* ***8****, 2949 (2003)*

In-situ Raman Spectroscopy on III-V semiconductors at high temperature in MOVPE

E. Speiser, T. Schmidtling, K. Fleischer, N. Esser, W. Richter
Institut für Festkörperphysik, Technische, Universität Berlin, Germany

Through the implementation of a Raman spectroscopic equipment into a metalorganic vapor phase epitaxy setup (MOVPE) via optical fibers we determine surface and bulk related properties of III-V semiconductors in a temperature range up to 1200 K. Surface damages due to high temperature are avoided by a stabilization with gaseous group V elements which allows for reproducible measurements. The temperature dependent changes are monitored and analyzed through the change in the vibrational properties which are sensitive indicators of the sample and surface status. The results can be grouped into two categories: (i) irreversible changes with temperature (crystal quality, doping) due to sample annealing during the measuring process at high temperatures, and (ii) anharmonic effects (reversible) on phonon frequencies and line widths. We show that the TO and LO-phonon shifts at high temperature can be described well including fourth order phonon decay. The maximum temperature which can be reached is at present only limited by the subscale heating system.

15. *Phys. Rev. B* ***69****, 165406 (2003)*

Optical reflectance anisotropy of Al(110): Experiment and *ab initio* calculation

Th. Herrmann[1], M. Gensch[2], M.J.G. Lee[3], A.I. Shkrebtii[4], N. Esser[1], W. Richter[1], and Ph. Hofmann[5]
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[2]*Institut für Spektrochemie und Angewandte Spektroskopie, Berlin, Germany*
[3]*Department of Physics, University of Toronto, Canada*
[4]*Faculty of Science, University of Ontario Institute of Technology, Canada*
[5]*University Aarhus, Inst. Storage Ring Facilities, Aarhus, Denmark*

The reflectance anisotropy of a clean Al(110)-vacuum interface has been measured experimentally, and compared with the results of an *ab-initio* self-consistent full-potential linear augmented plane-wave calculation. Good agreement is found in the interband regime, while a discrepancy in the Drude regime is consistent with anisotropy in the intraband contribution. The calculated surface dielectric anisotropy and reflectance anisotropy of Al(110) are not significantly affected by surface relaxation, suggesting that optical transitions between surface states and surface resonances make only a minor contribution to the surface dielectric response. The measured reflectance anisotropy of Al(110) is found to be only weakly affected by oxidation and by the deposition of Ni overlayers, providing further evidence in support of this conclusion.

19. *Journal of Crystal Growth* ***248****, 254(2003)*

Influence of the reconstruction of GaAs (0 0 1) on the electro-optical bulk properties

M. Pristovsek[1], S. Tsukamoto[1], B. Han[2], J. -T. Zettler[2] and W. Richter[2]
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[2]*Institut für Festkörperphysik, Technische, Universität Berlin, Germany*

We investigated the doping dependence of the reflectance anisotropy signal on different GaAs (0 0 1) reconstructions. The doping dependent signal amplitude at the E_1 transition is found to be proportional to the electrical field integrated over the penetration depth of light. However, the surface reconstruction strongly modifies amplitude and spectral shape of this signal.

20. *Computational Materials Science* ***30****, 98(2004)*

GW calculations on surfaces: an application to the study of clean and Sb-covered Si(0 0 1)

O. Pulci[1], J. Power[2], A. Shkrebtii[2,3], W. Richter[2] and R. Del Sole[1]
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[2]*Institut für Festkörperphysik, Technische, Universität Berlin,Germany*
[3]*Department of Physics, University of Toronto, Canada*

We describe an application of the many-body *GW* method to calculate the electronic band structure and optical properties of the clean Si(0 0 1) 1 × 2 surface and its changes upon antimony adsorption. We find that the so called (1 × 1) reconstruction of Si(0 0 1):Sb is actually a mixture of (2 × 1) and c(2 × 2)-Sb domains.

