HL 82: Quantum dots and wires: Cavities and photons

Time: Thursday 15:00–17:45 Location: H2

HL 82.1 Thu 15:00 H2

Qubit-cavity entanglement created with surface-acoustic waves — •Ralf Blattmann[1], Hubert Krenner[1], Sigmund Kohler[2], and Peter Hänggi[1] — [1]Institut für Physik, Universität Augsburg, 86159 Augsburg, Germany — [2]Instituto de Ciencia de Materiales de Madrid, CSIC, 28049 Madrid, Spain

We study the quantum dynamics of an exciton qubit in a quantum dot coupled to an optical nano cavity defined in a two-dimensional photonic crystal membrane. The effective interaction between these two systems depends on the cavity length. A surface-acoustic wave (SAW) renders this interaction time-dependent, such that the qubit-oscillator setup experiences an ac driving. Close to an avoided crossing of the adiabatic spectrum, the induced qubit excitations can be transferred via Landau-Zener transitions to the cavity, which allows one to entangle and disentangle cavity and qubit. We investigate the influence of higher harmonics of the SAW as well as decoherence due to photon losses. Additionally, we identify regimes with maximal entanglement and discuss the experimental feasibility. Work supported by SFB 631.

HL 82.2 Thu 15:15 H2

Triggered photon pair emission from semiconductor quantum dots via resonant two-photon absorption — •Markus Müller, Klaus D. Jöns, Samir Bounouar, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

As single-photon emitters with narrow spectral linewidths, semiconductor quantum dots have various application possibilities, e.g., for linear optical quantum computation, quantum communication or quantum information processing. To fully exploit their outstanding properties in a deterministic way, a coherent resonant excitation scheme is required. A two-photon absorption process allows us to coherently populate the biexciton state of a single In(Ga)As/GaAs quantum dot. Setting the energy of the excitation laser pulses between the exciton and biexciton transition will resonantly excite the quantum dot within a two-photon absorption process, without the disadvantage of having the pump and the detection light on the same wavelength. In autocorrelation measurements a full suppression of multi-photon-events is observed, with one of the cleanest single-photon emission reported in semiconductor quantum dots ($g^2(\tau) < 0.02$). In addition, this resonant excitation scheme is increasing the coherence time of the emitted light compared to non-resonant excitation processes.

HL 82.3 Thu 15:30 H2

Electrically driven quantum dot single-photon source at 2 GHz excitation repetition rate — •Fabian Hargart, Christian Kessler, Thomas Schwarzbäck, Elisabeth Koroknay, Susanne Weidenfeld, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart

Single-photon sources (SPSs) are key components for future applications in the field of quantum information technology such as quantum key distribution or linear optical quantum computing. Electrically driven semiconductor quantum dots (QDs) offer tailorable emission energy, narrow linewidth and an easy excitation scheme. Thus, they are promising candidates for such SPSs.

We investigated the influence of the bias voltage on the emission properties of a red emitting InP/GaInP QD based SPS. Under pulsed electrical excitation we can manipulate the band bending of the p-i-n diode with the applied bias voltage and thus the charge carrier escape by quantum tunneling. This leads to control over this non-radiative decay channel and allows carrier escape times as low as 40 ps, effectively reducing the time jitter of the photon emission. We realized high excitation repetition rates of up to 2 GHz while autocorrelation measurements with $g^{(2)}(0)$-values of 0.27 proof triggered single-photon emission.

HL 82.4 Thu 15:45 H2

Free-space quantum key distribution over 500 m using electrically triggered quantum dot - micropillar single photon sources — •Sebastian Unsleber[1,5], Tobias Heindel[1,5], Markus Rau[2], Christian Schneider[1], Martin Fürst[2,3], Sebastian Nauerth[2,3], Matthias Lermer[1], Henning Weier[2,3], Stephan Reitzenstein[1,5], Alfred Forchel[1], Sven Höfling[1], Harald Weinfurter[2,4], and Martin Kamp[1] — [1]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [3]qutools GmbH, 80539 Munich, Germany — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [5]Present address: Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

In 1984, Bennett and Brassard proposed a secret key-distribution protocol (BB84) that uses the quantum mechanical properties of single photons to avoid the possibility of eavesdropping on an encoded message. So far, most quantum key distribution (QKD) experiments have been performed with strongly attenuated lasers due to the lack of efficient single photon sources (SPS). First experiments utilizing optically pumped solid state based SPSs affirmed the great potential of QKD but still suffered from the drawbacks of this excitation scheme. In this work we report on a free-space QKD experiment over 500 m using electrically triggered quantum dot - micropillar SPSs. These devices generate sifted key rates of up to 16.8 kBits/s at a quantum bit error rate of 5.9 % and $g^{(2)}(0)$-values down to 0.39.

