HL 35: Poster I

Topics: Spintronics, Topological insulators, Group IV (other than C): Si/Ge/SiC, Nitrides: Preparation and Characterization, Nitrides: Devices, III-V semiconductors (other than nitrides))

Time: Tuesday 15:00–19:00 Location: Poster A

HL 35.1 Tue 15:00 Poster A

Properties and definitions of the spin current — •Thorsten Arnold[1], Vidar Gudmundsson[2], and Frank Ortmann[1] — [1]Institute for Materials Science and Dresden Center for Computational Materials Science, TU Dresden, Germany — [2]Science Institute, University of Iceland, Iceland

As opposed to the charge, the spin is not conserved in systems, where spin-orbit interaction or magnetic fields are present. As a consequence, the definition of the spin current is not unique and several suggestions for the definition of the spin current have been proposed [1-3]. The Rashba spin current [3] and the definition $\hat{\mathbf{j}}_\alpha = \frac{1}{2}\left[\hat{\sigma}_\alpha \hat{\mathbf{v}} + \hat{\mathbf{v}}\hat{\sigma}_\alpha\right]$ agree for many systems [4]. We use the latter definition to describe a spin current in a tight-binding model to calculate the spin conductivity. We show the spin current in an Aharonov-Casher ring as well as the energy and time resolved spin conductivity in graphene, which we compare to spin relaxation properties of graphene [5].

[1] J. Shi et al., Phys. Rev. Lett. **96**, 076604 (2006).
[2] N. Bray-Ali, and Z. Nussinov, Phys. Rev. B **80**, 012401 (2009).
[3] E.I. Rashba, Phys. Rev. B **68**, 241315 (2003).
[4] T. Arnold et al., Eur. Phys. J. B **87**, 113 (2014).
[5] D. V. Tuan et al., Nature Physics **10**, 857 (2014).

HL 35.2 Tue 15:00 Poster A

Spin Hall conductivity in topological insulators — •Francisco Mireles[1] and John Schliemann[2] — [1]Departamento de Física Teórica, Centro de Nanociencias y Nanotecnología, Universidad Nacional Autónoma de México, Ensenada, BC, 22800, México. — [2]Institut für Theoretische Physik, Universität Regensburg, D-93049 Regensburg, Germany.

Since the discovery of topological insulators in which topological states of matter are protected by time-reversal symmetry, there has been a great deal of interest in the physics of these materials. It is known that they can support helical two-dimensional states at its edges. An important feature is the hexagonal warping of the Hamiltonian of the charge carriers describing these systems. As a result, fundamentally different behavior is expected to appear in the spin and carrier transport in these systems. In particular, the physics of the spin transport and optical spin conductivities in topological insulators is still to be understood. In this work special attention is given to the study of spin-transport properties in such topological insulators. We study the Hall and optical Hall spin-conductivities within the Kubo formalism in linear response. We also present some useful analytical expressions describing the spin-currents in such topological massive Dirac Fermions systems.

* This work was supported by project 'Spin Phenomena in Reduced Dimensions' SFB 689, and DIONICOS project: 612707- FP7-PEOPLE-2013-IRSES.

HL 35.3 Tue 15:00 Poster A

Spin dynamics of Ce^{3+} ions in YAG crystals — •Felix Fobbe[1], Vasilii Belykh[1], Donghai Feng[1], Eiko Evers[1], Dmitry Yakovlev[1,2], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universitat Dortmund, D-44221 Dortmund, Germany — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

Spin dynamics of YAG crystals doped with Ce^{3+} ions were investigated by optical pump-probe Faraday rotation technique in a magnetic field. Resonant spin amplification (RSA) was measured by registering the amplitude of the Faraday rotation as a function of a magnetic field applied either in Voigt or Faraday geometry. Measurements were made at different temperatures and powers of the pump beam.

From the time resolved Faraday rotation it was shown that there are up to five electron spin precession frequencies that correspond to five g-factors ranging from 0.9 to 2.5 which show strong anisotropy. The spin ensemble dephasing time T_2^* is found to be in the range of 10 ns to 50 ns for the different frequencies. The RSA curve shows a strong peak around zero magnetic field in Voigt geometry and a strong dropdown in Faraday geometry. The amplitude of the peak and the dropdown decreases dramatically with increasing temperature. Their origin is presumably related to spin interaction.

HL 35.4 Tue 15:00 Poster A

Fine structure and coherent spin manipulation of the hidden transition of V_{Si} in 4H-SiC — •Matthias Niethammer[1], Sang-Yun Lee[1], Matthias Widmann[1], Ian Booker[2], Torsten Rendler[1], Takeshi Oshima[3], Nguyen Tien-Son[2], Erik Janzón[2], and Joerg Wrachtrup[1] — [1]3.Physikalisches Institut, Universitaet Stuttgart — [2]Department of Physics, Chemistry and Biology, Linkoeping University — [3]Japan Atomic Energy Agency, Takasaki

Silicon carbide has recently been recognized as a promising host material for mainstream room temperature quantum devices based on defects [1]. The silicon vacancy is a point defect with a spin $\frac{3}{2}$ ground state and a zero field splitting of 70MHz which allows for optical control and coherent manipulation even on the single spin level at room temperature [2]. As high impurity density is detrimental for defect based solid state quantum systems, wafer quality is a concern. Here we analyse various fine structures in optically detected spin signal at low magnetic field and present likely models related to wafer quality for their origin. When an axial magnetic field is applied, the spin Hamiltonian predicts three transitions, but usually only two are visible due to equal population. The third transition previously has been revealed by ENDOR measurements [3]. We demonstrate the hidden transition ($m_s = -\frac{1}{2} \leftrightarrow m_s = \frac{1}{2}$) also becomes optically observable by inducing population difference using ELDOR. Additionally we present the coherent manipulation of this hidden transition. 1. Weber et al, PNAS 2010 107 (19) 8513-8518 2. Widmann et al, Nat. Mater 14, 164-168 (2015) 3. Mizuochi et al, Phys. Rev. B 72, 235208 (2005)

HL 35.5 Tue 15:00 Poster A

All optical EPR in magnetically doped quantum structures — •Markus Kuhnert, Ilya Akimov, Dmitri Yakovlev, and Manfred Bayer — Experimentelle Physik 2, TU Dortmund

The field of spintronics, which in contrast to electronics, uses the spin instead of charge as information carrier, presents many interesting possibilities. For proper implementation of spintronic devices, research of adequate materials and methods is required. Here we present the results of our research into Manganese doped GaAs quantum wells, which might offer long lived spin coherence as well as spin manipulation mediated by the magnetic Manganese ions. Following initial studies of electron lifetime in Manganese-doped GaAs quantum wells via time resolved Kerr effect and time resolved Photoluminescence measurements, further investigation into such samples is done by Electron paramagnetic resonance measurements. In this case, a method of all optical Electron paramagnetic resonance was developed. This is achieved by intensity and polarization modulation of the incident laser beam by a frequency of about 9.2 GHz and applying varying external magnetic fields.

HL 35.6 Tue 15:00 Poster A

Spin-flip Raman scattering of the Mn^{2+} ions in (Zn,Mn)Se quantum wells — •Carolin Lüders[1], Henning Moldenhauer[1], Philipp Waldkirch[1], Dennis Kudlacik[1], Victor F. Sapega[1,2], Andreas Waag[3], Jörg Debus[1], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität, 44227 Dortmund, Germany — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [3]Institute of Semiconductor Technology, University of Braunschweig, 38106 Braunschweig, Germany

A comprehensive and unified picture of the Mn-ion interactions with carriers in diluted magnetic semiconductors is still missing up to now. Therefore, we have studied the resonant spin-flip Raman scattering (SFRS) of the Mn^{2+} ions in $Zn_{1-x}Mn_xSe$/(Zn,Be)Se quantum-well structures with low Mn concentrations ($x \leq 0.04$) and type-I band alignment. Previous studies focused on the multiple Mn^{2+} SFRS in tilted geometries, where the magnetic field direction embraced an angle with the quantum-well growth axis; while, for example, the explanation of the Faraday-geometry mechanism was not yet clarified. We propose a Mn^{2+} spin-flip mechanism for the Faraday geometry, and demonstrate the presence of anti-Stokes Mn^{2+} scattering signals, whose Ra-

man shifts are moreover considerably different to that of the Stokes lines. Additionally, the resonance profile shows that the spin-flips occur preferably under resonant excitation of the heavy-hole exciton.

