HL 35: HL Poster II

Time: Wednesday 17:30–20:00 Location: Poster E

HL 35.1 Wed 17:30 Poster E

Temperature dependent capacitance-voltage spectroscopy of self-assembled GaN quantum dot ensembles — •Carlo Alberto Sgroi[1], Julien Brault[2], Jean-Yves Duboz[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CNRS - CRHEA, Rue Bernard Grégory, 06560 Valbonne, France

We present temperature dependent capacitance voltage (CV) measurements of charge-tunable self-assembled wurtzite GaN quantum dots (QDs) in an $Al_xGa_{1-x}N$ matrix grown by MBE. GaN and its alloys have excellent properties such as their thermal stability, high thermal conductivity and wide bandgap energies which make them an ideal candidate for next-generation GaN-based power devices and QD storage devices. Due to polarization effects in wurtzite $GaN/Al_xGa_{1-x}N$ heterostructure layers the band structure is deformed and large electric fields promote charge transfer through defect states. Performing temperature dependent CV spectroscopy from 200 K to 300 K we were able to observe two different charging features that we attribute to trap state and quantum dot resonances.

HL 35.2 Wed 17:30 Poster E

Quantum well states of GaN/AlN studied by angle-resolved photoelectron spectroscopy — •Felix Passlack[1], Mahdi Hajlaoui[1], Stefano Ponzoni[1], Mirko Cinchetti[1], Thomas Zentgraf[2], Donat Josef As[2], and Michael Deppe[2] — [1]Experimentelle Physik VI, TU Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Universität Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

Quantum well states (QWS) are attracting a lot of interests due to their unique electronic properties. They have been used for many applications for electronic and optical devices such as diode lasers, high electron mobility transistors, thermoelectric devices, and solar cells. Understanding their ability for improving and developing new applications devices, requires experimental details of their electronic structure. In this contribution, we employ angle-resolved photoelectron spectroscopy (ARPES) to study the QWS in the GaN/AlGaN heterostructure. The experiments have been carried out at the DELTA synchrotron facility at the TU Dortmund University, where the photon energy was varied between 10 eV and 100 eV. We will compare the results with those recorded using a laser-based ARPES setup using an excitation energy of 6 eV.

HL 35.3 Wed 17:30 Poster E

Comparison of GaN layers grown by Molecular Beam Epitaxy and by Sputtering technique — •Anne Sekels, Pascal Hille, Philipp Schurig, Martin Becker, Jörg Schörmann, and Angelika Polity — Institute for Exp. Physics I and Center for Materials Research (LaMa), Justus Liebig University Giessen, Germany

In the last decade, group III-nitrides have become one of the most important classes of semiconductor materials. In particular, GaN and the ternary compounds (Al, In, Ga)N thin films are used in a variety of commercial optoelectronic and electronic devices. Nitride materials are pre-dominantly grown by heteroepitaxy on different substrates. Metal organic vapor phase epitaxy and molecular beam epitaxy (MBE) are the most important growth techniques. However, these substrates and growth techniques are quite expensive. In this study we compare cheap sputtering technique and plasma-assisted molecular beam epitaxy to grow GaN homoepitaxially on GaN/Si (001) templates. The GaN layer thickness was about 400-500 nm in both cases. The influence of growth parameters, e.g. Ga-flux, N-flux during MBE and additional Ar-flux during sputter process on the structural properties, carried out by X-ray diffraction (XRD) and atomic force microscopy (AFM), is investigated.

HL 35.4 Wed 17:30 Poster E

Electron Beam Induced Current (EBIC) Investigations of Freshly Introduced a-screw Dislocations in GaN — •Tobias Westphal and Michael Seibt — University of Göttingen, IV. Physical Institute, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Even though GaN is already a widely used semiconductor, the effect of defects on the properties of GaN is not fully understood yet. As GaN has a quite high grown-in dislocation density, in the order of $10^6\,cm^{-2}$ - $10^8\,cm^{-2}$ depending on the growth technique, investigating the electrical properties of dislocations is of particular interest.

In previous work it was shown that indentation perpendicular to the basal (0001) plane in specially undoped low-resistance GaN creates a-screw dislocations. Those freshly introduced dislocations are showing dislocation related luminescences (DRL) with an energy peak at around 3.18 eV. This red shift of about 300 meV with respect to the band gap can not be explained by a perfect dislocation. However a dissociated dislocation, where the stacking fault ribbon forms a quantum well, would be a possible explanation. Therefore, structural investigations of the dislocation core with high spatial resolution are of tremendous interest.

The freshly introduced dislocations as well as the grown-in dislocations are investigated with EBIC to make recombination centres visible. Under electron beam irradiation recombination enhanced dislocation glide (REDG) occurs, making high resolution TEM (HRTEM) challenging. Hence, EBIC studies of REDG are performed in order to prepare for HRTEM measurements.

HL 35.5 Wed 17:30 Poster E

Photoelectrochemical Etching of GaN/AlGaN Heterostructures — •Lukas Peters[1,2], Christoph Margenfeld[1,2], Hergo-Heinrich Wehmann[1,2], and Andreas Waag[1,2] — [1]Institut für Halbleitertechnik und epitaxy competence center ec[2], Technische Universität Braunschweig, 38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, 38092 Braunschweig, Germany

In this work, we demonstrate the adaptation of photoelectrochemical (PEC) wet etching on bandgap selective etching of three-dimensional core-shell GaN/AlGaN heterostructures using potassium hydroxide (KOH). As a basis, the influence of KOH molarity, temperature, and UV-A illumination power on the etch rate and surface morphology were studied. Analyses by profilometry, scanning electron microscopy (SEM), and cathodoluminescence (CL) confirm a strong etch rate enhancement using PEC etching compared to conventional KOH-based wet-etching, as well as strong selectivity to GaN. Furthermore, PEC etching was employed on core-shell structures for selective removal of the GaN core with respect to an AlGaN shell whose demonstration would constitute a major step towards manufacturing three-dimensional UV emitters.

HL 35.6 Wed 17:30 Poster E

Spectroscopic characterization of sputtered ScAlN thin films — •Tim Hofmann[1], Katja Tonisch[1], Bernd Hähnlein[1], Jaroslav Kovic Jr.[2], Jörg Pezoldt[1], and Stefan Krischok[1] — [1]TU Ilmenau, Ehrenbergstr. 29, 98693 Ilmenau — [2]Slovak University of Technology, Ilkovicova 3, Bratislava 81219, Slovakia

Wide-bandgap semiconductors represent an attractive option to meet the demands of microelectromechanical systems (MEMS). Especially aluminum nitride (AlN) is the material of choice when it comes to integrated MEMS structures for sensing, actuating and energy harvesting applications requiring a piezoelectric thin film. However, next to a low electromechanical coupling coefficient, the piezoelectric response is much lower than that of PZT, both facts limiting the scope of possible applications. Thus, increasing interest concentrates on a new, recently emerging ternary nitride alloy, namely scandium aluminum nitride or Sc(x)Al(1-x)N, whose piezoelectric response is reported to increase 5-fold for x = 0.3 compared to that of pure AlN. Next to its piezoelectric properties, also the structural, mechanical, electrical and optical properties need to be understood to implement ScAlN into new technological concepts. We analyzed the dependency of the built-in strain on the Scandium content for sputtered ScAlN thin films with a maximum Scandium content of x = 0.25 by X-ray diffraction. Additional Raman spectroscopy and infrared spectroscopy showed a strain dependent shift of the observed optical phonon modes in accordance with the XRD measurements. The stoichiometry of all samples was determined by X-ray photoemission spectroscopy.

HL 35.7 Wed 17:30 Poster E

A comparative study of ultrathin c-plane GaInN/GaN quantum wells grown by MBE and MOVPE — •André Schendel, Dominic Tetzlaff, Heiko Bremers, Uwe Rossow, and Andreas

Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

In this contribution we present our study of ultrathin c-plane GaInN/GaN quantum wells (QWs) grown by molecular beam epitaxy (MBE) compared to those grown by metal-organic vapor phase epitaxy (MOVPE) in terms of morphology and composition homogeneity. The ternary semiconductor GaInN has many opportunities for applications as optoelectronic device with its direct band gap tunable between 0.65 eV for InN and 3.42 eV for GaN. For large scale production of devices with GaInN/GaN QWs MOVPE is the fabrication process of choice nowadays. But due to the high operating temperatures of the MOVPE which are needed to break the ammonia bonds for nitrogen supply, MOVPE grown GaInN layers have a tendency to form indium clusters on the growth surface which cause an inhomogeneity of the composition. In contrast to that, growth temperatures used by MBE can be much lower which reduces the diffusion length of indium and therefore MBE grown layers should have a more homogeneous composition and very high indium concentrations can be more easily realized. In which extend the structural and optical properties of GaInN/GaN QWs differ by the named growth methods is the topic of our investigation and gives more insight into the growth process.

HL 35.8 Wed 17:30 Poster E

Optical properties of oxygen-doped TiN thin films — •Felix-Florian Delatowski, Chris Sturm, Michael Lorenz, Florian Jung, Stefan Hohenberger, and Marius Grundmann — Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig, Linnéstraße 5, 04103Leipzig

The epitaxial growth of MgO and TiN superlattices allows the realization of optical hyperbolic metamaterials [1]. Due to the high oxygen affinity of titanium, diffusion of the oxygen of the MgO layer into the TiN layers takes place [2]. Here we investigate the structural and optical properties of oxygen-doped TiN thin film layers as a function of the doping concentration in order to understand the impact of the oxygen doping on the properties of the superlattices. The thin films were fabricated by pulsed laser deposition on MgO substrates [3]. The oxygen doping was realized by using an oxygen-argon gas mixture during the deposition process.

The crystal properties and the thickness were measured using X-ray diffraction and reflection, whereas atomic force microscopy was used in order to investigate the surface properties. The dielectric function of the thin films was determined by spectroscopic ellipsometry. We found hints that even for an oxygen-argon gas mixture of 1 : 99 and less, we obtain a deposition of titanium oxides instead of TiN.

[1] G. Naik *et al.*, PNAS **111**, 7546-7551 (2014)

[2] F. Jung, *Optical and structural properties of TiN/MgO superlattices*, Master thesis (Universität Leipzig) (2018).

[3] M. Bonholzer *et al.*, Phys. Status Solidi A **211**, 2621-2624 (2014).

