HL 9: Quantum Dots: Preparation and Characterization

Time: Monday 9:30–12:30 Location: POT 112

HL 9.1 Mon 9:30 POT 112

Fabrication of spectrally homogeneous quantum dot micropillar laser arrays as a nanophotonic hardware for reservoir computing — •Jan Grosse[1], Tobias Heuser[1], Arsenty Kaganskiy[1], Daniel Brunner[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin, Germany — [2]FEMTO-ST, Département d'Optique, 15B Avenue des Montboucons, 25030 Besançon, France

Reservoir computing is a machine learning approach for a new way of efficient data processing. In this promising computing scheme, inspired by the neurons in the brain, the interaction of a network of nodes, called the reservoir, is evaluated by a trained readout to enable applications like fast speech recognition. To realize this concept with optically coupled nodes, a nanophotonic hardware implementation is of particular interest. Here, we report on the growth and fabrication process of spectrally homogeneous 2D arrays of up to 900 quantum dot micropillar lasers. Using diffractive coupling and sophisticated external optics [1], lasers in such arrays will form a nonlinear optical reservoir network. To enable this appealing application, spectral inhomogenities of the vertical laser structure, grown by MOCVD, are compensated by precisely adjusting the radius of individual micropillars [2] via high-resolution electron beam lithography to achieve an overall spectral homogeneity better than 200 μeV in the dense micropillar laser array.

References

[1] D.Brunner, I.Fischer, Opt. Lett. 40, 3854-3857 (2015).

[2] S.Reitzenstein, A.Forchel, J.Phys.D.Appl.Phys. 43, 033001 (2010)

HL 9.2 Mon 9:45 POT 112

Fluorescence behavior of semiconductor nanoparticles in vicinity of plasmonic metals — •Simon Schneider, Elvira Kröger, Xiao Tang, Christian Strelow, Tobias Kipp, and Alf Mews — Institute of Physical Chemistry, University of Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Interactions of plasmonic metal nanoparticles with semiconductor nanoparticles greatly influence the fluorescence behavior of the latter. If introduced to a plasmonic resonant system, the rate of spontaneous emission can be enhanced (Purcell effect). Here, the distance between the metal- and semiconductor nanoparticles has a huge influence on the fluorescence behavior of the whole system, direct contact of the two parts leads to complete fluorescence quenching. We control the distance between metal and CdSe/CdS semiconductor dot-in-rod (DR) structures on the nanometer scale using a silica shell around the DRs as a dielectric spacer and investigate the effect of attached plasmonic metals (Ag & Au) on the fluorescence behavior of the DRs. Metal nanoparticles of 2-3 nm in diameter only showed little to no effect whereas the growth of a continuous gold shell around the DRs doubled the fluorescence-decay rate.

HL 9.3 Mon 10:00 POT 112

P-doping of Silicon Nanocrystals: Free Carriers vs. Defects — •Daniel Hiller[1], Julian Lopez-Vidrier[1], Sebastian Gutsch[1], Margit Zacharias[1], Keita Nomoto[2,3], and Dirk König[3] — [1]Laboratory for Nanotechnology, IMTEK, University of Freiburg, Germany — [2]The University of Sydney, Australia — [3]University of New South Wales (UNSW), Sydney, Australia

We study the size limitations of conventional P-doping of ultra-small Si volumes using Si nanocrystals (Si NCs) of 2-5 nm as a model system. Theoretical studies predicted that P-doping of Si nanocrystals fails due to self-purification, increased formation energies of substitutional P-atoms, and increased ionization energies of donor electrons due to quantum- and dielectric confinement. However, several groups reported a quenching of photoluminescence (PL) from Si NCs by P-doping and attributed that to non-radiative Auger recombination with donor electrons. In this work, we address this contradiction. We disprove the self-purification effect by atom probe tomography (APT) measurements [1]. However, a correlation of APT-statistics, PL- and I-V-measurements reveals that the PL quenching cannot be explained by free carriers. X-ray absorption (XAS) measurements at the P-K-edge indicate that the majority of P-atoms in Si NCs is not ionized at 300 K [3]. I-V shows that P-ionization requires 100-500 meV depending on the NC size [2]. Using density functional theory (DFT) simulations [3], we explain the PL-quenching by P-induced defect states.