HL 35.7 Tue 15:00 Poster A

Conductance Correction in semiconductor nanorods with Rashba and Dresselhaus Spin-Orbit Coupling — •Michael Kammermeier[1], Paul Wenk[1], John Schliemann[1], Sebastian Heedt[2], and Thomas Schäpers[2] — [1]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Peter Grünberg Institute and JARA-Fundamentals of Future Information Technology, Forschungszentrum Jülich, 52425 Jülich, Germany

We compute analytically the quantum correction to the Drude conductivity for electrons in zincblende type nanorods following former approaches [1,2]. In the systems of consideration a tubular quantum well is formed below the nanorods surface which can be a result of Fermi surface pinning [3] or band mismatch in core/shell nanowires [4]. The confinement gives rise to both Rashba and Dresselhaus spin-orbit coupling (SOC) which we comprise in our calculations and compare for wires of standard growth directions $\langle 111\rangle$, $\langle 001\rangle$ and $\langle 110\rangle$. The motion on the quasi two-dimensional surface is considered diffusive in both in-plane directions. By fitting the theory to experimental data we extract SOC strength as well as dephasing and relaxation rates.

* * *

[1] S. Kettemann, PRL **98** 176808 (2007)
[2] P. Wenk *et al.*, PRB **83** 115301 (2011)
[3] S. Heedt *et al.*, Nanoscale **7** 18188 (2015)
[4] A. Blömers *et al.*, Nanotechnology **24** 035203 (2013)

HL 35.8 Tue 15:00 Poster A

Identification and magneto-optical properties of the NV center in 4H-SiC — Hans Jürgen von Bardeleben[1], Jean-Louis Cantin[1], Soroush Abbasi-Zargaleh[2], Benoît Eblé[1], Sophie Hameau[1], Eva Rauls[3], and •Uwe Gerstmann[3] — [1]INSP, Université Pierre et Marie Curie, 75005 Paris — [2]Université Paris-Sud, 91405 Orsay — [3]Uni Paderborn, Warburger Strasse 100, 33098 Paderborn

Single spin carrying defects are key elements in quantum information and nanosensing technology with the nitrogen-vacancy (NV) center in diamond being the outstanding example [1], stimulating the search for similar defects in alternative materials with superior material properties. In a combined electron paramagnetic resonance and density functional theory (DFT) study we verify the existence of such NV centers in 4H-SiC in the form of silicon vacancy-nitrogen pairs ($V_{Si}N_C$) and explore their basic magneto-optical properties [2].

Optical polarization of the ground state is indeed very similar to that of the NV center in diamond, whereby in 4H-SiC: (i) the sensitivity with temperature is found to be two times larger, and (ii) the PL spectrum is shifted towards the near infrared. Given the high potential of 4H-SiC as concerns doping and nanostructuring, the NV center in 4H-SiC is expected to be suitable for multiple applications.

[1] M.W. Doherty, N.B. Manson, P. Delaney, F. Jelezko, J. Wrachtrup, and L.C.L. Hollenberg, Physics Reports **528**, 1, (2013).
[2] H.J. von Bardeleben, J.L. Cantin, E. Rauls, and U. Gerstmann, Phys. Rev. B **92**, 064104 (2015).

HL 35.9 Tue 15:00 Poster A

Time-resolved photoluminescence and spin dynamics of GaSe crystals — •Maike Halbhuber, Philipp Nagler, Christian Schüller, and Tobias Korn — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, 93040, Regensburg, Germany

Gallium Selenide (GaSe) is a layered semiconductor with a direct band gap of about 2.02 eV at room temperature at the Γ-point. Its peculiar band structure allows optical generation and detection of spin polarization. Here, we investigate the emission spectra of GaSe thin films by means of continuous-wave (cw) and time-resolved μ-photoluminescence (PL). Our samples are prepared by mechanical exfoliation from GaSe bulk. In temperature-dependent cw PL measurements we could extract a red-shift of the direct free-exciton recombination energy which can be well explained by a Varshni Fit. The degree of spin polarization showed a strong temperature dependence, resulting in a decrease of the time-averaged spin polarization with increasing temperature. Furthermore we studied the lifetime of the PL and the spin polarization by using a streak camera system. Thereby we see dependencies of the spin polarization on both temperature and excitation wavelength. By applying an in-plane magnetic field we observe precession of the spin polarization which enables the determination of the g-factor of GaSe.

HL 35.10 Tue 15:00 Poster A

Low magnetic field wavelength modulation absorption spectroscopy of donor bound excitons in ^{28}Si:P — •Michael Beck[1], Helge Riemann[2], Jens Hübner[1], and Michael Oestreich[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstrasse 2, D-30167 Hannover — [2]Leibniz Institut für Kristallzüchtung, Max-Born-Strasse 2, D-12489 Berlin

Donor atoms in a crystalline silicon host are promising candidates for the implementation of quantum information devices [1]. The decoupling of donor atoms from the nuclear spin bath of the host lattice by means of isotopical enrichment leads to very long coherence times of donor electron spins [2]. We will employ non-perturbative spin noise spectroscopy [3] to unveil the intrinsic spin dynamics of donor bound electrons in weakly doped ^{28}Si:P in the millikelvin temperature regime. As preparatory measurements, we investigate the electronic structure of the donor-bound exciton in a magnetic field by means of modulation absorption spectroscopy, which allows for a determination of the oscillator strength and fine structure. The ultra-narrow linewidth [4] of the bound exciton transition furthermore reveals the magnetic field dependence of the electron and hole Landé
g-factor at low magnetic fields.

[1] B.E. Kane, Nature **393**, 133 (1998).
[2] A.M. Tyryshkin *et al.*, Nature Matter. **11**, 143, (2012).
[3] J. Hübner *et al.*, Phys. Stat. Solidi (B) **251**, 1824 (2014).
[4] M. L. W. Thewalt *et al.*, J. Appl. Phys. **101**, 081724 (2007).

HL 35.11 Tue 15:00 Poster A

Spin Noise Spectroscopy on single InAs Quantum Dots — •Julia Wiegand[1], Ramin Dahbashi[1], Jens Hübner[1], Klaus Pierz[2], and Michael Oestreich[1] — [1]Leibniz Universität Hannover, Institut für Festkörperphysik, Abteilung Nanostrukturen, Appelstraße 2, D-30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

The spin dynamics of electrons and holes confined in InAs quantum dots (QDs) are of particular interest for future applications in solid state quantum information processing. We implement spin noise spectroscoscopy (SNS) to access the intrinsic spin dynamics of confined carriers in individual QDs [1]. Measurements on single heavy hole spins reveal a strong magnetic field dependence of the longitudinal spin relaxation time for low magnetic fields with relaxation times up to 180 μs [2]. The dependence of the relaxation times on the probe laser intensity suggests residual light absorption that shortens the measured times. Improvement of the SNS method for single QDs should be achieved for increased probe laser detunings, that avoid light absorption and allow for higher probe intensities to enhance the signal-to-noise ratio.

[1] J. Hübner, F. Berski, R. Dahbashi, and M. Oestreich, physica status solidi (b) **251**, 1824 (2014).
[2] R. Dahbashi, J.Hübner, F. Berski, K. Pierz, and M. Oestreich, Phys. Rev. Lett. **112**, 156601 (2014).

HL 35.12 Tue 15:00 Poster A

Stokes Polarimetry of Magnetic Linear Birefringence in Gallium Arsenide — •Pavel Sterin, Fabian Berski, Agnes Beichert, Jens Hübner, and Michael Oestreich — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany

Recently, an intriguing excitation mechanism of spin polarized carriers by linearly polarized light was observed in non-centrosymmetric InGaAs. Interestingly, the experimental signatures were interpreted as two dimensional control of the electron spin orientation. [1] However, for an in-depth understanding we employ a highly sensitive, self-built polarimeter and explore the interplay of oblique light propagation and linear birefringence caused by an applied magnetic field. A generalized Mueller-matrix approach allows us to recover unambiguously the complete polarization state of the transmitted laser light. Moreover, the ellipticity and orientation as function of angle of incidence and magnetic field strength are investigated using a 4×4-matrix formalism. [2] Finally, first measurements on well-known gallium arsenide prove the general suitability of our method.

[1] K. Schmalbuch, S. Göbbels, P. Schäfers, C. Rodenbücher, P. Schlammes, T. Schäpers, M. Lepsa, G. Güntherodt, B. Beschoten, Phys. Rev. Lett., **105**, 246603 (2010)
[2] D. W. Berreman, JOSA **62** 502-510 (1972)

HL 35.13 Tue 15:00 Poster A

Weak Anti-Localization and Bulk-Surface-Correspondence in

Topological Insulators — •Sebastian Hutsch and Frank Ortmann — Institute for Materials Science and Dresden Center for Computational Materials Science, TU Dresden, Germany

Topological Insulators have drawn considerable attention in solid state physics in recent years, also leading to investigations of their properties by the means of simulations. Effective models for isolated surface states of 3D TIs have been used to describe experimentally studied phenomena like Weak Anti-Localization of such states. Beyond that, an influence of the bulk states on transport properties as observed in experiment could not be modeled accurately because a full 3D model of the topological insulators (including both, bulk and surface) is needed for realistic simulations.