HL 35.9 Wed 17:30 Poster E

Capacitance spectroscopy on GaN quantum dots — •Peter Conrad[1], Carlo Sgroi[1], Julien Brault[2], Laurin Schnorr[3], Andreas D. Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CNRS-CRHEA, Rue Bernard Grégory, 06560 Valbonne, France — [3]Lehrstuhl für Festkörperphysik, Heinrich-Heine-Universität Düsseldorf, D-40204 Düsseldorf, Germany

The aim of this work is to gain insights in the tunnel behaviour of charge carriers in self-assembled GaN quantum dots by means of different measurement methods. Based on previous capacitance-voltage measurements (CV measurements) on GaN quantum dots, CV measurements under illumination will be performed in this thesis [1]. On the basis of these measurements we will try to characterize defects in the sample more precisely. In addition, the CV measurement under illumination can be carried out as a function of the temperature in order to gain further information about their thermal activation energy. Another method to be used to investigate electrically active defects is the Deep Level Transient Spectroscopy (DLTS). With the help of the signals obtained by the DLTS measurement, it is possible to determine the activation energy at the GaN quantum dot interface.

[1] Labud et al.: Physical Review Letters 112 (4), 046803

HL 35.10 Wed 17:30 Poster E

Structural and optical investigation of metamorphic AlInGaN barriers — •Carina Walz, Michael Jetter, and Peter Michler — IHFG, Universität Stuttgart

Nitride semiconductors are already widely used as they are key components for solid-state lightning and have the ability to cover the complete visible spectral range. A drawback in this material system is the piezoelectric effect in hetero-structures, which gets more pronounced as larger the lattice mismatch between the barrier layers and the light emitting quantum well (QW) gets. These intrinsic electric fields lead to a reduced recombination, respectively emission efficiency due to the quantum confined Stark effect (QCSE). In order to reduce this QCSE and reach higher emission efficiencies at higher In-content inside the InGaN QWs, the implementation of metamorphic aluminum-indium-gallium-nitride (AlInGaN) barriers can be advantageous. With AlInGaN barriers the strain situation and the band offsets to the QW can be adjusted in a certain range independently, thus reduce the electric field at the position of the InGaN QW.

In our contribution a sample series of quaternary nitride barriers with varying strain state from tensile to compressive with respect to the GaN layer were fabricated by metal-organic vapour-phase epitaxy (MOVPE. The structural properties of the AlInGaN layers were investigated by high-resolution x-ray diffraction (XRD) measurements. In order to examine surface defects atomic force microscopy (AFM) and scanning electron microscopy (SEM) is used. Additionally, photoluminescence spectra of the sample series were recorded.

HL 35.11 Wed 17:30 Poster E

Micro-photoluminescence spectroscopy of microstructured light emitters based on InGaN quantum wells — •Jonas Quatuor[1], Mursal A. Baggash[1], Ulrich T. Schwarz[1], Jana Hartmann[2], and Andreas Waag[2] — [1]Institute of Physics, Chemnitz University of Technology — [2]Institute for Semiconductor Technology, Braunschweig University of Technology

Light emitters with mictrostroctured, threedimensional surface have several advantages with respect to such with planar ones: the InGaN quantum wells on side facets of microstructures like μ-rods or fins may be of semi- or nonpolar orientation with reduced internal fields, the ratio of QW area to wafer area is increased, threading dislocation density in the QWs is reduced, and the indium uptake during epitaxy is enhanced. We investigate the spectral properties (wavelength shift, intensity, linewidth) of the InGaN QW by micro-photoluminescence. From temperature dependent droop measurements we estimate the internal quantum efficiency (IQE). Nonpolar QWs on sidewalls emit polarized light because of the lower symmetrie. From excitation density dependent measurements of the degree of polarization, we determine the carrier density.

HL 35.12 Wed 17:30 Poster E

Low temperature spectroscopy of phonon replica in group-III-nitride quantum wells — •Conny Becht, Mursal A. Baggash, and Ulrich T. Schwarz — Institude of Physics, Chemnitz University of Technology, Experimental Sensor Science

Phonon replica are side peaks of photoluminescence emission spectra. For InGaN quantum wells (QWs), the energy difference between phonon replica and main peak are multiple of 91 meV, given by the energy of the longitudinal optical phonon (LO phonon). The relative height of the phonon replica and correspondingly for electron-phonon coupling strength is the Huang-Rhys factor S. As coupling to the phonons is relevant for recombination processes, we investigate the spatial variation of the Huang-Rhys factor in InGaN multi quantum well samples. We observe a spatial correlation of the Huang-Rhys factor with dislocation distribution in these samples. The aim of the study is to develop an understanding of the role of phonons in Shockley-Read-Hall and Auger nonradiative recombination.

HL 35.13 Wed 17:30 Poster E

Temperature-dependent electroluminescence studies of AlGaN-based UVB-LEDs — •Jakob Höpfner[1], Priti Gupta[1], Martin Guttmann[1], Markus Weyers[2], Tim Wernicke[1], and Michael Kneissel[1,2] — [1]Technische Universität Berlin, Institut of Solid State Physics, Berlin, Germany — [2]Ferdinand Braun Institut, Berlin, Germany

One of the important contributors to the external quantum efficiency (EQE) and output power of the AlGaN-based deep UV-LEDs is the injection efficiency (η_{inj}). It is mainly determined by electron overflow into the p-doped region and the restricted hole Transport into the quantum wells due to a high acceptor activation energy and band offsets at heterointerfaces. By measuring the temperature (T)-dependent electroluminescence (EL) characteristics of UVB-LEDs, we can provide insights on hole and electron transport in these LEDs. From the T (20-

350 K)-dependent EL specta, current-voltage and current-light output power characteristics, we observed the typical behavior of UVB-LEDs. Starting at 350 K, the EQE first increases with decreasing T due to the reduced non-radiative recombination rate within the quantum wells. At a certain T, the EQE decreases strongly staying at low values for lower T. The origin of the EQE breakdown is possibly the freeze out of holes in conjunction with increased electron overflow. Our results show that the temperature, at which EQE reaches its maximum, depends strongly on the η_{inj}, which can be pushed to even lower temperature with improved p-doping and bandgap profile.

HL 35.14 Wed 17:30 Poster E

AlGaN-based LEDs with extremely short emission wavelengths — Frank Mehnke, Luca Sulmoni, Martin Guttmann, •Tim Wernicke, and Michael Kneissl — Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany

In this paper, we will present the development of AlGaN-based multiple quantum well (MQW) LEDs with emission between 217 nm and 239 nm applicable in gas sensing systems (e.g. NO: $\lambda = 226$ nm, NH_3: $\lambda = 217$ nm). Commonly a strong decrease in emission power and external quantum efficiency is observed with decreasing emission wavelength and attributed to a reduction of carrier injection efficiency and light extraction efficiency. We discuss systematical variations of the heterostructure in order to improve the device efficiency. In order to maximize the spectral power needed for applications, the tradeoff between the cut-off wavelength of the current spreading layer and its conductivity needs to be considered. Additionally, realizing ohmic contacts to $Al_xGa_{1-x}N$:Si with high aluminum content is extremely challenging and typically results in high operating voltages. By optimizing the four-metal electrode V/Al/Ni/Au configuration, we were able to sensibly reduce the contact resistivity of the n-contacts on $Al_{0.9}Ga_{0.1}N$:Si. Finally, we fabricated UV LEDs emitting between 239 nm and 217 nm with on-wafer measured integrated output powers ranging between 310 μW and 0.15 μW, respectively, at 20 mA in cw operation. Additionally, electroluminescence measurements under pulsed mode operation will be presented.

HL 35.15 Wed 17:30 Poster E

Optical polarization of AlGaN multiple quantum wells emitting between 212 nm and 261 nm — •Bettina Belde[1], Fynn Wolf[1], Frank Mehnke[1], Martin Guttmann[1], Christoph Reich[1], Luca Sulmoni[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

The output power and external quantum efficiency of AlGaN based LEDs is dropping rapidly for emission wavelengths below 240 nm. This can partly be explained by the transition of the optical polarization from transverse electric (TE) to transverse magnetic (TM) which is determined by the valence band ordering and symmetry in multiple quantum wells (MQW) that depend strongly on the aluminum content.

Using photoluminescence (PL), the optical polarization of the emitted light of AlGaN MQW has been investigated at room temperature in dependence of the aluminum content in the QWs and the barriers. The polarization degree P=(TE-TM)/(TE+TM) for 1 nm $Al_xGa_{1-x}N$ / $Al_yGa_{1-x}N$ QWs changes from +0.85 (TE) for x=0.48 and y=0.61 to -0.58 (TM) for x=0.9 and y=100. The transition from TE to TM occurs at an emission wavelength of 238 nm in good agreement with simulations based on $\boldsymbol{k \cdot p}$-perturbation theory. Furthermore, the investigation of the polarization degree was confirmed by polarization resolved electroluminescence (EL) measurements of processed LEDs with similiar active regions.

HL 35.16 Wed 17:30 Poster E

UVB LED with narrow emission angle using advanced silicon-based reflector package and Fresnel lens — •Anna Ghazaryan[1], Martin Guttmann[1], Tim Wernicke[1], Neysha Lobo Ploch[2], Tim Kolbe[2], Katrin Hilbrich[2], Steffen Knigge[2], Dennis Mitrenga[3], Indira Käpplinger[3], Thomas Ortlepp[3], Sven Einfeldt[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany — [3]CiS Forschungsinstitut für Mikrosensorik GmbH, Erfurt, Germany

InAlGaN-based LEDs in the UVB spectral range are interesting for a number of applications. Depending on the application of the UVB LEDs, a specific radiation pattern typically with a strong forward emission is needed. In this paper we investigate the influence of different package designs and optical elements on the far-field radiation pattern of UVB LEDs emitting around 310 nm by measuring the angle dependent electroluminescence and total output power. The optimized package with Al reflector and Fresnel lens allows a more directional light emission, a remarkable threefold increase of the radiant intensity from 0.34 mW/sr to 0.92 mW/sr at $\theta = 0°$ and 20 mA as well as a twofold increase of the total optical power from 0.43 mW to 0.86 mW emitted within a cone of half opening angle of $\theta = 35°$ at 20 mA.

