HL 7: Quantum dots: Optical properties I

Time: Monday 13:30–17:00 Location: BEY 118

HL 7.1 Mon 13:30 BEY 118

(111)-Grown InGaAs/GaAs Quantum Dots as Ideal Source for Entangled Photon Pairs — •Andrei Schliwa, Momme Winkelnkemper, and Dieter Bimberg — Inst. für Festkörperphysik, TU-Berlin

For a number of protocols of future secure communication systems the generation of entangled photon pairs are essential. Thier creation, based on the XX => X => 0 recombination cascade in QDs, requires necessarily a vanishing excitonic fine-structure splitting (fss). The latter is hard to achieve for QDs grown on (001)-substrate, because piezoelectricity and QD elongation induce a lateral anisotropy leading to sizable values of the fss. The structural anisotropy and the piezoelectricity are intrinsic characteristics of the (001) substrate orientation featuring different surface mobilities along [110] and [1-10] and polar axes with non-vanishing projections on the growth plane. Therefore, we propose the use of QDs grown on (111)-GaAs substrates. Using eight-band k.p theory in conjunction with an enhanced configuration interaction (CI) method we calculate the fss for (111)-grown QDs in conjunction with their exciton-biexciton separation as function of size, aspect ratio and chemical composition. Assuming an, at least, threefold rotational structural symmetry of the Qds, we show that the corresponding piezoelectric field does not lower this symmetry any further. Thus, the excitonic bright states remain degenerate; an intrinsically perfect source of entangled photon pairs is available. This result is of general character and applies to all self-organized QDs in the zinc-blende system.

HL 7.2 Mon 13:45 BEY 118

InGaAs QDs on GaAs(111) substrate for entangled photon pairs — •Irina Ostapenko[1], Andrei Schliwa[1], Erik Stock[1], Sven Rodt[1], Vladimir Haisler[2], and Dieter Bimberg[1] — [1]IFP, TU Berlin — [2]Institute of Semiconductor Physics, Novosibirsk, Russia

Quantum dots (QDs) are ideally suited for the generation of polarization-entangled photon pairs [1] that enable certain quantum cryptography protocols [2] and quantum teleportation [3]. However, even a small fine-structure splitting of the bright-exciton state may hinder the formation of such pairs based on the biexciton to exciton to vacuum recombination cascade. Our recent calculations [4] have revealed that growth of InGaAs QDs on GaAs(111) substrates leads to a vanishing fine-structure splitting. Here we expect a three-fold rotational symmetry in the growth plane and piezoelectric effects will not reduce the symmetry of the confining potential in contrast to QDs grown on GaAs(001) substrates [5]. We report on a successful approach to grow such QDs via droplet-mode MBE. Optical characterization is performed by cathodoluminescence and electroluminescence in combination with metal shadow masks. The results are compared to droplet-exiptaxy QDs on "standard" GaAs(001) substrates.

[1] O. Benson et al., Phys. Rev. Lett. 84, 2513 (2000)
[2] A. K. Ekert, Phys. Rev. Lett. 67, 661 (1991)
[3] T. Jennewein et al.,Phys. Rev. Lett. 88, 017903 (2002)
[4] A.Schliwa et al., Deutsche Patentanmeldung (2008)
[5] O.Stier et al., Phys. Rev. B 59, 8 (1999)

HL 7.3 Mon 14:00 BEY 118

Time-resolved studies of pulsed electrical spin initialization in single InGaAs quantum dots — •P. Asshoff, W. Löffler, J. Zimmer, H. Flügge, H. Füser, M. Hetterich, and H. Kalt — Institut für Angewandte Physik, Universität Karlsruhe (TH), and DFG Center for Functional Nanostructures, CFN, D-76128 Karlsruhe

For spin-injection light-emitting diodes with a diluted magnetic semiconductor as spin aligner, we have recently demonstrated that the achievable spin-injection fidelity in quantum dots ranges from near-unity to even negative values depending on the individual dot. To study the origin of this phenomenon, we investigated the temporal behavior of the spin-injection fidelity using ns-pulses for the electrical injection into the dots. In quantum dot ensemble measurements, we clearly see that the polarization degree drops within the first nanoseconds of the electrical pulse. Measurements concerning the temporal evolution of the polarization degree for single quantum dots as well as approaches to theoretically model the observed dynamics will be presented. The latter should open up the possibility to relate the spin-injection fidelity of individual quantum dots to scattering mechanisms, which may allow for improved designs to enhance spin injection significantly. Furthermore, our time-resolved studies of the pulsed spin initialization process are a first step towards future spin manipulation experiments.