In this work, the Fu-Kane-Mele model, a 3D generalization of the Quantum-Spin-Hall system graphene, is used for the transport simulations in the Kubo framework, where we study localization behaviour for the strong topological phase and weak disorder.

HL 35.14 Tue 15:00 Poster A

Topological phases in interfacial phase-change materials — •Peter Schmitz[1,3], Wei Zhang[2], Yuriy Mokrousov[3], and Riccardo Mazzarello[1] — [1]Institute for Theoretical Solid State Physics, RWTH Aachen — [2]CAMP Nano, Xi'an Jiaotong university, China — [3]IAS-1 and JARA, Forschungszentrum Jülich

We investigate the topological, spectral and structural properties of $[Sb_2Te_3]_x[GeTe]_y$ compounds, some of which are interfacial phase-change materials (IPCMs), as a function of strain and stacking sequence using density functional theory.
Induced by electric fields and heat, IPCMs can perform fast reversible transitions between crystalline states of different stacking. Since they possess strong SOC and a TI+NI layering, they are a promising platform for nontrivial interface states and switching between topological phases. So far they were shown to exhibit TIs and unstable TI/NI transition points [1], yet no consistent classification exists.
We analyze if the novel **3D topological Dirac semimetal** (TDSM) phase [2] is relevant to these C_3 systems: Under parameter variation, 2 cones move through the bulk spectrum, gapped due to symmetry breaking potentials between the blocks which enables nonzero 3D Z_2 invariants. We show that corresponding states are localized at the interfaces of iPCMs and the effective topological phase is controlled by their van der Waals interaction.
[1] J. Tominaga et al, Adv. Mat. Inter. 1 (2014)
[2] B. Yang and N. Nagaosa, Nature Commun. 5, 4898 (2014)

HL 35.15 Tue 15:00 Poster A

Constructing spintronic devices from topological insulators via combination with ferromagnetic materials — •Matthias Götte, Tomi Paananen, Günther Reiss, Michael Joppe, and Thomas Dahm — Fakultät für Physik, Universität Bielefeld, Germany

Topological insulators with their spin-momentum coupled edge or surface states are promising candidates for future spintronic applications. Combining topological insulators with ferromagnetic materials opens possibilities to control current flow in these states, e.g. via quantum tunneling or proximity induced ferromagnetic exchange fields. Here, we construct tunneling magnetoresistance (TMR) devices from ferromagnet/isolator/topological insulator junctions and calculate their potential TMR ratios using realistic tight-binding models. The theoretical values are of the same order of magnitude as in state of the art TMR devices based on conventional ferromagnets.

By performing numerical transport calculations, we investigate the influence of local ferromagnetic exchange fields on charge transport in edge states of two-dimensional topological insulators. Based thereupon we propose a device that creates pure spin currents along the edge of the topological insulators. All calculations are based on a tight-binding model suitable for the Bi_2Se_3 class of materials.

HL 35.16 Tue 15:00 Poster A

Superconductor-topological insulator junctions based on an Sb_2Te_3/Bi_2Te_3 p-n heterostructure — •Daniel Rosenbach[1], Peter Schüffelgen[1], Martin Lanius[1], Jörn Kampmeier[1], Gregor Mussler[1], Markus Eschbach[1], Ewa Mlynczak[1], Lukasz Plucinski[1], Martina Luysberg[1], Stefan Trellenkamp[1], Martin Stehno[2], Prosper Ngabonziza[2], Alexander Brinkman[2], Detlev Grützmacher[1], and Thomas Schäpers[1] — [1]Peter Grünberg Institut and Jülich Aachen Research Alliance (JARA-FIT), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Faculty of Science and Technology and MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands

Topological insulators combined with superconducting electrodes are very promising systems for realizing Majorana bound states. However, realizing functional structures including 3D topological insulator (TI) materials suffer from a high unintentional background doping as well as surface state degradation due to oxygen inclusion as soon as the sample is exposed to air. Here, we present the successful integration of niobium superconducting contacts on top of a 3D TI layer system. The TI layers were grown by means of molecular beam epitaxy on Si (111) substrates and are capped *in-situ* by a few nm of aluminumoxide to protect the Dirac-like surface states. Utilizing a layer stack of p-type doped Sb_2Te_3 on top of n-type doped Bi_2Te_3, defining a p-n heterostructure, pushes the Fermilevel at the upper surface to the Dirac-point.

HL 35.17 Tue 15:00 Poster A

Combined structural, electronic and transport investigations on metallic and semiconducting micro flakes from a topological insulator Bi_2Se_3 single crystal — •Dominic Lawrenz[1], Olivio Chiatti[1], Christian Riha[1], Marco Busch[1], Franz Herling[1], Srujana Dusari[1], Jaime Sanchez-Barriga[2], Anna Mogilatenko[3], Lada V. Yashina[4], Sergio Valencia[2], Ahmet A. Ünal[2], Oliver Rader[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Institut für Physik, Humboldt Universität zu Berlin, D-12489 Berlin — [2]Helmholtz-Zentrum-Berlin für Materialien und Energie, D-12489 Berlin — [3]Ferdinand-Braun-Institut, D-12489 Berlin — [4]Department of Chemistry, Moscow State University, 119992 Moscow, Russia

High-quality Bi_2Se_3 bulk and exfoliated micro flakes are investigated via temperature dependent magneto-transport measurements. To achieve a comprehensive picture, these results are combined with high resolution transmission electron microscopy, energy dispersive x-ray spectroscopy and photoemission electron microscopy to confirm the structure and stoichometry of bulk and flakes. A well-defined bulk band-gap and the presence of a single Dirac cone are proven by angle-resolved photoemission spectroscopy. We investigate Bi_2Se_3 in the regime of high electron density ($> 10^{19}$ cm^{-3}) and find two-dimensional (2D) layered metallic transport in the Shubnikov-de Haas oscillations and quantized Hall resistance. In exfoliated micro flakes the low-field magneto-conductivity shows weak antilocalization that is analyzed in the Hikami-Larkin-Nagaoka (HLN) model for 2D systems.

HL 35.18 Tue 15:00 Poster A

Terahertz radiation induced photocurrents in $(Bi_{1-x}Sb_x)_2Te_3$ based topological insulators — •Helene Plank[1], Leonid E. Golub[2], Stefan Bauer[1], Vasily V. Bel'kov[2], Markus Eschbach[3], Lukasz Plucinski[3], Gregor Mussler[3], Detlev Grützmacher[3], and Sergey. D. Ganichev[1] — [1]Terahertz Center, University of Regensburg, Regensburg, Germany — [2]Ioffe Physical-Technical Institute, St. Petersburg, Russia — [3]Jülich Aachen Research Alliance (JARA-FIT), Jülich, Germany

Here we report on the observation of terahertz (THz) laser radiation induced photocurrents in epitaxially grown $(Bi_{1-x}Sb_x)_2Te_3$ three dimensional topological insulators with antimony concentrations x varying from 0 (n-type) to 1 (p-type conductivity). At normal incidence the photocurrent is dominated by the photogalvanic effect (PGE). It is allowed in the surface states only due to a "symmetry filtration" [1]. However, at oblique incidence the PGE diminishes and a photon drag effect, arising in the trigonal symmetry of the samples due to an in-plane component of the photon momentum, is dominating the photocurrent formation at certain frequencies. We show that this trigonal PDE results in a photocurrent even in the angle of incidence θ and that it is caused by the in-plane gradient of the radiation electric field accompanied by asymmetric elastic scattering. [1] P. Olbrich *et al.*, Phys. Rev. Lett. **113**, 096601(2014)

HL 35.19 Tue 15:00 Poster A

Optical properties of compensated topological insulators — •Alessandro Revelli[1], Nick Borgwardt[1], Jonathan Lux[2], Zhiwei Wang[1,3], Ignacio Vergara[1], Malte Langenbach[1], Achim Rosch[2], Yoichi Ando[1,3], Paul van Loosdrecht[1], and Markus Grüninger[1] — [1]II. Physikalisches Institut, Universität zu Köln — [2]Institut für theoretische Physik, Universität zu Köln — [3]Institute of Scientific and Industrial Research, Osaka University, Japan

We report on the optical properties of bulk-insulting $BiSbTeSe_2$ for frequencies from 6 meV to 5.5 eV. Combining transmittance data for

different sample thicknesses with normal incidence reflectivity data as well as ellipsometric results, we obtain a detailed view on the optical conductivity of the bulk, ranging from $\sigma_1(\omega) = 0.3\,(\Omega\text{cm})^{-1}$ below the gap to $10^4\,(\Omega\text{cm})^{-1}$ at 2eV. At 50 K, we find a nearly fully compensated semiconductor with a carrier density $N \approx 4{\cdot}10^{16}\,\text{cm}^{-3}$. The intrinsic band gap Δ shows a strong temperature dependence, it shifts from 0.26 eV at 5 K to 0.18 eV at 300 K. Below the gap, the optical conductivity $\sigma_1(\omega)$ reaches values lower than $0.3\,(\Omega\text{cm})^{-1}$ at 50 K. These are the lowest values of $\sigma_1(\omega)$ reported thus far for the entire tetradymite family. Above 50 K, we observe activated behavior of free carriers with an activation energy $E_A \approx 26$ meV, in agreement with transport data. Upon cooling below 50 K, $\sigma_1(\omega)$ rises again due to the formation of puddles of localized carriers which arise from the random potential fluctuations caused by charged defects in a fully compensated semiconductor. Monte Carlo simulations show a screening effect arising from thermally activated carriers, explaining the experimental observations.