HL 35.17 Wed 17:30 Poster E

MOVPE Growth of Semipolar (11-22) $Al_{0.8}Ga_{0.2}N$ on (10-10) Sapphire — •Sarina Graupeter, Humberto M. Foronda, Frank Mehnke, Tim Wernicke, and Michael Kneissl — Institute of Solid State Physics, Technische Universität Berlin

AlGaN materials grown along the polar c-axis are the most common approach to realize optoelectronic devices in the deep ultraviolet spectral range. However, the external quantum efficiency (EQE) at emission wavelenghts below 240 nm drops drastically. This can be explained by the light emission polarized with electrical field vector parallel to the c-axis with increasing aluminum content. UV emitters grown on semipolar AlGaN offer a promising alternative due to the improved light extraction and the reduced quantum confined stark effect (QCSE). In this study we investigate the growth of semipolar AlGaN on m-plane sapphire by metalorganic vapor phase epitaxy (MOVPE). However, the growth of high quality semipolar AlGaN layers is challenging due to the simultaneaus formation of crystallites with other orientations leading to a deterioration of layer quality. We investigated the influence of growth parameters on the surface morphology and density of misoriented grains to achieve high quality AlGaN buffer layers. Variations of the reactor pressure, V/III ratio and metal organic flows all influenced the grain density. By analyzing the data we found that the grain density is correlated mainly to the growth rate. By growing a buffer layer 0.15 μm/h a grain density as low as $3 \cdot 10^6\ cm^{-2}$ was achieved. This was grain density was preserved also when subsequent layers where grown at higher growth rates.

HL 35.18 Wed 17:30 Poster E

Stopping in Gallium Arsenide — •Alrik Stegmaier and Hans Hofsäss — 2. Physikalisches Institut, Georg-August Universität Göttingen

GaAs is a technologically important III-V compound semiconductor. Doping of this material via ion implantation is common and requires an accurate understanding of the stopping process of ions. The electrical properties are further influenced by the amount of defects that are produced during irradiation, which has applications in implantation isolation or proton beam writing.

Because of this, accurate simulations are required for planning implantation, predicting defect production and even simulations of sputtering and ion induced surface dynamics.

Here we compare several common simulation methods against experimental data and DFT and TDDFT simulations. We present a new software to accurately predict the implantation, sputtering and defect production of GaAs during ion irradiation.

HL 35.19 Wed 17:30 Poster E

Measuring the 1D subband energies of wurtzite GaAs wires by inelastic light scattering — •Sebastian Meier, Florian Dirnberger, Paulo de Faria Junior, Jaroslav Fabian, Dominique Bougeard, and Christian Schüller — Universität Regensburg, 93040 Regensburg, Germany

Resonant Raman scattering has been performed to measure the subband energies of wurtzite GaAs nanowires. Our wires were grown by MBE using the VLS method and are nominally undoped. They have a GaAs core of down to 25 nm thickness which is protected by an AlGaAs shell. For laser excitation, we use a Ti:Sapphire laser, which can be tuned continuously in the energy region of the band gap.

In our Raman experiment, we find a number of peaks which are resonantly enhanced at different excitation energies. We interpret the peaks to stem from intersubband excitations of photoexcited electrons or holes. Therefore, every peak can be attributed to the energy splitting of different neighboring subbands. We also did PLE measurements to investigate the absorption behavior of the wires, and explain for which excitation energies Raman peaks are observable.

HL 35.20 Wed 17:30 Poster E

Capacitance-voltage spectroscopy on no-wetting layer quantum dots — •Ismail Bölükbasi, Sven Scholz, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, D-44780 Bochum, Germany

Quantum dots have interesting physical properties and allow research in zero dimensional systems. They are used in modern displays and may become important for the progress of semiconductor and information technology in the form of qubits in quantum computers and quantum memories or quantum communication applications.

Quantum dots are created by molecular-beam-epitaxy (MBE) in Stranski-Krastanov growth. InAs is deposited epitaxially onto GaAs and grows without relaxation to up to 1.5 monolayers of InAs. This layer is called the wetting layer, on top of which the self-organized quantum dots form. We find, that a monolayer of AlAs after the growth of quantum dots can suppress certain states in this wetting layer, allowing to purify the quantum dots from electronic contributions such as for example a two-dimensional-electron gas.

Capacitance-voltage measurements are carried out to investigate the effects of this monolayer of AlAs on the physical properties of the quantum dots and the modified charging behaviour around flat band conditions.

HL 35.21 Wed 17:30 Poster E

Degradation of telecom wavelength LEDs by high energy proton irradiation — •Heinz-Christoph Neitzert[1], Giovanni Landi[1], Juergen Bundesmann[2], and Andrea Denker[2] — [1]Dept. of Industrial Engineering (DIIn), Salerno University, Via Giovanni Paolo II 132, 84084 Fisciano (SA), Italy — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Protons for Therapy, Hahn-Meitner Platz 1, 14109 Berlin, Germany

Future space mission utilize more and more optical links for internal data transmission but also for long-range open-space communications between different satellites. While silicon based components are strongly degrading under high energy particle irradiation, wide bandgap semiconductors are generally found to be more radiation hard. Low bandgap semiconductors are, however also often employed in space for data transmission and for high efficient solar cells. InGaAsP LEDs emitting at 1550 nm have been irradiated with a 68 MeV proton beam with fluences up to 1e13 p+/cm^2. While the peak emission wavelength and the spectral width did not change with irradiation, a more than 2 orders of magnitude decrease of the emitted power has been found for maximum fluence. Besides the properties as light emitters, also the complete characterization of the electrical characteristics as receiver under illumination with 1550 nm light has been done. The changes of the extracted device parameters are discussed, which enabled, together with impedance spectroscopy data to give a detailed picture of the irradiation induced electronic defects.

HL 35.22 Wed 17:30 Poster E

Influence of ohmic contact material, doping and temperature on current-induced charge carrier density change — •Zoe Fiedler, Christian Schulte-Braucks, Carlo Alberto Sgroi, Carsten Ebler, Andreas Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Deutschland

The charge carrier density and mobility in heterostructures made of GaAs and AlGaAs can be varied by illumination, gate voltage and also voltage pulses applied to the ohmic contacts [Zitat: APL Christian Schulte-Braucks].

Based on the latter effect, the current-induced charge carrier density change is examined in detail both at different temperatures from 4.2K to 40K (above that, the effect subside too quickly) and with different contact materials.

The explanation of the charge carrier density change is related to DX centers, which are probably caused by a combination of donor atoms and As defects [Zitat: Mooney1990], which is why the doping method is also varied from volume doping to delta doping.

It will also be tested whether the change in charge carrier density can be reversed with voltage pulses.
The procedure and first results will be presented.

HL 35.23 Wed 17:30 Poster E

CVD growth of ZnO on sapphire with methane as reducing agent: Initial crystal formation process. — •Raphael Müller[1], Florian Huber[1], Okan Gelme[1], Manfred Madel[1], Alexander Minkow[2], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University — [2]Institute for Functional Nanosystems, Ulm University

he initial crystal formation of zinc oxide (ZnO) layers in a high temperature chemical vapor deposition (CVD)-based growth process was investigated. In our process we use methane (CH_4) to reduce ZnO powder. The resulting zinc vapor is locally re-oxidized at the spot of the substrate with pure oxygen, and thereby formes a ZnO layer. By controlling the gas flows one can control the II-VI ratio very precisely, as well as the duration of the growth. In the work presented, this scheme was used to grow a series of samples with increasing supply of zinc vapor in order to monitor the resulting layer formation. C-plane sapphire with aluminum nitride nucleation layer were used as substrates. To visualize and characterize the samples grown, atomic force microscopy, scanning electron microscopy and electron backscatter diffraction measurements were performed, as well as high resolution X-ray diffraction and photoluminescence measurements. We show that the ZnO heteroepitaxial layer is growing in c-direction right from the start of the process and forms a closed, smooth, high-quality single crystalline layer after a growth time of ten minutes only. The fundamental understanding of the layer formation is important for the ongoing studies of doping the ZnO layers with various donors.

HL 35.24 Wed 17:30 Poster E

Investigation of optical properties for Fe^{3+} in ZnO — •Martin Mangold[1], Raphael Müller[1], Florian Huber[1], Benjamin Neuschl[1], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter, Semiconductor Physics Group, University Ulm, Germany — [2]Institute for Functional Nanosystems, University Ulm, Germany

Ferromagnetism in II-VI-semiconductors like ZnO, due to doping with transition metals, rose attention over the last years. A candidate for realization are iron impurities which can be incorporated in high concentrations. In this study high-quality crystalline wurtzite ZnO layers grown by a CVD-based method were used as a host crystal for the investigation of internal spin-forbidden electric-dipole transitions of Fe^{3+}. Therefore iron was incorporated by a seed growth technique using iron(II) acetate. High-resolution, low-temperature Photoluminescence and magneto-optical photoluminescence investigations on the iron atom and its optical band at 1.78 eV are presented. This band emerges for a transition from the excited state $^4T_1(G)$ to the ground state $^6A_1(S)$.

HL 35.25 Wed 17:30 Poster E

CVD based growth of ZnO layers on Si(111) with AlN nucleation layer — •Matthias Töws[1], Okan Gelme[1], Raphael Müller[1], Florian Huber[1], Jan-Patrick Scholz[2], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, Germany — [2]Institute for Functional Nanosystems, Ulm University, Germany

In the present work, zinc oxide (ZnO) layers were grown by methane (CH_4) based CVD on Si(111) substrate with aluminum nitride (AlN) nucleation layer. For the AlN nucleation layer growth temperature, III-V-ratio, and the growth duration of the MOVPE process were varied. The resulting nucleation layers were analyzed by scanning electron microscopy and atomic force microscopy. Afterwards, the different nucleation layers were overgrown with ZnO. In order to find the best combination of growth parameters for both processes, a whole series of growth parameters for the ZnO deposition was tested on each of the nucleation types. For the evaluation of the sample quality, scanning electron microscopy, electron backscatter diffraction, high resolution X-ray diffraction, and low temperature photoluminescence measurements were performed.

HL 35.26 Wed 17:30 Poster E

Growth of epitaxial ZnO layers on Si(111) by chemical vapor deposition with methane as reducing agent — •Okan Gelme[1], Raphael Müller[1], Florian Huber[1], Alexander Minkow[2], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, Germany — [2]Institute for Functional Nanosystems, Ulm University, Germany

Epitaxial zinc oxide (ZnO) layers were grown on Si(111) substrate using a high temperature chemical vapor deposition (CVD)-based growth method. The process requires two steps, which both were investigated in detail. In the first step zinc acetate ($C_4H_6O_4Zn$) is heated up and

thereby elementary zinc vapor is created, which is transported in an argon flow and with the aid of pure oxygen re-oxidized, forming ZnO seed crystals on the Si substrate. In the second step ZnO powder is reduced by CH_4 in order to obtain again a constant flow of elementary zinc vapor. By the provided pure oxygen the zinc vapor is re-oxidized at the spot of the substrate, which then results in the formation of a heteroepitaxial ZnO layer. For both steps the influence of different growth parameters was investigated, in order to optimize the crystal quality. The samples were characterized by scanning electron microscopy, electron backscattering diffraction, high resolution X-ray diffraction, and low temperature photoluminescence.

