# HL 15: Quantum Dots and Wires: Fabrication and Devices

Time: Monday 14:45–18:45 Location: H16

HL 15.1 Mon 14:45 H16

**1.3 $\mu$m low-density quantum dots for single photon emitters**
— •David Quandt[1], Pierce Munnelly[1], Udo Pohl[1], Stephan Reitzenstein[1], and André Strittmatter[2] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, D-10623 Berlin, Germany — [2]Otto-von-Guericke Universität Magdeburg, Universitätsplatz 2, D-39106 Magdeburg, Germany

The positioning of In(Ga)As quantum dots by means of a buried stressor has successfully been used to fabricate an electrically driven single photon source emitting in the wavelength range around 960 nm with a $g^{(2)}(0)$ value of 0.05 at 12.5 K. It is highly attractive to adopt this technique for the deterministic realization of practical single photons sources emitting at telecom wavelengths. Indeed it has been shown that it is possible to achieve emission wavelengths of 1.3 $\mu$m and beyond using In(Ga)As quantum dots on GaAs. Thus, a buried stressor based single photon source operating at telecommunication wavelengths is feasible. As preliminary work towards this goal, low density InGaAs quantum dots with an InGaAs strain reducing layer have been grown by MOCVD. First micro photoluminescence measurements show discrete excitonic emission lines of single quantum dots ranging from 1200 nm to 1400 nm.

HL 15.2 Mon 15:00 H16

**Hybrid architecture for shallow accumulation mode AlGaAs/GaAs heterostructures with epitaxial gates**
— S. J. MacLeod[1], A. M. See[1], A. R. Hamilton[1], I. Farrer[2], D. A. Ritchie[2], •J. Ritzmann[3], A. Ludwig[3], and A. D. Wieck[3] — [1]School of Physics, University of New South Wales, Sydney, Australia — [2]Cavendish Laboratory, University of Cambridge, United Kingdom — [3]Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

In accumulation-mode GaAs based heterostructures, the charge carriers are induced by a gate. Usually the top-gate spans the entire transport region and slightly overlaps the ohmic contacts in order to effectively contact and induce a continuous two dimensional conducting region. The close proximity of the contacts to the top-gate can easily cause electrical shorts. The shorting of the top-gate to the contacts is particularly problematic in shallow SISFETs in which the top-gate is an in situ, degenerately doped GaAs cap. Here, we demonstrate a hybrid device where the transport region is a SISFET. The gate recess is realized by a two dimensional electron system induced with a metal gate, insulated from an ohmic contact and the SISFET gate by a dielectric layer. Samples with spacer thicknesses of 50 nm and 160 nm are grown and processed in hybrid devices. Ohmic contact resistance, density tunability, mobiltiy and quantum Hall effect measurements are performed. We observe no shift in the bias point for different cooldown cycles. Additionally devices from different MBE setups, show identical bias point operations and nearly identical mobility.

HL 15.3 Mon 15:15 H16

**In(Ga)As/GaAs quantum dots grown on GaP/Si(001) investigated on the atomic scale**
— •Celina S. Schulze[1], Xue Huang[2], Christopher Prohl[1], Vivien Füllert[1], Stavros Rybank[1], Scott J. Maddox[3], Stephen D. March[3], Seth R. Bank[3], Minjoo L. Lee[2], and Andrea Lenz[1,2] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Germany — [2]Yale University, Department of Electrical Engineering, USA — [3]The University of Texas at Austin, Microelectronics Research Center and ECE Dept., USA

The epitaxial growth of III-V laser structures on Si(001) substrates is of high interest for future applications in the silicon-device technology. In this work the atomic structure, stoichiometry, and optical properties of InAs/InGaAs quantum-dot-in-a-well structures grown in a GaAs matrix on an exactly oriented GaP/Si(001) template are studied. Similar photoluminescence spectra are observed for nanostructures grown on GaP/Si(001) compared to those on GaAs(001) substrates. For a fundamental understanding of these optical properties a detailed knowledge of the atomic structure is required, which is ideally studied using cross-sectional scanning tunneling microscopy (XSTM). In detailed XSTM experiments quantum dots with lateral sizes of about 20 nm and heights up to 8 nm were observed. An inhomogeneous In concentration indicates strong segregation effects.

