HL 44: Semiconductor Microcavities and Entangled States in Quantum Dots

Time: Thursday 14:00–18:15 Location: H15

Invited Talk HL 44.1 Thu 14:00 H15

Electron spin dynamics in quantum dots — •Manfred Bayer — Experimentelle Physik II, Universität Dortmund, D-44221 Dortmund, Germany

Electron spins in quantum dots (QDs) are promising candidates to serve as building blocks for semiconductor based quantum information technologies. Due to the unavoidable inhomogeneities in a QD ensemble it is common believe that coherent manipulations need to be performed on a single dot level. In this contribution we will show that by proper addressing of QDs by pulsed laser protocols it might be possible to perform corresponding studies on QD ensembles, with all the related benefits such as strong spectroscopic response.

For our experiments we have primarily used a time-resolved Faraday rotation technique on (In,Ga)As/GaAs quantum dots single charged with on electron. Using this methodology we will show: (i) trains of circularly polarized laser pulses are extremely efficient to create spin coherence (spin initialization) [1]. (ii) Such pulse trains can be used to synchronize certain spin subsets within the ensemble. From the dependence of the synchronization on the pulse separation the electron spin coherence time can be measured to be 3 μs at cryogenic temperatures [2]. (iii) The spins can be clocked by pulse doublet sequences such that they show periodic coherent responses. The period of these responses can be tailored by the details of the laser excitation [3].

Finally we will also address the impact of the interaction of the electron spins with the background of nuclei, which is considered to be one of the prime reasons for spin dephasing. We will show that under specific conditions a strong interaction between electron and nuclear spins will be established leading to a drastic enhancement of the spin relaxation time.

[1] A. Greilich, R. Oulton, E. A. Zhukov, I. A. Yugova, D. R. Yakovlev, M. Bayer, A. Shabaev, Al. L. Efros, I. A. Merkulov, V. Stavarache, D. Reuter, and A. Wieck, Phys. Rev. Lett. 96, 227401 (2006).

[2] A. Greilich, D. R. Yakovlev, A. Shabaev, Al. L. Efros, I. A. Yugova, R. Oulton, V. Stavarache, D. Reuter, A. Wieck, and M. Bayer, Science 313, 341 (2006).

[3] A. Greilich, M. Wiemann, F.G.G. Hernandez, D.R. Yakovlev, I.A. Yugova, M. Bayer, A. Shabaev, Al.L. Efros, D. Reuter and A.D. Wieck, submitted for publication.

[4] R. Oulton, A. Greilich, S. Yu. Verbin, R. V. Cherbunin, T. Auer, D.R.Yakovlev, M. Bayer, I. A. Merkulov, V. Stavarache, D. Reuter, and A. D. Wieck, submitted for publication.

Invited Talk HL 44.2 Thu 14:30 H15

Electrical control of entangled excitons in self-assembled quantum dot molecules — •Hubert J. Krenner — Walter Schottky Institut, Technical University of Munich, 85748 Garching, Germany

In this talk I will discuss recent experiments in which we electrically manipulate coupled exciton states in individual QD-molecules (QDMs). The samples investigated consist of a single pair of vertically stacked self assembled $In_{0.5}Ga_{0.5}As$ quantum dots embedded into the intrinsic region of an n-type GaAs Schottky photodiode. This device enables us to control the coherent coupling between exciton states in the upper and lower dots by tuning the electric field oriented along the axis of the QD-molecule via the gate voltage. New information is obtained on the charge distribution and spin structure of negatively charged trions in coupled quantum dot nanostructures and we directly probe Coulomb and Pauli blockade effects and inter-dot tunnel coupling using fully optical techniques. Electric field dependent μ-photoluminescence measurements reveal a clear anticrossing between spatially direct (e,h in the same dot) and indirect (e,h in different dots) neutral excitons with coupling energies in the range $2E_{1e+1h} = 1.2 - 3.2 meV$.[1] Our experimental findings are shown to be in good accord with realistic calculations of the single exciton spectrum, confirming that the tunnel coupling is mediated by hybridization of the electron component of the exciton wavefunction over the two dots. In contrast, observations for negatively charged excitons are shown to be much richer due to the complex spectrum of negatively charged exciton states ($X^{-1} = 2e + 1h$) that can exist in a QD-molecule.[2] Both inter- and intra-dot Coulomb couplings are directly measured for a wide range of different charge initial X^{-n_e}, $n_e = 0, 1, 2$ states and the tunnel couplings and ground state spin configurations are tuned using electric field. Our findings are in good agreement with realistic calculations providing a fairly complete description of the behaviour of negatively charged excitons in quantum dot molecules.