HL 35.27 Wed 17:30 Poster E

Optical and magnetic studies of CrSe thin films on ZnSe and CdSe buffer layers — •Johannes Röder[1], Dana Vieweg[2], Hans-Albrecht Krug von Nidda[2], Alois Loidl[2], and Wolfram Heimbrodt[1] — [1]Department of Physics and Material Science Center, Philipps University, Marburg, Germany — [2]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Germany

Theoretical calculations predicted Chromium chalcogenides in the zinc blende (ZB) structure to be promising candidates for half-metallic spin-aligner at room temperature. The thermodynamically stable phase of CrSe is the hexagonal NiAs-structure which exhibits antiferromagnetic behaviour.

We investigated and compared two different approaches to stabilize the ZB state of CrSe. CrSe layers have been grown by MBE either on a ZB-CdSe buffer on InAs substrate or on a ZB-ZnSe buffer on GaAs substrate. To study the magnetic phase transitions we did temperature dependent SQUID measurements. We observed ferromagnetic behaviour for the sample on ZnSe but anti-ferromagnetic behaviour for the sample grown on CdSe.

Furthermore, we did cw- as well as time resolved optical spectroscopic measurements. We were able to observe different excitonic transitions from the CrSe as well as from the ZnSe or CdSe layers. Of special interest was a spatially indirect transition in the CrSe/ZnSe heterostructure with the holes in ZnSe and the electrons in CrSe. The lifetimes and the polarization propertuies will be discussed in detail.

HL 35.28 Wed 17:30 Poster E

Influence of substrate material and growth parameters on donor concentration in CVD grown ZnO layers — •Stefan Pokrivka[1], Raphael Müller[1], Okan Gelme[1], Tom Lacmann[1], Florian Huber[1], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, Germany — [2]Institute for Functional Nanosystems, Ulm University, Germany

In the present work, the influence of different substrate materials and growth parameters on the donor concentration in high temperature CVD grown ZnO layers is investigated. Capacitance-voltage measurements with a circular contact structure, as well as Hall measurements were performed on ZnO layers grown either directly on Si(111) or on c-plane sapphire with aluminum nitride nucleation layer underneath. These measurements show, that in the ZnO layers grown on sapphire the donor concentration is slightly higher than in samples grown on silicon. From these results and by correlation with findings from low temperature photoluminescence measurements, we conclude that aluminum diffuses from the aluminum nitride nucleation layer into the ZnO layer. Despite the fact, that the layers on silicon substrate were grown at lower temperature as compared to those grown on sapphire, we find similar donor concentrations for both cases. Furthermore, the influence of in-situ annealing for samples grown on sapphire was evaluated in order to confirm our conclusions.

HL 35.29 Wed 17:30 Poster E

Optoelectronic Interaction Between Colloidal Quantum Dots and Buried Quantum Wells — •Mikko Wilhelm[1], Shyam Kommadath[1], Atif Masood[1], Torsten Henning[2], Wolfgang Parak[3], and Wolfram Heimbrodt[1] — [1]Philipps-Universität Marburg — [2]Justus-Liebig-Universität Gießen — [3]Universität Hamburg

The optoelectronic coupling between colloidal quantum dots and different substrates is studied. CdS quantum dots and CdS/ZnS core/shell quantum dots are deposited via drop casting and spin coating on the substrates, for which different semiconductor and quantum well structures are used. The MBE grown quantum well structures consist of a 5nm thick ZnSe quantum well between (Zn, Mn)Se barriers, which differ in their manganese concentration. The thickness of the top barrier of the quantum well structure is modified by chemical etching. The energy transfer between the quantum dots and the substrate is investigated with time-resolved photoluminescence measurements in the nano- and picosecond range at different temperatures. The results are discussed in detail.

HL 35.30 Wed 17:30 Poster E

Exciton spin relaxation and recombination dynamics in CdSe nanocrystals in glass matrix — •Gang Qiang[1], Elena V. Shornikova[1], Dmitri R. Yakovle[1,2], Aleksandr A. Golovatenko[2], Anna V. Rodina[2], Evgeniy A. Zhukov[1], Alexsei A. Onushchenko[3], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany. — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia. — [3]ITMO University, 199053, St.-Petersburg, Russia.

We studied CdSe nanocrystal (NC) samples with diameter from 2.8 to 6.2 nm grown in glass matrix in this work. Temperature and magnetic field dependence of photoluminescence (PL) decay demonstrates the exciton nature of emission states. The longest component of the PL decay is ascribed to the dark exciton with a time constant 212 ns at 0 T, 2.2 K, which decreases to 118 ns at 17 T because of the magnetic field induced mixing between bright and dark states. The time and polarization resolved PL intensity reveals very fast spin relaxation dynamics which is beyond our time-resolution. And the acoustic phonons are expected to be involved in the coupling between upper 0 and 2 levels and give rise to the emission of linearly polarized light.

HL 35.31 Wed 17:30 Poster E

Exciton spin relaxation and recombination dynamics in CdSe nanocrystals in glass matrix — •Gang Qiang[1], Elena V. Shornikova[1], Dmitri R. Yakovle[1,2], Aleksandr A. Golovatenko[2], Anna V. Rodina[2], Evgeniy A. Zhukov[1], Alexsei A. Onushchenko[3], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany. — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia. — [3]ITMO University, 199053, St.-Petersburg, Russia.

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HL 35.32 Wed 17:30 Poster E

First-principles study of the structural and electronic properties of the GaP surface and GaP/Si interface — •Marsel Karmo[1] and Erich Runge[2] — [1]TU ILmenau,Weimarer Str.32,98693 ILmenau — [2]TU ILmenau,Weimarer Str.32,98693 ILmenau

The heteroepitaxial growth of III-V semiconductors on silicon enables the combination of the advantages of both materials. GaP/Si(001) is an attractive quasi-substrate. However, both, the GaP-interface as well as the GaP surface with its crystal quality and electronic properties has a high impact on the device performance. Thus, surface and interface need to be studied in detail. The atomic and electronic band structure of abrupt and mixed GaP/Si interfaces were investigated by ab-initio density functional theory calculations using the Vienna Ab initio Simulation Package (VASP). Thereby the electronic band structure and dielectric function of both types of termination, i.e. of abrupt Si-P and Si-Ga interfaces was calculated. Moreover, the GaP surface with hydrogen adsorption was studied, as it is a typical result of MOCVD epitaxial growth.

HL 35.33 Wed 17:30 Poster E

Influence of material supply and capping layer thickness on the density and emission properties of MOVPE grown InAs quantum dots on linear-graded InGaAs metamorphic buffers — •Robert Sittig, Diana Pfezer, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart, Allman-

dring 3, 70569 Stuttgart

Semiconductor quantum dots (QDs) are an excellent source of non-classical light, which is a key element for quantum information technologies. For compatibility with low-loss glass fiber communication networks, emission at telecom wavelengths is crucial.

We have recently shown single-photon emission at 1.55 μm from InAs QDs grown on a linear-graded InGaAs metamorphic buffer (MMB), which reduces the lattice misfit to the GaAs substrate. Here, we maintain the MMB design but vary the material supply during QD growth and the capping layer thickness. The influence of those parameters on the QD emission is studied via (μ-)photoluminescence spectroscopy. On the basis of the resulting spectra the QD size distribution and density is discussed, with special focus on the impact of metamorphic lattice relaxation processes.

HL 35.34 Wed 17:30 Poster E

Non-Markovian quantum feedback control of driven few-level quantum systems — Leon Droenner, •Kisa Barkemeyer, Andreas Knorr, and Alexander Carmele — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Motivated by classical Pyragas control and its impressive successes in laser physics and self-organizing nonlinear systems [1], the concept of non-invasive, coherent feedback is investigated in the quantum regime. In case of a pulsed excitation, a few-level system fundamentally acts as a single-photon source when excited with a π-pulse, while for a 2π-pulse two-photon emission is more likely to occur [2]. Employing feedback, we observe a qualitatively different reaction of single- and two-photon events to the feedback-induced coupling strength. The delay-dependent phase of the feedback signal results either in the enhancement or the suppression of single-photon events, whereas two-photon events become more probable [3]. Furthermore, we discuss how the delay-dependent phase shapes the photon-statistics and how this phase can be addressed externally.

[1] E. Schöll, S. H. Klapp, and P. Hövel (Eds.), *Control of Self-Organizing Nonlinear Systems* (Springer, 2016).
[2] K. A. Fischer, L. Hanschke, J. Wierzbowski, T. Simmet, C. Dory, J. J. Finley, J. Vučković, and K. Müller, Nature Physics 13, 649 (2017).
[3] L. Droenner, N. L. Naumann, A. Knorr, and A. Carmele, arXiv:1801.03342v2 (2018).

HL 35.35 Wed 17:30 Poster E

Pulsed electrically excited single-photon emission from a determnistically integrated quantum dot in a resonant cavity light emitting diode — •Simon Seyfferle, Marc Sartison, Sascha Kolatschek, Simone L. Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart

The realization of future quantum technologies based on semiconductor single-photon sources and the performances of the individual implemented device crucially depend on the systems parameters such as a high repetition rate of pure and triggered single photons, high transfer rates and a convenient method of excitation.

On the way to realizing an efficient device satisfying these requirements, we combine two promising approaches, namely deterministic integration of a quantum dot (QD) into the device by in-situ lithography and electric excitation of the resulting resonant cavity light emitting diodes (RCLED). With the in-situ approach we selectively place a single InP QD into the intrinsic region of a *pin*-diode, which in turn enables the pulsed electric excitation of the RCLED with high repetition rates. The inclusion of InP dots allows for emission in the red spectral regime, where the maximum detection efficiency of conventional silicon-based photo-detectors is situated, thus high transfer rates in future quantum information processing experiments should be feasible.

We show the process of such a device as well as first results on electrically triggered single-photon emission.