HL 7.4 Mon 14:15 BEY 118

Microphotoluminescence on in situ stressed single InAs quantum dots — •Sven Wildfang, Matthias Klingbeil, Matthias Grave, Andrea Stemmann, Christian Heyn, Wolfgang Hansen, Detlef Heitmann, and Stefan Mendach — Institut für Angewandte Physik, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg

We have set up an experiment that enables us to vary and control the strain state of self-assembled InAs quantum dots (QDs) utilizing a micro mechanical device. We monitor the energy spectrum of a single QD by means of microphotoluminescence. When applying stress to a QD we find a reversible change in the spectrum. The distributions of stress in our structure during the experiments were simulated with COMSOL Multiphysics. The simulations were based on the works of van de Walle [1]. We simulated the behavior of the global band gap of InAs embedded in GaAs under stress induction. The results of our simulations could in principle be verified. Additionally in high resolution measurements we observe a change in the relative energy spacing both in the s- and the p-shell transitions. This arises from a change of the shape of the confining potential of a QD. [2, 3, 4]

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

[1] C. G. Van de Walle, Phys. Rev. B 39, 1871 (1989).
[2] A. Schliwa et al., Phys. Rev. B 76, 205324 (2007).
[3] M. Grundmann et al., Phys. Rev. B 52, 11969 (1995).
[4] S. Mendach et al., Phys. Rev. B 78, 035317 (2008).

15 min. break

HL 7.5 Mon 14:45 BEY 118

Cavity-enhanced emission of single photons by electrically driven InGaAs/GaAs-Quantum dot based RC-LEDs — •Jan Amaru Töfflinger[1], Erik Stock[1], Anatol Lochmann[1], Dieter Bimberg[1], Askhat K. Bakarov[2], Aleksandr I. Toropov[2], Aleksandr K. Kalagin[2], and Vladimir A. Haisler[2] — [1]Institut für Festkörperphysik, TU-Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institute of Semiconductor Physics, Lavrenteva avenue 13, 630090 Novosibirsk, Russia

In order to optimize single photon emitting devices we developed Resonant-Cavity LEDs (RC-LED). MBE was employed to grow quantum dot densities of about $10^8 cm^{-2}$. Such devices are a key for the realization of quantum cryptography systems. A main feature of our RC-LEDs is a built-in AlGaO current aperture allowing us to electrically excite a single quantum dot at very low currents below 15 nA. A specially designed resonant cavity leads to increased external quantum efficiency due to an increase of the spontaneous emission rate by the Purcell effect and a controlled direction of emission. We were able to focus on our APD-detectors a photon rate of almost 10^9 photons/sec which is a factor 10 times higher compared to devices without a resonant cavity [1]. Photon-correlation measurements prove that indeed single photons are emitted by a single quantum dot at a wavelength of about 940nm. This work is partly funded by the SfB 787 and the NATO SfP 982735.

[1] A. Lochmann et al., Electron. Lett. 42, 774 (2006)

HL 7.6 Mon 15:00 BEY 118

Electronic and optical properties of laterally coupled InGaAs quantum dots — •Jie Peng and Gabriel Bester — Max Planck Institute for Solid State Research, Stuttgart, Germany

We calculate the electronic and optical properties of laterally coupled InGaAs/GaAs quantum dot molecules under lateral electric field using empirical pseudopotentials and configuration interaction. Our model structure is directly taken from recent experiments where an In-poor basin develops below the dots. The coupling of the electron states is significantly enhanced by the presence of the basin, while the holes remain mainly uncoupled. At the proper electric field —between 0 V/cm and 300 V/cm, depending on the dot molecule— the electron states can be tuned to be evenly distributed between both dots, form-

ing bonding and antibonding states. The optical absorption is shown to exhibit two bright transitions, mostly independent of the applied field. In emission, we argue that a fast electron-dynamics must be introduced, since the electrons are not subject to a true potential barrier between the dots and consequently only the lowest of the electron states is occupied. Following this approach, we obtain only one bright peak at high electric fields and two peaks (at higher temperature, four peaks) at the tuning point of the electron states. The results are shown to compare very well with recent experiments. A simple 4x4 Hamiltonian is derived to explain the results in the intuitive dot-localized basis.