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HL 15.4 Mon 15:30 H16

**Growth and structure of In0.5Ga0.5Sb quantum dots on GaP**
— •Elisa Maddalena Sala[1], Gernot Stracke[1], Sören Selve[2], Tore Niermann[2], Michael Lehmann[2], Andre Strittmatter[1], and Dieter Bimberg[1] — [1]Institut für Festkörperphysik, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Zentraleinrichtung Elektronenmikroskopie, TU Berlin, Str. des 17. Juni 135, 10623 Berlin, Germany

III-V self-assembled QDs on GaP have recently attracted great interest for application in nanomemory cells. As demonstrated by Marent, Geller, Bimberg et al[1], such QDs can be employed as storage units in a novel type of non-volatile nanomemory, the QD-Flash. Retention times of more than 10 years for holes in In0.5Ga0.5Sb QDs embedded in a GaP matrix are predicted. Here we demonstrate for the first time the Stranski-Krastanov (S-K) growth of In0.5Ga0.5Sb QDs on GaP(001) by metalorganic vapor phase epitaxy (MOVPE). Taking advantage of the initial 2D growth of GaAs on GaP, the few GaAs layers mimic a virtual substrate for the following In0.5Ga0.5Sb deposition, playing a decisive role adjusting the surface energetics. The QD density shows a typical S-K trend, i.e. a logarithmic dependence on the amount of deposited In0.5Ga0.5Sb. High resolution cross-sectional TEM micrographs of buried QDs show a typical truncated-pyramid shape. Before supplying QD material, a short Sb-flush is used to initiate Sb incorporation. Experimental results show that Sb apparently modifies the growth kinetics by reducing the In and Ga surface diffusion length.

[1] A. Marent et al, Microelectronics Journal 40 (2009), 492-495.

HL 15.5 Mon 15:45 H16

**Electrostatically defined quantum dots in undoped Si/SiGe heterostructures**
— •Floyd Schauer[1], Christian Neumann[1], Christian Fritsch[1], Sebastian Schwägerl[1], Simon Pfaehler[1], Dieter Weiss[1], Kentarou Sawano[2], and Dominique Bougeard[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]Advanced Research Laboratories, Tokio City University, Japan

Two-dimensional electron systems (2DES) in undoped heterostructures represent a promising building block for the development of electrostatically defined spin qubits. Omitting the dopants in the heterostructure eliminates fluctuating charge traps due to ionized impurities. The hyperfine interaction with the nuclear spin bath being a dominant qubit decoherence mechanism, Si/SiGe heterostructures have been receiving steadily increasing attention for building devices almost free of nuclear spin carrying isotopes.

In this contribution, we present the realization of capacitively-induced Si/SiGe Quantum Dot (QD) devices. A global top gate is used to accumulate electrons and induce a 2DES in the undoped Si quantum well via the field effect. We examine the capacitive coupling between surface gates and the 2DES as well as remaining charge noise sources in these undoped structures. A second gate layer in the devices allows to locally deplete the 2DES and to form QDs: we discuss the operation in the single QD regime.

HL 15.6 Mon 16:00 H16

**Preparation of Silicon Nanocrystals in Silicon Carbide by a Multilayer Approach**
— •Charlotte Weiss, Andreas Reichert, and Stefan Janz — Fraunhofer Institut für Solare Energiesysteme ISE, Heidenhofstraße 2, 79110 Freiburg, Germany

The embedment of Si nanocrystals (NC) in a SiC matrix yields a promising semiconductor for tandem solar cell applications, due to its tunable bandgap by the variation of the Si NC size. The samples are prepared by plasma enhanced chemical vapour deposition (PECVD) of alternating stoichiometric SiC and Si-rich SiC (SRC) layers. During the subsequent annealing step at 1100°C phase separation into Si and SiC takes place in the SRC layers and NC form. The stochiometric SiC layer is intended to act as barrier layer for Si NC growth, which would mean that the thickness of the SRC layers define the Si NC size. It turns out that this so called multilayer (ML) approach does not control the Si NC size sufficiently, due to Si/SiC interdiffusion during annealing, accompanied with the loss of the ML structure.

Now we successfully preserved the multilayer structure by the incorporation of oxygen in the samples. This was achieved by providing CO2 during PECVD. The successful incorporation in the form of Si-O was confirmed by fourier transformed infrared spectroscopy while the preserved ML structure is observed in scanning electron micrographs. Raman measurements provide further evidence for lowered intermixing, as they show enhanced Si crystallinity in the ML with oxygen compared to samples without oxygen.

**Invited Talk** HL 15.7 Mon 16:15 H16

**Mechanical Control of Excitonic States in Quantum Dots** — Rinaldo Trotta, Javier Martín-Sánchez, and •Armando Rastelli — Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Austria

Several systems are under investigation for their potential use in the fields of quantum information and communication. Semiconductor quantum dots (QDs), also dubbed “artificial atoms”, are one of such systems, as they can be used both as sources and hosts of “quantum bits” and can be easily integrated into compact devices and photonic structures. However, unlike natural atoms, no two QDs are identical - a major obstacle towards their actual application.