HL 35.36 Wed 17:30 Poster E

Implementing Emission Tuning Mechanisms in Photonic Integrated Circuits — •Florian Hornung[1], Mario Schwartz[1], Ekkehart Schmidt[2], Stefan Hepp[1], Ulrich Rengstl[1], Huiying Huang[3], Simone Luca Portalupi[1], Michael Jetter[1], Konstantin Illin[2], Michael Siegel[2], Armando Rastelli[3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Research Center SCoPE and IQST, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology (KIT), Hertzstrasse 16, 76131 Karlsruhe, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Altenbergerstraße 69, 4040 Linz, Austria

The scheme for linear optics quantum computing as proposed by Knill, Laflamme and Milburn requires sources of single and indistinguishable photons, which will non-classically interfere at beamsplitter structures, phase-shifters and single-photon detectors. Photonic integrated circuits (PICs) offer a scalable way to realize the scheme. Semiconductor quantum dots can serve as efficient on-demand sources of single photons in PICs, however when grown in Stranski-Krastanov mode they usually emit over a broad distribution of different wavelengths due to the statistical size-distribution of the dots.
Here, we present possibilities of tuning the emission wavelengths of metal-organic vapor-phase epitaxy (MOVPE) grown semiconductor quantum dots and show how these mechanisms can be implemented in PICs to enable two-photon interference in such a circuit.

HL 35.37 Wed 17:30 Poster E

Resonance fluorescence on plasmon-quantum dot hybrids — •Gerhard Johannes Schäfer[1], Armando Rastelli[2,3], and Markus Lippitz[1] — [1]Experimentalphysik III, Universität Bayreuth, Bayreuth, Germany — [2]Institute for Integrative Nanosciences, IWF Dresden, Dresden, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria

Resonance fluorescence spectroscopy is a well established tool to investigate single quantum dots in bulk experiments. I present simulations and experiments on single quantum dots which are coupled to plasmonic structures. We investigated GaAs quantum dots which are embedded in a membrane between two nanostructured gold layers.

HL 35.38 Wed 17:30 Poster E

Wet chemical etching of Gaussian shaped micro lenses in GaAs to enhance the extraction efficiency of QDs — •Lena Engel, Marc Sartison, Sascha Kolatschek, Fabian Olbrich, Cornelius Nawrath, Stefan Hepp, Michael Jetter, Peter Michler, and Simone Luca Portalupi — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Semiconductor quantum dots (QDs) are promising candidates for applications in quantum communication and quantum computing, as they show emission of single, indistinguishable photons. Since the QDs are embedded in a semiconductor environment, the extraction efficiency is firmly limited. As high brightness of the single photon source is crucial for the aforementioned applications, various mechanisms for enhancing the extraction efficiency of QDs are under current investigation, using either broadband approaches or narrow band cavity quantum electrodynamic systems. Due to their superior surface quality and variability in aspect ratio and size, wet chemically etched Gaussian shaped micro lenses have proven their applicability in broadband approaches and are auspicious suitors for more complex optical devices. We have placed them deterministically over pre-selected QDs emitting in the telecom O-band and have compared the enhancement factor and the fiber coupling efficiency for different lens geometries. FDTD simulations confirm the shaping of the emitted farfield.

HL 35.39 Wed 17:30 Poster E

Correlation of Auger Recombination in Self-Assembled InAs Quantum Dots with their Opto-Electrical Properties — •Nikolai Bart[1], Nikolai Spitzer[1], Martin Geller[2], Axel Lorke[2], Andreas D. Wieck[1], and Arne Ludwig[1] — [1]Ruhr-Universität Bochum — [2]Universität Duisburg-Essen

An Auger recombination is a usually undesired, non-radiative process in which the energy of an otherwise radiative exciton recombination gets absorbed by a secondary electron, thereby scattering it. By growing precisely tailored charge-tunable quantum dot devices, we aim to manipulate the conditions for Auger recombination to occur. For this, we make use of techniques such as indium-flushing and rapid thermal annealing to modify the QDs' size, shape and composition. In order to manipulate the coupling of the quantum dots to their surroundings, we predefine the tunnel barrier, which separates the QDs from an electron reservoir, suppress wettinglayer bound states or modify the QDs' capping layers. After characterization of the QDs' opto-electrical properties via photoluminescence and capacitance-voltage spectroscopy, Auger recombination rates are examined via two laser

resonance fluorescence. Correlating the QDs' characteristics to the occurrence of Auger recombination might give us crucial information to further decrease the decoherence and linewidth of photons from our devices and improve their quantum efficiency.

HL 35.40 Wed 17:30 Poster E

Occupation and Light Field Dynamics of a Quantum Dot in a Photonic Cavity — •Kevin Jürgens, Tilmann Kuhn, and Doris E. Reiter — Institut für Festkörpertheorie, Universität Münster, Münster

To enable the use of quantum dots (QDs) as efficient single photon emitters, the QDs are embedded in photonic structures. In such structures the light-matter interaction is enhanced due to the Purcell effect and the QD exciton and light field dynamics are strongly modified.

In this contribution we analyze these dynamics in a semi-classical model, where the QD is described as a two-level system and the light field is treated within the finite-difference time-domain (FDTD) method. The photonic cavity is realized as a defect between two Bragg mirrors. The electric field in this structure induces a polarization in the QD which again couples back in the Maxwell-equations, such that the QD modulates the electric field. This modified field propagates and scatters at the mirrors. Therefore the QD can interact with the self-generated fields resulting in interesting occupation dynamics.

We investigate the combined dynamics of the exciton occupation and the cavity mode induced by a Gaussian pulse and find a transition from exciton-polariton dynamics to Rabi oscillations for increased pulse intensities. These results help in understanding QDs in photonic structures.

HL 35.41 Wed 17:30 Poster E

Hot carrier cooling dynamics in PbS quantum dots - The influence of surface termination — •Emanuele Minutella[1,2], Nuri Yazdani[3], Vanessa Wood[3], and Holger Lange[1,2] — [1]Institute for Physical Chemistry, University of Hamburg — [2]The Hamburg Centre For Ultrafast Imaging, CUI — [3]Labratory for Nanoelectronics, Department of Information Technology and Electrical Engineering, ETH Zurich

Carrier multiplication (CM) in PbS quantum dots (QD) is an intriguing phenomenon with promises towards applications such as field-effect transistors, light-emitting diodes or solar cells due to their optical properties.(1) CM occurs in direct competition with carrier cooling via phonon emission or other relaxation channels.(2)In an experimental study, it was shown that halide-terminated PbS QDs feature an improved performance in solar energy conversion.(3) Our recent theoretical work showed that electron-phonon interactions are strongly suppressed in halide-terminated QDs due to reduction of the thermal displacement of the surface atoms.(4)

In our contribution we present an experimental study of the surface-termination impact. We observe the cooling of photo-induced hot carriers by femtosecond transient absorption spectroscopy in PbS QDs capped with different ligands. Our experimental results agree with the theoretical predictions and enable a tuning of the electron-phonon coupling in colloidal QDs.

(1) Adv. Mater. 2018, 30, 1800082 (2) ACS Nano 2017, 11, 6286-6294 (3) Nat. Mater. 2017, 16, 258-263 (4) Nano Lett. 2018, 18, 2233-2242

HL 35.42 Wed 17:30 Poster E

Optimized metamorphic buffer heterointerfaces for $\lambda = 1.55$ μm quantum dot growth — •Marcel Schmidt, Tim Bergmeier, Andreas D. Wieck, and Arne Ludwig — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Quantum dots emitting at the wavelength of 1550 nm are a key technology for future optical fibre transmitted quantum information exchange. At this wavelength, the attenuation in the optical fibre has an absolute minimum. Self assembled quantum dots (SAQDs) are very promising as nearly ideal sources for single indistinguishable photons or entgenled photon pairs which can be used for quantum information purposes like quantum key distribution or quantum repeaters. To shift the energy levels of SAQDs to an emission wavelength of 1550 nm, we investigate molecular beam epitaxy - grown InAs SAQDs on lattice-mismatch reduced InGaAs/InAlAs heterostructure layers with short period superlattices. We present first results of SAQDs already emitting at 1550 nm in photoluminescence spectroscopy at the temperature of T = 77 K.

HL 35.43 Wed 17:30 Poster E

The influence of the tunnel coupling to a charge reservoir on the Auger process in self-assembled quantum dots — •Pia Lochner[1], Annika Kurzmann[1], Jens Kerski[1], Rüdiger Schott[2], Andreas Dirk Wieck[2], Arne Ludwig[2], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Auger recombination is a non-radiative process, where the recombination energy of an electron hole pair is transferred to a third charge carrier. In colloidal quantum dots (QDs), this is a common effect which quenches the radiative emission with recombination times in the order of picoseconds [1]. In self-assembled QDs, it was speculated to be absent, and only recently, it has become possible to observe Auger recombination in these structures [2].

In this contribution, we investigate Auger recombination on a single self-assembled QD coupled to a charge reservoir with a small tunneling rate in the order of ms^{-1}. We observe in time-resolved resonance fluorescence measurements how the small tunneling rate of the sample structure influences the Auger rate and the quenching of the trion fluorescence intensity. Furthermore, we perform real-time measurements of the random telegraph signal which gives access to the statistics of the Auger process.

[1] R. Vaxenburg, et al., Nano Lett. 15, 2092 (2015).
[2] A. Kurzmann, et al., Nano Lett. 16, 3367 (2016).

HL 35.44 Wed 17:30 Poster E

Capacitance-voltage spectroscopy and temperature dependent photoluminescence spectroscopy on $\lambda = 1.55$ μm quantum dots — •Tim Bergmeier, Marcel Schmidt, Andreas Dirk Wieck, and Arne Ludwig — Institut für angewandte Festkörperphysik, Ruhr-Universität Bochum

Single λ=1.55 μm-wavelength photons are ideal for quantum communication, as fibre losses are minimal at this wavelength. Quantum dots can function as ideal single photon sources [Kuhlmann et al., Transform-limited single photons from a single quantum dot, Nat. Commun. 6, 8204 (2015)]. However, excellent photon quality is not yet achieved at the desired wavelength due to material issues accompanying needed metamorphic strain reduction layers, grown on GaAs substrates. We present temperature dependent photoluminescence spectroscopy and capacitance-voltage spectroscopy on molecular beam epitaxy-grown self-assembled InAs/InGaAs quantum dots emitting at λ=1.55 μm. We discuss the results in the framework of trap associated charge and non-radiative recombination processes.