HL 7.7 Mon 15:15 BEY 118

Piezoelectric versus shape-induced optical anisotropy of InAs/GaAs quantum dots — •Thomas Eissfeller, Stefan Birner, Till Andlauer, and Peter Vogl — Walter Schottky Institut, TU München, 85748 Garching

We predict anisotropic optical properties of self-assembled overgrown InAs/GaAs quantum dots invoking a detailed 3D electronic structure theory such as implemented in nextnano. For InAs quantum dots grown on [001] n-GaAs substrate, a strong optical anisotropy between [1$\bar{1}$0] and [110] linearly polarized light has been observed experimentally for the two lowest intrasubband s-p$^-$ and s-p$^+$ transitions within the conduction band. Here, p$^-$ and p$^+$ are the first two excited quantum dot states and are oriented along [1$\bar{1}$0] and [110]. We show that the experimentally observed energy splitting of a few meV between the p$^-$ and p$^+$ state with $E(p^-) < E(p^+)$ can be explained satisfactorily by an elaborate 3D 8-band k.p model that includes the linear piezoelectric effect but does not include higher order piezoelectric couplings. Previous work [1] suggested a different result since the piezoelectric potential was incorrectly rotated by 90°. We find that dot shape elongation along [1$\bar{1}$0] combined with the correct linear piezoelectric effect is incompatible with the experimental findings. However, we predict that for dot elongations along [100] or [010], the optical spectrum for linearly polarized light becomes nearly isotropic and both s-p$^-$ and s-p$^+$ transitions become allowed transitions. [1] A. Schliwa, M. Winkelnkemper, D. Bimberg, PRB **76** (2007)

HL 7.8 Mon 15:30 BEY 118

Effect of uniaxial stress on single particle states and fine structure splitting of excitons in InGaAs self-assembled quantum dots — •Ranber Singh and Gabriel Bester — Max Planck Institute for Solid State Research, Stuttgart, Germany

We investigate the effect of uniaxial stress on single particle states and fine structure splitting (FSS) of excitons in InGaAs self-assembled quantum dots by applying uniaxial stress along the [110] and [100] crystallographic directions using the empirical pseudopotential approach and configuration interaction. It is shown that the tuning of FSS in quantum dots is sensitive to the atomistic symmetry of the structures and the direction of applied stress. Related to the structure's symmetry, is the appearance of crossings as well as anti-crossings of the bright exciton lines. For stresses along [100], the minimum FFS is at 0 MPa (40 MPa) in InAs/GaAs ($In_{0.6}Ga_{0.4}As/GaAs$) dots. For the stress along [110] direction, the minimum FFS is at -19 MPa (-40 MPa) in InAs/GaAs ($In_{0.6}Ga_{0.4}As/GaAs$) dots. The single particle energies of S, P electron and hole states increases linearly with the increase in stress. The P hole states tend to spilt under [110] stress, while P electron states show no significant splittings.

15 min. break

HL 7.9 Mon 16:00 BEY 118

(111)-Grown InGaAs/GaAs Quantum Dots as Ideal Source for Entangled Photon Pairs — •Andrei Schliwa, Momme Winkelnkemper, and Dieter Bimberg — IFP, Fak. II, TU-Berlin

For a number of protocols of future secure communication systems the generation of entangled photon pairs are essential. Their creation, based on the $XX \rightarrow X \rightarrow 0$ recombination cascade in QDs, requires necessarily a vanishing excitonic fine-structure splitting (fss). The latter is hard to achieve in a controlled way for QDs grown on (001)-substrate. Dot to dot variations of piezoelectricity and QD elongation, which induce a lateral electronic anisotropy, lead to variations of the fss. The structural anisotropy and the piezoelectricity are intrinsic characteristics of the (001) substrate orientation featuring different surface mobilities along [110] and [1-10] and polar axes with non-vanishing projections on the growth plane. Therefore, we propose the use of QDs grown on (111)-GaAs substrates. Using eight-band $\mathbf{k}\cdot\mathbf{p}$ theory in conjunction with an improved configuration interaction method we calculate the fss for (111)-grown QDs together with the biexciton binding energy as function of size, aspect ratio and chemical composition. Assuming a threefold rotational structural symmetry of the QDs, we show that the corresponding piezoelectric field does not lower this symmetry any further. Thus, the excitonic bright states remain degenerate and the $XX \rightarrow X \rightarrow 0$ cascade presents an intrinsically perfect source of entangled photon pairs. This result is of general character and applies to all self-organized QDs in a zinc-blende system [1].

