HL 12: Quantum Dots and Wires 3: Growth

Time: Tuesday 9:30–12:45 Location: H32

Invited Talk HL 12.1 Tue 9:30 H32

Wafer-Scale Epitaxial Modulation of Quantum Dot Densitiy — •Nikolai Bart[1], Christian Dangel[2], Peter Zajac[1], Nikolai Spitzer[1], Marcel Schmidt[1], Kai Müller[2,3], Andreas D. Wieck[1], Jonathan Finley[2], and Arne Ludwig[1] — [1]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44801 Bochum, Germany — [2]Walter Schottky Institut and Physik Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany — [3]Walter Schottky Institut and Department of Electrical and Computer Engineering, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

The effect of nanoscale surface roughness on the nucleation of self-assembled InAs quantum dots (QD) is investigated with photoluminescence (PL) spectroscopy and atomic force microscopy. We show in-situ control of the roughness modulation by common epitaxial layer-by-layer growth, leaving alternating atomically smooth (rough) surfaces for integer (fractional) completion of a monolayer. We report significant differences in both PL intensity and QD surface density at the critical threshold of nucleation. By varying the underlying GaAs thickness gradients, we create and control 1- and 2-dimensional density modulation patterns on entire 3-inch wafers with modulation periods between a few mm and down to hundreds of μm and densities between 1 and 10 QDs/μm^2.

Bart, N., Dangel, C. et al. Wafer-scale epitaxial modulation of quantum dot density. *Nat Commun* **13**, 1633 (2022).

HL 12.2 Tue 10:00 H32

Full Wafer Property Control of Local Droplet Etched GaAs Quantum Dots — •Hans-Georg Babin, Nikolai Bart, Marcel Schmidt, Nikolai Spitzer, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Deutschland

Local droplet etched GaAs quantum dots (LDE-QDs) are a promising candidate for excellent single and entangled photon sources [1]. It is important that the carefully developed and highly complex structures are matched perfectly with the embedded QDs [2]. In this submission, we show a way to control QD properties during molecular beam epitaxy on a single wafer, which opens the opportunity to find optimally fitting QDs for the desired experiments by just changing the position on the wafer.

We induce flux gradients by stopping sample rotation and using the parallax of the effusion-cells, resulting in a gradual change of deposited material and cell flux. By this we can vary properties of the QDs like density and emission wavelength on a single wafer. In this work, the widest achieved wavelength shift of the ground state emission energy at 100 K extends over the range of 795 nm to 737 nm [3]. The induced surface roughness modulation additionally induces a stripe-patterned modulation, which was shown before only with Stranski-Krastanov QDs [4].

[1] Huber, D. et al., Nat. Commun. 8 (1), S. 15506 (2017).
[2] Zhai, L. et al., Nat. Commun. 11 (1), S. 4745 (2020).
[3] Babin, H.G. et al., J. Cryst. Growth 591, S. 126713 (2022).
[4] Bart, N.; Dangel, C.; et al., Nat. Commun. 13, 1663 (2022).

HL 12.3 Tue 10:15 H32

Towards MOVPE-grown c-band emitting InAs quantum dots on a Si (001) substrate based on heterogeneous integration of membrane and epitaxial regrowth — •Ponraj Vijayan, Robert Sittig, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, Universität Stuttgart, Germany

Silicon photonics for telecommunications applications has garnered much attention in recent decades. The optical transparency and the large refractive index contrast of silicon in the telecommunication wavelengths allow the implementation of high-density photonic integrated circuit. The drawback of silicon photonics is that there is no native light source due to the indirect band-gap nature of silicon. Integration of III-V material, which offers outstanding optical emission properties, on silicon provides a potential solution. The monolithic integration i.e. the direct growth of III-V materials on silicon is the most desired approach. However, it is very challenging because of large lattice mismatch and material polarity difference between the III-V materials and silicon. An alternate monolithic approach is through heterogeneous integration of thin III-V membrane using direct bonding techniques followed by epitaxial regrowth. Our group has previously developed InAs QD/InGaAs MMB/GaAs substrate structures for long-distance optical fiber applications. Here, we report on the route to monolithically integrate the telecom C-band emitting InAs QD on a wafer bonded GaAs/Si substrate using MOVPE.