HL 35.45 Wed 17:30 Poster E

Enhanced Biexciton Emission from single Quantum Dots encased in N-type Semiconductor — •Zhijie Li[1,2,3,4], Guofeng Zhang[3,4], Bin Li[3,4], Ruiyun Chen[3,4], Chengbing Qin[3,4], Yan Gao[3,4], Liantuan Xiao[3,4], and Suotang Jia[3,4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstraße 400, Dresden 01328, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Laser Spectroscopy, Shanxi University, Taiyuan, 030006, China — [4]Collaborative Innovation Center of Extreme Optics, Shanxi University, Taiyuan, Shanxi, 030006, China

By encasing single near-infrared emitting CdSeTe/ZnS3ML core/multishell quantum dots (QDs) in N-type semiconductor indium tin oxide (ITO) nanoparticles, an enhanced biexciton emission can be realized. The ITO nanoparticles with a high electron density can increase the dielectric screening of single QDs to reduce the Coulomb interactions between carriers, thus suppressing the nonradiative Auger recombination of biexcitons. It is observed that an average g(2)(0)=0.57 in the second-order correlation function curves, which indicates the effective creation of biexciton and subsequent twophoton emission from single QDs encased in ITO nanoparticles. The fluorescence quantum yield ratio of the biexciton to single-exciton emission is increased to ~4.8 times, while the Auger recombination rate reduces by almost an order of magnitude.

HL 35.46 Wed 17:30 Poster E

Improving the Purcell-enhancement for InAs-QDs in Fabry-Perot fiber-microcavities — •Martin Fischer[1], Thomas Herzog[1], Sascha Böhrkircher[2], Steffen Both[2], Michael Jetter[1], Simone Luca Portalupi[1], Thomas Weiss[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technol-

ogy (IQ^{ST}) and SCoPE, University of Stuttgart, D-70569 Stuttgart, Germany — [2]4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70550, Stuttgart, Germany

Cavity quantum electrodynamics (cQED) deliver basic insight into fundamental principles of quantum-mechanics and its captivating nature. One specific phenomenon, for instance, can be the enhancement of a quantum system's spontaneous emission rate, the so-called Purcell effect. Recent studies of QDs in a Fabry-Perot-based fiber microcavity already presented clear Purcell enhancement of the investigated transitions[1]. Here scattering losses and cavity-to-fiber mode mismatching limit the full exploitation of the setup's potential.

We consequently present theoretical approaches which are leading to an optimized experimental setup.

We apply finite element methods (FEM) and mode-mixing in paraxial approximation to numerically determine the cavity modes. Furthermore, we investigate the influence of the curvature on the fiber in-coupling efficiency, hence paving the way for the pursuit of higher Purcell-enhancements.

[1] T. Herzog et al. , Quantum Sci. Technol. 3 (2018) 034009

HL 35.47 Wed 17:30 Poster E

A single quantum emitter in a Mach Zehnder interferometer — •Hendrik Mannel[1], Pia Lochner[1], Jens Kerski[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

A Mach-Zehnder interferometer can be used to measure the coherence of a photon stream by a two-path experiment. In the ultimate limit of a single photon in the interferometer, it is also a realization for the so-called *which-path experiment*. A measurement of the photon path will destroy the interference in the same way, as blocking one arm of the interferometer. *In this contribution, we place a single self-assembled quantum dot in one arm of the interferometer to answer the question if a single quantum emitter in the Heitler regime [1] acts as an optical block and, thus, destroys the interference pattern. A stabilized Mach*Zehnder interferometer has been built and a single quantum dot was placed in one arm of the interferometer. An applied gate voltage shifts the QD transition in resonance due to the quantum confined Stark effect. We analyzed the interference pattern with and without the quantum dot to answer the question if a resonantly excited quantum dot in one arm destroys or conserves interference.

*[1] C. Matthiesen et al., Phys. Rev. Lett. **108**, 093602 (2012)

HL 35.48 Wed 17:30 Poster E

Single hole storage and non-equilibrium tunneling dynamics of quantum dots — •Carsten Ebler, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Bochum, Germany

Approaching the goal of a memory, storing single charge quanta, especially in quantum dots are interesting. Therefore, we use epitaxially grown self-assembled InAs QDs (SAQD) as crystalline hosts compatible with coupling to photons. This is envisaged as a progress compared to amorphous indirect semiconductors used in today's flash memories [1]. We establish SAQDs in tunnel contact with a 2-dimensional electron gas (2DEG), manipulate the system with electronical and optical pulses and perform time resolved conductivity measurements of the 2DEG to readout the charge occupation of the QDs [2]. The structure is biased such, that the Fermi level is in electronic resonance with the X^0 state in the QD to store one single hole. This metastable hole state is read out over conductivity changes of the 2DEG. Thereby it is possible to resolve electron tunneling dynamics and furthermore the interaction with the holes trapped inside the QDs. We prove metastable hole storage for at least 10 s and successful readout. Further experimentation with different voltage pulses provide information about tunneling processes of the electron states and dynamics of non-equilibrium states. [1] A. Marent et al, Semiconductor Science and Technology 26, 014026 (2011) [2] B. Marquardt1, et al, Appl. Phys. Lett. 95, 022113 (2009)

HL 35.49 Wed 17:30 Poster E

High brightness quantum dot source of telecom O-band photons — •Jingzhong Yang[1], Cornelius Nawrath[2], Robert Keil[3], Michael Zopf[1], Xi Zhang[3], Yan Chen[4], Bianca Höfer[3], Simone Portalupi[2], Peter Michler[2], Fei Ding[1], and Oliver G. Schmidt[3] — [1]Institute for Solid State Physics, Leibniz University of Hannover, Hannover, Germany — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Stuttgart, Germany — [3]Institute for Integrative Nanosciences, Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden, Dresden, Germany — [4]National University of Defense Technology, Changsha, Hunan,China

In order to realize long-distance quantum communication applications, the efficient single or entangled photon generation at telecommunication wavelengths is essential. Semiconductor quantum dots (QDs) are a very promising photon source for realizing quantum teleportation due to their non-Poissonian emission characteristics and compatibility with semiconductor technology. However, the extraction efficiency is restricted because of the significant total internal reflection caused by the high refractive index host material. Here we show high extraction efficiency from InAs/GaAs QDs emitting in the telecom O-band by using an optical antenna structure. Combining a nano-membrane containing QDs with gallium phosphide hemispherical lenses results in an increased photon extraction by two orders of magnitude. This versatile approach may therefore enable new developments for long-haul quantum communication technologies.

HL 35.50 Wed 17:30 Poster E

Factorial moments of photon-number states heralded from parametric down-conversion — •K. Laiho[1], M. Schmidt[1], G. Weihs[2], and S. Reitzenstein[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Well-behaved twin beams from parametric down-conversion (PDC) are routinely used for preparing single photons or other quantum optical states with higher photon numbers [1,2]. However, experimental imperfections such as optical losses both in the herald and in the target state cause degradation and it is difficult to decouple their effect, especially if losses are high. We utilize the normalized factorial moments of photon number, which can be extracted independent of losses, to characterize heralded photon-number states. With this regard, the differences between heralding with a click-detector [1] and a true photon-number resolving detector [3] can easily be visualized. Additionally, the higher-order moments provide a direct loss-tolerant access to other photon-number properties, like the parity. We investigate the boundaries for the reliability of such a state reconstruction method.

[1] K. Laiho et al., Opt. Lett. 36, 1476 (2011).
[2] T. Guenthner et al., J. Opt. 17, 125201 (2015).
[3] M. Schmidt et al., J. Low Temp. Phys. 193, 1243 (2018).

HL 35.51 Wed 17:30 Poster E

Transport Properties of Self-Assembeld InAs Double Quantum Dots — •Felix Opiela, Jan. K Kühne, and Rolf. J Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hannover, Germany

This work focuses on the analysis of transport measurements with variable parameters such as the magnetic field or the temperature, on self-assembeld InAs double quantum dots which are embedded in a GaAs/AlGaAs heterostructure. Due to the different size of the middle tunneling barrier (3/5/7nm), we were able to differentiate between a weak coupling and a strong coupling [1]. Likewise we examined a dependency of the thermal broadend fermi-edge with the expanded molecular resonant state of the coupled quantum dot[2].In the I/V measurements a decreasing amplitude and a thermal broadened peak width were observed. Thus leading to the analysis of a phononic contribution and a detailed examination of the thermal dependency at low temperatures. In addition to that we analyzed the different samples in a varying magnetic field in the range of 0 to 14 Tesla. Parallel as well as perpendicular magnetic field orientation were analyzed in respect to the current flow.

[1] W. G. van der Wiel et.al. Rev.Mod.Phys. 75,1 (2002)
[2] G. Kiesslich Phys. Rev. Lett. 99,206602 (2007)

HL 35.52 Wed 17:30 Poster E

Conductive nanorods generated by Cu exchange on contacted CdSe/CdS-rods — •Benedikt Brechtken[1], Franziska Lübkemann[2], Dirk Dorfs[2], Nadja Bigall[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover — [2]Institut für Physikalische Chemie und Elektrochemie, Leibniz Universität Hannover, 30167 Hannover

The classical fabrication procedures for electrical devices reaches their limits in miniaturization. The incorporation of chemical methods in the fabrication could be a way of surpassing those limits.

Chemical bottom up processes can create CdSe/CdS-nanorods with

5 nm diameter and 80 nm length. Single nanorods are individually contacted with electron beam lithography. To increase the measureable current in some cases a small number of rods are contacted in parallel by Cr/Au-contacts.

With the chemical cation exchange Cd can be replaced by Cu in these nanorods [1]. This transforms CdS with a resistivity around 10^12 Ωcm [2] to CuS which has a 15 orders of magnitude lower resistivity [3]. This method is applied to already contacted nanorods. These rods are electrically measured under ambient conditions. By measuring the same rods before and after the exchange, a drastic decrease in resistance is observed. The resulting resistance is stable for at least 14 days.

[1] B. Sadler et. al., J. AM. CHEM. SOC. 131, (2009)
[2] R. H. Bube, S.M.Thomsen, J. of Chemical Physics 23, (1955)
[3] M. Najdoski et al., J. of Solid State Chemistry 114, (1995)

HL 35.53 Wed 17:30 Poster E

Time-resolved reflectometry measurements on self-assembled quantum dots — •Jakob Penner[1], Kevin Eltrudis[1], Isabel Oppenberg[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Time-resolved transconductance measurements on the electron dynamics of self-assembled quantum dots (QDs) [1] can be used to access excited spin- and charge states in an all-electrical measurement [2], an important step towards quantum state manipulation and detection for future quantum information technologies. However, for fast and high-fidelity measurements, the signal-to-noise ratio of the read-out signal is of great importance. Combining transconductance with time-resolved reflectometry in a lock-in measurement scheme promises to significantly increase the signal-to-noise ratio. We use a high-mobility electron transistor (HEMT) with a layer of QDs that are coupled to a two-dimensional electron gas. This allows us to observe the tunneling dynamics between the 2DEG and the QDs in a reflectometry measurement setup. A high-frequency ac driving voltage in combination with a lock-in technique is set to an electrical resonance of an internal LC circuit. The reflected signal depends on the impedance of the sample, where the change in impedance is related the number of electron in the quantum dot layer, hence, to the tunneling dynamics.

