HL 14: Focus Session: Site-selective Growth of single Quantum Dots

The vision of semiconductor device operation based on the quantum mechanical properties of a single quantum dot is stimulating many activities towards site-selective growth of quantum dots in order to achieve deterministic device properties. Site-selective quantum dot growth simultaneously represents one of the most challenging frontiers for epitaxial growth today as it requires precise control over lateral assembly of a few thousands of atoms on a few tens of nanometers scale. Many details of the process affect quantum dot properties such as size, emission energies, and linewidth. This focus session highlights different approaches for site-selective quantum dot growth and discusses in-situ and ex-situ concepts for tailoring of their electronic properties. (Organizers: Andre Strittmatter, TU Berlin, and Armando Rastelli, Leibniz Institute for Solid State and Materials Research Dresden)

Time: Monday 15:00–18:15 Location: ER 164

Invited Talk HL 14.1 Mon 15:00 ER 164

Growth and Device Integration of Site-Controlled Quantum Dots — •Sven Höfling[1], Christian Schneider[1], Alexander Huggenberger[1], Vasilij Baumann[1], Micha Strauss[1], Thomas Sünner[1], Tobias Heindel[1], Lukas Worschech[1], Stephan Reitzenstein[1,2], Martin Kamp[1], and Alfred Forchel[1] — [1]Technische Physik, Physikalisches Institut and Wilhelm Conrad Röntgen-Center for Complex Material Systems, Würzburg University, Am Hubland, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany

Single semiconductor quantum dots (QDs) are very attractive candidates to control charge and spin carries at the quantum level. One of the major challenges regarding the scalable fabrication of single QD based devices is however the precise control of the QD position within device structures. Within this work, we present a site-controlled growth technique using pre-patterned nanohole templates for the controlled integration of site-controlled quantum dots into nanoscale devices. By combining this growth technique with a process capable of accurately aligning QDs relatively to subsequently fabricated device structures, several interesting devices could be fabricated based on positioned QDs. For instance, cavity enhanced emission of single site-controlled QDs that were deterministically placed within photonic crystal or micropillar cavities has been demonstrated. Single photon emission of a coupled QD-resonator system has been proven by photon auto-correlation measurements, thus underlining the promise of the devices for quantum communication technologies.

Topical Talk HL 14.2 Mon 15:30 ER 164

Growth and characterization of site-selective quantum dots — •Mathieu Helfrich[1], Philipp Schroth[2], Sergey Lazarev[2], Daniil Grigoriev[3], Taras Slobodskyy[4], Tilo Baumbach[2,3], and Daniel M. Schaadt[1,5] — [1]DFG-Centrum für funktionelle Nanostrukturen (DFG-CFN), Karlsruher Institut für Technologie (KIT), Wolfgang-Gaede-Str. 1a, 76131 Karlsruhe, Germany — [2]Institut für Synchrotronstrahlung / ANKA, Karlsruher Institut für Technologie (KIT), Hermann-von-Helmholtz-Platz 1 ,76344 Eggenstein-Leopoldshafen, Germany — [3]Laboratorium für Applikationen der Synchrotronstrahlung, Karlsruher Institut für Technologie (KIT), Engesserstraße 15, 76131 Karlsruhe, Germany — [4]Institut für Angewandte Physik, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg, Germany — [5]Institut für Energieforschung und Physikalische Technologien, Technische Universität Clausthal, Am Stollen 19B, 38640 Goslar, Germany

Site-selective quantum dots (QDs) can be fabricated by lateral self-alignment or pre-structuring substrates. The latter method allows for a high degree of control of different parameters such as QD locations, size and shape. We will present a quantitative analysis of site-selective InAs QDs grown on pre-structured GaAs substrates. We tested several fabrication parameters including different fabrication techniques. Furthermore, we investigated post growth annealing as means of additional control on above mentioned parameters.

Topical Talk HL 14.3 Mon 16:00 ER 164

Positioned growth and optical properties of InP/GaInP islands and coupled quantum dot structures — •Michael Jetter[1], Elisabeth Koroknay[1], Ulrich Rengstl[1], Moritz Bommer[1], Christian Kessler[1], Heinz Schweizer[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen und Research Center SCoPE, Universität Stuttgart, Deutschland — [2]4. Physikalisches Institut, Universität Stuttgart, Deutschland

In this talk we show a route towards the realization of laterally and vertically positioned quantum dot structures. The lateral positioning is achieved by self-assembled nucleation of InP islands on a regular patterned GaAs surface during the growth process in the metal-organic vapour-phase (MOVPE) system. A low-cost method, called microsphere photolithography, is presented to produce the regular hole pattern.