[1] Phys. Status Solidi RRL (2016), DOI: 10.1002/pssr.201600376 [2] Appl. Phys. Lett. 106, 113103 (2015) [3] Sci. Rep. 5, 09702 (2015)

HL 9.4 Mon 10:15 POT 112

Electrical characterization of sub-20 nm silicon nanowires fabricated using electron beam lithography and inductively coupled plasma etching — •Muhammad Bilal Khan, Dipjyoti Deb, Yordan M. Georgiev, and Artur Erbe — Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany.

Scaling down of CMOS faces strong challenges due to which new materials, enhanced functionality and new device concepts have gained importance. These concepts include undoped silicon nanowire based reconfigurable devices, which can be programmed as p-FET or n-FET by controlling the electrostatic potential applied via gate electrodes. In this work, electrical characterization of undoped sub-20 silicon nanowires (SiNWs) is reported. SiNWs are fabricated on intrinsic silicon-on-insulator (SOI) substrates in <110> and <100> crystal directions by a top down approach. Hydrogen silsesquioxane (HSQ), a negative tone electron beam resist, is used for nano- patterning and as a hard mask for etching. Nanowire etching process is optimized using an inductively coupled plasma (ICP) source and $C_4F_8/SF_6/O_2$ mixed gas recipe at 18 ^oC. These NWs are oxidized to form a SiO_2 shell and subsequently silicidized. For silicidation, the SiO_2 shell is wet etched at pre-defined positions followed by Nickel (Ni) sputtering and diffusion which yield silicide-silicon (Schottky) junctions. Ni is used for silicidation to selectively control the charge carriers injection at the junctions. Different silicidation progress and charge carrier transport was observed in <110> and <100> crystal directions.

HL 9.5 Mon 10:30 POT 112

Monolithical integration of III-V Quantum Dots into Silicon towards a new silicon based material platform for optoelectronics — •Marc Sebastian Wolf and Johann Peter Reithmaier — Technische Physik, Institute of Nanostructure Technologies and Analytics (INA), CINSaT, University of Kassel

Beyond the successful integration of III-V light emitting material on silicon by wafer-bonding or direct planar growth by using thick relaxation layers, no approach yet is fully process compatible with silicon fabrication technologies. To avoid III-V processing, a new hybrid material based on III-V quantum dots (QDs) embedded in a silicon matrix is under investigation (Benyoucef et al., pss a 211, 817 (2014). A key parameter is the development of core-shell QDs directly grown on silicon surfaces, which could be already successfully demonstrated at low-density structures (Benyoucef et al., APL 102, 132101 (2013)). In this work, the III-V quantum dots are grown in a solid source molecular beam epitaxy system directly on the silicon substrate and subsequently capped with Silicon. The growth and characterisation of InAs/GaAs quantum dots with densities of $> 10^{10} cm^{-2}$ on the silicon surface will be discussed. Additionally, photocurrent measurements of InAs nanocluster monolithically embedded in a silicon p-i-n diode will be shown.

HL 9.6 Mon 10:45 POT 112

MOVPE grown InAs quantum dots on InGaAs/GaAs metamorphic buffers — •Susanne Schreier, Matthias Paul, Fabian Olbrich, Jonatan Höschele, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und funktionelle Grenzflächen, Universität Stuttgart and Research Centers SCoPE and IQ^{ST}, Allmandring 3, 70569 Stuttgart

In the last years the interest in quantum computing and cryptography and therefore the need for single-photon sources increased strongly. InAs semiconductor quantum dots (QDs) are promising candidates for sources of entangled or indistinguishable photons due to their good optical properties. The implementation in glass fiber networks requires emission wavelengths of 1310 nm (O-band) and 1550 nm (C-band), corresponding to the dispersion and absorption minima. To reach these wavelengths the typical emission energies of InAs QDs need to be red shifted. This can be realized by reducing the lattice mismatch between GaAs and InAs by the use of an InGaAs metamorphic buffer layer below the QDs. The buffer layer functions, similar to InP substrates, to reduce the strain in the QDs. This leads to a reduction of the effective band gap and to an increase in size of the QDs, which results in a lower emission energy. In contrast to InP substrates, the extraction efficiency for photoluminescence (PL) measurements can be enhanced by AlAs/GaAs distributed Bragg reflectors below both the metamorphic buffer and the QDs. The characterization involves XRD and AFM to investigate the structural properties and PL to investigate the optical properties of the InAs QDs.