HL 35.20 Tue 15:00 Poster A

The structure and electrical properties of Se hyperdoped Si by ion implantation followed by short-time annealing — •Fang Liu[1,2], Slawomir Prucnal[1], Ye Yuan[1,2], Kun Gao[1,2], Yonder Berencén[1], Lars Rebohle[1], Wolfgang Skorupa[1], Manfred Helm[1,2], and Shengqiang Zhou[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden, Germany — [2]Technische Universität Dresden, Dresden, Germany

Si hyperdoped with Se layers was obtained by ion implantation of 60 keV Se at fluence of 5*1E15 cm-2 followed by both pulsed laser annealing (PLA) and flash lamp annealing (FLA). We show that the degree of crystalline lattice recovery of the implanted layers and the Se substitutional fraction depend on the pulse duration and energy density of FLA and PLA. While the annealing at low energy densities leads to an incomplete recrystallization, annealing at higher energy densities results in more defects. The impurities have more chance of redistribution if the sample is maintained at higher temperature for longer time. The electrical properties of the implanted layers can be well correlated to the structural properties resulted from different annealing processing.

HL 35.21 Tue 15:00 Poster A

In situ TEM investigations of the back surface field of aluminum in multi-crystalline silicon — •Hendrik Spende, Patrick Peretzki, and Michael Seibt — IV. Physikalisches Institut der Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen

The rear contact of a solar cell requires a uniform low-resistance ohmic contact, minority-carrier reflection, photon reflection and effective gettering of impurities while processing. Standard solar cells use alloyed backside contacts because of their positive effect on the cell efficiency. Screen printing or evaporating Al on the silicon wafer and thermal annealing lead to the formation of an aluminum alloyed back surface field (Al-BSF) at the Al-Si interface. This creates a heavily Al doped p+-region, which forms a pn-junction with the n-type Si, or a p+/p-junction reducing backside recombination.

The formation of the Al-BSF and the effect of grain boundaries in n-type multicrystalline silicon (mc-Si) - used here for preparation issues - were studied by in situ transmission electron microscopy. The grain boundaries were made visible by etching with HNO_3 and HF, then Al was evaporated onto the surface and lamellas were prepared by FIB. During heating the temperature was increased above the eutectic point of Al and Si. The Si dissolved into the Al and then the Al penetrated the Si wafer. During cooling Si doped with Al recrystallized and left a doped BSF region.

HL 35.22 Tue 15:00 Poster A

Si Nanowires Prepared by Glancing Angle Deposition Technique — •Andrii Kulyk[1], Christoph Grüner[1], Andriy Lotnyk[1], Dietmar Hirsch[1], Gal Schkolnik[2], Isom Hilmi[1], and Bernd Rauschenbach[1] — [1]Leibniz Institute of Surface Modification, Permoserstr. 15, D-04318, Leipzig, Germany — [2]Helmholtz Centre for Environmental Research, Permoserstr. 15, D-04318, Leipzig, Germany

Si nanostructures can be engineered to form a variety of useful shapes by glancing angle deposition there has been recent interest in this new materials class. For example, they can be used as optical sensor, porous electroluminescent material or solar absorber. In this work Si nanostructures are obtained by glancing angle deposition and studied by TEM, XRD, SEM and confocal Raman spectroscopy at various parameters. The nanosphere lithography is used to realize ordered Si nanostructure pattern. Epitaxial and crystalline structures of SiNWs were achieved. Raman spectra have shown high intensity peaks from Si nanostructures in a region from 517 cm-1 to 523 cm-1, which is well agreed with literatures data. XRD investigations identified Si peaks orientated to (111) and (220). The growth of crystalline structure is possible in temperature region 400 - 680 °C.

HL 35.23 Tue 15:00 Poster A

Deep electronic levels in crystalline silicon after irradiation with femtosecond laser pulses in SF_6-atmosphere — •Arne Ahrens[1], Philipp Saring[1], Anna Lena Baumann[2], Stefan Kontermann[2,3], and Michael Seibt[1] — [1]IV. Physikalisches Institut, Georg-August Universität Göttingen, Germany — [2]Fraunhofer Heinrich Hertz Institut, Goslar, Germany — [3]present address: Hochschule RheinMain, Rüsselsheim, Germany

Femtosecond laser pulse irradiation in sulfur hexafluoride (SF_6) atmosphere leads to sulfur incorporation into the silicon beyond the solubility limit (hyperdoping) and structuring of the surface. Enhanced optical absorption in the sub-bandgap range due to introduced deep defect levels is known for such materials. This makes such a material a promising candidate for intermediate band solar cell applications, especially if impurity bands form due to a Mott transition. Considering a p-type silicon substrate, sulfur hyperdoping leads to the formation of a buried pn-junction which has been studied in detail by means of cross-section transmission electron microscopy (TEM) and electron-beam induced current (EBIC) [1] as well as capacitance-voltage (CV) and SIMS measurements [2]. This work presents results of additional cross sectional EBIC and TEM experiments. Furthermore, this work presents the results of an extensive deep-level transient spectroscopy (DLTS) study of deep levels in the vicinity of the buried pn-junction, which points out the existence of two dominant deep levels. [1] P. Saring et al., Appl. Phys. Lett. 103, 061904 (2013). [2] K.-M. Guenther et al., Appl. Phys. Lett. 102, 202104 (2013).

HL 35.24 Tue 15:00 Poster A

Structure and chemistry of crystalline silicon-aluminum oxide interfaces — •Arne Ahrens, Patrick Peretzki, and Michael Seibt — IV. Physikalisches Institut, Georg-August Universität Göttingen, Germany

Aluminum oxide deposited on crystalline silicon by atomic layer deposition (ALD) is known for its high surface passivation capabilities. This surface passivation is attributed to a high negative fixed charge density of about $-4{\times}10^{12}\text{cm}^{-2}$[1] in the aluminum oxide layer close to the silicon-aluminum oxide interface [2]. This makes aluminum oxide an interesting material to increase the efficiency of solar cells by passivation of surface states. Examples of use are passivated emitter and rear cells (PERC) [3] and rear-emitter inversion layer solar cell [4], for which efficiencies of 20% [3] and 18,1% [4] have been reported, respectively.

In this work, we apply transmission electron microscopy (TEM), electron energy loss spectroscopy (EELS) and energy dispersive x-ray spectroscopy (EDX) to study the structure and chemistry of the interface of crystalline silicon and aluminum oxide deposited by ALD for different production parameters, as e.g. post-deposition heat treatments or layer thickness. In addition, we investigate the influence of UV irradiation on the structure and chemistry of the silicon-aluminum oxide interface. [1] F. Werner and J. Schmidt Appl. Phys. Lett. Vol.104, 091604 (2014). [2] B. Hoex et al., J. Appl. Phy. Vol.104, 113703 (2008). [3] J. Schmidt et al., Prog. Photovol: Res. Appl. Vol. 16 461-466 (2008). [4] F. Werner et al., J. Appl. Phy. Vol. 115, 073702 (2014).