21. *Appl. Surf. Science* ***234****, 302(2004)*

Atomic indium nanowires on Si(1 1 1): the (4 × 1)–(8 × 2) phase transition studied with reflectance anisotropy spectroscopy

K. Fleischer[1], S. Chandola[1,3], N. Esser[2], W. Richter[1], J. F. McGilp[3], W. G. Schmidt[4], S. Wang[4], W. Lu[4] and J. Bernholc[4]
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[3]*Department of Physics, Trinity College, Dublin, Ireland*
[1] *Department of Physics, North Carolina State University, Raleigh, USA*

Despite much experimental and theoretical effort, the electronic and the structural properties of the (4 × 2)/(8 × 2)-low-temperature phase of in nanowires on Si(1 1 1) are still under discussion. In our combined experimental and theoretical work we utilize the surface selectivity of reflectance anisotropy spectroscopy (RAS) to analyze the electronic (surface electronic states) properties. The RAS response is directly compared with &bslash;emph{ab-initio} density functional theory (DFT)–local density approximation (LDA) calculations of the optical anisotropy of different surface models.

22. *J. Phys.: Condens. Matter* ***16****, 4367 (2004)*

Structural analysis by reflectance anisotropy spectroscopy: As and Sb on GaAs(110)

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We present calculated and measured reflectance anisotropy spectra (RAS) in the energy range from 1 to 6 eV of cleaved GaAs(110) surfaces covered with one monolayer of As and Sb in a (1 × 1) pattern. The spectral range and the accuracy of the data were improved and correlated for the first time with *ab initio* calculations of RAS spectra for the ECLS (epitaxial continued layer structure) and EOTS (epitaxial on top structure) surface models. The theoretical spectra for the two models completely differ and rule out the EOTS for both adsorbates. For Sb/GaAs(110) this finding agrees with the previous experimental and theoretical results reported on the structure. For As on GaAs(110) the ECLS structure was also suggested, but so far no direct proof for this model has been given. In this paper we show how RAS, thanks to its sensitivity to details of the surface structure and *ab initio* theoretical description, demonstrates its potential to conclusively determine surface structures.

23. *phys. stat. sol. (c)* ***8****, 2938 (2003)*

In-situ ellipsometry: Identification of surface terminations during GaN growth

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Spectroscopic ellipsometry (SE) is used to determine GaN surface termination during growth with metal-organic vapor phase epitaxy (MOVPE) by a correlation to well known results of plasma-assisted molecular beam epitaxy (PAMBE). The results manifest that in MOVPE under typical growth conditions the surface is not terminated by a Ga-bilayer as suggested for MBE. Moreover, it turns out that ellipsometry can be used to characterize the surface reconstruction in wurtzite GaN similar as reflectance anisotropy does for cubic III-V-compounds. The optical spectra for the PAMBE reveal clear differences between growth under Ga-rich and N-rich conditions, which are attributed to the presence of a Ga-bilayer and various N-rich reconstructions on the surface [1].

25. *J. Phys.: Condens. Matter* ***16****, 4353 (2004)*

Optical anisotropy of Cs nanostructures on III–V(110) surfaces

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We present reflectance anisotropy spectra in the energy range 1.0–5.5 eV, measured for cleaved III–V surfaces after adsorption of caesium. In such a system Cs forms one-dimensional wire-like structures at low Cs coverages ($\Theta \langle\langle 1\,\mathrm{ML}$). The formation of these Cs wires leads to characteristic changes in the reflectance anisotropy spectra of the cleaved surface such as a minimum between the E_0 and E_1 bulk critical points of the substrate. For higher coverages the development of a two-dimensional layer can be optically monitored, as can the gradual transition to a three-dimensional disordered layer close to the saturation coverage.

26. *Journal of Crystal Growth* ***272****, 30 (2004)*

Nitrogen–arsenic exchange processes and investigation of the nitrided GaAs surfaces in MOVPE

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We studied nitrided surfaces and the kinetics of nitridation with tertiarybutylhydrazine (tBHy) in metal organic vapor-phase epitaxy (MOVPE). Reflectance anisotropy spectroscopy (RAS) and X-ray diffraction (XRD) were used for in situ and ex situ analysis. By comparing RAS spectra with molecular beam epitaxy (MBE) results we found a (3x3)-like reconstruction of the nitrided surfaces. The kinetics of the nitrogen–arsenic exchange were studied by RAS transients. An activation energy of $E_a \simeq 1.7\,\mathrm{eV}$ was calculated for the exchange process. This value was independent from the tBHy partial pressure. Incorporation of nitrogen into GaAs up to six monolayers was further demonstrated by ex situ XRD for samples grown between 460 and 560° C.

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