Coffee Break

HL 9.7 Mon 11:30 POT 112

Single shot spin readout in a 3D crystalline transistor — •Matthias Koch[1,2], Eldad Peretz[2,3], Joris G. Keizer[2], and Michelle Y. Simmons[2] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft — [2]University of New South Wales — [3]Bar Ilan University

Atomic-scale fabrication has recently been demonstrated in silicon using scanning tunneling microscope (STM) hydrogen resit lithography[1]. Dopants can be placed in silicon with atomic precision to fabricate a single atom transistor[2], where a single atom controls the device opacity. Scalable architectures, i.e. based on cross wires, demand from hydrogen resist lithography to separate the individual elements of the electronic circuit on different planes. Here, we demonstrate a new fabrication recipe by performing single shot spin readout with a vertically aligned top gate. The additional device layer does not cause instabilities which reflects in a high readout fidelity of 97%. Our results show that hydrogen resist lithography can be extended easily to multiple planes, a premises for the development of complex device architectures.

[1] A. Fuhrer, M. Füchsle, T. C. G. Reusch, B. Weber, and M. Y. Simmons, Nano Letters 9, 707 (2009)

[2] F. Martin, M. Jill A., M. Suddhasatta, R. Hoon, L. Sunhee, W. Oliver, H. Lloyd C. L., K. Gerhard, and S. Michelle Y., Nat Nano 7, 242 (2012)

HL 9.8 Mon 11:45 POT 112

Quantum Dots grown by Local Droplet Etching on GaAs (111)A Substrates — •Julian Ritzmann[1], Nand Lal Sharma[2], Dirk Reuter[2], Carolin Lüders[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)[1]. 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[2]. 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.

[1] T. Mano et al., Appl. Phys. Express 3, 065203 (2010).

[2] Ch. Heyn et al., Appl. Phys. Lett. 94, 183113 (2009).

HL 9.9 Mon 12:00 POT 112

Efficient deterministic single-photon sources based on quantum-dots in suspended circular Bragg grating cavities — •Tobias Heuser, Arsenty Kaganskiy, Esra B. Yarar Tauscher, Ronny Schmidt, Anna Musial, Sven Rodt, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin, Germany

Applications in the field of quantum communication will benefit strongly from deterministic single-photon sources (SPSs) based on single semiconductor quantum dots (QDs). Such non-classical light sources feature close to ideal single-photon emission as well as photon-indistinguishability. However, maximizing the photon extraction efficiency of these sources remains an important issue.

Here, we report on the implementation of a highly efficient semiconductor QD-based SPS using a circular Bragg grating which is patterned into a suspended membrane. The high refractive index contrast at the grating leads to in-plane light confinement as well as vertically asymmetric out-of-plane scattering. Maximizing the photon extraction efficiency by finite element simulations of the device geometry yields values up to even 80%. To implement this approach with a high device yield, we apply deterministic high-resolution in-situ electron beam lithography [1] at cryogenic temperatures. In this way, specific QDs can be pre-selected according to their position and emission energy to ensure spatial and spectral matching for optimal extraction efficiency.

References

[1] M. Gschrey, Appl. Phys. Lett. ,vol. 102, p. 251113, 2013

HL 9.10 Mon 12:15 POT 112

Investigating the crystal structure of CdSe and CdTe semiconductor nanowires — •Philip Harder, Tobias Redder, Andreas Nielsen, Tobias Kipp, and Alf Mews — Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Deutschland

The Solution-Liquid-Solid method allows to synthesize CdSe and CdTe nanowires with very small diameters (below 10 nm), that have interesting optical and electronical properties. These properties mainly depend on the ligands on the surface and the crystal structure, i. e. the zincblende to wurtzite ratio. We developed a method to determine the ratio in these nanowires via powder X-ray diffraction measurements. The analysis of the experimental powder diffraction patterns was carried out via genetic evolutional algorithms and the results were correlated with high resolution TEM measurements. We acknowledge financial support by the DFG via KI 1257/2 and ME 1380/16-3.