In this talk we will show how elastic strain can be used to overcome problems arising from unavoidable fluctuations during QD growth and to reshape the QD electronic structure and excitonic emission after fabrication. In particular, we will illustrate how any arbitrarily chosen QD can be employed as a wavelength-tunable source of entangled-photon pairs. This is achieved by integrating the QDs onto micro-machined piezoelectric actuators capable of controlling the in-plane strain in the QD and surrounding matrix [1-3].

[1] R. Trotta et al., Phys. Rev. Lett. 114, 150502 (2015)
[2] R. Trotta et al., Nature Comm. (in press)
[3] J. Martín-Sánchez et al., Adv. Opt. Mater. (in press)

**30 min. Coffee Break**

HL 15.8 Mon 17:15 H16

**An electro-photo-sensitive memristor for neuromorphic and arithmetic computing applications** — •Patrick Maier[1], Fabian Hartmann[1], Monika Emmerling[1], Christian Schneider[1], Martin Kamp[1], Sven Höfling[1,2], and Lukas Worschech[1] — [1]Technische Physik and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Physikalisches Institut, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]SUPA, School of Physics and Astronomy, University of St. Andrews, St. Andrews, KY16 9SS, UK

Memristors have state- and time-dependent resistances that allow the emulation of synaptic functionalities which are essential for learning and memory. We report the realization of a memristor on the mature III-V-semiconductor platform and present an electro-optical control of the conductance by tuning the amount of localized charge on a quantum dot floating gate. In analogy to synaptic strength modifications in neural networks, we show that the conductance can be increased (potentiation) or decreased (depression) by tuning the time difference between incoming voltage pulses. In addition, the localized charge on the quantum dot shifts the threshold voltages for the induction of potentiation and depression. The dependency of the threshold voltage for potentiation on the initial state in combination with the optical control of the conductance enables arithmetic computing applications of low power light pulses. Our findings may pave the way to the realization of electro-optical, memristor-based artificial neural networks with a memory-dependent ability of learning.

HL 15.9 Mon 17:30 H16

**Site-Controlled MBE Growth of III/V Semiconductor Nanowires Induced by Focused Ion Beam** — •Sven Scholz, Rüdiger Schott, Arne Ludwig, and Andreas D. Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Nanowires (NWs) are near one-dimensional structures that typically have a huge length-to-width ratio. This is the base of fascinating properties. Heterostructures of highly lattice mismatched materials can be combined without dislocations. Metastable phases, unattainable in bulk materials like wurtzite GaAs or InAs, are feasible. We present focused ion beam (FIB) induced molecular beam epitaxy (MBE) grown NWs from site selectively deposited Au seeds. The possibility of maskless patterning makes FIB a powerful tool and an alternative to conventional lithography based methods in semiconductor processing. By implanting distinct spots of Au ions in arbitrary distributions on GaAs substrates, we initiate GaAs and InAs NW growth in the MBE. We show, that a small amount of ions resulting in small droplets appropriate to catalyse a single NW per site with a yield of above 60%. The small size of the droplets leads to NWs with diameters of 20 nm and below, which results in high aspect ratios. Additionally to the optimization of the morphology, the crystal structure was investigated and improved to achieve defect free and single crystalline NWs. Also the bandgap modulation due to the growth of heterostructures in single NWs will be presented.

HL 15.10 Mon 17:45 H16

**Selective area growth of GaAs nanowires combining high vertical yield and desirable morphology** — •Hanno Küpers, Abbes Tahraoui, Ryan B. Lewis, Henning Riechert, and Lutz Geelhaar — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin

The Ga-assisted growth of GaAs nanowires (NWs) is a promising way to integrate III-V materials with Si. Toward this goal, selective area NW growth on an oxide mask by molecular beam epitaxy has been widely investigated, focusing mainly on obtaining high vertical NW yields rather than optimal NW morphologies. Key requirements for high NW yields are a high mask quality and a low V/III ratio, however, NWs grown under these conditions exhibit large diameters and a high degree of tapering, both undesired properties for applications relying on a core-shell geometry. In this study we present a two-step growth approach which results in high vertical yields with small diameters and negligible tapering: First, NWs start to grow under growth conditions optimized for a high vertical yield. Second, after some time the growth conditions are changed in order to shape the morphology of the growing NWs. Even though the V/III ratio is increased the NW growth remains stable and does not cease. This growth approach enables the growth of NW ensembles with a vertical yield of exceeding 70%, diameters of 50 nm and tapering of below 0.4%.

