HL 24: Poster Session II

Time: Tuesday 18:30–20:30 Location: Poster F

HL 24.1 Tue 18:30 Poster F

Applying Photon-Number Resolving Detectors for the Metrology of Quantum Light Sources — •Jonas Böhm[1], Martin von Helversen[1], Marco Schmidt[1,2], Jan-Hindrik Schulze[1], André Strittmatter[1], Sven Rodt[1], Tobias Heindel[1], Jörn Beyer[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany

Single-photon sources are key building blocks for future applications in quantum information, communication, cryptography and computation. The most important characteristics for single-photon sources are the brightness, the purity of single-photon emission and the indistinguishability of the emitted photons. Directly accessing the number of detected photons via transition-edge sensors, it is theoretically possible to reduce the number of required measurements to obtain these properties and to improve their statistical certainty.

In this work, we analyze deterministically fabricated single-photon sources by means of HBT and HOM experiments exploiting PNR detectors and compare the results with those obtained with Silicon-based click-detectors. Furthermore, we demonstrate statistical methods to evaluate the data obtained from experiments using PNR detectors and to extract key parameters, such as the $g^{(2)}(0)$ value and the two-photon interference visibility. Our analysis demonstrates, that PNR detectors can be used for the metrology of solid-state based quantum-light sources.

HL 24.2 Tue 18:30 Poster F

Deterministic integration of QDs into advanced on-chip photonic elements with in-situ electron beam lithography — •Johannes Schall[1], Peter Schnauber[1], Samir Bounouar[1], Jin-Dong Song[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Korea Institute of Science and Technology, Seoul, Korea

Deterministic integration of quantum emitters into on-chip photonic circuits is a crucial step towards scalable quantum optics. Using in-situ electron beam lithography [1], we present a one-step process for the spectrally and spatially controlled integration of quantum dots (QD) into on-chip photonic elements. We prove the basic functionality of our approach by integrating preselected QDs into waveguides and 50/50 multimode interference (MMI) splitters, measuring single photon emission on-chip. We further discuss a variety of advanced photonic structures that can be realized having full spectral and spatial control during integration. This includes resonators and mode converter approaches to increase the coupling of QD emission to the guided mode[2]. Furthermore, it allows the realization of chiral waveguides, where a controlled displacement of the QD inside the WG is necessary, and enables interfacing two QDs with identical exciton energy inside a single waveguide[3].

[1] Gschrey et al., Nature Communications 6, 7662 (2015)
[2] Davanco et al., Nature Communications 8, 889 (2017)
[3] Coles et al., Nature Communications 7, 11183 (2016)

HL 24.3 Tue 18:30 Poster F

Optical enhancement of quantum dot emission by nanowires — •Sven Scholz, Rüdiger Schott, Marcel Schmidt, Arne Ludwig, and Andreas D. Wieck — Ruhr-Universität Bochum, Universitätsstr. 150, D-44801 Bochum

Molecular beam epitaxy (MBE) quantum dot (QD) structures are used as fundamental research structures. To further enhance their optical properties we use nanowires as a subwavelength waveguide. While common photonic crystal structures work with holes or micro pillars, we use focused ion beam (FIB) to catalyze nanowire growth on QD structures. An LED-NW-QD structure is optimized regarding the optical emission. Therefore we use an AlAs layer to remove the wetting layers (WL) PL signal. To access a wide emission spectrum we use rapid-thermal annealing (RTA) and a flushing technique coupled with the WL suppression. This results in tunable and good separated QD emission peaks. The NW growth is characterized and optimized with regards to crystalline quality and morphology. The samples are characterized by photoluminescence/electroluminescence and scanning electron microscope imaging.

HL 24.4 Tue 18:30 Poster F

Self-assembled InAs and GaN quantum dots upon ion impact — •Charlotte Rothfuchs, Andreas D. Wieck, and Arne Ludwig — Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum

In the flourishing field of quantum communication, there is a great demand for single photon sources. Single electrically and optically active quantum dots (QDs) are promising candidates due to the appealing properties of QDs generally and of self-assembled QDs particularly. These features range from high stability and wide spectral tunability to narrow linewidths and strong quantum confinement. Focused ion beam implantation into QD structures provides a possible pathway towards their fabrication based on QD disabling around an intentional self-assembled one.

Here, we present a study on the ion impact on QD structures. For this purpose, fluence-dependent models for QD morphology and luminescence are developed based on ion-induced intermixing processes and an altered quantum efficiency. The luminescence of both InAs and GaN QDs and the size and density of the latter are described by the models. A high radiation hardness is hereby observed for GaN QDs. These are influenced by a change of the quantum confined Stark effect.

HL 24.5 Tue 18:30 Poster F

Speeding up a single quantum dot pump-probe experiment — •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

We recently showed [1] that it is possible to measure transient reflection on single semiconductor quantum dots in the far field. Here we discuss how to improve these measurements. Due to the short lifetime of an excited quantum dot of around 300 ps we plan to increase the measurement speed. We increase the repetition rate of our laser system by a factor of 13 now the time delay between two laser pulses in the new setup is only 1 ns.

We are interested in the characterization of a single quantum dot two-level system and its interaction with the environment through transient absorption spectroscopy. We plan to add plasmonic structures for antenna-enhanced single quantum dot spectroscopy.

[1] C. Wolpert, C. Dicken, P. Atkinson, L. Wang, A. Rastelli, O. G. Schmidt, H. Giessen, and M. Lippitz, Nano Lett. 12, 453 (2012).

HL 24.6 Tue 18:30 Poster F

Tunneling rates of quantum dots for single electron pumps — •Tobias Wenz[1], Friederike Stein[1], Frank Hohls[1], Hans Werner Schumacher[1], Jevgeny Klochan[2], and Vyacheslavs Kashcheyevs[2] — [1]Physikalisch-Technische Bundesanstalt (PTB), 38116 Braunschweig, Germany — [2]Faculty of Physics and Mathematics, University of Latvia, LV 1002 Riga, Latvia

Quantum dots with tunable barriers can be used as single electron pumps. By capturing a well-defined number of electrons n from source and emitting them to drain with a high frequency f a quantized current $I = nef$ is produced, where e is the electron charge [1]. This concept is useful for on-demand electron sources for electron quantum optics and for the redefinition of the ampere by fixing the value of e.