HL 82.5 Thu 16:00 H2

Electrically driven adiabatic AlAs/GaAs Micropillar cavities — •Matthias Lermer[1], Stephan Kuhn[1], Niels Gregersen[2], Jesper Mørk[2], Christian Schneider[1], Alfred Forchel[1], Sven Höfling[1], and Martin Kamp[1] — [1]Technische Physik and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Building 343, DK-2800 Kongens Lyngby, Denmark

Adiabatic Micropillar (MP) cavities are excellent testbeds for pronounced cavity quantum electrodynamic (cQED) effects. Due to the positive influence of the adiabatic mode transition in a taper region, this sort of MP cavities provide both, high Q factors and small mode volumes at the same time allowing e.g. for the observation of low threshold lasing and strong Quantum Dot (QD) - cavity coupling [1]. Moreover, for MP cavities in general, an elegant contacting routine is established [2] paving the way for daily use devices e.g. efficient single photon sources under electrical excitation [3]. We have carefully implemented a doping scheme for pin-Diode like, adiabatic MPs. High Q factors exceeding 10,000 have been measured in Photoluminescence (PL) and Electroluminescence (EL) and a distinct Purcell enhancement of a single QD line has been determined in a detuning experiment both in PL and EL. [1] M. Lermer et al., Physical Review Letters 108, 057402 (2012) [2] C. Böckler et al., Applied Physics Letters 92, 091107 (2008) [3] T. Heindel et al., Applied Physics Letters 96, 011107 (2010)

Coffee break

HL 82.6 Thu 16:30 H2

On-Chip Quantum Optics with Quantum Dot Microcavities — •Tobias Heindel[1], Erik Stock[1], Caspar Hopfmann[1], Ferdinand Albert[2], Matthias Lermer[2], Christian Schneider[2], Sven Höfling[2], Alfred Forchel[2], Martin Kamp[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Technische Physik and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

The prospect of studying quantum optics in solid state systems has triggered enormous efforts in the development of microcavity structures with embedded quantum dots. The success story in this field of modern optics includes the observation of fundamental light-matter interaction in the cavity quantum electrodynamics regime and the realization of novel nonclassical light sources. Up till now, the respective research has focused almost exclusively on individual microcavities excited optically by rather bulky external laser systems.

In this contribution, we demonstrate a novel approach for on-chip quantum optics using an integrated electrically driven whispering gallery mode microlaser. The latter allows for the observation of Purcell enhancement for an integrated, in-plane pumped quantum-dot microcavity system [1].

[1] E. Stock et al., Adv. Mater. 2012, DOI: 10.1002/adma.201202778

HL 82.7 Thu 16:45 H2

Photocurrent spectroscopy on single quantum dots in micropillar cavities - coherent optical manipulation and cavity quantum electrodynamics effects — •Peter Gold[1], Manuel Gschrey[2], Matthias Lermer[1], Christian Schneider[1], Sven Höfling[1], Alfred Forchel[1], Martin Kamp[1], and Stephan Reitzenstein[2] — [1]Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg — [2]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin

We report on photocurrent (PC) studies of single quantum dots (QDs) in electrically contacted micropillar cavities. The PC response originates from the tunneling of strictly resonantly excited charge carriers in the QDs. Here, we demonstrate coherent optical manipulation of an exciton qubit by exciting a single QD inside a micropillar cavity with picosecond laser pulses. The coherent interaction with the pulsed laser field leads to Rabi oscillations in the population dynamics of the excitonic ground state, which are monitored by the corresponding PC signal. Moreover, we study cavity quantum electrodynamics (cQED) effects in coupled QD-microcavity systems under electrical readout. We find a strong anticorrelation between radiative recombination and nonradiative tunnel escape of photoexcited carries which can be controlled by cQED effects in the Purcell regime. In fact, cavity enhanced radiative emission from a QD results in a weaker photocurrent signal which reflects the cQED controlled competition between radiative and nonradiative recombination at the single emitter level [1].
[1] Gold et al., Phys. Rev. B **86**, 161301(R) (2012)

