HL 13: Optical properties

Time: Tuesday 9:30–13:00 Location: BEY 118

HL 13.1 Tue 9:30 BEY 118

THz sideband generation in multi quantum wells — Martin Wagner[1], Harald Schneider[1], Manfred Helm[1], •Stephan Schartner[2], Aaron Maxwell Andrews[2], Tomas Roch[2], and Gottfried Strasser[2] — [1]Institut für Ionenstrahlphysik und Materialforschung, Forschungszentrum Dresden-Rossendorf, Postfach 51 01 19, 01314 Dresden — [2]Institut für Festkörperelektronik, TU Wien, Floragasse 7, 1040 Wien, Austria

THz sideband generation is a nonlinear mixing process where a near-infrared (NIR) laser beam is mixed with a THz beam to generate new frequencies (sidebands) $\omega = \omega(\mathrm{NIR}) * \mathrm{n} * \omega(\mathrm{THz})$ (with integer n). This effect has been investigated in various semiconductor systems (e. g., in bulk GaAs [1] and in multi quantum wells [2]).

We report on third-order nonlinear mixing between a NIR laser and a free-electron laser (FEL) in an undoped AlGaAs/GaAs multi quantum well. Differently from the literature where electronic and heavy-hole intersubband transitions were used, we are covering different transitions by tuning the FEL wavelength. We directly compare the n=+2 sideband generation efficiency when the FEL pumps the heavy-hole light-hole transition with the efficiency when the intraexcitonic 1s-2p transition of the heavy-hole is pumped. In the latter case the efficiency increases up to 0.2%, which is comparable to the best values achieved for an even stronger n=+1 sideband process [2].

[1] M. A. Zudov et al., Phys. Rev. B 64, 121204, 2001
[2] S. G. Carter et al., Appl. Phys. Lett. 84, 840, 2004

HL 13.2 Tue 9:45 BEY 118

Excitonic signatures in the intersubband THz absorption of optically excited semiconductor quantum wells — •Daniel Golde, Mackillo Kira, and Stephan W. Koch — Fachbereich Physik, Philipps-Universität, Renthof 5, D-35032 Marburg

We present a theoretical study of the intersubband absorption of an optically excited undoped semiconductor quantum well using our recently developed microscopic THz theory [1]. In the past, intersubband transitions were often studied using doped quantum wells. In this case, the absorption follows entirely from the equilibrium carrier distribution in the lowest subband. For photoexcited quantum wells, however, there are two distinct contributions to the intersubband response. The optically generated charge carriers can be excited to a higher subband giving rise to usual *band-to-band transitions*. The optical pump pulse can also create an excitonic polarization which is under certain conditions converted into an incoherent exciton population [1]. We show that the presence of such coherent or incoherent excitons yields additional *excitonic THz transitions* that are spectrally different from the band-to-band transitions.

In my talk, I will show how the intersubband absorption is influenced by excitons and for which experimental conditions one can expect to observe them in a measurement.

[1] M. Kira and S. W. Koch, Prog. Quantum Electron. **30,** 155 (2006).

HL 13.3 Tue 10:00 BEY 118

Excitonic electroreflectance spectra of hexagonal GaN — •Steve Lenk and Erich Runge — Institut für Physik, Technische Universität Ilmenau, Germany

We calculate the dielectric function including the A-, B-, and C-excitons of hexagonal GaN in the presence of an external electric field by using a multi-valence band formalism. The importance of excitons for the interpretation of electroreflectance spectroscopy of GaN was emphasized by several experimental groups, but only recently theoretical calculations were presented [1]. We derive the dielectric function from a numerical solution of an initial value problem [2] via an exponential split-operator method, taking into account the full 6x6 valence band structure of Chuang and Chang [3]. We present the complex dielectric function as well as the deduced reflectivity and absorption spectra of the excitons in GaN. These and the electroreflectance spectra are compared with recent experimental studies.

[1] A.T. Winzer, G. Gobsch, and R. Goldhahn, Phys. Rev. B **74**, 125207 (2006).

[2] S. Glutsch, *Excitons in Low−Dimensional Semiconductors*, Springer Heidelberg (2004).

[3] S.L. Chuang and C.S. Chang, Phys. Rev. B **54**, 2491 (1996).