So far, mainly the back-tunneling process has been studied, as it is the limiting factor to the accuracy of a single-electron pump. In this work, we study the loading of electrons into the dynamic quantum dot using custom-tailored waveforms. This allows us to investigate in-tunneling rates to the dot and extract information on ground- and excited states. Their dependencies are studied as a function of temperature and magnetic field. Our goal is to extract an absolute energy scale that may be used for the description of the back-tunneling process, for example in the decay-cascade model [2].

[1] Kaestner and Kashcheyevs, Rep. Prog. Phys. 78, 103901 (2015)
[2] Kashcheyevs and Kaestner, Phys. Rev. Lett. 104, 186805 (2010)

HL 24.7 Tue 18:30 Poster F

Spectroscopy of Single Silicon quantum dots in the vicinity of metal films — •Aswin Asaithambi, Guenther Prinz, and Axel Lorke — Lotharstrasse 1, Faculty of Physics, CENIDE, University of

Duisburg-Essen, Duisburg 47057

Silicon is the most important and extensively used semiconductor concerning industrial production of electronic devices. However, the indirect band nature of Silicon makes it a poor light emitter. Light emitting efficiency can be increased by different methods such as use of III/V integration or using Si quantum dots (SiQDs).

In this contribution, we focus on photo-luminescence (PL) spectroscopy of single SiQDs. For this purpose, we use fluoride passivated SiQDs with a good ensemble PL quantum yield. We choose flourinated SiQDs because of their stable luminescence from 100K to RT. This makes them promising for building devices. These SiQDs are immobilized in a PMMA matrix on top of different metal films namely Au, Ag and Al. The optically excited SiQDs can couple to the metal film which can alter their luminescence behavior. We find that suitable metal films can couple effectively with SiQDs located at an optimal distance and can enhance the luminescence of the SiQDs. This makes it possible to measure time traces of PL spectra of single SiQDs to obtain data showing single dot optical phenomena such as PL intermittency and spectral jitter of the emission line. The measured data is discussed within the framework of the Efros-Rosen model and compared to the results available for CdSe QDs.

HL 24.8 Tue 18:30 Poster F

InP-based quantum dots for telecom wavelength: Growth and characterisations — •Birk Fritsch, Andrei Kors, Johann-Peter Reithmaier, and Mohamed Benyoucef — Institute of Nanostructure Technologies and Analystics (INA), CINSaT, Kassel University, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Semiconductor quantum dots (QDs) enable intriguing optoelectronic devices due to their discrete density of states and morphology-dependent band gap. Self-assembled InP-based QDs have proven to emit single photon emission at the telecom C band [1]. Utilising them for long-distance quantum communication requires precise growth control to obtain high quality QDs [2].

Here, we investigate the effects of different growth parameters to optimise Stranski-Krastov telecom wavelengths InP-based QD structures grown by molecular beam epitaxy with controlled dot density. High-resolution micro-photoluminescence measurements performed on the QD structures show single dot emission with narrow spectral linewidths and small fine structure splittings. Temperature dependent measurements exhibit a characteristic band gap shift, activation energy and charge carrier diffusion. Morphological analyses of the QDs using atomic force microscopy are compared with photoluminescence measurements. Moreover, studies related to doped QD structures and fabrication of pin-diode structures with embedded QDs emitting at telecom wavelength are presented.

[1] Benyoucef et al., Appl. Phys. Lett. 103 162101 (2013)
[2] Yacob et al., Appl. Phys. Lett. 104 022113 (2014)

HL 24.9 Tue 18:30 Poster F

Long-lasting fluorescence enhancement of CdSe-nanowires — •Jonas Albert, Subhasis Adhikari, and Markus Lippitz — Experimentalphysik III, Universität Bayreuth

One dimensional structures like semiconductor or molecular nanowires are interesting systems for optoelectronic devices, because generated charges can be directed along the wire axis.We combine optical microscopy with atomic force microscopy (AFM) to study these structures and how they can be manipulated. By introducing a metallic AFM tip to CdSe nanowires these can show different behavior from photoluminescence quenching to very strong fluorescence enhancement. We want to emphasise on the enhancement effect by the presence of the AFM tip. This enhancement effect can even occur when the tip is micrometers away from the diffraction limited excitation spot. Also a memory effect is present, since the enhanced luminescence decays only on a second timescale when the tip is removed.

HL 24.10 Tue 18:30 Poster F

Spin relaxation in self-assembled quantum dots — •Isabel Oppenberg[1], Kevin Eltrudis[1], Annika Kurzmann[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg — [2]Chair for Applied Solid State Physics, Ruhr-Universität Bochum, Universitätsstr. 150, 44780 Bochum, Germany

Self-assembled quantum dots (QDs) are promising candidates for quantum information devices that require a two level system. One possible realization is the excited two-electron spin triplet state and its singlet ground state. We use self-assembled InAs QDs that are embedded in a GaAs/AlGaAs heterostructure (FET). An electron reservoir (2DEG) is coupled to the QDs for controlled charging and sensitive detection of the charge state of the dots. The method we use is time-resolved transconductance spectroscopy with spin-to-charge conversion [1]. By preparation of the excited two-electron triplet states, we can subsequently observe the spin relaxation in electron emission during the discharging process. At zero magnetic field, we observe spin relaxation times of about 25 μs [2].Optical experiments have already shown a very strong magnetic field dependence of the spin relaxation, even for low fields of a few ten mT [3]. Here, we investigate the magnetic field dependence with our all-electrical measurement technique with fields up of 2 T. [1] B. Marquardt. et al., Nature Commun. 2, 209 (2011) [2] K. Eltrudis. et al., Appl. Phys. Lett. 111, 092103 (2017) [3] R. Dahbashi. PRL 112, 156601 (2014)