HL 35.25 Tue 15:00 Poster A

On deep level transient spectroscopy of extended defects in n-type 4H-SiC — •Jonas Weber, Heiko Weber, and Michael Krieger — Department of Physics, Applied Physics, FAU Erlangen-Nuremberg, Germany

Deep level transient spectroscopy (DLTS) is an electrical measurement technique used for the investigation of point defects having deep levels in the bandgap of semiconductors. In defective materials, negative DLTS signals are frequently observed and ascribed to extended defects, although the origin is not yet understood. We have investigated triangular shaped extended defects in lightly nitrogen doped n-type 4H-SiC epitaxial layers by means of DLTS. For this purpose, triangular defects have been located by photoluminescence mapping and scanning electron microscopy. Schottky contacts for DLTS investigations have been prepared on top of those defects. DLTS measurement parameters, i.

e. reverse bias, pulse bias and pulse length have been varied to gain insight into the electrical behavior of the system. It has been found that the appearance of negative DLTS signals depends on the choice of measurement parameters. A model is developed that qualitatively explains the DLTS spectra observed.

HL 35.26 Tue 15:00 Poster A

ion implantation induced damage in nonpolar a-plane GaN films — •Fengfeng Cheng[1,2], Lin Li[2], Slawomir Prucnal[2], M. X. Feng[3], Qian Sun[3], J. Grenzer[2], M. Helm[2], and Shengqiang Zhou[2] — [1]key Lab of Beam Technology and Material Modification of Ministry of Education, College of Nuclear Science and Technology, Beijing Normal University, Beijing Radiation Center, Beijing 100875, China — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, P. O. Box 510119, Dresden 01314, Germany — [3]key Laboratory of Nanodevices and Applications, Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO), Chinese Academy of Sciences (CAS), Suzhou 215123, China

In this study, we investigated ion implantation induced damages in nonpolar alpha-plane GaN films. X-ray diffraction (XRD), Raman scattering, Rutherford backscattering/channeling (RBS/C), are employed to study samples with different implantation fluences. For Si implanted samples, with increasing the implanted fluences, besides the main (102) peak from the XRD $2\theta/\theta$ scan, a bump peak is observed and shifts to a lower angle, which indicates the lattice expansion. It is consistent with newly arising peaks in the Raman spectra, which may associate with the lattice disorder and distortion caused by radiation damage. RBS/C results are also provided as complement to evidence the preview conclusion.

HL 35.27 Tue 15:00 Poster A

Annealing behavior of Er implanted GaN — •Fengfeng Cheng[1,2], Linxiang Chi[2], Ding Li[3], Slawomir Prucnal[2], Fang Liu[2], René Heller[2], M. Helm[2], Xiaodong Hu[3], Guoyi Zhang[3], and Shengqiang Zhou[2] — [1]Key Lab of Beam Technology and Material Modification of Ministry of Education, College of Nuclear Science and Technology, Beijing Normal University, Beijing Radiation Center, Beijing 100875, China — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, P. O. Box 510119, Dresden 01314, Germany — [3]Research Centre for Wide-gap Semiconductor, State Key Laboratory of Artificial Microstructure and Mesosciopic Physics, School of Physics, Peking University, Beijing 100871, China

In this study, we report the annealing behavior of 100 keV Er-implanted GaN with fluence of 1E15/cm2. The microstructural and optical property evolution of samples with different thermal treatment is studied by room temperature photoluminescence (PL), Raman spectra, and Rutherford backscattering. From the results, we try to establish a correlations between microstructural and optical properties. The PL peak around ~1540 nm is clearly observed for all as-implanted and post-annealed samples, with increasing annealing temperature, the PL peak intensity reaches to maximum at annealing temperature of 900 , while the PL intensity reduction with further higher temperature annealing (namely 1050) could be attributed to reduction of optically active Er sites , while RBS/C results shows the out diffusion of Er with increasing annealing temperature.

HL 35.28 Tue 15:00 Poster A

Nanoimprint lithography for selective area growth of GaN-based nanocolumns — •Stefan Behrenz and Philipp Henning — IV. Physikalisches Institut, Georg-August-Universität Göttingen

Ordered arrays of GaN-based nanocolumns provide a promising material basis for novel device applications. Selective area growth by means of a patterned metal mask is a suitable method for the growth of such structures. For the mask preparation a variety of lithography methods is used, most of which are time consuming if applied for a large number of substrates and on large scales. For this scope, nanoimprint lithography (NIL) has been proven to be an efficient method. Due to the fact that the structure size does not affect the processing time high throughput can be achieved. In this work, we show how NIL can be successfully applied for molecular beam epitaxy of GaN nanostructures. By means of soft imprinting homogeneously patterned arrays of sizes up to (400x400) μm^2 and column diameters ranging from 1200 nm down to 350 nm could be produced. The entire process has been optimized for the selective area growth of GaN. Compared to the growth on masks patterned by electron beam lithography an equally good quality is achieved.

HL 35.29 Tue 15:00 Poster A

Structural and optical properties of a GaN/AlN quantum heterostructure — •Alexander Reuper[1], Gordon Schmidt[1], Silke Petzold[1], Peter Veit[1], Konrad Bellmann[2], Tim Wernicke[2], Frank Bertram[1], Michael Kneissl[2], and Jürgen Christen[1] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute of Solid State Physics, Technical University Berlin, Germany

III-nitride based quantum dots (QD) are promising candidates for room-temperature quantum emitters due to the large exciton binding energies and strong confinement of this material system. Using transmission electron microscopy combined with cathodoluminescence spectroscopy (STEM-CL) we report on structural and spatially resolved optical properties of a GaN/AlN heterostructure with GaN grown under low V/III ratio to promote QD formation.

The GaN layer has been grown by metal-organic vapor phase epitaxy on a c-plane AlN/sapphire template at 1050°C and immediately capped by AlN.

Structural investigations showed a continuously formed GaN layer with local thickness fluctuations. Nanoscale cathodoluminescence measurements at room temperature as well as 16 K revealed spots of high intensity within GaN-layer. Highly spatially resolved CL investigations show various sharp emission peaks around 300 nm from these spots.

HL 35.30 Tue 15:00 Poster A

Time-resolved photoluminescence spectroscopy of InGaN nanowires — •Vanessa Dahmen[1], Nils W. Rosemann[1], Pascal Hille[2], Jörg Schörmann[2], Felix Walther[2], Martin Eickhoff[2], and Sangam Chatterjee[1] — [1]Faculty of Physics and Materials Science Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany — [2]I. Physical Institute, Justus-Liebig-Universität Gießen, Gießen, Germany

The incorporation of Indium into GaN drastically reduced the band gap of the alloy material. This shift towards the visible regime is exploited in the active material of commercially available blue and green laser diodes. Nanowires (NW) provide a good model system to investigate the intrinsic effects of alloying as they are virtually free of defects due to their self-assembled growth. Here, we study two series of (Ga,In)N NWs by time-resolved photoluminescence. The samples were grown by plasma-enhanced molecular beam epitaxy under different growth conditions. In particular, effects of the plasma power or the nitrogen flux are studied by systematic variations during growth. The time-resolved photoluminescence spectroscopy reveals ensembles of 3 states with similar decay dynamics are found for both series while the spectral position of the peak emissions are shift towards lower energies with increasing nitrogen flux.

HL 35.31 Tue 15:00 Poster A

Time-resolved luminescence studies of rare earth doped high pressure high temperature aluminium nitride — Tristan Koppe, Oliver Beck, Hans Hofsäss, and •Ulrich Vetter — II. Physikalisches Institut der Georg-August-Universität Göttingen, Deutschland

We report on studies of time-resolved defect luminescence processes in undoped and rare earth doped AlN. The material was synthesised by the temperature gradient method in a belt-type HP-HT apparatus. As solvent Li_3AlN_2 is used which was, in the case of doped samples, previously mixed with e. g. EuF_3 to achieve rare earth doped AlN.

The measurements were realised with a tunable femtosecond laser system, which contributes excitation energies from deep UV up to the near infrared region. In combination with a Streak Camera time-resolved spectra with time windows between 1 ns and several hundred milliseconds from 200 - 800 nm with temporal resolutions down to 20 ps are achievable.

To overcome the limitation of the Streak Camera system to measure lifetimes in the millisecond range or above, for e. g. to investigate longer living rare earth decays as well as some types of long living defect related luminescences in AlN, the connected trigger system was extended by an additional trigger unit.

HL 35.32 Tue 15:00 Poster A

Optical Characterization of GaN:Fe — •Sebastian Bauer[1], Matthias Hocker[1], Benjamin Neuschl[1], Maria L. Gödecke[1], Martin Klein[2], Frank Lipski[2], Eberhard Richter[3], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter, Semiconductor Physics Group, University Ulm — [2]Institute of Optoelectronics, University Ulm — [3]Ferdinand-Braun Institute, Berlin

Nominally undoped GaN is typically n-type in the range of some $[n] = 10^{16}$-10^{19} cm^{-3} carriers introduced by uncontrolled silicon and oxygen impurities. To remove this background conductivity, incorporation of iron on Ga sites acting as deep acceptors is a viable way to create so-called semi-insulating material, similar to semi-insulating GaAs:Fe. The electrical Fe^{2+}/Fe^{3+} level associated with Fe in GaN is located some 0.6 eV below the conduction band.