[1] Deutsche Patentanmeldung Nr.: 10 2008 036 400.2

HL 7.10 Mon 16:15 BEY 118

Independent Tuning of Different Few Particle States in Single InGaAs Quantum Dots Using Lateral Electric Fields — •Malte Frederik Huck, Michael Kaniber, Max Bichler, and Jonathan James Finley — Walter Schottky Institut, Technische Universität München, Am Coulombwall 3, 85748 Garching

We present studies of the optical emission from single quantum dots (QDs) subject to electric field perturbations applied in the plane of the QDs. The samples consist of low density ($\sim 5\mu m^{-2}$) self-assembled InGaAs QDs grown by molecular beam epitaxy embedded in a GaAs slab. Metal split gate contacts with a 2μm separation were established on top of the sample allowing the optical properties of the QDs to be probed with static electric fields up to 50 kV/cm. Photoluminescence and photocurrent measurements were performed to identify the different charge configurations of the QD and to study the influence of the external electric fields on the corresponding few particle states. We observe pronounced energy shifts of individual emission lines up to $|\Delta E|$=4meV, due to the quantum confined Stark effect. Surprisingly, different states from the same QD are found to exhibit characteristic red- and blue-shifts. This behaviour is attributed to the interplay between the field induced polarization of the state, producing the Stark shift, and the change of the Coulomb interaction and correlation effects. The observed shift rates are in good agreement with theoretical predictions. Our results show that single charge neutral exciton and biexciton transitions can be tuned into resonance, providing strong potential to realize a source of energy-time entangled photon pairs.

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Phonon replica of a single electrically pumped InAs/GaAs quantum dot from large diodes without current constriction — •Erik Stock[1], Andreas Baumgartner[2], Till Warming[1], Amalia Patane[2], Laurence Eaves[2], Mohamed Henini[2], and Dieter Bimberg[1] — [1]Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, D — [2]School of Physics and Astronomy, University of Nottingham NG7 2RD, UK

Electrical pumping of a single self organized quantum dots (QD) is essential for the fabrication of semiconductor based single photon and entangled photon pair sources. By controlling the applied bias we are able to pump a single quantum dot in a pin diode with a diameter of 200 μm containing a large number ($\approx 10^7$) of InAs/GaAs QDs. No current constriction or shadow mask were necessary to observe single well resolved ($<$ 0.2 meV) lines in the electroluminescence. This demonstrates the high carrier capture efficiency of a single QD.

We measure high resolution EL spectra, taken with large dynamic range. The observed emission line exhibits a broadening consistent with theoretically modelled acoustic phonon scattering. 36 and 39 meV below the emission line we observe a triangular shaped emission as it has been predicted theoretically for the optical phonon scattering [2]. These results show, how low-dimensional lattice vibrations couple to a single QD, which will be important for future applications. We acknowledge the SfB 787, NATO SfP 982735 and EPSRC, UK.

[1]L. Turyanska et al., Appl. Phys. Lett **89**, 092106 (2006) [2]E. A. Muljarov, and R. Zimmermann, Phys. Rev. Lett. **98**, 187401 (2007).

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Spectroscopic studies of stacked InGaAs QDs structures with and without strain coupling — •Lewis Lingys, Aleksandar Gushterov, and Johann-Peter Reithmaier — Universität Kassel, Technische Physik, Institut für Nanostrukturtechnologie und Analytik

InGaAs/GaAs quantum dots are of great interest for studying light-matter interactions on a basic level also leading to new device applications like quantum dot (QD) lasers or single-photon sources. Here we present spectroscopic studies of stacked QDs structures which consist of a number of alternating layers of InGaAs QDs and barriers of GaAs. The samples were grown with solid source molecular beam epitaxy (MBE). We investigated e.g. stacks with 30 layers of QDs with high dots density with absorption spectroscopy and photoluminescence (PL) spectroscopy in the regime where no strain coupling can be expected, i.e. with GaAs barrier thicknesses of 50 nm. Then we reduced the thicknesses of the barrier layers for different stacks down to regions where the formation of islands is influenced by the localized strain fields caused by the underlying dots layer. Absorption spectroscopy and PL spectroscopy provide here together a complementary analysis as for example absorption spectroscopy gives direct information about the wetting layer states whereas with PL spectroscopy in most cases the wetting layer cannot be analysed. Morphology data was gained by atomic force microscopy (AFM).