HL 24.11 Tue 18:30 Poster F

Designing a charge counter for a single electron counting scanning tunneling microscope — •Felix Jekat[1], Benjamin Pestka[1], Sebastian Heedt[2], Patrick Zellekens[3], Stefan Trellenkamp[4], Werner Prost[5], Marcus Liebmann[1], and Markus Morgenstern[1] — [1]II. Institute of Physics, RWTH Aachen University — [2]QUtech, Kouwenhoven Lab, TU Delft — [3]PGI-9, Forschungszentrum Jülich — [4]PGI-8, Forschungszentrum Jülich — [5]Center for Semiconductor Technology and Optoelectronics, University of Duisburg-Essen

Single electron counting provides access to the statistical distribution of tunneling events eventually leading to information of electronic correlations. While this approach is established in quantum devices, it has not been employed to a spatially resolving technique. We aim to implement single electron counting within a STM using indium arsenide nanowires as tips. Such nanowires have been shown to be as suitable as tungsten tips for STM [1]. Here, we show the design of a device, which should enable time-resolved detection of single electrons directly at the STM tip. To this end, we place a second nanowire in close proximity and couple the two wires via a floating gate [2]. Hexagonal boron nitride as a dielectric separates the nanowire from a set of fingergates, which enable the formation of quantum dots.
[1] K. Flöhr et al. "Scanning tunneling microscopy with InAs nanowire tips", Appl. Phys. Lett. 101, 243101 (2012) [2] Y. Hu et al. "A Ge/Si heterostructure nanowire-based double quantum dot with integrated charge sensor", Nature Nanotechnol. 2, 622 (2007)

HL 24.12 Tue 18:30 Poster F

Quantum Dots grown by Local Droplet Etching on GaAs (111)A Substrates — •Julian Ritzmann[1], Nandlal Sharma[2], Dirk Reuter[1,2], Henning Moldenhauer[3], Jörg Debus[3], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Ruhr-Universität Bochum, D-44780 Bochum — [2]Universität Paderborn, D-33098 Paderborn — [3]Technische Universität Dortmund, D-44227 Dortmund

The generation of entangled photon pairs is a key to practical quantum communications. In the case of biexcitons in SK-grown quantum dots (QD), the fine structure splitting (FSS) of the energy levels causes the transition paths of biexciton and exciton to be distinguishable. Therefore, we need quantum dots with strongly reduced FSS. This was theoretically proposed and experimentally shown for GaAs quantum dots on (111)A-oriented AlGaAs by droplet epitaxy (DE). However, these QDs exhibit a strong distribution in size resulting in rather broad photoluminescence (PL) spectra. Nearly uniform quantum dots were achieved by filling up nanoholes on (001)-oriented Al(Ga)As with GaAs achieving a PL linewidth of less than 10 meV. These nanoholes were generated via local droplet etching (LDE) of gallium droplets on an Al(Ga)As surface. Our approach is to use LDE for the growth of uniform, triangular QDs on (111)A-oriented substrates with low density and reduced FSS. Here, we present a study on different parameters for the LDE and LDE QD process on GaAs (111)A surfaces using atomic force microscopy, PL and micro-PL.

HL 24.13 Tue 18:30 Poster F

Far-Field imaging of Solid-State Quantum-Light Sources using Fourier-Optics — •Christoph Vincent Heine, Peter Schnauber, Sarah Fischbach, Sven Rodt, Jan-Hindrik Schulze, André Strittmatter, Manuel Gschrey, Tobias Heindel, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623, Berlin, Germany

Quantum-light sources based on semiconductor quantum dots (QDs)

play an important role in future development of quantum information science. For practical applications it is crucial, to efficiently couple the emission of the respective quantum emitters to a single-mode optical fiber. This coupling efficiency is largly determined by the far-field emission of the emitter.

In this work, we investigate the far-field emission characteristics of QD-based quantum light sources using Fourier imaging. The experimntal setup is introduced and exploited to measure the far-field of deterministically fabricated single-QD microlenses. These measurements and their comparison to simulations enables us to optimize the lens designs and verify theoretical simulations.

HL 24.14 Tue 18:30 Poster F

Optical detection of Coulomb interaction in self-assembled quantum dots — •Jens Kerski[1], Pia Eickelmann[1], Arne Ludwig[2], Andreas D. Wieck[2], Annika Kurzmann[1], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Self-assembled quantum dots (QDs) can be used in an optical detection scheme to probe their electrical and spin environment on the nanoscale [1, 2]. In resonance fluorescence, such a nano-electrometer could be also used to investigate transport phenomena, like single electron tunneling into a single quantum dot [3].

In this work, we combine the optical detection with transport measurements by using two quantum dots that are coupled by Coulomb interaction. We perform resonant time-resolved optical measurements on a single InAs QD, which acts as a nanoscale electrometer for detection of tunneling events into a second, nearby dot. The latter is charged by applying a gate voltage. Once an electron is captured in the second QD, its electric field changes the exciton transition energy by the quantum-confined Stark effect of the first dot, which can be observed in a time-resolved measurement.

[1] A. V. Kuhlmann et al., Nature Physics **9**, 570-575 (2013).
[2] J. Houel et al., Phys. Rev. Lett. **108**, 107401 (2012).
[3] A. Kurzmann et al., Phys. Rev. Lett. **117**, 017401 (2016).