In the present study we present electrical and mainly optical data of thick GaN:Fe layers grown by hydride vapour phase epitaxy, using a ferrocen source for Fe. The samples show different concentrations of iron and background donors incorporated, and thus different degrees of compensation. In optical absorption measurements, we established – based on secondary ion mass spectrometry and electrical data – a correlation between the absorption signal and the actually present compensation status of iron.

HL 35.33 Tue 15:00 Poster A

Self-catalyzed and Si-induced growth of vertically aligned InN nanorods by MOVPE — •C. Tessarek[1,2,3], S. Fladischer[4], C. Dieker[4], G. Sarau[1,2], B. Hoffmann[2], M. Bashouti[2], M. Heilmann[2], S. Figge[5], A. Gust[5], E. Spiecker[4], and S. Christiansen[1,2,6] — [1]Institut für Nanoarchitekturen für die Energieumwandlung, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin — [2]Max Planck Institute for the Science of Light, Erlangen — [3]Institute of Optics, Information and Photonics, Friedrich-Alexander-University Erlangen-Nürnberg — [4]Institut für Mikro- und Nanostrukturforschung & Center for Nanoanalysis and Electron Microscopy (CENEM), Friedrich-Alexander-University Erlangen-Nürnberg — [5]Institute of Solid State Physics, University of Bremen — [6]Physics Department, Freie Universität Berlin

InN with its small photonic and large phononic band gap has the potential to be used for hot carrier solar cells. However, InN layers suffer from high defect densities due to the lack of native substrates. A self-catalyzed nanorod approach carried out in metal-organic vapor phase epitaxy is used to reduce the defect density leaving the upper part of the nanorods nearly free of defects. A detailed study of growth parameters influencing the formation and morphology of InN nanorods is carried out. The structural properties are analyzed using transmission electron microscopy, energy dispersive X-ray spectroscopy, X-ray diffraction and Raman spectroscopy. The optical properties are investigated using cathodoluminescence. Finally, the similarities between InN and GaN nanorod growth will be discussed.

HL 35.34 Tue 15:00 Poster A

Carrier-induced refractive index change observed by a whispering gallery mode shift in GaN microrods — •Christian Tessarek[1,2,3], Rüdiger Goldhahn[4], George Sarau[1,2], Martin Heilmann[2], and Silke Christiansen[1,2,5] — [1]Institut für Nanoarchitekturen für die Energieumwandlung, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin — [2]Max Planck Institute for the Science of Light, Erlangen — [3]Institute of Optics, Information and Photonics, Friedrich-Alexander-University Erlangen-Nürnberg — [4]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg — [5]Physics Department, Freie Universität Berlin

The influence of the carrier concentration on the refractive index of GaN is investigated. Vertical oriented GaN microrods were grown by metal-organic vapor phase epitaxy. During growth the silane flux was modified to obtain four sections with different n-type carrier concentrations above 10^{19} cm^{-3} along the *c*-axis. Whispering gallery modes can be observed in this type of microrods due to the regular hexagonal shape, the smooth sidewall facets and the sharp edges [1]. The presence of an energy dependent mode shift with respect to the four microrod sections with different doping concentrations is attributed to a carrier-induced refractive index change. The observed mode shift can be calculated by a proper adjustment of the band gap parameter in the analytical expression of the refractive index [2].

[1] C. Tessarek et al., ACS Photonics **1**, 990 (2014).
[2] C. Tessarek et al., New J. Phys. **17**, 083047 (2015).

HL 35.35 Tue 15:00 Poster A

Excitation spectroscopy of higher quantized states in GaInN quantum wells — •Tim Käseberg, Fedor Alexej Ketzer, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

In order to gain better knowledge about their structure and composition, we examine thin GaInN single and multiple quantum well structures with the help of their higher quantized states. Thus we set up a photoluminescence excitation spectroscopy (PLE) experiment. We excite the samples using a 150 W xenon arc lamp in the region of 360 to 520 nm, dispersed by a double-prism monochromator. The photoluminescence is then detected by a second monochromator and a silicon photodiode using a lock-in amplifier. Similar samples with different growth parameters were examined at various excitation wavelengths at room temperature. The composition of the samples influence the overlap of the wave functions and therefore their efficiency. Higher quantized states help to investigate the inner structure of these samples. Since the inhomogeneous broadening is relatively high, higher quantized states are hard to determine. Therefore we computed the absorption spectra of the samples by simulation of the quantum well and compared them to the observed PLE spectra. Similar characteristics are observed.

HL 35.36 Tue 15:00 Poster A

Ohmic Ti/Al/TiN Contacts to n-GaN Fabricated by Sputter Deposition — •Valentin Garbe[1], Juliane Walter[1], Wolfram Münchgesang[1], Alexander Schmid[2], Ronald Otto[2], Thomas Behm[1], Barbara Abendroth[1], and Dirk C. Meyer[1] — [1]Institute of Experimental Physics, TU Bergakademie Freiberg, Leipziger Str. 23, 09599 Freiberg, Germany — [2]Institute of Applied Physics, TU Bergakademie Freiberg, Leipziger Str. 23, 09599 Freiberg, Germany

The annealed Ti/Al/metal/Au contact metallization has emerged as the most used Ohmic contact to *n*-GaN. While the Ti/Al bilayer is crucial for contact formation, the metal/Au capping layer prevents oxidation and Ga and Al diffusion. However, Au degrades the contact resistance, as itself diffuses to the GaN interface. Here, we present the fabrication and characterization of an Au-free Ti/Al/TiN contact stack to *n*-GaN with TiN serving as the diffusion barrier. Sputter deposition and lift-off in combination with post deposition annealing at 850 °C for 300 s are used for contact formation. After annealing, contacts show Ohmic behavior to *n*-GaN and a resistivity of 1.60×10^{-3} Ω cm^2. To understand the contact formation on the microscopic scale, the contacts were characterized by current–voltage measurements, linear transmission line method, X-ray reflectivity, X-ray diffraction, and X-ray photoelectron spectroscopy. Results show diffusion of Ti, Al, N and Ga during annealing, formation of TiN at the GaN/Ti interface, as well as formation of cubic and hexagonal AlN. However, the TiN layer was stable during annealing and proved to be an effective diffusion barrier and prevented oxidation successfully.

HL 35.37 Tue 15:00 Poster A

Influence of the p-AlGaN superlattice on the performance characteristics of deep UV laser diode heterostructures — •E. Ziffer[1], M. Martens[1], C. Kuhn[1], T. Simoneit[1], J. Rass[1], T. Wernicke[1], A. Knauer[2], V. Kueller[2], M. Weyers[2], S. Einfeldt[2], and M. Kneissl[1,2] — [1]Technische Universität Berlin, Institut für Festköperphysik, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

AlGaN-based deep UV laser diodes (LD) require p-AlGaN cladding layers (CL) with high Al mole fractions. However, with increasing Al content the ionization energy of Mg dopants in AlGaN layers also increases, leading to high series resistance. We have investigated the influence of the p-side CL on AlGaN-based LD structures. The heterostructures consist of AlGaN multiple quantum well (MQW) active regions emitting near 270 nm, embedded in $Al_{0.70}Ga_{0.30}N$ waveguide layers, an $Al_{0.80}Ga_{0.20}N$:Si n-CL and different AlGaN:Mg p-CLs, including a 200 nm thick AlGaN layer, 150 - 200 nm superlattices (SL) with different Al contents and a p-GaN contact layer. The structures were analyzed by transfer length method, I-V characterization and electroluminescence spectroscopy. All diodes exhibit dominant QW emission with peak wavelengths between 258 nm and 276 nm. By increasing the average Al content of the p-SL from 37% to 81%, the diodes' turn-on voltage increases from 17 V to 26 V, whereas the series resistance stays constant on average (60 Ω for a contact size of 100x100 μm^2). This is an improvement in series resistance by one order of magnitude compared to LDs with a bulk $Al_{0.81}Ga_{0.19}N$ p-CL.