HL 15.11 Mon 18:00 H16

**Top-down fabrication and characterization of reconfigurable silicon nanowires** — •Dipjyoti Deb[1], Muhammad Bilal Khan[1], Yordan Georgiev[1], Markus Löffler[3], Walter Weber[2], Manfred Helm[1], and Artur Erbe[1] — [1]HZDR, Bautzner Landstraße 400, 01328 Dresden, Germany — [2]Namlab gGmbH, Nöthnitzer Str. 64, 01187 Dresden, Germany — [3]Center for Advancing Electronics Dresden, 01062 Dresden, Germany

The following work illustrates characterization of reconfigurable, undoped silicon nanowire field effect transistors with Schottky junctions fabricated on silicon on insulator (SOI) substrate by top-down process. The fabrication scheme is based on electron beam lithography (EBL) using hydrogen silsesquioxane (HSQ), a negative tone electron beam resist, followed by inductively coupled plasma (ICP) etching. The etch recipe was optimised in context of selectivity, sidewall roughness and anisotropy by selecting an appropriate gas chemistry (SF6/C4F8) and controlling the ICP hardware parameters like gas flow, mixed gas ratio, plasma power and chamber pressure. We produced silicon nanowires of 20 nm width and nanowire arrays with pitch of 200 nm. 50 nm thick nickel (Ni) layer was sputtered on the SiNWs at lithographically defined areas followed by lift-off and thermal annealing to create Nickel-Silicide Schottky junctions inside the nanowires. In this way, the source and drain region was formed creating silicide-silicon-silicide contacts. Transport properties of these nanowires can be modulated from P-type to N-type and vice-versa by changing polarity of the back gate.

HL 15.12 Mon 18:15 H16

**Electrical characterization and modelling of p-GaAs nanowires by MT-STM** — •Andreas Nägelein[1], Matthias Steidl[1], Weihong Zhao[1], Stefan Korte[2], Peter Kleinschmidt[1], and Thomas Hannappel[1] — [1]TU Ilmenau, Institut für Physik, FG Photovoltaik, 98693 Ilmenau — [2]Forschungszentrum Jülich, Peter Grünberg Institut (PGI-3), 52425 Jülich

Doped nanowires are promising candidates as components for advanced applications such as FETs or solar cells. To increase the efficiency of these upcoming applications detailed knowledge of dopant distribution along the nanowire is necessary. In this work a nondestructive method is used, where freestanding nanowires can be characterized using a multi-tip STM (MT-STM) as a prober for four-point measure-

ments. Here, a continuous resistance profile can be recorded which is proportional to the doping profile. The nanowires were grown in the Au-catalyzed VLS growth mode on p-GaAs(111)B by metal-organic chemical vapor phase epitaxy (MOVPE) in an "AIX200" system.
Resistance profiles of p-GaAs nanowires were recorded using the MT-STM. With help of a suitable model we are able to simulate the resistances and calculate the doping of the nanowire which results in a constant doping profile. In order to establish a valid electrical model for doped nanowires we developed in the first step a simulation with resistances and diodes. We could show that a simple model is in good agreement with the measured data. Applying an extended model to nanowire measurements allows analysis of more complex dopant distributions and nanowire geometries.

HL 15.13 Mon 18:30 H16

**In-situ growth of semiconductor/superconductor core-shell nanowires** — •Nicholas Güsken[1,2], Torsten Rieger[1,2], Thomas Schäpers[1,2], Detlev Grützmacher[1,2], and Mihail Ion Lepsa[1,2] — [1]Peter Grünberg Institute 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jülich Aachen Research Alliance for Fundamentals of Future Information Technology (JARA-FIT), Germany

Semiconductor/superconductor(SM/SC) nanowire (NW) hybrid structures are of main interest for future research as they enable to investigate a variety of quantum effects such as Andreev reflections and the proximity effect. Additionally, InAs/Nb as well as InAs/Al core-shell NWs, might pave the way for a breakthrough with regard to Majorana-fermion related research and quantum computing. For all of the experiments, a clean SM/SC interface and low SM resistivity is crucial, to circumvent unambiguous core results. In this sense, the best solution is to fabricate the SM-NW core and the SC shell in-situ. In this work, we show results of the in-situ growth and preliminary morphological and electrical characterization of InAs/Al and InAs/Nb hybrid NWs.

The InAs NWs were grown self-assisted on Si substrates, using molecular beam epitaxy. Expecting more efficient and uniform doping, Te doping was employed to tailor the electron concentration of the NWs. Electrical characterization was conducted after the NW growth to investigate the impact of Te doping on the NWs. Finally, Al or Nb, were deposited on the side facets of the NWs.

The quality of the SM/SC core-shell NWs was investigated by SEM and preliminary transport measurements at low temperatures.