HL 24.15 Tue 18:30 Poster F

Low-Temperature Transport Measurements of Selectively-Grown Te-doped InAs Nanowires — •Patrick Liebisch, Patrick Zellekens, Pujitha Perla, Dinesh Kumar Arumugam Gurunathan, Nicholas Güsken, Mihail Ion Lepsa, Detlev Grützmacher, and Thomas Schäpers — Peter Grünberg Institute 9, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

We investigated the transport properties of n-type InAs nanowires grown by selective-area molecular beam epitaxy. Instead of Si doping, which is known for strongly disturbing the lattice structure, we employed Te as n-type dopant. In a series of growth runs the doping concentration was varied systematically up to a value corresponding to $1 \cdot 10^{19}$ cm^{-3} in (100) GaAs. For doping a stoichiometric GaTe source was used. In order to gain information on the doping efficiency, transport experiments were performed on Nb contacted nanowires. From field effect transistor measurements using either a back gate or a top gate the carrier concentration as well as the mobility were extracted. We found that the electron concentration systematically increases with supply of Te dopants. The results of the field-effect transistors are compared to photoluminescence as well as thermoelectric measurements performed on nanowires from the same growth runs.

HL 24.16 Tue 18:30 Poster F

Energy Tuning of Self-Organised Quantum Dot Ensembles via Piezomechanical Strain — •Nikolai Bart[1], Sascha Valentin[1], Arne Ludwig[1], Andreas Wieck[1], Yan Chen[2], Fei Ding[2], and Oliver Schmidt[2] — [1]Lehrstuhl für Angewandte Festkörperpyhsik, Ruhr-Universität Bochum — [2]Institute for Integrative Nanosciences, IFW Dresden

Beside temperature, magnetic and electric fields tuning of the energetic states in quantum dots (QDs) for opto-electronic applications, piezomechanical strain offers an additional tuning knob. We present photoluminescence (PL) and capacitance-voltage (CV) spectroscopy measurements of bi-axially strained self-organised InAs QD ensembles on a piezoelectric actuator. While for PL at room temperature a redshift of 5 meV and inhomogeneous ensemble linewidth broadening of 20 % can be observed when the piezo actuator is biased with 550 V (tensile strain), this effect is diminished at 77 K. CV spectroscopy at 4.2 K on the other hand exhibits a shift in the opposite direction, towards higher gate voltages. While the PL redshift is well documented by others and can be attributed to an altered QD confinement potential due to piezo strain induced morphological changes, the CV results require additional research, which may be provided by introducing a magnetic field to the CV measurements and by wave function mapping.

HL 24.17 Tue 18:30 Poster F

Simulating Optical Signals of the Spatiotemporal Dynamics of Carrier Capture Processes — •Frank Lengers, Roberto Rosati, Tilmann Kuhn, and Doris E. Reiter — Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

Carrier capture processes are frequently encountered in semiconductor structures as, e.g., scattering from the wetting layer to an embedded quantum dot or as trapping of carriers in defects or strain-induced potentials. Those processes happen on an ultrafast timescale and on nanometric length scales such that a quantum description is necessary. These scales require an ultrafast and localized measurement as found in spatially resolved pump-probe measurements.

In this contribution we study the optical signals resulting from the phonon-mediated carrier-capture from a GaAs quantum wire into an embedded quantum dot. To this end we consider a two-band model coupled to a light field and under the influence of carrier-carrier and carrier-phonon interaction. The microscopic description of the carrier-phonon scattering is treated within a Markovian Lindblad single-particle (LSP) approach, which is able to account for the local nature of carrier-phonon scattering [1]. We propose a two-pulse measurement: The first pulse excites a wave packet far from the quantum dot which travels onto the quantum dot where the local capture occurs. The dynamics of the capture process is probed by a second pulse. We find that the capture dynamics is clearly reflected in the probe spectra.

[1] Rosati et al, Phys. Rev. B **95**, 165302 (2017)

HL 24.18 Tue 18:30 Poster F

Room-temperature photoluminescence mapping of GaAs quantum dots — •Roman Korneev, Michael Zocher, Christian Heyn, and Wolfgang Hansen — Center for Hybrid Nanostructures, University of Hamburg, D-22761 Hamburg, Germany

We study the photoluminescence (PL) emission from spatially well separated GaAs quantum dots (QDs) in refilled AlGaAs nanoholes at room temperature (RT). The self-assembled nanoholes are produced by local droplet etching during molecular beam epitaxy. Afterwards, the holes are filled with GaAs and capped with AlGaAs for QD generation. At T = 4 K, the QDs show clear excitonic peaks and nearly perfect single-photon emission. On the other hand, at RT the intensity of emitted light is strongly reduced. Although the emission of an ensemble of QDs is easily detected, the study of single QD emission at RT remains difficult. We demonstrate the detection of single-dot emission at RT by using a modified Raman microscope. Furthermore, a xy-stage allows us to produce PL maps of the samples. PL maps recorded at different wavelengths will be discussed in view of the QD ensemble properties like the density and the average luminescence energy.

HL 24.19 Tue 18:30 Poster F

Deterministic fabrication of circular Bragg gratings around pre-selected quantum dots for high performance light sources — •Sascha Kolatschek, Stefan Hepp, Marc Sartison, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart.

Highly efficient single photon sources are a crucial component for quantum information processes. Semiconductor quantum dots (QDs) have been proven to be excellent candidates due to their outstanding optical properties. Among different stratergies to increase light extraction, the use of photonic nanostructures enables, together with increased brightness, also an improved indistinguishability and reduced lifetime using linear optics and cavity quantum electrodynamic effects. Here we show Purcell enhancement for non-deterministically positioned circular Bragg grating cavities and, together with a novel deterministic fabrication method for the integration of preselected QDs into the respective cavities, count rate increases up to a factor of 60 with respect to measurements before cavity fabrication.

HL 24.20 Tue 18:30 Poster F

Development of GaAs based QD structures for VECSEL and MIXSEL applications — •Tanja Finke[1], Vitalii Sichkovskyi[1], Cesare Alfieri[2], Matthias Golling[2], Ursula Keller[2], and Jo-

hann Peter Reithmaier[1] — [1]Institute of Nanostructure Technologies and Analytics (INA), Technische Physik, CINSaT, University of Kassel, Germany — [2]Institute for Quantum Electronics, Ultrafast Laser Physics Laboratory, ETH Zürich, Switzerland

By integration of vertical external cavity surface emitting lasers (VECSEL) with a semiconductor saturable absorbing mirror (SESAM), one can form a so-called mode-locked integrated external-cavity surface emitting laser (MIXSEL). With MIXSEL structures it is possible to realize very compact ultra-short high power femtosecond laser source for the frequency comb generation. By using quantum dots (QDs) for the gain and absorber material, the material properties can be tailored by additional geometry based degrees of freedom.

