HL 21: Quantum Dots and Wires, Optical Properties I: Nitrides

Time: Tuesday 9:30–11:15 Location: H17

HL 21.1 Tue 9:30 H17

Theory for Optical Properties of Nitride-based Quantum Dot Systems — •Kolja Schuh, Michael Lorke, Jan Seebeck, Stefan Schulz, Paul Gartner, Gerd Czycholl, and Frank Jahnke — Institute for Theoretical Physics, University of Bremen, Germany

The influence of structural properties and interaction-induced effects on optical spectra of self-assembled Nitride-based quantum-dot (QD) systems is analyzed within a microscopic theory. Beside the QDs, the wetting-layer (WL) plays an important role for laser applications since it is involved in the carrier generation and scattering processes, which modify the optical properties of the QDs. The single-particle properties are determined on an atomistic level from tight-binding calculations [1]. Coulomb interaction effects and carrier-phonon interaction are considered in a second step to study excitation-induced effects for elevated carrier densities at room temperature.

Numerical results are presented for InN/GaN QD-WL systems. Nearly degenerate top valence-subbands lead to strong subband mixing [1, 2]. We also find modified dipole selection rules with a dark ground state exciton and rather strong excitation-induced line shifts of the QD transitions in addition to the excitation-induced line-broadening [3]. While these results are masked in conventional lasers due to strong inhomogeneous broadening, they are directly relevant for the application of QDs in microcavity lasers.

[1] S. Schulz et al., Phys. Rev. B 73, 245327(2006)
[2] S.L. Chuang et al., Phys. Rev. B 54, 2491(1996)
[3] M. Lorke et al., APL 95, 081108 (2009)

HL 21.2 Tue 9:45 H17

Polarization-induced charge carrier separation in GaN quantum dots on polar and nonpolar surfaces — •Oliver Marquardt, Tilmann Hickel, and Jörg Neugebauer — Max-Planck-Institut für Eisenforschung, Düsseldorf

Wurtzite III-nitride quantum dots (QDs) show a strongly reduced light emission efficiency when grown in the polar direction, due to strong built-in potentials which spatially separate electrons and holes, leading to weak recombination rates. To overcome this problem, QDs grown on nonpolar substrates have received much research interest, recently. We have compared GaN QDs grown on polar and nonpolar surfaces using an eight-band $\mathbf{k}\cdot\mathbf{p}$ model, employing geometries observed in recent experimental studies. Our studies indicate that the spatial separation of electrons and holes is even larger in QDs on nonpolar surfaces than in polar ones of comparable size, leading to even weaker recombination rates. A systematic investigation of various modifications on the above reference systems allowed us to identify the size of nonpolar QDs as the key parameter to achieve a higher efficiency in light emission processes. In particular, it has been found that this effect is stronger in nonpolar than in polar QDs by several orders of magnitude, making nonpolar QDs a promising research object for future light emission devices.

HL 21.3 Tue 10:00 H17

Microphotoluminescence Investigations of Single Group-III-Nitride Quantum Dots — •Stefan Werner, Christian Kindel, Thomas Switaiski, and Axel Hoffmann — Institut für Festkörperphysik, Technische Universität Berlin

The optical research of single InGaN quantum dots is difficult due to the fact that their emission lines are significantly broadened. The emission energies of wurtzite InGaN QDs are strongly influenced by fluctuating electric fields, resulting in line-width broadening. We present spatially- and time-resolved photoluminescence measurements of single InGaN/GaN quantum dots. Therefore, a new microphotoluminescence setup was built. In order to investigate the behavior of different excitonic complexes and their recombination dynamics, power, polarization and time-dependent measurements were performed. Some lines saturate at high-power excitation, giving an indication for exciton-like behavior. Others have a super-linear intensity increase. Those lines might be biexcitionic. Most emission lines showed a strong linear polarization but with different polarization angels. That fact helps to assign the lines to different quantum dots. The presented time-resolved PL measurements might give addional informations about the origin of the observed emission lines. For some lines, the decay time is increased by a factor of 2 in respect to other lines, indicating biexcitionic behavior.

HL 21.4 Tue 10:15 H17

Electroluminescence from an isolated single InGaN QD up to 150 K in the green spectral region — •Joachim Kalden, Christian Tessarek, Kathrin Sebald, Stephan Figge, Carsten Kruse, Detlef Hommel, and Jürgen Gutowski — Institute of Solid State Physics, University of Bremen, P.O. Box 330 440, D-28334 Bremen, Germany

Semiconductor quantum dots (QDs) are known to be favourable for solid state single photon sources. As state-of-the-art detectors have their efficiency maximum in the green spectral region, InGaN QDs are particularly suitable to realize such devices, providing emission in the visible spectral range. However, only few reports exist on the electroluminescence (EL) of nitride QDs. We present EL from a p-i-n diode containing InGaN QDs as active layer. The onset bias is 3.15 V at room temperature (RT), which is raised to 8.8 V at 4 K mainly due to carrier freeze-out effects. The intensity at RT remains at 28% of the intensity at 4 K. Further, slope variation or shift of the ensemble EL are shown to be negligible at RT for driving currents from 10 mA to 150 mA. This demonstrates the excellent stability of the EL. At 4 K and for a constant driving current of 19 mA, sharp emission lines are detectable nearly background-free at the lower energy tail of the emission band. EL from an isolated single InGaN QD emitting at 527 nm is obtained from 4 – 90 K. From 100 K onwards, the distinct QD emission is still visible may be traced up to 150 K as a shoulder on a raising background. These results hold much promise for future electrically driven single photon emission at room temperature.