HL 35.38 Tue 15:00 Poster A

Influence of acceptor concentration on burn-in effects in AlGaN-based deep UV LEDs — •Jakob Jordan[1], Martin Guttmann[1], Frank Mehnke[1], Johannes Enslin[1], Simon Kapanke[1], Tim Wernicke[1], Mickael Lapeyrade[2], Markus Weyers[2], Sven Einfeldt[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztech-

nik, Berlin, Germany

Light in the deep ultraviolet (UVC) spectral range is used in diverse areas such as sewage water treatment and gas sensing. The toxicity and relative bulkiness of conventional UV mercury lamps necessitates development of light emitting diodes (LEDs) operating in this wavelength region. In this contribution, the optical and electronic properties of AlGaN-based LEDs emitting near 233 nm are analyzed with regards to a variation of the magnesium doping concentration in the electron blocking heterostructure and p-side superlattice. Electroluminescence (EL) measurements are used to determine changes in emission spectrum, light output power, device yield, and temperature response. During measurements, burn-in effects were discovered for LEDs with low Mg-doping. These burn-in effects produce a significant increase in output power that persists after cool down. Annealing in a high temperature environment does not lead to an increase in power, implying that the injected charge carriers are aiding in the activation process. The influence of time, temperature, and current on the observed burn-in effects will be presented and possible explanations will be discussed.

HL 35.39 Tue 15:00 Poster A

Deep UV light emitting diodes with transparent conductive electrodes of multi-layer graphene — •Luca Sulmoni[1], Marc Gluba[2], Norbert Nickel[2], Mickael Lapeyrade[3], Sven Einfeldt[3], Veit Hoffmann[3], Johannes Enslin[1], Christian Kuhn[1], Frank Mehnke[1], Tim Wernicke[1], and Michael Kneissl[1,3] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Berlin, Germany — [2]Institut für Silizium Photovoltaik, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Light extraction from bottom-emitting ultraviolet (UV) LEDs is challenging, since all metals typically used as p-contacts strongly absorb the light emitted from the active region. In addition, metal contacts directly on p-AlGaN suffer from high p-contact resistances and Schottky type behavior resulting in large operating voltages. This contribution investigates the current injection in AlGaN-based multi-quantum-well UVC LEDs exploiting UV-transparent multi-layer (ML) graphene-based p-electrodes. The p-(Al)GaN/graphene bi-layer exhibit a sheet resistance of 1200, 700 and 400 Ω/square for 1, 2 and 3 ML, respectively. For deep UV LEDs emitting near 265 nm, the excellent lateral current-spreading of the graphene layers and the vertical current injection into the p-n junction are demonstrated with an output power of 1 mW at 70 mA and 21 V. Finally, highly reflective Al/graphene-based p-electrodes on the same UVC LEDs with and without the absorbing p-GaN cap layer will also be presented.

HL 35.40 Tue 15:00 Poster A

Spectrally pure deep UV LEDs for gas sensing applications — •Frank Mehnke[1], Martin Guttmann[1], Johannes Enslin[1], Simon Kapanke[1], Christian Kuhn[1], Hendrik Krüger[2], Marian Rabe[2], Mickael Lapeyrade[3], Ute Zeimer[3], Sven Einfeldt[3], Tim Wernicke[1], Markus Weyers[3], and Michael Kneissl[1,3] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Universität Rostock, Institut für Allgemeine Elektrotechnik, Albert-Einstein.Str. 2, 18059 Rostock, Germany — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12480 Berlin, Germany

Ultraviolet (UV) light emitting diodes (LEDs) emitting at wavelengths near 230 nm could enable compact and highly sensitive NO gas detection systems. Although the required spectral power densities are moderate, spectrally clear single peak emission without parasitic luminescence is of utmost importance. Unfortunately, such very short wavelength LEDs often suffer from various parasitic luminescences which mainly originate from electron leakage into the p-side of the LED and Mg-related deep level transitions. In this contribution, we will present our recent investigations on the influence of the heterostructure design and p-side doping on the charge carrier injection and the emission characteristics of 233 nm LEDs. By optimizing the electron blocking layer thickness as well as the Mg doping concentration of the p-superlattice we were able to achieve single peak 233 nm LEDs with an emission power of 26 μW at 25 mA. Incorporated into a gas detection system those LEDs are capable to detect nitrogen oxide in the ppm range.

HL 35.41 Tue 15:00 Poster A

Large-scale defect calculations using atomic effective potentials and LATEPP — •Elisabeth Dietze[1], Jerome Jackson[1], and Gabriel Bester[1,2] — [1]Institute for Physical Chemistry, University of Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We present an electronic structure method which overcomes usual supercell size restrictions for the calculation of point defects in IV-IV and III-V semiconductors. For this we have developed a method to parametrize ab initio the changes in the total Kohn-Sham potential induced by the defect, giving a defect AEP [1, 2] that can be employed in very large supercell calculations.

As an example we present the properties of substitutional Mn defects in Si and GaAs showing that our description reproduces well the results of density functional calculations with the general gradient approximation for system sizes where this is possible, and discuss the energy eigenvalues of the states for very large supercells. The calculations show defect states in the range from shallow to intermediate binding energies, which our method is able to treat in a general way.

[1] J. R. Cardenas and G. Bester, Physical Review B 86, 115332 (2012).

[2] F. Zirkelbach P.-Y. Prodhomme, Peng Han, R. Cherian, and G. Bester, Physical Review B 91, 075119 (2015).

HL 35.42 Tue 15:00 Poster A

Optical Characterization of Ga(N,As,P)/(B,Ga)(As,P)/Ga(N,As,P) Heterostructures — •Julian Veletas[1], Peter Ludewig[2], Nils W. Rosemann[1], Kerstin Volz[1], Wolfgang Stolz[1,2], and Sangam Chatterjee[1] — [1]Faculty of Physics and Materials Science Center, Philipps-Universität Marburg, D-35032 Marburg, Germany — [2]NAsPIII/V GmbH, Am Knechtsacker 19, D-35041 Marburg, Germany

The quarternary semiconductor alloy Ga(N,As,P) is a promising material system for laser devices on silicon substrates to open up new routes towards off-chip optical data transmission. While the active material Ga(N,As,P) is comparatively well characterized many questions remain regarding the optoelectronic properties of the barrier material (BGa)(AsP). In particular, the hetero-offsets at the (B,Ga)(As,P)/Ga(N,As,P) Interface remain under discussion. Several scenarios discussed including a staggered band alignment, which would offer the potential for advanced W-Laser structures at telecom wavelength. Here, a series of Ga(N,As,P) /(B,Ga)(As,P)/Ga(N,As,P) *W-structures* are investigated by modulation and photoluminescence spectroscopy to identify optically allowed transitions and help to clarify the band alignment.

HL 35.43 Tue 15:00 Poster A

Influences of molecular flux gradients on the optical characteristics of GaAs/AlGaAs quantum wells — •Pia Eickelmann, Rüdiger Schott, Andreas D. Wieck, and Arne Ludwig — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstr. 150, D-44780 Bochum, Germany

Semiconductor heterostructures with quantum wells (QW) find application e.g. in high electron mobility transistors, diode lasers or quantum cascade lasers. A good control of the well thicknesses and alloy compositions during the molecular beam epitaxy (MBE) growth is vital, as these mainly determine the quantization energies.

In this contribution, we present the effect of a spatial molecular flux gradient on an MBE grown GaAs/AlGaAs QW structure. Mounting the substrate in the MBE chamber nonaxially with respect to the Ga and Al effusion cell and stopping the rotation of the wafer cause this present flux gradient. We simulate the QW transition energies due to the change in Al concentration in the barrier and the width of the QW. The trend observed by photoluminescence measurements on the flux gradient grown QW wafer is well reproduced. Furthermore we investigate monolayer steps for the QWs in the same sample.

HL 35.44 Tue 15:00 Poster A

Local etching of a SiO_x layer on Si(111) by Ga droplets and its influence on GaAs nanowire growth — •Tina Tauchnitz[1,2], Harald Schneider[1], Manfred Helm[1,2], and Emmanouil Dimakis[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden — [2]cfaed, TU Dresden, 01062 Dresden, Germany

GaAs nanowires (NWs) can be grown epitaxially on Si(111) substrates in the vapour-liquid-solid mode. Typically, Au is used as catalyst, but affects the NW and substrate properties due to contamination. Thus, the self-catalyzed mode appears to be advantageous. The NW growth is initialized by the formation of Ga droplets on the substrate surface, which is normally covered by a thin SiO_x layer. The yield of vertical

NWs depends on the thickness and the nature of the SiO_x [1], pointing out the complex interaction of the liquid Ga with the SiO_x.

This work investigates the local etching of a native SiO_x on Si(111) by liquid Ga droplets, a mechanism, which is thought to precede the NW nucleation. The droplet formation, the etching process, and their effect on the NW growth were studied as a function of the substrate temperature and the etching time using molecular beam epitaxy. In contrast to previous studies, the oxide etching is distinguished from the subsequent NW nucleation by inserting a thermal annealing step, during which the Ga droplets are evaporated completely from the surface. Finally, the yield of vertical NWs and the NW number density can be controlled just by choosing the appropriate conditions for the oxide etching, independent of those used for the subsequent NW growth.