For the VECSEL and MIXSEL structures gain section series of test samples optimized for high dot density have been grown by MBE. The influence of the growth parameters on the optical and morphological properties of InGaAs QDs was studied by PL and AFM respectively. An overall reduction of PL FWHM down to 26 meV at 10 K was achieved. The optimum QDs were included into VECSEL gain section. For SESAM structures InGaAs QDs test samples with different designs were grown on DBR mirrors and characterized by pump-probe experiment. Fast recovery time of only 10 ps and good saturation parameters very close to QW based SESAMs were shown.

HL 24.21 Tue 18:30 Poster F

Identification of individual transitions in InGaAsSb/GaP quantum dot by power and temperature dependent photoluminescence — •Petr Steindl[1,2], Petr Petr Klenovský[1,2], Elisa Maddalena Sala[3], Benito Alén[4], and Dieter Bimberg[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institut für Festkörperphysik Technische Universität Berlin, Hardenbergstraße 36 10623 Berlin, Germany — [4]Instituto de Micro y Nanotecnología, IMN-CNM, CSIC Isaac Newton, 8 PTM Tres Cantos 28760 Madrid, Spain

We investigated a set of InGaAsSb/GaP quantum dot samples by photoluminescence spectroscopy. These structures are interesting because they combine direct and indirect optical transitions. We reveal those transitions by performing power, temperature and polarization depended measurements and find the dominant emission band from these dots to occur around 700 nm (1.77 eV). A considerable blueshift of the emission of 27 meV typical for type-II transitions is found by increasing the laser power by 3 orders of magnitude. Temperature resolved data facilitate deconvolution of the broad emission band to contributions of individual transitions.

HL 24.22 Tue 18:30 Poster F

Recombination dynamics of InGaAsSb/GaP quantum dots — •Petr Steindl[1,2], Petr Petr Klenovský[1,2], Elisa Maddalena Sala[3], Benito Alén[4], and Dieter Bimberg[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institut für Festkörperphysik Technische Universität Berlin, Hardenbergstraße 36 10623 Berlin, Germany — [4]Instituto de Micro y Nanotecnología, IMN-CNM, CSIC Isaac Newton, 8 PTM Tres Cantos 28760 Madrid, Spain

We examined the dynamics of optical transitions in ensemble InGaAsSb/GaP quantum dot samples by time-resolved photoluminescence spectroscopy. The studied dots provide a simultaneous occurrence of direct and indirect optical transitions. We focused on discerning those for the dominant dot emission band around 700 nm (1.77 eV) by performing time-resolved measurements for different wavelengths, sample temperatures and excitation intensities. We fit the time-resolved data by a double exponential model characterizing two separate recombination processes with average lifetimes of 60 ns and 10 ns. For the former we observe a considerable decrease of lifetime with temperature and we attribute that to spatially indirect transitions in quantum dots. On the other hand, lifetime of the latter transition does not appreciably depend on temperature and is probably connected with bulk recombinations.

HL 24.23 Tue 18:30 Poster F

Focussed ion beam induced site selective growth of single gallium arsenide and indium arsenide nanowires — •Schott Rüdiger, Scholz Sven, Schmidt Marcel, Ludwig Arne, and Wieck Andreas D. — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Semiconductor nanowires (NWs) are used as building blocks for a new generation of advanced devices intended for different applications in the field of nanoelectronics, nanophotonics and nanomechanics. NWs are near one-dimensional structures that typically have a high length-to-width ratio. This is the fundament of fascinating structural properties. Heterostructures of highly lattice mismatched materials can be combined without dislocations and metastable phases are feasible, unattainable in bulk materials like wurtzite GaAs. We present the possibility to modify the surface of a semiconductor substrate by focussed ion beam (FIB) lithography for site selective catalyst-assisted and catalyst-free growth of NWs. In implanting distinct spots of Au ions and clusters in arbitrary distributions on GaAs(111)B, we initiate GaAs and InAs NW growth in molecular beam epitaxy (MBE) via the vapor-liquid-solid mechanism [1,2]. By heating up the GaAs(111)B substrate before growth, the implanted Au ions form small droplets on predefined sites as NW seeds. Ordered catalyst-free NW growth is possible on Si(111) substrates covered with a thin silicon oxide layer by implanting Si or Ga ions.

[1] G. Bussone et al., J. Appl Crystallogr., 46, 887-892 (2013).
[2] S. Scholz et Al., J. of Crystal Growth, 470, 45-50 (2017).

HL 24.24 Tue 18:30 Poster F

Soft- and Hardware Development of a Compact Ultra High Vacuum Pressure Monitoring for Process Control of the Molecular Beam Epitaxy — •Christoph Ringkamp[1,2], Arne Ludwig[1,2], and Andreas Wieck[1,2] — [1]Ruhr-Universität Bochum — [2]Lehrstuhl für Angewandte Festkörperphysik

Monitoring the pressure is an important part to ensure quality while growing semiconductor structures with a molecular beam epitaxy system. For this matter, we have built a compact real-time monitoring system for an ultra-high vacuum out of a Raspberry Pi. The use of a 12-bit A/D in combination with using Python for the software allowed us to have a good resolution at a high sample rate. Continuous reading and averaging increase the 12-bit depth to an effectively higher value. Furthermore one has to deal with an enclosed measurement system of which one cannot test if it is fully calibrated. By comparing the analog signal to the electrometer display in addition with the instructions we tried to compensate for the lack of comparability as we adjusted the linear factor of the voltage-pressure relation.