HL 21.5 Tue 10:30 H17

Electronic and optical properties of nitride semiconductor quantum dots with wurtzite structure — •Stefan Barthel, Daniel Mourad, and Gerd Czycholl — Institut für Theoretische Physik, Universität Bremen, 28359 Bremen

A multiband empirical tight-binding model for group-III-nitride semiconductors with a wurtzite structure has been developed and applied to the calculation of the electronic and optical properties of (embedded) InN/GaN quantum dots. As a minimal basis set we assume one s-orbital and three p-orbitals localized in the unit cell of the hexagonal Bravais lattice, from which one (s-like) conduction band and three (p-like) valence bands are formed. Non-vanishing matrix elements up to second nearest neighbors are taken into account. These matrix elements are determined so that the resulting tight-binding band-structure reproduces the known Γ-point parameters. Furthermore, the tight-binding band-structure is also fitted to the band energies at other special symmetry (boundary) points of the Brillouin zone (known, in particular, from recent first-principles GW-calculations). These matrix elements allow for supercell calculations of the electronic properties of single and coupled quantum dots and for a separate wetting layer (quantum well) treatment. Crystal-field-splitting, spin-orbit coupling and the influence of intrinsic fields (spontaneous polarization, etc.) can be taken into account. The calculation of dipole and Coulomb matrix elements allows for the determination of excitonic spectra and selection rules within the configuration interaction (CI) scheme.

HL 21.6 Tue 10:45 H17

Complete Study of Excitonic Fine-Structure Splitting in GaN/AlN Quantum Dots — •Gerald Hönig[1], Momme Winkelnkemper[1], Andrei Schliwa[1], Axel Hoffmann[1], Dieter Bimberg[1], Christian Kindel[1,2], Satoshi Kako[3], Takeshi Kawano[2], Hiroaki Oishi[2], and Yasuhiko Arakawa[2,3,4] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, D-10623 Berlin, Germany — [2]Research Center for Advanced Science and Technology, University of Tokyo, Japan — [3]Institute for Nano Quantum Information Electronics, University of Tokyo, Japan — [4]Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro, Tokyo 153-8505, Japan

A detailed understanding of the excitonic fine structure in quantum dots (QDs) is indispensable for their use in quantum cryptography devices. While the fine structure in As-based QDs has been studied extensively, there is a lack of such investigations for N-based QDs, which might operate at room temperature. We present the first complete study of excitonic fine-structure splitting (FSS) in GaN/AlN QDs. Our experimental studies reveal a huge FSS of up to 7meV with a strong dependence on the emission energy inverse to that in As-based QDs. Our theoretical studies, performed with a configuration-interaction method based on realistic 8-band-$k \cdot p$ Hartree-Fock states, confirm the experimental results and identify the origin of FSS as lattice strain induced. Based on our results it is possible to induce a strain gradient (by micro mechanic techniques or structuring methods), which will reduce the FSS to zero for the emission of entangled photon pairs.

HL 21.7 Tue 11:00 H17

Optical properties of GaN/AlGaN heterostructures embedded in GaN nanowires — Florian Furtmayr[2], •Jörg Teubert[1], Pascal Becker[1], Martin Stutzmann[2], and Martin Eickhoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität, 34392 Gießen, Germany — [2]Walter Schottky Institut, Technische Universität München, 85748 Garching, Germany

A fascinating property of self-assembled III-N nanowires grown by molecular beam epitaxy (MBE) is their high crystal quality as it provides the possibility to perform fundamental studies of the material properties without the perturbing influence of structural defects. In this context, heterostructures such as quantum wells embedded in nanowires are of special interest. We report on structural and optical properties of GaN/$Al_xGa_{1-x}N$ nanowires with embedded GaN nanodisks grown by plasma assisted MBE on Si(111) substrates. Lateral overgrowth with the AlGaN barrier material during the synthesis of multi quantum-disk structures leads to the formation of a core-shell system that influences the mechanical strain in the quantum well regions. The effect on the optical properties of multi quantum-disk structures was investigated by temperature dependent photoluminescence measurements on samples with different structural parameters. The results will be discussed in terms of carrier confinement, strain and piezoelectric effects and will be compared to theoretical simulations.