1 H.J. Krenner et al. Phys. Rev. Lett. 94, 057402, (2005)

2 H.J. Krenner et al. Phys. Rev. Lett. 97, 076403, (2006)

Acknowledgements:

J. J. Finley, E. C. Clark, T. Nakaoka, C. Scheurer, M. Bichler and G. Abstreiter

Invited Talk HL 44.3 Thu 15:00 H15

Quantum optical studies on laterally coupled quantum dots and pillar microcavities — •P. Michler[1], Gareth Beirne[1], C. Hermannstädter[1], S. M. Ulrich[1], Serkan Ates[1], L. Wang[2], A. Rastelli[2], O. G. Schmidt[2], C. Gies[3], J. Wiersing[3], F. Jahnke[3], S. Reitzenstein[4], C. Hoffmann[4], A. Löffler[4], and A. Forchel[4] — [1]Universität Stuttgart, Institut für Strahlenphysik, Allmandring 3, 70569 Stuttgart — [2]Max-Planck Institut für Festkörperforschung, Heisenbergstr.1, 70569 Stuttgart — [3]Institut für Theoretische Physik, Universität Bremen, Otto-Hahn-Allee, 28359 Bremen — [4]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg

During the last few years remarkable progress has been achieved in the development of coupled semiconductor quantum dots and high-quality microcavities which might open the way for new applications in the field of quantum information processing. We have fabricated pairs of laterally coupled (In,Ga)As QDs and demonstrate interdot electron coupling using optical techniques. The degree of tunnel coupling can be controlled by applying a static electric field along the quantum dot molecule (QDM) axis. By applying a voltage the electron probability can be reversibly shifted to either QD, and the QDM can be used to create a wavelength-tunable single photon emitter. Furthermore we present measurements of first- and second-order coherence of quantum-dot micropillar lasers. Our results show a broad threshold region for the observed high-β microcavities. The intensity jump is accompanied by both pronounced photon intensity fluctuations and strong coherence length changes. The results are in good agreement with a novel semiconductor laser theory.

Invited Talk HL 44.4 Thu 15:30 H15

Exciton qubits: From Rabi oscillations towards optoelectronic quantum gates — •Artur Zrenner[1], Stefan Stufler[1], Patrik Ester[1], Steffen Michaelis de Vasconcellos[1], Marc C. Hübner[1], Max Bichler[2], Pawel Machnikowski[3], Vollrath M. Axt[4], and Tilmann Kuhn[4] — [1]Universität Paderborn, Warburger Straße 100, D-33098 Paderborn, Germany — [2]Walter Schottky Institut, Technische Universität München, Am Coulombwall, D-85748 Garching, Germany — [3]Instytut Fizyki Politechniki Wrocławskiej, Wybrzeze Wyspiańskiego 27, PL-50-370 Wrocław, Poland — [4]Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Straße 10, D-48149 Münster, Germany

In optical experiments on single self-assembled InGaAs quantum dots we detect the exciton ground state transition as an extremely narrow resonance. For the case of pulsed laser fields and in the absence of decoherence, the ground state exciton represents a qubit. Excitations with ps laser pulses result in multiple qubit rotations, which are demonstrated in a quantitative way as Rabi oscillations in photocurrent experiments. By resonant two-photon excitation we are further able to create and control coherent biexciton states. Under the condition of slight electric field induced detuning we observe Ramsey fringes of a single exciton qubit. In those experiments we are able to demonstrate fringes with a spectral half period below the homogeneous linewidth of the quantum dot. With our results we demonstrate voltage controlled qubit manipulations, which are essential for new types of optoelectronic quantum gates and precision quantum measurements.

15 min. break

Invited Talk HL 44.5 Thu 16:15 H15

Optical Semiconductor Microtube Ring Cavities — •Tobias Kipp, Christian Strelow, Holger Welsch, Hagen Rehberg, Christoph M. Schultz, Christian Heyn, and Detlef Heitmann — Institute of Applied Physics, University of Hamburg, Germany

Recently we demonstrated that self-supporting microtubes can act as novel kinds of optical microcavites [1]. These microtubes are fabricated, starting from an epitaxially grown InGaAs/GaAs bilayer and using optical lithography and wet-etching processes, by utilizing the self-rolling mechanism of strained bilayers. The diameters of these microtubes are typically about 5 μm, whereas their walls are only 50-200 nm thick. We incorporate either self-assembled quantum dots or quantum wells as optically active material inside the tube walls. In photoluminescence spectra we find in both cases sharp modes arising from constructive interference of light running around the microtube's axis. The mode structure is in very good agreement to theoretical calculations, modelling the microtube as a closed dielectric waveguide. We discuss possibilities and show evidences of a three-dimensional confinement of light in these novel microtube ring cavities

We gratefully acknowledge financial support of the Deutsche Forschungsgemeinschaft via the SFB 508 and the Graduiertenkolleg 1286.

[1] T. Kipp *et al.*, PRL **96**, 077403 (2006).

Invited Talk HL 44.6 Thu 16:45 H15

Semiconductor quantum dots as entangled light sources — •David Gershoni — Technion - Israel Institute of Technology, Haifa, 32000, Israel

Entangled photon pairs are emitted from a biexciton decay cascade of single quantum dots when spectral filtering is applied. We show this by experimentally measuring the density matrix of the polarization state of the photon pair emitted from a continuously pumped quantum dot. The matrix clearly satisfies the Peres criterion for entanglement. By applying in addition a temporal window, the quantum dot becomes an entangled light source.