HL 24.25 Tue 18:30 Poster F

Resistance profiling along tapered nanowires: Multi-tip-technique vs. transmission line method — •Andreas Nägelein[1], Lisa Liborius[2], Matthias Steidl[1], Christian Blumberg[2], Peter Kleinschmidt[1], Artur Poloczek[2], and Thomas Hannappel[1] — [1]TU Ilmenau, Ilmenau, Germany — [2]University Duisburg-Essen, Duisburg, Germany

The advantageous properties of nanowire (NW) structures for electronic or optoelectronic devices are well-established. However, precise control of the dopant distribution within the NWs is difficult to obtain and its determination is challenging. Here, the transmission line measurement (TLM) method provides an access via the electrical transport properties, but its spatial resolution is limited and it cannot be applied to as-grown NWs. In contrast, a multi-tip scanning tunneling microscope (MT-STM), with its independently moveable tips, enables the in-system measurement of continuous axial resistance profiles and avoids the necessity of ex-situ deposition of ohmic contacts. In this paper, a comparative analysis of NW resistance profiling is presented. NWs from the very same sample were first measured and evaluated by MT-STM and then detached and transferred to a non-conducting substrate where TLM measurements were performed. Here, tapering of the measured NWs complicates the evaluation of the TLM data. A new model and correction factors were introduced to determine specific resistances and transfer length. We found an agreement of the measured data of both methods and demonstrate the accuracy and the superior resolution of the MT-STM method.

HL 24.26 Tue 18:30 Poster F

Covalent coupling of plasmonic metal and semiconductor nanoparticles — •Jannik Rebmann, Phillip Witthöft, Simon Schneider, Christian Strelow, Tobias Kipp, and Alf Mews — Institute of Physical Chemistry, University Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Hybrid structures consisting of plasmonic metals and semiconductor nanoparticles are of great importance since the plasmonic properties

of the metal can strongly influence the fluorescent behavior of the semiconductor. For instance, if the plasmon of the metal is in resonance with the excitonic recombination energy of the semiconductor this would influence the recombination rate and can be observed by a change of the decay of fluorescence lifetime, provided that the semiconductor and metal are not in direct contact, which would lead to fluorescence quenching due to charge transfer processes. Hence, the distance between the metal and the semiconductor has a huge influence on these effects. Therefore, we present a new method for building hybrid structures consisting of gold-nanorods covalently bonded to CdSe/CdS-dot-in-rod (DR) structure, which are covered with a thin silica shell with variable thickness. Using the EDC-NHS-coupling mechanism a covalent amide bond is formed between the carboxyl groups on the plasmonic metal particle and the terminal amine groups on the DRs. The anisotropic geometry of gold nanorods gives great opportunities to tune the plasmon resonance in order to enhance plasmon-exciton-coupling.

HL 24.27 Tue 18:30 Poster F

Optimization of cavity-enhanced single-photon generation from optical two-photon Raman processes in quantum dot systems — •Tom Praschan[1], Dominik Breddermann[1], Dirk Heinze[1], Rolf Binder[2], and Stefan Schumacher[1,2] — [1]Department of Physics and CeOPP, Paderborn University, Paderborn, Germany — [2]College of Optical Sciences, University of Arizona, Tucson, Arizona, USA

We investigate cavity-enhanced single-photon emission from optical two-photon Raman transitions in quantum dot systems. For this emission process, it has been shown that basic properties such as frequency, linewidth and emission time of the emitted Raman photon are determined by the external control laser [1,2]. In this context, especially Λ-shaped systems, e.g. in quantum dots or atomic systems, have already been studied in great detail [3]. However, higher Raman photon output towards on-demand generation – which is crucial for quantum communication networks – has not been realized yet. We use numerical algorithms to design an optimized chirped laser pulse in order to achieve on-demand single photon emission. As an optimization criterion, here we use the Raman emission probability that can be defined based on the cluster-expansion approach [4].

[1] D. Heinze, D. Breddermann, et al., Nat. Commun. 6, 8473 (2015).
[2] D. Breddermann, D. Heinze, et al., Phys. Rev. B 94, 165310 (2016).
[3] T. M. Sweeney, S. G. Carter, et al., Nat. Photonics 8, 442 (2014).
[4] D. Breddermann, T. Praschan, et al., arXiv:1711.11490 (2017).

HL 24.28 Tue 18:30 Poster F

MBE growth and characterization of InAs/GaSb core-shell nanowire arrays — •Gunjan Nagda[1,3], Dinesh Arumugam[1,3], Pujitha Perla[1,3], Torsten Rieger[1,3], Thomas Schäpers[1,3], Detlev Grützmacher[1,2,3], and Mihail Lepsa[2,3] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich GmbH, 52425 Jülich — [2]Peter Grünberg Institute (PGI-10), Forschungszentrum Jülich GmbH, 52425 Jülich — [3]JARA - Fundamentals of Future Information Technology

InAs and GaSb are almost lattice matched and when in contact, the structure has a broken gap heterointerface. In a core-shell NW geometry, these particularities make the combination interesting for low power electronic devices (TFETs) and the study of new physical properties, e.g. two-dimensional topological insulator behavior, Majorana fermions, etc. We report on the MBE growth and characterization of InAs/GaSb nanowire arrays.

For the growth, Si (111) substrates were covered with a thin thermal SiO2 film in which two-dimensional, periodic arrays of nano-sized holes were patterned. The InAs NW growth was optimized regarding the yield and morphology. The substrate preparation is crucial for achieving a high NW yield. The growth of GaSb shell was investigated similarly obtaining optimum growth conditions. NW morphological and structural characteristics have been obtained using different microscopy methods. The small lattice mismatch between InAs and GaSb combined with the one-dimensional geometry results in misfit dislocation free core-shell NW heterointerface.