HL 82.8 Thu 17:00 H2

Nonlinear emission characteristics of quantum dot - micropillar lasers in the presence of polarized optical feedback — •Caspar Hopfmann[1], Ferdinand Albert[2], Christan Schneider[2], Sven Höfling[2], Martin Kamp[2], Alfred Forchel[2], Ido Kanter[3], and Stephan Reitzenstein[1] — [1]Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany — [2]Technische Physik, Universität Würzburg, D-97074 Würzburg, Germany — [3]Minerva Center and Department of Physics, Bar-Ilan University, Ramat Gan, 52900 Israel

Cavity quantum electrodynamics in high quality quantum dot (QD) microcavities has been subject of extensive research interest in recent years. In this field, nonlinear light-matter interaction and dynamical processes are of particular interest. We report on electrically pumped QD microlasers in presence of polarized external self-feedback. These high-β micropillar lasers feature Q-factors of up to 20000 and threshold currents of about 1 μA. Moreover, the lasers have two orthogonal linearly polarized fundamental modes which are coupled by the common few QD gain medium. This gain coupling is reflected in pronounced anti-correlations in the current dependence of the two mode components with respect to the output power, the coherence time and the second order photon autocorrelation function. By applying polarized self-feedback we are able to effectively control these emission characteristics. Additionally, self-feedback provides an attractive tool for inspection of light-matter interaction properties (i.e. Purcell factor and exciton lifetime) of the QDs at high excitation conditions.

HL 82.9 Thu 17:15 H2

Gain competition enhanced intensity fluctuations in bimodal quantum dot – micropillar lasers — •Heinrich A. M. Leymann, Mikayel Khanbekyan, Alexander Foerster, and Jan Wiersig — Institut für Theoretische Physik, Universität Magdeburg, Postfach 4120, D-39016 Magdeburg, Germany

In the last decade intense research on the physics of microcavity lasers based on semiconductor quantum dots has been performed due to their high potential for ultralow threshold lasing [1]. For lasers with a spontaneous emission factor close to unity the onset of lasing can be more reliably monitored by means of the photon statistics.

In this contribution, we present a theoretical study of a quantum-dot-based microcavity laser where two nearly degenerate high-Q modes are involved in the laser dynamics. To analyze the coupled carrier-photon system we have extended a single mode microscopic semiconductor theory [2] to the case of two modes and have also taken the crosscorrelation functions into account.

Our theoretical results show that the mode which loses the mode competition exhibit super-thermal photon bunching ($g^{(2)}(0) > 2$). This interesting feature is traced back to mode coupling induced by the gain medium. Calculations of the photon cross-correlations reveal that the two modes are strongly entangled.

[1] J. Wiersig et al., Nature 460, 245 (2009).
[2] C. Gies et al., Phys. Rev. A 75, 013803 (2007).

HL 82.10 Thu 17:30 H2

Quantum limit of nuclear spin polarization in semiconductor quantum dots — •Julia Hildmann[1], Eleftheria Kavousanaki[2], Hugo Ribeiro[1], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Femtosecond Spectroscopy Unit, Okinawa Institute of Science and Technology, Graduate University, Okinawa, 904-0412 Japan

Since the original proposal by Loss and DiVincenzo to use single electron spins confined in quantum dots (QDs) as quantum bits (qubits) [1], a lot of effort has been made to perform coherent control of electron spins in QDs. One of the challenges for using electron spins as qubits remains decoherence due to hyperfine interaction with the nuclear spin bath of the host material (III-V semiconductors). Among various proposals to extend coherence times, there is the possibility to polarize the nuclear spins to a high degree (close to 100% [2]). A recent experiment, which relies on spin-forbidden transitions between heavy holes and positive trions, shows the highest until now reported polarization of about 65% [3]. Simple rate equations describing the pumping mechanism fail to describe the observed saturation predicting a fully polarized nuclear state and not constituting an appropriate description of the nuclear spin bath dynamics. We present a full quantum mechanical approach to this particular problem and show that the pumping saturation is a consequence of the collective nuclear spin quantum dynamics. [1] D. Loss and D. P. DiVincenzo, Phys Rev. A 57, 120 (1998). [2] W. A. Coish and D. Loss, Phys. Rev. B 70, 195340 (2004). [3] E. A. Chekhovich et al, Phys. Rev. Lett. 104, 066804 (2010).