HL 12.4 Tue 10:30 H32

Non-vapor-liquid-solid selective area epitaxy of GaAs1-xSbx nanowires on silicon — Akhil Ajay[1], Hyowon Jeong[1], •Haiting Yu[1], Nitin Mukhundhan[1], Tobias Schreitmüller[1], Markus Döblinger[2], and Gregor Koblmüller[1] — [1]Walter Schottky Institute & Physics Department Technical University of Munich, Garching, Germany — [2]Ludwig-Maximilians-University, Munich, Germany

Epitaxial growth of semiconductor nanowires(NWs)is generally known to proceed via a vapor-liquid-solid(VLS). However,an absence of the liquid droplet would be ideal for III-V NW integration on Si and the exploration of atomically abrupt NW heterostructures.In this work,we report a novel non-VLS growth mechanism for the selective area growth of GaAs1-xSbx NWs on Si(111)substrates using molecular beam epitaxy.Non-VLS NWs are known to have many structural defects and poor aspect ratios.Surprisingly,we observe an increased axial growth and aspect ratio in these NWs by adding low concentrations of Sb.This also contrasts the commonly believed enhancement in radial growth for VLS growth claimed to be due to the surfactant effect of Sb.We report on realizing control over aspect ratio and yield by optimizing SiO2 mask hole diameter,growth time and growth temperature.In this process we observe a hitherto unreported dynamic growth rate that increases with time.We also investigate the initial growth of such non-VLS NWs forming inside the SiO2 mask opening,describing the facets and morphology.We also explore n-doping in these NWs with Si which also helps in realizing nearly unity yield and homogeneity.

HL 12.5 Tue 10:45 H32

Epitaxial growth and characterization of multilayer site-controlled InGaAs quantum dots based on the buried stressor method — •Imad Limame, Ching-Wen Shih, Alexej Koltchanov, Moritz Plattner, Johannes Shall, Sven Rodt, and Stephan Reitzenstein — Institute for Solid State Physics, Technical University of Berlin, Germany

The buried-stressor epitaxial growth concept is a prim approach for the realization of site- and number- controlled quantum dots (QDs) with optical high quality. This advanced technique has a wide application spectrum including nanophotonics devices such as single-photon sources (SPSs), microlasers, and emitter-arrays for neuromorphic photonic computing. Here, we report on the development of multi-layer site-controlled QDs (ML-SCQDs) integrated in micropillar laser arrays with low threshold pump power. The buried-stressor technique utilizes a partially oxidized buried AlAs aperture to engineer the strain profile in the following GaAs capping layer and control the position and number of the QDs at the GaAs surface. Thanks to the unetched GaAs surface, the buried-stressor SCQDs exhibits excellent optical properties in comparison to other SCQDs growth approaches, using for instance nano-hole arrays as nucleation centers. Additionally, after integration into micropillar cavities the partially oxidized aperture results in additional confinement of the optical mode in lateral direction, leading to lower mode volume and higher Q-factor for a given micropillar geometry. The grown ML-SCQDs are investigated using atomic force microscopy , micro-photo- and cathodoluminescence spectroscopy.

30 min. break

HL 12.6 Tue 11:30 H32

Growth of shallow GaAs quantum dots and investigation of their optical properties — •Moritz Langer[1], Nand Lal Sharma[1], Ghata Satish Bhayani[1], Ankita Choudhary[1], Oliver G. Schmidt[2], and Caspar Hopfmann[1] — [1]Institute for Integrative Nanoscience - IFW Dresden, Dresden, Germany — [2]Center for Materials, Architectures, and Integration of Nanomembranes (MAIN), TU Chemnitz, Chemnitz, Germany

In recent years local droplet etching developed into an attractive growth process for strain-free semiconductor quantum dots. Typically, conical nanoholes etched into Al0.15Ga0.85As buffer layer by the droplet etching process using molecular beam epitaxy machine [1], have a width of about 50 nm and a depth of 15 nm. By using migration enhanced epitaxy, these nanoholes filled with GaAs and capped with an Al0.15Ga0.85As layer, buried around 6 nm high quantum dot structures of high optical quality are obtained. For enhanced interaction of quantum dots with external stimuli e.g. magnetic fields of thin films -, it is desirable to produce quantum dots close to the surface. Consequentially, the nature of the sample surface and the electronic and optical properties the quantum dot cannot be considered independently. For this purpose, the influence of capping layer thickness on the optical properties of GaAs/Al0.15Ga0.85As quantum dots are investigated using photoluminescence spectroscopy.

[1] Xiaoying Huang et al, 2020 Nanotechnology 31 495701 (2020)

HL 12.7 Tue 11:45 H32

Local droplet etching on InAlAs/InP surfaces with InAl droplets — •Yiteng Zhang[1], Xin Cao[1], Chenxi Ma[1], Yinan Wang[1], Benedikt Brechtken[2], Rolf J. Haug[2], Eddy P. Rugeramigabo[1], Michael Zopf[1], and Fei Ding[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany — [2]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

GaAs quantum dots (QDs) grown by local droplet etching (LDE) have been studied extensively in recent years. The LDE method allows for high crystallinity, as well as precise control of the density, morphology, and size of QDs. These properties make GaAs QDs an ideal candidate as single photon and entangled photon sources at short wavelengths (<800 nm). For technologically important telecom wavelengths, however, it is still unclear whether LDE grown QDs can be realized. In this work, we study Indium-Aluminum (InAl) droplet etching on ultrasmooth In0.55Al0.45As surfaces on InP substrates, with a goal to lay the foundation for growing symmetrical and strain-free telecom QDs using the LDE method. We report that both droplets start to etch nanoholes at a substrate temperature above 415 °C, showing varying nanohole morphology and rapidly changing density (by more than one order of magnitude) at different temperatures. Al and In droplets are found to not intermix during etching, and instead etch nanoholes individually. The obtained nanoholes show a symmetric profile and very low densities, enabling infilling of lattice-matched InGaAs QDs on InAlAs/InP surfaces in further works.