Invited Talk HL 44.7 Thu 17:15 H15

Configuration mixing of electronic states in quantum dots — Kroner M.[1], Govorov S.[2], Remi S.[1], Seidl S.[1], Badoleto A.[4], Petroff P.[4], Warburton R.[3], and •Kahled Karrai[1] — [1]Center for NanoScience, Sektion Physik, Ludwig-Maximilians-Universität,Geschwister-Scholl-Platz 1, 80539 München, Germany — [2]Department of Physics and Astronomy, Ohio University, Athens, OH, USA — [3]Department of Physics, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh EH14 4AS, UK — [4]Materials Department, University of California, Santa Barbara, CA 93106, USA

Charge tunable self-assembled semiconductor quantum dots are typically charac-terized by extremely sharp lines in their optical absorption and emission spectra. When the probing laser frequency is in resonance with one of such exciton lines, the quantum dot states can couple very strongly to the radiation field, to the point that the photon and electron states hybridize to become indistinguishable. A signature for such coherent dressed states formed under modest laser power is the observation of Rabi oscillations, of ac-stark effect and of cavity quantum electrodynamics in the weak and strong coupling regime. In this talk we present new data showing that when the laser power is further in-creased, a competing pathway for optical excitations in charge tunable quantum dots is revealed through a novel quantum optical interference. The interfering optical excitation channel originates from a weak transition of the charge tunable quantum dot ground state to an electronic continuum of states extended beyond the dot location. We will argue that this effect should apply generally to optically active few-level quantum systems in which one of the levels interacts with a continuum of states. The existence of alternative optical transition channels to localized and delocalized states has implications on coherence is-sues in quantum information processing. We developed a new quantum optical version of the ubiquitous Fano model that describes interactions between localized and extended dressed states. The model is in good qualitative agreement with the data.

Invited Talk HL 44.8 Thu 17:45 H15

Coupled Quantum Dots for Quantum Information — •Tom Reinecke — Naval Research Laboratory, Washington, DC USA

Spins in quantum dots (QDs) are attractive candidates for quantum bits (qubits) for quantum information technologies. A key need is for coherent coupling between qubits that can be manipulated in two-qubit gates needed for quantum logic. Recent advances in the understanding of two different physical systems for this purpose made in joint work involving fabrication, experiment and theory will be discussed.

Vertically coupled InAs quantum dots are formed by Stanski-Krastanov MBE growth on adjacent GaAs layers. We have shown that the quantum tunnel coupling between QDs can be manipulated by an external electric field [1,2]. Electron states, hole states or excitons can be brought into and out of resonance with fields and appropriate sample design [3]. Exchange interactions between spins in coupled QDs have been elucidated, including a novel 'kinetic exchange' interaction [4]. A novel mechanism to turn on interactions between spins optically has been found. Strongly tunable biexciton-exciton cascades of interest in quantum optics have been demonstrated [5]. An electric field dependent g-factor for spin splitting has been found, which provides opportunities for single qubit and two qubit operations with fast electric fields [6].

Coherent ('strong') interactions between QD excitons and cavity photon modes have long been sought as a basis for fast optical coupling between distant QDs and for distributed quantum computing. We have demonstrated this strong coupling with high finesse pillar microcavities and large dipole moment $In_{.30}Ga_{.70}As/GaAs$ QDs [7]. Recently we have also found strong coupling between two quantum dots within the linewidth of a single cavity mode [8].

[1] G. Ortner, M. Bayer, Y. B. Lyanda-Geller T. L. Reinecke and A. Forchel, Phys. Rev. Lett. 94, 157401 (2005).

[2] E.A. Stinaff, M. Scheibner, A.S. Bracker, I. Ponomarev, V.L. Korenev, M.E. Ware, M.F. Doty, T.L. Reinecke and D. Gammon , Science 311, 627 (2005).

[3] A. S. Bracker, M. Sheibner, M. F. Doty, E. A. Stinaff, I. V. Ponomarev, J. C. Kim, L. J. Whitman, T. L. Reinecke and D. Gammon, Appl. Phys. Lett. 89, 233110 92006)

[4] M. Scheibner, M. F. Doty, I. V. Ponomarev, A. S. Bracker, E. A. Stinaff, V. L. Korenev, T. L. Reinecke and D. Gammon, condmat 0607241

[5] M. Scheibner, M.F. Doty, I.V. Ponomarev, A.S. Bracker, E.A. Stinaff, T.L. Reinecke, C. S. Hellberg, D. Gammon (to be published)

[6] M. F. Doty, M. Scheibner, I. V. Ponomarev, E. A. Stinaff, A. S. Bracker, V. L. Korenev, T. L. Reinecke and D. Gammon, Phys. Rev. Lett. 97, 197202 (2006)

[7] J.-P. Reithmaier, G. S*k, A. Löffler, C. Hofmann, S. Kuhn , S. Reitzenstein, L. Keldysh, V.Kulakovskii, T.L. Reinecke, and A. Forchel, Nature 432, 197 (2004).

[8] S. Reitzenstein, A. Löffler, C.Hofmann, J.-P. Reithmaier, M. Kamp, , V.D. Kulakovskii, L.V. Keldysh , T. L. Reinecke and A. Forchel, Optics Letters 31, 1738 (2006)