HL 24.29 Tue 18:30 Poster F

Quenching of the photoluminescence of CdTe QDs by PEDOT:PSS conductive polymer in water solutions and thin films — •Oleksandr Selyshchev[1], Volodymyr Dzhagan[2], Nikolai Gaponik[3], and Dietrich R.T. Zahn[1] — [1]Semiconductor Physics, Chemnitz University of Technology, Chemnitz D-09107, Germany — [2]V. Lashkaryov Institute of Semiconductor Physics, Nat. Acad. Sci. of Ukraine, 03028 Kyiv, Ukraine — [3]Physical Chemistry and Center for Advancing Electronics Dresden, TU Dresden, 01062 Dresden, Germany

Quantum dots attract significant interest first of all due to their optical properties and they are considered for applications in light harvesting and emitting devices, photocatalysts, luminescent biomarkers etc. In all of these applications QDs are not "particles-in-a-box" but interact with other objects such as ligands, substrates, other QDs, which have influence on the properties of the QDs. Here we report about quenching of the PL of CdTe QDs of different sizes by the conductive polymer PEDOT:PSS in aqueous solutions and thin films. PEDOT:PSS resulted in a significant red shift (upto 0.3 eV) of the PL band of CdTe QDs. The magnitude of the shift decreased with increasing QD size. The value of the shift was proportional to the amount of PEDOT:PSS and increased with storage time of the samples. The results obtained reveal a strong and controllable interaction between the QDs and the PEDOT:PSS. The possible mechanisms underlying the observed effects are discussed based on additional information obtained by XPS, UPS, Raman and IR spectroscopies, time-resolved PL, and TEM.

HL 24.30 Tue 18:30 Poster F

Optoelectronic Coupling Between Colloidal Quantum Dots and Burrowed Quantum Wells — •Mikko Wilhelm[1], Atif Masood[1], Wolfgang Parak[2], and Wolfram Heimbrodt[1] — [1]Philipps-Universität Marburg — [2]Universität Hamburg

The optoelectronic coupling between colloidal CdS quantums and a buried quantum well is studied. CdS quantum dots of different sizes have been deposited via drop casting on a MBE grown quantum well structure, which consists of a 5nm thick ZnSe quantum well and a (Zn, Mn)Se barrier of different thickness and Mn concentration. The energy transfer between the quantum dots on top of the substrate and the burrowed quantum well is investigated with cw- and time resolved luminescence measurements in the nano- and picosecond range. Measurements were performed at different temperatures and the results are discussed in detail.

HL 24.31 Tue 18:30 Poster F

Steady state optical spectroscopy and time- and spatially-resolved pump-probe measurements on a plasmonic CdZnTe/CdMgTe waveguiding structure — •Alexander Trautmann[1], Jonas Vondran[2], Felix Spitzer[2], Ilya Akimov[2], Manfred Bayer[2], Nils Weber[1], Cedric Meier[1], Régis Andre[3], Henri Mariette[3], Matthias Reichelt[1], and Torsten Meier[1] — [1]Department of Physics and CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany — [2]Experimentelle Physik 2, TU Dortmund, Otto-Hahn-Str. 4, D-44221 Dortmund, Germany — [3]CEA-CNRS Group Nanophysique et Semiconducteurs, Institut Néel, Université Grenoble-Alpes, 38042 Grenoble, France

A plasmonic gold grating on a CdZnTe/CdMgTe waveguide structure leads to different signatures in the reflectivity spectra for s- and p-polarized light. Experiments and simulations show a significant decrease of the reflectivity for p-polarization due to the excitation of surface plasmon polaritons. Furthermore, nonlinear optical pump-probe experiments with femtosecond laser pulses using spatially-localized excitation pulses are investigated. Both, the experiment and the simulations, using a model based on the Maxwell-Bloch equations, show several interesting effects in the differential reflectivity transients including contributions from the optical Stark effect. The obtained transients are discussed as function of the spatial separation and other relevant parameters.

HL 24.32 Tue 18:30 Poster F

Coherence and Population Dynamics of Excitons in Single Quantum Dots Revealed by Four-Wave Mixing Micro-Spectroscopy — •Daniel Wigger[1], Tilmann Kuhn[1], and Jacek Kasprzak[2,3] — [1]Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Univ. Grenoble Alpes, F-38000 Grenoble, France — [3]CNRS, Institut Néel, "Nanophysique et Semiconducteurs" Group, F-38000 Grenoble, France

Four-Wave Mixing (FWM) micro-spectroscopy is a powerful tool to investigate the level structure and coupling mechanisms of single few-level systems. This knowledge is essential for the use of single emitters in quantum technology. We investigate single self-assembled quantum dots (QDs), which stand out as scalable solid state single emitters. By using two and three exciting pulses, we have access to the dynamics of the microscopic exciton coherences and populations, respectively [1].

We present combined theoretical and experimental studies on the dynamics of FWM signals and discuss the influence of laser intensities [2] and the coupling to phonons [3].

[1] Q. Mermillod et al., Optica **3**, 377 (2016)
[2] D. Wigger et al., Phys. Rev. B **96**, 165311 (2017)
[3] T. Jakubczyk et al., ACS Photonics **3**, 2461 (2016)

HL 24.33 Tue 18:30 Poster F

Ultrafast spin-dependent dynamics and high harmonic generation in semiconductor nanostructures — •Dominik Schulze and Jamal Berakdar — Institute of Physics, Martin-Luther-University Halle-Wittenberg, 06099 Halle/Saale, Germany

Using a direct time propagation technique, we investigate the time-resolved charge and spin quantum dynamics of semiconductor based heterostructures subjected to ultrashort laser pulses. Special attention is devoted to effects related to spin-orbital coupling. It is shown how the time and polarization-resolved emission spectrum can be controlled via the parameters of the driving field as well as by nanostructuring. It is pointed out how the footprints of the spin dynamics can be traced via monitoring in the emission spectrum.