[1] B. Marquardt. et al., Nature Commun. 2, 209 (2011).
[2] K. Eltrudis et al., Appl. Phys. Lett. 111, 092103 (2017).

HL 35.54 Wed 17:30 Poster E

Spatiotemporal Dynamics of correlated Carrier Wave Packets in Semiconductors — •Frank Lengers[1], Roberto Rosati[2], Tilmann Kuhn[1], and Doris E. Reiter[1] — [1]Westfälische Wilhelms-Universität Münster, Germany — [2]Chalmers University of Technology, Sweden

Highly focused optical excitation of semiconductors in real space results in strongly localized carrier distributions in the material. Subsequent transport of the excited carrier wave packets occurs on nanometer and picosecond scales and is influenced by the Coulomb interaction. Since the Coulomb interaction in heterostructures of low dimensionality is enhanced with respect to the bulk, we here study a one-dimensional quantum wire as an example system where strongly interacting electrons and holes can be excited. We treat a system of up to two photoexcited electron-hole pairs within a wave function approach and are thereby able to treat the carrier correlations exactly. The wave packet dynamics is analyzed as function of the excited density and excitation energy. We show that high densities can lead to travelling electron-hole wave packets or to enhanced wave packet broadening depending on the excitation conditions.

HL 35.55 Wed 17:30 Poster E

Charging dynamics of self-assembled InAs quantum dots in n-GaAs Schottky diodes — •Lars Kürten[1], Laurin Schnorr[1], Thomas Heinzel[1], Sven Scholz[2], Arne Ludwig[2], and Andreas D. Wieck[2] — [1]Lehrstuhl für Festkörperphysik, Heinrich-Heine-Universität Düsseldorf — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

We study the charge transfer dynamics between self-assembled InAs quantum dots (SAQD) embedded in n-GaAs Schottky diodes and the space charge region by Laplace deep level transient spectroscopy (LDLTS). The filling dynamics of the electronic SAQD states are investigated at liquid nitrogen temperature as a function of the applied bias voltage and modeled using band structure calculations. We find a non-trivial dependence of the apparent total charge transfer on the bias voltage and are able to quantitatively model our data by assuming a competing re-emission of electrons during the filling process via separately measured emission paths.

HL 35.56 Wed 17:30 Poster E

Simulation of mode competition phenomena in (Al,In)GaN laser diodes — •Eduard Kuhn, Lukas Uhlig, Matthias Wachs, Ulrich T. Schwarz, and Angela Thränhardt — Institut für Physik, Technische Universität Chemnitz

Experiments show interesting mode competition phenomena in laser diodes. For example streak camera measurements show cyclic mode hopping, where the currently active mode changes from lower to higher wavelengths. This can be explained by third order effects such as beating vibrations of the carrier density. In this work we describe these mode dynamics using a model based on the semiconductor Bloch equations and discuss the influence of the Hartree-Fock terms and different dephasing terms.

HL 35.57 Wed 17:30 Poster E

Blue InGaAs-VECSELs for Rydberg atom spectroscopy — •Ana Ćutuk[1], Marija Ćurčić[2], Marius Plach[3], Richard Hermann[3], Marius Grossmann[1], Roman Bek[1], Robert Löw[3], Harald Kübler[3], Michael Jetter[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart — [2]Photonics Center, Institute of Physics, Belgrade, Serbia — [3]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

The Rydberg state of atoms is very attractive for applications in quantum information due to its large dipole moment, lifetime and polarizability. For the excitation of the Rydberg states in rubidium and potassium, laser emission in the blue spectral range is necessary. The vertical external-cavity surface-emitting laser (VECSEL) turns out to be an excellent candidate due to its wavelength versatility and high output power combined with a near diffraction-limited beam profile and the flexibility to add optical components inside the cavity. Our focus is on the development of InGaAs-based VECSELs with the fundamental wavelength in the near-infrared spectral range. By inserting a BBO crystal in a v-shaped cavity, second harmonic generation at around 475 nm and 455 nm can be achieved. Further improvements will be made on reducing the laser linewidth to achieve single mode operation and with analog stabilization according to the Pound-Drever-Hall technique.

HL 35.58 Wed 17:30 Poster E

Characterization of mode competition phenomena in (Al,In)GaN laser diodes — •Lukas Uhlig, Eduard Kuhn, Matthias Wachs, Angela Thränhardt, and Ulrich T. Schwarz — Institute of Physics, Chemnitz University of Technology

(Al,In)GaN laser diodes have various recent applications, such as laser projection systems in augmented/virtual reality glasses, which require a modulation with frequencies ranging from 100 MHz to 1 GHz. Laser diodes show a rich dynamic behavior of the longitudinal modes on a nanosecond to microsecond time scale. We investigate the spectral-temporal dynamics of green InGaN laser diodes in high resolution using a streak camera setup combined with a monochromator. For interpretation we simulate the longitudinal mode dynamics using a multi-mode rate equation model.

The observed effects at pulse onset include the turn-on delay and relaxation oscillations as well as a fast red shift. In longer pulses, we investigate mode competition with mode hopping towards longer wavelengths, which repeats cyclically. Single shot measurements show significant variations between single pulses. Consequently, much of the dynamics cannot be observed in usual averaged / time-integrated characterization.

HL 35.59 Wed 17:30 Poster E

Towards mode locking with a membrane saturable absorber mirror — •Ana Ćutuk, Roman Bek, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Although providing several superior laser properties, the vertical

external-cavity surface-emitting laser (VECSEL) is limited to a certain range of laser wavelengths. An improvement can be made by removing the Bragg reflector and sandwiching the active region between heat spreaders and using another external dielectric mirror in the cavity instead. This membrane external-cavity surface-emitting laser (MECSEL) now allows for an extension of laser wavelengths and therefore new applications. A similar procedure can also be transferred to semiconductor saturable absorber mirrors (SESAMs) for mode-locked laser operation in order to extend the application range even further.

We present the concept of a membrane saturable absorber mirror (MESAM). Instead of a semiconductor DBR, a simple dielectric mirror is used as a cavity end mirror. The absorber active region containing two GaInP quantum wells is wet-chemically released from the substrate and then bonded onto the dielectric mirror in order to simulate a SESAM device. The MESAM is employed in a v-shaped VECSEL cavity to achieve pulsed laser emission in the red spectral range. Current investigations focus on achieving stable mode-locked operation and on the characterization of the MESAM nonlinear reflectivity.

HL 35.60 Wed 17:30 Poster E

Towards near-infrared emitting InP quantum dot VECSELs — •Marius Grossmann, Lea Stassen, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

The near-infrared spectral range has various applications in atom spectroscopy as well as medicine. These benefit from a diffraction-limited beam profile and high output powers which can be obtained using e.g. vertical external-cavity surface-emitting lasers (VECSELs). Implementing quantum dots (QDs) as the active region provides advantages compared to quantum well (QW) VECSELs such as a decreased lasing threshold and temperature dependence, improved gain and tunability of emission wavelength. Especially the wavelength flexibility allows a target emission wavelength just above 700 nm, where GaInP and AlGaAs QWs suffer from high compressive strain and oxidation, respectively.

Our semiconductor structures comprise an InP QD/AlGaInP active region and VECSEL structures are fabricated including AlGaAs/AlAs based DBRs grown using metal-organic vapor-phase epitaxy.

Current research focuses on optimization of growth parameters of the individual active region layers in view of spectral and luminescence properties as well as interfacial morphology.

HL 35.61 Wed 17:30 Poster E

Monolithic quantum well mode-locked laser subject to short optical feedback with nanometric resolution — •Pascal Sauer[1], Dominik Auth[1], Christoph Weber[1], Andreas Klehr[2], Andrea Knigge[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

Self feedback by long external optical cavities significantly enhances the timing stability and repetition rate agility of optical pulse trains generated by monolithic passively mode-locked semiconductor lasers. The impact of very short feedback cavities with nanometric feedback delay control has recently been suggested and studied by simulations [Simos et al., Appl. Phys. B 123 (2017), 222]. In this contribution, the impact of a free-space external cavity configuration with macroscopic delay lengths ranging from 10 mm to 40 mm and nanometric resolution fine-delay control on the emission properties of a quantum-well passively mode-locked semiconductor laser emitting at 1070 nm at a free-running repetition rate of 13.6 GHz is studied experimentally. Wavelength scale dynamics of the center wavelength, the repetition rate and the optical output power are identified experimentally and discussed in the framework of recent long-cavity optical self feedback results [Auth et al., Electron. Lett. 54 (2018), 374].

HL 35.62 Wed 17:30 Poster E

Self mode-locked monolithic quantum dash lasers emitting at 1535 nm subject to optical self feedback by complex external cavity geometries — •Patrick Fiala[1], Dominik Auth[1], Christoph Weber[1], Klara Maria Neumann[1], Quentin Gaimard[2], Abderrahim Ramdane[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Centre de Nanosciences et Nanotechnologies (C2N), CNRS, Marcoussis 91460, France

The impact of optical self feedback onto self mode-locked quantum dash lasers emitting at 1535 nm is investigated in dependence of feedback cavity geometry and varying optical feedback strengths. The linear external cavity with a broadband reflecting mirror is compared to a ring geometry [Haji et al., Opt. Express 20 (2012), 3268-74] and a teardrop geometry [Liu et al., Appl. Phys. Lett. 113 (2018), 041108]. These complex feedback geometries deliver bi-directionally propagating feedback signals. The experimental results are compared to a mono-directional self feedback geometry. The obtained experimental results are validated by applying a stochastic time-domain model [Drzewietzki et al., Opt. Express 21 (2013), 16142].

HL 35.63 Wed 17:30 Poster E

Response of passively mode-locked quantum-well and quantum dot lasers subject to optical self feedback — •Dominik Auth[1], Christoph Weber[1], Igor Krestnikov[2], Andreas Klehr[3], Andrea Knigge[3], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Innolume GmbH, Konrad-Adenauer-Allee 11, 44263 Dortmund, Germany — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

In this conference contribution the response of two monolithic passively mode-locked semiconductor lasers are compared whereby one laser has a quantum-well gain material and the other laser consists of a quantum dot gain material. Both as-cleaved lasers are 3 mm long with a saturable absorber section length of 10%. The two lasers are studied in an optical self feedback set-up with an optical feedback cavity length of 5.9 m and are compared by adapting a stochastic time-domain model [Drzewietzki et al., Opt. Express 21 (2013), 16142] to predict the repetition rate tuning trends, timing jitter reduction and response to optical self feedback.