[1] Matteini *et al.*, J. Cryst. Growth **404**, 2014

HL 35.45 Tue 15:00 Poster A

Treatment of concentrated solar radiation PV modules on the basis of AlGaAs-GaAs heterostructures — •Lia Trapaidze[1], Rafiel Chikovani[2], Ia Trapaidze[2], and Gela Goderdzishvii[2] — [1]3 Chavchavadze Ave., 0179 Tbilisi, Georgia — [2]Kostava 77, 0175 Tbilisi, Georgia

Among the alternative and renewable sources of energy the transformation of solar energy directly into electric energy attracts more growing attention. Till present the photoelectric transformers of solar radiation practically have been prepared only on crystalline silicon. The goal of researchers is to increase efficiency of photoelectric transforming systems and to lower the cost. In the present work for fabrication of heterostructures we have used the low-temperature liquid-phase epitaxial method in which we have introduced the changes and identified: a chemical composition of solid solutions of separate layers of multilayer heterostructures; the optimal thicknesses; type and concentration of doping material; the temperature-time modes of the growing processes. As a result in the obtained heterostructures the high value of efficiency coefficient of solar concentrated radiation up to 23,4% (K=100-500) and stability of technological process have been achieved. By using of testing methods of elements and modules we have studied the main parameters both in laboratory and field conditions. We have developed design and fabricated a pilot model of low power tourist mobile photoelectric system.

HL 35.46 Tue 15:00 Poster A

GaAs/air Bragg mirrors to enable strong light-matter interaction — •Meico Heinke-Becker, Sascha René Valentin, Arne Ludwig, and Andreas D. Wieck — Ruhr-Uni Bochum, 44780 Bochum, Deutschland

To obtain strong light matter interaction in cavity QED systems, a small mode volume and high mirror reflectivity is necessary. We present our first attempts to create a distributed Bragg reflector consisting of GaAs/air mirror pairs. This is performed by molecular beam epitaxy (MBE) and partial epitaxial-lift-off techniques.

HL 35.47 Tue 15:00 Poster A

Microfabricated SiN-masks for selective area epitaxy of InAs and GaAs — •Viktoryia Zolatanosha and Dirk Reuter — Optoelectronic Materials and Devices, University of Paderborn, Warburgerstr. 100, 33098, Paderborn, Germany

Selective area epitaxy (SAE) has the potential to open the path to novel semiconductor devices by allowing for laterally patterned material deposition. In SAE various types of masks define local areas, in which materials are deposited. In this contribution, we present a shadow mask approach for SAE in the InAs/GaAs-system.

The mechanical mask is realized from a SiN-membrane by employing nanofabrication technology allowing for hole sizes down to 100 nm. The membrane is made from a Si-wafer covered with 100 nm Si3N4 by anisotropic chemical etching of Si(100) employing KOH. The membrane itself is patterned by electron beam lithography and reactive ion etching. First test shows that the mask is fully compatible with ultra-high-vacuum and can withstand temperatures up to 800°C. GaAs and InAs deposited on the mask can be re-evaporated without damaging the mask.

HL 35.48 Tue 15:00 Poster A

Growth of Low Density InAs Quantum Dot Molecules — •Nandlal Sharma and Dirk Reuter — Optoelectronic Materials and Devices, University of Paderborn, Warburgerstr. 100, 33098, Paderborn, Germany

In this contribution, we present a modified gradient approach for the fabrication of low density vertically stacked InAs quantum dots (QDs), so called quantum dot molecules (QDM). The samples were grown by solid source molecular beam epitaxy (MBE) on GaAs (100). The density of the QDMs was varied across the wafer by the following approach: the bottom-layer of QDs was grown without substrate rotation, which resulted in an Indium gradient over the substrate surface, generating a QD density gradient. The emission wavelength of the bottom QDs were controlled by partial capping with 2.2 nm GaAs [1]. After growing a GaAs barrier of 6-18 nm, uncapped top-layer QDs were grown with (!) substrate rotation. The influence of the In amount in the top QD layer and of the GaAs inter-dot barrier thickness will be discussed. References [1] S. Fafard et al., Phys. Rev. B 59, 15368 (1999)

HL 35.49 Tue 15:00 Poster A

Emission wavelength tuning of InAs quantum dot molecules by rapid thermal annealing — •Alexander Karlisch, Nandlal Sharma, Stepan Shvarkov, and Dirk Reuter — Optoelektronische Materialien und Bauelemente, Universität Paderborn, Paderborn, Germany

Vertically stacked InAs quantum dots (QDs), so-called quantum dot molecules (QDM), have attracted much interest in the framework of solid state based quantum information processing. The realization of such applications require addressing a single QDM, e. g. by optical methods. To use effective, silicon based detectors and pump lasers that allow single QDM experiments, a ground state emission wavelength of around 950 nm at low temperatures is required. In this contribution, we present a study of emission wavelength tuning by rapid thermal annealing (RTA) for single layer QDs as well as QDM. The samples have been grown by solid-source molecular beam epitaxy on GaAs(100) substrates employing the Stranski-Krastanov growth mode. The as-grown samples show a ground state emission around 1150 nm at low temperatures. The samples have been annealed for 30 s at various temperatures under nitrogen gas atmosphere. To avoid As desorption during annealing, the samples were covered with pieces of a GaAs-wafer as proximity caps. Photoluminescence spectra showed that the emission wavelength at low temperatures could be blue-shifted below 950 nm for the single layer QDs as well as for the QDM while maintaining high luminescence intensities. We attribute the blue-shift to the interdiffusion of Ga and In. The influence of the annealing temperature is discussed in detail.

HL 35.50 Tue 15:00 Poster A

In Plane Gate transistors based on GaAs as sensors for dielectrics — •Benjamin Feldern, Sascha Valentin, Arne Ludwig, and Andreas D. Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum

In-Plane Gate transistors (IPG) [1] based on $Al_xGa_{1-x}As$ / GaAs HEMTs are used for the sensing of gases and liquids in the environment of the IPGs. For this purpose, IPGs are written in GaAs HEMT structures using Focused Ion Beam (FIB) implantation. In this work, the transconductance of IPGs in different gaseous and liquid environments is examined. It is found that the dielectric changes the transconductance of the IPG which in turn is attributed to the change in the electric field in the half space that contains the dielectric. In addition, the effect of surface treatment is examined. It is found that the surface states additionally screen the dielectric and thus reduce the effect of the dielectric. As an outlook, a possible passivation of the devices is envisaged. Hereby, we intend to shorten the time constant of the gate * source/drain transconductance signal path from ms towards the RC-time-constant of the inherent in-plane geometry, being orders of magnitudes shorter. [1] J. Nieder, A D. Wieck, P. Grambow, H. Lage, D. Heitmann, K. v. Klitzing, and K. Ploog, "One-dimensional lateral field-effect transistor with trench gate-channel insulation", Appl. Phys. Lett . 57, 2695 (1990).

HL 35.51 Tue 15:00 Poster A

Growth kinetics of GaP-nanowires employing TBP and TMGa — •Matthias Steidl, Christian Koppka, Peter Kleinschmidt, and Thomas Hannappel — TU Ilmenau, Institute of Physics, Department of Photovoltaics, Gustav-Kirchhoff-Str. 5, D-98693 Ilmenau, Germany

III-V nanowires (NWs) are promising candidates as components of future third generation photovoltaic devices and solar water splitting cells. Here, the moderately high band gap (Eg=2.3eV) and stability in many electrolytes makes GaP a suitable material. Moreover,

by adding As or N the band gap can be tuned making the material highly interesting for tandem devices e.g. with silicon sub cells. While the growth kinetics of GaP and GaAs NWs using PH_3 and AsH_3 are already studied in detail, the growth kinetics of GaP NWs applying TBP have not been thoroughly investigated so far. Here, we report on the influence of V/III ratio, temperature and carrier gas on the Au-assisted VLS growth of GaP NWs by MOVPE. We found a great impact of the temperature on the growth behaviour. For low temperatures (450°C) the NW length does not increase linear with time - the longer the NW the smaller its growth rate (GR). In contrast, above 475°C, the GR is constant. The GR reaches its maximum at around 488°C and decreases above. As no Arrhenius dependency can be derived, the growth kinetics in this parameter regime are not governed by only one rate determining step. Moreover, a linear dependency of the GR on the V/III ratio (=5-20) was found for 450°C. Here, changing the carrier gas from pure H_2 to a mixture of H_2/N_2 increases the GR by a factor of two.