HL 24.34 Tue 18:30 Poster F

Photo-induced magnetic moments in nanostructered quantum rings — •Michael Kraus, Jonas Wätzel, and Jamal Berakdar — Institute for Physics, Martin-Luther-University Halle-Wittenberg, 06099 Halle (Saale), Germany

The generation of strongly focused light beams carrying orbital angular momentum (OAM) for a wide range of pulse parameters opens the door to fascinating new applications in optoelectronics and optical communications. These spatially inhomogeneous light fields allow to change the angular momentum of the sample by an amount set by the topological charge of the OAM beam which can be varied in a large range. Here we focus on nanostructured quantum rings irradiated by OAM beams inducing a substantial magnetic moment which is totally controllable by the laser parameters. Based on a full-fledged quantum simulation we investigate different laser setups to achieve the maximal magnetic moment during and after the application of the pulse. For instance, by increasing the winding number of the optical vortex the magnetic moment can be enlarged as long as the frequencies of the photo-induced electric transitions are within the bandwidth of the pulse. The irreversible relaxation processes induced by the interaction between the photoexcited electrons and acoustic phonons is included by a density matrix approach and indicates how long the generated magnetic moments are detectable.

HL 24.35 Tue 18:30 Poster F

Spatio-temporal resolution studies on a highly compact femtosecond electron diffraction and understanding the phenomena of phonon decay in single crystalline graphite — Christian Gerbig[1], Silvio Morgenstern[1], Marlene Adrian[1], Cristian Sarpe[1], •Muhammad Abdullah Umer[1], Arne Senftleben[1], Matthias Wollenhaupt[2], and Thomas Baumert[1] — [1]University of Kassel, Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany — [2]University of Oldenburg, Institute of Physics, D-26111 Oldenburg, Germany

Ultrafast time resolved electron diffraction has become a promising technique because of its higher temporal and atomic scale spatial resolution and allow to study the ultrafast phenomena occurring in the atomic structure of matter with ultrafast precision.

We report here the application of ultrafast electron diffraction to study the dynamical processes in single crystalline graphite in order to understand the effect of phonon generation and decay mechanism which is being essential for future carbon based electron devices.

With our highly compact setup we are able to achieve excellent spatial- temporal resolution with coherence length >8nm and electron pulse duration <200 fs. We further present generation and decay processes of incoherent as well as coherent phonons in graphite as a function of film thickness down to few-layer graphene.

HL 24.36 Tue 18:30 Poster F

Directional optical switching and transistor functionality using optical parametric oscillation in a spinor polariton fluid — •Matthias Pukrop[1], Przemyslaw Lewandowski[1], Samuel M. H. Luk[2], Chris K. P. Chan[3], P.T. Leung[3], N.H. Kwong[4], Rolf Binder[2,4], and Stefan Schumacher[1,4] — [1]Physics Department and CeOPP, Universität Paderborn, 33098 Paderborn, Germany — [2]Department of Physics, University of Arizona, Tucson, AZ 85721, USA — [3]Department of Physics, The Chinese University of Hongkong, Hongkong SAR, China — [4]College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA

Over the past decade, spontaneously emerging patterns in the density of polaritons in semiconductor microcavities [1] were found to be a promising candidate for all-optical switching. But recent approaches were mostly restricted to scalar fields, did not benefit from the polariton's unique spin-dependent properties, and utilized switching based on hexagon far-field patterns with 60° beam switching (i.e. in the far field the beam propagation direction is switched by 60°). Since hexagon far-field patterns are challenging, we present here an approach for a linearly polarized spinor field, that allows for a transistor-like (e.g., crucial for cascadability) orthogonal beam switching, i.e. in the far field the beam is switched by 90°. We show that switching specifications such as amplification and speed can be adjusted using only optical means [2].

[1] V. Ardizzone et al., Scientific Reports 3, 3016 (2013)
[2] P. Lewandowski et al., Opt. Express 25, 31056-31063 (2017)

HL 24.37 Tue 18:30 Poster F

Lift-off of GaN LEDs with ultrashort laser pulses — •Steffen Bornemann[1,2], Nursidik Yulianto[1,2], Andreas Waag[1,2], and Hutomo Suryo Wasisto[1,2] — [1]Institut für Halbleitertechnik (IHT), Technische Universität Braunschweig, Hans-Sommer-Str. 66, 38106 Braunschweig — [2]Laboratory for Emerging Nanometrology (LENA), Technische Universität Braunschweig, Langer Kamp 6a, 38106 Braunschweig

Due to their high efficiency and compact design, GaN-based LEDs are nowadays the light source of choice for many applications. Sapphire is usually taken as a low-cost substrate for epitaxial growth of the InGaN/GaN heterostructure. However, it provides poor electrical and thermal conductivity, limiting its practicability for commercial high-power LEDs as well as for structured light sources. Therefore, a transfer of thin LED structures to more suitable substrates, e.g. rigid silicon or flexible polyimide, is applied. The detachment from sapphire is normally realized with a UV excimer laser, leading to linear absorption in the first layers of GaN.

In this project, we present the successful implementation of a lift-off process based on a versatile femtosecond laser system operating at a wavelength of 520 nm. The corresponding photon energy is too low for direct absorption, but non-linear processes during the high-energy pulses enable separation of the LED from the original substrate. Luminescence experiments prove the functionality of the lifted chip, whereas SEM measurements reveal local laser induced damage on the surface. Possible mechanisms for these phenomena are discussed.

HL 24.38 Tue 18:30 Poster F

Universal short-time response and formation of correlations after quantum quenches — •Klaus Morawetz — Münster University of Applied Sciences, Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — Max-Planck- Institute for the Physics of Complex Systems, 01187 Dresden, Germany

The short-time evolutions of two distinct systems, the pump and probe experiments with a semiconductor and the sudden quench of cold atoms in an optical lattice, are found to be described by the same universal response function. This analytic formula at short time scales is derived from the quantum kinetic-theory approach observing that correlations need time to form. The demand of density conservation leads to a reduction of the relaxation time by a factor of 4 in quench setups. The influence of the finite-trapping potential is derived and discussed along with Singwi-Sjølander local-field corrections including the proof of sum rules. The quantum kinetic equation allows to understand how two-particle correlations are formed and how the screening and collective modes are build up.

Phys. Rev. B 90 (2014) 075303, Phys. Rev. E 66 (2002) 022103, Phys. Rev. E 63 (2001) 20102, Phys. Lett. A 246 (1998) 311