HL 35.64 Wed 17:30 Poster E

Optical frequency comb quantum dash semiconductor lasers subject to optical self feedback — •Patrick Fiala[1], Dominik Auth[1], Christoph Weber[1], Quentin Gaimard[2], Abderrahim Ramdane[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Centre de Nanosciences et Nanotechnologies (C2N), CNRS, Marcoussis 91460, France

Self mode-locked quantum dash lasers emitting at 1535 nm are compact photonic sources for broadband optical frequency comb generation. They find application as super-channel sources in datacom. Their mode comb spacing can be dynamically controlled by optical self feedback [Fiala et al, DPG Spring Meeting Berlin (2018), DY 69.18]. In this work, the impact of different optical feedback delays and strengths on the radio-frequency line width, the repetitions rate and thus the comb mode spacing are investigated experimentally. Feedback cavity lengths range from 6 m to 73 m. A dynamic mode spacing control from 2 to 22.5 MHz is demonstrated. A considerable reduction in RF line width from 20 kHz (free-running) to 2.5 kHz is reported. The experimental results are confirmed by a simple stochastic time-domain model [Drzewietzki et al., Opt. Express 21 (2013) 16142; Auth et al., Electron. Lett. 54 (2018), 374].

HL 35.65 Wed 17:30 Poster E

Synchronization of two mutually optically injected passively mode-locked quantum dot lasers — •Christoph Weber[1], Dominik Auth[1], Iraklis Hercules Simos[2], Christos Simos[3], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Electrical and Electronics Engineering, University of West Attica, Athens, Greece — [3]Department of Electronic Engineering, Technological Educational Institute of Sterea Ellada, 35100 Lamia, Greece

All-optical mutual injection is proposed to be a new technique for synchronization of two or more mode-locked semiconductor lasers with applications for example in novel secure communication schemes or optical clock synchronization, as initially theoretically predicted in [Simos et al., IEEE J.Quantum Electron. 54 (2018), 2001106]. In this contribution, two passively mode-locked quantum dot semiconductor lasers emitting at 1250 nm are mutually injected by a free-space all-optical experimental configuration. Pulse train repetition

rate and laser emission wavelength synchronization are experimentally demonstrated across a broad operating regime. Emission dynamics are analysed as a function of optical delay time and laser biasing conditions. A broad synchronization regime spanning 150 mA is reported. Simulations are in good agreement with the experimental results.

HL 35.66 Wed 17:30 Poster E

Ultrafast pulse generation and pulse train stability of an InP generic foundry platform passively mode-locked symmetric ring laser with dual saturable absorbers — •Christoph Weber[1], Mu-Chieh Lo[2], Dominik Auth[1], Patrick Fiala[1], Pascal Sauer[1], Guillermo Carpintero[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Departamento de Tecnología Electrónica, Universidad Carlos III de Madrid, Av de la Universidad, 30. 28911 Leganés, Madrid, Spain

Passively mode-locked semiconductor lasers in photonic integrated circuits are promising compact sources for generating coherent optical frequency combs and ultrashort optical pulse trains for metrology, spectroscopy and millimeter wave/terahertz applications. An InP foundry-fabricated semiconductor ring laser emitting at 1570 nm with two saturable absorbers is experimentally investigated. A symmetry geometry allows the circulating optical pulses to collide in the two reverse-biased saturable absorbers placed opposite to each other enhancing the pulse shortening. Stable optical pulse trains with repetition rates at 23.3 GHz, spectral bandwidth exceeding 10 nm, a radio-frequency line width of 80 kHz corresponding to a pulse-to-pulse timing jitter of 31.7 fs and optical pulses as short as 1.2 ps at a time-bandwidth-product of 0.7 are experimentally reported.

HL 35.67 Wed 17:30 Poster E

External optical self feedback stabilization of an InP generic foundry platform based passively mode-locked ring laser — •Dominik Auth[1], Mu-Chieh Lo[2], Christoph Weber[1], Patrick Fiala[1], Pascal Sauer[1], Guillermo Carpintero[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Departamento de Tecnología Electrónica, Universidad Carlos III de Madrid, Av de la Universidad, 30, 28911 Leganés, Madrid, Spain

Passively mode-locked semiconductor ring lasers in photonic integrated circuits (PIC) platforms are promising compact sources for generating ultrashort optical pulse trains for telecommunication applications at 1550 nm. To allow for a dynamic mode spacing or pulse train repetition rate control, in this contribution, the impact of optical self feedback on a PIC ring laser is demonstrated experimentally. A stochastic time-domain model [Drzewietzki et al., Opt. Expr. 21 (2013), 16142] is applied to confirm the repetition rate tuning trends and pulse timing jitter reduction. A considerable improvement of the pulse train stability is reported. Thereby, the impact of the optical feedback strength and the macroscopic and microscopic optical feedback length on the stability of the emitted pulse train is studied experimentally and by modelling.

HL 35.68 Wed 17:30 Poster E

Optical pulse train stability of monolithic passively mode-locked quantum dot lasers on silicon emitting at 1310 nm — Dominik Auth[1], Songtao Liu[2], •Stefan Breuer[1], and John Bowers[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106-9560, USA

Passively mode-locked InAs/InGaAs quantum dot lasers directly grown on silicon and emitting at 1310 nm are promising sources for high-speed, high-capacity communication applications. Their ultrafast carrier dynamics, broadband gain spectra and easily saturated gain and absorption allow for the generation of ultra-short optical pulses [Liu et al., Appl. Phys. Lett. 113 (2018), 041108]. In this contribution, the pulse train stability of monolithic passively mode-locked quantum dot lasers consisting of InAs/InGaAs dots-in-a-well structures and directly grown on on-axis (001) Si is experimentally studied. Pulse train stability is quantified by relative amplitude jitter and pulse-to-pulse timing jitter in the radio-frequency domain and is complemented by temporal and spectral domain analysis. Stable mode-locking with a pulse-to-pulse timing jitter well below 100 fs, ultra-low relative amplitude jitter and optical spectra widths exceeding 5 nm are experimentally demonstrated.

HL 35.69 Wed 17:30 Poster E

Experimental studies on modal gain, absorption and dispersion of nanostructured edge-emitting monolithic semiconductor lasers — Felix Wilke[1], Stefan Heppe[1], •Christoph Weber[1], Dominik Auth[1], Quentin Gaimard[2], Abderrahim Ramdane[2], Andreas Klehr[3], Andrea Knigge[3], Igor Krestnikov[4], Thomas Walther[1], Jérôme Faist[5], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Centre de Nanosciences et Nanotechnologies (C2N), CNRS, Marcoussis 91460, France — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany — [4]Innolume GmbH, Konrad-Adenauer-Allee 11, 44263 Dortmund, Germany — [5]Institute for Quantum Electronics, ETH Zürich, Auguste-Piccard-Hof 1, 8093 Zürich, Switzerland

The generation of stable and ultrafast optical pulse trains by edge-emitting monolithic passive mode-locked and self mode-locked semiconductor lasers in the near-infrared wavelength range requires a delicate balance of differential gain, absorption and dispersion. Spectrally resolved modal gain, absorption and group delay dispersion properties of monolithic cavity single-section and two-section semiconductor lasers with quantum well and nanostructured active regions are studied experimentally. The laser structures include quantum well lasers emitting at 1070 nm, quantum dot lasers emitting at 1250 nm and quantum dash lasers emitting at 1550 nm.

HL 35.70 Wed 17:30 Poster E

Emission dynamics of monolithic broad-area InAs/InGaAs quantum dot lasers — •Dominik Auth[1], Christoph Weber[1], Stefan Breuer[1], Vladimir V. Korenev[2], Artem V. Savelyev[2], Mikhail V. Maximov[2], and Alexey E. Zhukov[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]St. Petersburg Academic University RAS, ul. Khlopina 8/3, 194021 St. Petersburg, Russia

Monolithic mode-locked edge-emitting semiconductor quantum dot lasers emitting at 1.31 micrometer are ideal sources for the generation of broad optical frequency combs for short-reach inter and intra data-center links. In this contribution, the emission dynamics of InAs/InGaAs quantum dot lasers with broad-ridge waveguide are studied experimentally. Our analysis focuses on spectral, radio-frequency and time-domain analysis as well as initial spectro-temporal emission properties. This work is supported by the Russian Foundation for Basic Research (project #18-502-12081).

HL 35.71 Wed 17:30 Poster E

Modal gain and dispersion of monolithic broad-area InAs/InGaAs quantum dot lasers — •Dominik Auth[1], Christoph Weber[1], Stefan Breuer[1], Vladimir V. Korenev[2], Artem V. Savelyev[2], Mikhail V. Maximov[2], and Alexey E. Zhukov[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]St. Petersburg Academic University RAS, ul. Khlopina 8/3, 194021 St. Petersburg, Russia

Monolithic mode-locked edge-emitting semiconductor quantum dot lasers emitting at 1.31 micrometer are ideal sources for the generation of broad optical frequency combs for short-reach inter- and intra data-center links. The modal dispersion and gain properties determine their suitability for ultrashort optical pulse generation by mode-locking. In this contribution, the modal gain and dispersion properties of InAs/InGaAs quantum dot lasers with broad-ridge waveguide are studied experimentally. Our analysis focuses on spectrally-resolved gain and group delay dispersion analysis. This work is supported by the Russian Foundation for Basic Research (project #18-502-12081).

HL 35.72 Wed 17:30 Poster E

Optical frequency comb splitting of nanostructured semiconductor lasers — •Christoph Weber[1], Lorenzo L. Columbo[2], Paolo Bardella[2], Luke F. Lester[3], Stefan Breuer[1], and Mariangela Gioannini[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Electronics and Telecommunications, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy — [3]Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, Virginia 24061, USA

Self mode-locked semiconductor lasers with nanostructured active regions based on quantum wells, quantum dashes, quantum dots or quan-

tum cascade lasers are promising optical frequency comb sources in crucial wavelength ranges for e.g. optical communication or spectroscopy applications. We experimentally investigate and study by simulations the spectral emission of a single-section InAs/InGaAs quantum dot laser emitting at near infrared wavelengths. We recently identified a temperature dependent mode-locking threshold [Bardella et al., Proc. SPIE 10682 (2018), 1068223], where unlocked multimodal emission switches to mode-locked emission. At this threshold, a splitting in the optical comb is detected and further analyzed in dependence of applied gain current and device temperature. We discuss the obtained results in the framework of published results on nanostructured semiconductor lasers within a broad emission wavelengths range.