HL 12.8 Tue 12:00 H32

Influence of miscut angle on the exciton fine structure in GaAs/AlAs(111) and InAs/GaAs(111) quantum dots — •Geoffrey Pirard[1] and Gabriel Bester[1,2] — [1]Physical Chemistry and Physics Departments, University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee, 149, D-22761 Hamburg, Germany

Self-assembled quantum dots (QDs) grown on (111) surfaces constitute, in principle, excellent solid-state quantum emitters of polarized-entangled photon pairs making them promising candidates for quantum information processing applications. However, in practice, the growth on such substrates introduces limitations on the growth rate hindering the generation of sufficiently intense signal for such applications. One potential solution to address this problem is to grow these systems on misoriented substrates.

Using atomistic, million-atom screened pseudopotential theory together with configuration interaction, we perform numerical calculations and analyze the influence of the miscut on the exciton fine structure (FS) of GaAs/AlAs(111) and InAs/GaAs(111) QDs. We show that the presence the miscut modifies the spatial distribution of the electron and hole wave functions, which elongate along the $[1\bar{1}0]$ crystal axis. In turn, the polarization of the excitonic states acquires a clear preferential orientation and this effect is strongly enhanced in strained systems. Finally, the FS splitting increases with the miscut within a range depending on the material and the amplitude of the miscut.

HL 12.9 Tue 12:15 H32

Controlled MOF growth on functionalized carbon nanotubes — •Marvin J. Dzinnik[1], Necmettin E. Akmaz[1], Adrian Hannebauer[2], Peter Behrens[2], and Rolf J. Haug[1] — [1]Leibniz Universität Hannover, Institut für Festkörperphysik, 30167 Hannover — [2]Leibniz Universität Hannover, Institut für Anorganische Chemie, 30167 Hannover

The class of metal organic frameworks (MOFs) is continuously growing. These materials consist of inorganic building blocks, held together by organic linker molecules. Schulze *et al.* [1] showed that adding functionalized multi-walled carbon nanotubes (MWCNTs) to a UiO-66 synthesis drastically decreased the nucleation time. The MOFs preferably grow on the MWCNT until they fully encapsulate it. We demonstrate a mechanism to spacially control the UiO-66 MOF growth on individual carbon nanotubes and deplete the encapsulation. The MWCNTs are drop-casted on a silicon dioxide surface and then locally modified. The samples are then submerged in the synthesis solution. This process leads to a growth of MOF crystals on the MWCNT surface leaving the modified areas depleted. With this method we are able to define lines free of MOF on the length of a single MWCNT down to several hundred nanometres for example to electrically contact the tubes ends.

[1] Schulze, H. A., et al. Electrically Conducting Nanocomposites of Carbon Nanotubes and Metal-Organic Frameworks with Strong Interactions between the two Components. ChemNanoMat, 5(9), (2019), 1159-1169.

HL 12.10 Tue 12:30 H32

Surface quantum dots with pure, coherent, and blinking-free single photon emission — •Michael Zopf[1], Xin Cao[1], Jingzhong Yang[1], Pengji Li[1], Tom Fandrich[1], Eddy P. Rugeramigabo[1], Chenxi Ma[1], Robert Keil[2], Frederik Benthin[1], Benedikt Brechtken[1], Rolf J. Haug[1,4], Yiteng Zhang[1], Susanne Woche[3], Zhao An[1], Constantin Schmidt[1], and Fei Ding[1,4] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Fraunhofer-institut für Angewandte Festkörperphysik IAF, Freiburg, Germany — [3]Institut für Bodenkunde, Leibniz Universität Hannover, Germany — [4]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Germany

The surface of semiconductor micro- and nanostructure-based devices has a major impact on their performance. Disorder and defects in the crystal typically lead to electronic states in the bandgap, degrading charge carrier transport and radiative recombination. In next generation semiconductor devices such as single or entangled photon sources, surface effects lead to low efficiency, photon dephasing, blinking or spectral jittering. Here we show unprecedented optical quality of GaAs quantum dots that are grown directly on an AlGaAs surface and passivated with 1-Octadecanethiol. Single photons are generated with 98.8 % purity, 78 % indistinguishability and narrow linewidths down to $7\,\mu$eV, close to the radiative limit. The emission is unaffected by the surface and shows no blinking over more than 12 orders of magnitude in time, yielding an on-fraction of 99.7 %. These results are likely to stimulate new fundamental studies and quantum applications.