Next to this, strain driven vertically aligned asymmetric coupled quantum dots (QDs) were highlighted. By controlling the vertical distance between the single QD layers the electronic coupling between the nanostructures can be modified. Photoluminescence experiments reveal the phonon assisted tunneling behavior of either the electron or the whole exciton in dependence of the spacer distance between the dots.

Coffee Break (15 min)

Invited Talk HL 14.4 Mon 16:45 ER 164

Spatial and spectral control of self-assembled quantum dots. — •Oliver G. Schmidt — IFW Dresden, Germany

Two major challenges in the development of quantum dot (QD) based applications are addressed in this talk: First, the need to accurately position QDs and second feasible ways to fully control their spectral properties. The first challenge has been dealt with for several years and has already matured. The second point seems more challenging and postgrowth techniques need to be developed to tune single exciton emission either to the required absolute wavelength or relative to other excitonic recombination lines. To reach these goals self assembled QDs embedded in thin GaAs nanomembranes are transferred to piezo-substrates, where large amounts of strain can be applied to the quantum dots. This technique allows shifting single QD emission lines by more than 20meV and to tune excitonic and biexcitonic lines into resonance [1]. For instance, the single QD emission can be easily tuned into resonance with certain transition lines of Rubidium atoms [2], which is important to efficiently slow down single photons on demand [3]. If embedded into a nanomembrane p-i-n device including Bragg reflectors, the wavelength, emission intensity and charging state of the QDs can be independently controlled at will [4].

[1] F. Ding et al., Phys. Rev. Lett. 104, 067405 (2010) [2] S. Kumar et al., Appl. Phys. Lett. 99, 161118 (2011) [3] N. Akopian et al., Nature Photonics 5, 230 (2011) [4] R. Trotta, P. Atkinson, J. D. Plumhof, E. Zallo, R. Razaev, S. Kumar, S. Baunack, J. R. Schröter, A. Rastelli, O. G. Schmidt, unpublished.

Topical Talk HL 14.5 Mon 17:15 ER 164

Pre-patterned silicon and GaAs substrates for the growth of III-V nanostructures: morphological and optical properties — •Mohamed Benyoucef, Muhammad Usman, Tariq Al Zoubi, Aleksandar Gushterov, Tino Pfau, and Johann Peter Reithmaier — Institute of Nanostructure Technologies and Analytics (INA), Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Strasse 40, D-34132 Kassel, Germany

Light emission from direct growth of III-V quantum dots (QDs) on silicon (Si) is a future dream. However, the presence of high-density threading dislocations due to the lattice mismatch and the formation of antiphase boundaries due to the polar/non polar nature destroy the light emission. Growth on pre-patterned substrates could results in reducing or eliminating such defects due to size effect.

In this talk, we report on growth of site-controlled InAs QDs on pre-patterned GaAs and Si substrates based on dry and wet-chemical etching. In the first part, a review on the recent work on pre-patterned GaAs will be provided. Results of an optimized wet-chemically etching holes and a special MBE growth stack technique will be presented. GaAs based single QDs emissions is probed by micro-PL and reveals clear spectra with single lines. In the second part, we present the results of the optimized electron beam lithography and dry etching processes for the patterning of Si substrates. The MBE growth of QDs on patterned Si surface with highly selective formation of localized InAs nanostructures in patterned holes with 1 μm period will be discussed.

Topical Talk HL 14.6 Mon 17:45 ER 164

Lateral positioning of InGaAs quantum dots using a buried stressor — •André Strittmatter — Institut für Festkörperphysik, Technische Universität Berlin, Sekr. EW 5-2, Hardenbergstrasse 36, D-10623 Berlin, Germany

We present a bottom-up approach for the lateral alignment of semiconductor quantum dots (QDs) based on strain-driven self-organization. A buried stressor formed by partial oxidation of (Al,Ga)As layers is employed in order to create a locally varying strain field at a GaAs(001) growth surface. During subsequent strained layer growth, local self-organization of (In,Ga)As QDs is controlled by the contour shape of the stressor. Large vertical separation of the QD growth plane from the buried stressor interface of 150 nm is achieved enabling high optical quality of QDs. Optical characterization confirms narrow QD emission lines without spectral diffusion.