HL 13.4 Tue 10:15 BEY 118

Two-color pump-probe spectroscopy of self-assembled GaAs/AlGaAs quantum dots — •Christian Wolpert[1,2], Manuel Huber[1,2], Markus Lippitz[1,2], Lijuan Wang[3], Armando Rastelli[3], and Oliver G. Schmidt[3] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [2]4. Physikalisches Institut, Universität Stuttgart, Germany — [3]Institut für Integrative Nanowissenschaften, IFW Dresden, Germany

Semiconductor quantum dots (QDs) are a promising candidate for the realization of qbits in quantum computing. With coherence times of below 1 ns, manipulation and read-out of the quantum mechanical state requires ultrafast laser pulses. In order to address single QDs, we can restrict ourselves to optical far-field microscopy, as our GaAs/AlGaAs QD samples show QD densities well below $1/\mu m^2$. We present a scheme for ultrafast spectroscopy of single QDs using a pump-probe technique with a confocal laser-scanning microscope. Pump and probe pulses are derived from a 150 fs pulse by spectral pulse shaping. Single exciton transitions were identified in μ-photoluminescence (μ-PL) measurements around 1.73 eV. Our approach is to resonantly pump and probe excitonic states, enabling us to directly control the phase and population dynamics in the QD. We present the experimental setup as well as first results.

HL 13.5 Tue 10:30 BEY 118

Microscopic Theory of the optical properties of Ga(AsBi) quantum wells — •Sebastian Imhof[1], Christina Bückers[2], Angela Thränhardt[1], Jörg Hader[3], Jerome V. Moloney[3], and Stephan W. Koch[2] — [1]Fakultät für Naturwissenschaften, Technische Universität Chemnitz, 09107 Chemnitz — [2]Fachbereich Physik und Wissenschaftliches Zentrum für Materialwissenschaften, Philipps Universität Marburg, Renthof 5, 35032 Marburg — [3]Optical Sciences Center, University of Arizona, Tucson, Arizona 85721, USA

Ga(AsBi) is a serious candidate for infrared diode lasers because the bandgap of GaAs is reduced by as much as 60–80 meV per percent Bi that is incorporated. Thus, a wide wavelength range in the infrared region can be reached.

Although the growth of heterostructures is still not feasible in this material system, we have access to the optical properties, e.g. material gain and photoluminescence as well as radiative and non-radiative laser loss processes of Ga(AsBi)/(AlGa)As quantum wells, by using a consistent microscopic theory. We calculate the bandstructure by using a valence band anticrossing model and investigate the influence of the anticrossing parameters on the optical properties.

HL 13.6 Tue 10:45 BEY 118

Electronic coupling in ZnO/MgZnO Double Quantum Wells — •Jan Zippel, Martin Lange, Gabriele Benndorf, Jörg Lenzner, Holger Hochmuth, Michael Lorenz, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II,Linnéstraße 5, 04103 Leipzig

The band-gap of ZnO can be tuned from about 3 eV to 4.5 eV by alloying with Cd or Mg, respectively. This allows the realization of quantum well (QW) structures emitting between the blue and the near UV (NUV) part of the electromagnetic spectrum. In this contribution we focus on the electronic coupling of $ZnO/Mg_xZn_{1-x}O$ double quantum well (DQW) structures. Besides structures with two identical wells, we fabricated DQW*s with different thickness. All samples were grown by pulsed-laser deposition on *a*-plane sapphire substrate. The thickness of the barrier between the two QWs was varied from 1 nm up to 6 nm for well widths of 2 nm and 4.5 nm. The magnesium content (x) in the barrier was determined by photoluminescence measurements to be about 14% for all samples [1].

All samples are investigated using cathodoluminescence at room temperature and at 10 K. With decreasing barrier thickness between the two QWs we observed a clear red shift of the QW luminescence proving the coupling between the QWs at room temperature. The observed shift is in good agreement with effective mass theory. For the structures with different well width, an additional peak between the two direct excitonic transitions occurs.

[1] S. Heitsch et *al.*, J. Appl. Phys. **101**, 083521 (2006).

HL 13.7 Tue 11:00 BEY 118

Temperature dependent dielectric function of nonpolar ZnO — •Philipp Kühne, Rüdiger Schmidt-Grund, Chris Sturm, Matthias Brandt, and Marius Grundmann — Universität Leipzig Institut für Experimentelle Physik II Halbleiterphysik Linnéstraße 5 04103 Leipzig Germany

ZnO is a direct semiconductor which crystallizes in the wurtzite structure. Due to its wide band gap of 3.4 eV and a high exciton binding energy of 60 meV, ZnO is a promising material for optoelectronic devices. Non-polar surfaces like m-plane (1-100) are of special interest since they avoid electric fields at interfaces, which can negatively influence the performance of optoelectronic devices grown on these surfaces.In this work we study the temperature dependence of the tensor of the dielectric function of nonpolar m-plane bulk ZnO single crystals by means of spectroscopic ellipsometry in the spectral range 1 eV−4.5 eV and for temperatures 5 K−470 K. The independent components parallel $\epsilon_{||}$ and perpendicular $\epsilon_{\perp}$ to the crystal axis were found by layer stack model analysis, using parameterised model dielectric functions.

Ellipsometry is very sensitive to surface morphology and surface contamination. We gave emphasis to the sample preparation. After an annealing process the sample exhibits atomic steps at the surface. To avoid the growth of films by resublimation of residual gases at low temperatures, we are working in an UHV system at $p < 10^{-9}$ mbar. For this pressure the growth rate is reduced to maximal one mono-layer per hour. Finally we derive the near band gap band-to-band transition energies, exciton binding energies and broadening parameters.

15 min. break

HL 13.8 Tue 11:30 BEY 118

Measurements in Voigt configuration on PLD grown NiO thin films — •Kah Ming Mok[1], Camelia Scarlat[1], Lars Hartmann[2], Shengqiang Zhou[1], Mycola Vinnichenko[1], Michael Lorenz[3], Marius Grundmann[3], Manfred Helm[1], Mathias Schubert[4], and Heidemarie Schmidt[1] — [1]Forschungszentrum Dresden-Rossendorf, Germany — [2]Solarion AG/Photovoltaics, Germany — [3]University of Leipzig, Germany — [4]University of Nebraska-Lincoln, USA

NiO has great potential applications in gas sensors, optical fibers, solar thermal absorbers, or in non-volatile resistive random memories. In our study NiO, NiMnO, and NiMnLiO have been grown on double-side polished r-plane sapphire substrates by pulsed laser deposition. In contrast to the antiferromagnetic behaviour of bulk NiO, we probed weak ferromagnetism with a coercivity ranging between 150 and 250 Oe by means of SQUID magnetometry. We measured the complex Voigt angle using a HeCd laser, a Glan Taylor polarizer, a Hinds PEM-100 and two LockIns. The polarization state of light after transmission through a sample consisting of ca. 1 μm thick, weak ferromagnetic and diamagnetic NiO thin films on diamagnetic r-plane sapphire substrates has been modelled using the 4*4 matrix formalism in dependence of an external magnetic field applied in-plane. The modelling results revealed that for the bare diamagnetic substrate the Voigt angle depends parabolically on the external magnetic field and that the weak ferromagnetic and diamagnetic NiO thin films changed the parabolic dependence of the Voigt angle in the range of ±0.1 T to a flat-top shape in agreement with the experimentally determined Voigt angle.

HL 13.9 Tue 11:45 BEY 118

Time-resolved photoluminescence on ZnO based quantum well structures — •Marko Stölzel, Alexander Müller, Jan Zippel, Gabriele Benndorf, Holger Hochmuth, Michael Lorenz, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig, Germany

We have investigated the optical properties of MgZnO/ZnO QW structures using time-resolved photoluminescence (TRPL) to understand recombination in these heterostructures. The layers have been grown with a ZnO buffer layer on a-plane sapphire substrate by pulsed laser deposition.

TRPL was excited by a frequency-doubled/tripled femtosecond Ti:Sa laser tuned to resonant and nonresonant excitation. For resonant excitation the QW behaves mono-exponential. When the barrier is excited, the QW decay is superposed by a slow non-exponential decay which matches the temporal behavior of the barrier luminescence. Temperature dependent measurements show a decrease of the exciton lifetime in the QW for increasing temperatures due to nonradiative recombination.

We compare this single QW with a set of symmetric double-QWs seperated by barriers of different thicknesses. For large barriers they behave like a single QW. In the case of small barriers (< 6nm) the peak of the QW luminescence shifts towards lower energies and a second non-exponential decay appears in addition to the mono-exponential decay of the QW. This is taken as an indication for the coupling.

HL 13.10 Tue 12:00 BEY 118

Optical Microtube Bottle Resonators — •Christian Strelow, Christoph M. Schultz, Hagen Rehberg, Christian Heyn, Detlef Heitmann, and Tobias Kipp — Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg

Using the self-rolling mechanism of strained InGaAs/GaAs bilayers freestanding microtube bridges can be fabricated acting as optical ring resonators [1]. Here, we report on the realization of novel microtube resonators with a bottlelike geometry [2]. Spatially and energetically resolved photoluminescence (PL) measurements show that the PL light of self-assembled InAs quantum dots embedded in the tube wall is confined similar to charged particles in a magnetic bottle. The measured eigenenergies and the measured axial field distributions resemble the eigenenergies and the probability densities of particles in a one dimensional potential. This can be described by a straight and intuitive model using an adiabatic separation of the circulating and the axial propagation. The dispersion of the axial mode energies follows a photonic quasi-Schrödinger equation including a quasipotential. We demonstrate that the quasipotential and, consequently, the dispersion of the axial modeenergies can be tailored precisely by simple adjustments of the microtube geometry. We acknowledge financial support by the Deutsche Forschungsgemeinschaft via SFB 508 "Quantum Materials"and GK 1286 "Functional Metal-Semiconductor Hybrid Systems".

[1] T. Kipp et al., Phys. Rev. Lett. **96**, 077403 (2006)
[2] Ch. Strelow et al., Phys. Rev. Lett. **101**, 127403 (2008)

HL 13.11 Tue 12:15 BEY 118

Cyclotron resonance of a massless quasi-particle in graphene — •Sergey A. Mikhailov — Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany

The classical motion of a massless graphene quasi-particle in a magnetic field and under a weak electromagnetic radiation with the frequency ω is considered. It is shown that, due to the non-parabolic, linear energy dispersion of the quasi-particle, it responds not only at the frequency ω but generates a broad frequency spectrum around it. The linewidth of the cyclotron resonance turns out to be very broad *even in a perfectly pure material* which allows one to explain recent experimental data [1,2]. It is concluded that the *linear response theory does not work in graphene* in finite magnetic fields and the electromagnetic response of graphene should be studied by the methods of non-linear dynamics and chaos.

[1] Z. Jiang et al, Phys. Rev. Lett. **98**, 197403 (2007)
[2] R. S. Deacon et al, Phys. Rev. B **76**, 081406 (2007).

HL 13.12 Tue 12:30 BEY 118

Determination of the stress evolution in strained semiconductor lamellae — •Matthias Grave, Sven Wildfang, Matthias Klingbeil, Andrea Stemmann, Christian Heyn, Wolfgang Hansen, Detlef Heitmann, and Stefan Mendach — Institut für Angewandte Physik, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg

We investigate the influence of a controlled deformation of thin lamellae containing a quantum well by means of micro-photoluminescence experiments. Our experimental setup allows a reversible in situ deformation. The induction of stress in a lamella leads to significant changes in the obtained emission spectra of the quantum well. The removal of stress leads to a return of the spectra to the initial state. We obtained spatial images of the strain distribution in the lamella by scanning the photoluminescence spot over the sample and monitoring the locally varying energetic position of the quantum well signal. We simulated the influence of external applied stress to a quantum well potential [1] via COMSOL Multiphysics. We compared the results to our experiment and found a good agreement.

We acknowledge financial support by the Deutsche Forschungsgemeinschaft via GrK 1286 and SFB 508.

[1] C. G. Van de Walle, Phys. Rev. B 39, 1871 (1989).

HL 13.13 Tue 12:45 BEY 118

Resonant bonding in crystalline phase-change materials — •Stephan Kremers[1], Kostiantyn Shportko[1], Michael Woda[1], Dominic Lencer[1], John Robertson[2], and Matthias Wuttig[1] — [1]I. Physikalisches Institut (IA), RWTH Aachen, Deutschland — [2]Engineering Department, Cambridge University, UK

Phase-change materials are of considerable scientific and technological interest. These materials are already employed for rewriteable optical data storage and are strong contenders to replace non-volatile flash memory. They are based on a unique class of materials, which feature a special property combination. The two phases, amorphous and crystalline, show a pronounced contrast of electrical and optical properties. They are stable on a long time scale and at the same time, they can be rapidly switched on a time scale of some ten nanoseconds when heated to appropriate elevated temperatures. To improve these materials for dedicated applications, an in-depth understanding of the relevant properties is crucial. Therefore we have employed optical spectroscopy in the energy range from 0.025 to 3 eV to probe the electronic states. The optical dielectric constant is 70-200% larger for the crystalline than the amorphous phases. This difference is attributed to a significant change in bonding between the two phases. The optical dielectric constant of the amorphous phases is that expected of a covalent semiconductor, whereas that of the crystalline phases is strongly enhanced by resonant bonding effects. This finding allows us to discuss the physical origin of the unique behavior of this class of materials.