HL 49: Quantum dots: preparation and characterization

Time: Friday 10:15–12:45 Location: BEY 81

HL 49.1 Fri 10:15 BEY 81

Growth and characterization of InP quantum dots deposited on InAs seed layer — •Daniel Richter, Robert Rossbach, Wolfang-Michael Schulz, Matthias Reischle, Claus Hermannstädter, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3 70569 Stuttgart, Germany

As current single-photon detectors have their highest photon detection efficiency in the red spectral range it is preferable to fabricate single quantum dots (QD) with luminescence at such wavelengths.

Self assembled InP QDs emitting at around 670nm exhibit high densities up to $1 * 10^{10} cm^{-2}$. For single QD applications this density has to be reduced drastically. To achieve a low density of optical active InP QDs we used low density InAs islands as a seed layer.

We focus on the MOVPE growth of low density InAs quantum dots in the Stranski-Krastanow (SK) growth mode. An extensive characterization has been accomplished. Scanning electron microscopy measurements confirmed a QD density less than $1 * 10^7 cm^{-2}$ and atomic force microscopy was used to measure the height distribution. To complete the characterization optical measurements, like microphotoluminescence (μ-PL) and ensemble PL have been performed. Equipped with the control over the InAs QD growth it is possible to use InAs QD-layers as seeds for the growth of InP QDs with a reduced density. Here we present the influence of the InAs seed layer on the InP QD density and their optical properties.

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Growth of InAs Quantum Dots on Silicon substrates: Formation and Characterization — •Tariq Al-Zoubi, Emil-Mihai Pavelescu, and Johann Peter Reithmaier — Universität Kassel, Technische Physik, Institute of Nanotechnologies and Analytics (INA)

Self-assembled InAs quantum dots (QDs) were grown by solid source molecular beam epitaxy on different Si substrate orientations (100) and (111) using Stranski-Krastanov growth mode. The grown QDs were characterized using atomic force microscopy .The evolution of size and shape of quantum dots with InAs coverage was examined after ex-situ surface preparation (oxide desorption) of the Si wafers with (NH4)HF etchant and in-situ with temperature between 730°C-750°C (pyrometer). Dashed-like InAs dots of high density (9*10 to the 10th cm-2) were observed on (111) orientation compared to circular shaped QDs with a lower density (3.8*10 to the 10th cm-2) on (100) Si orientation. The dot size and density grew with increasing InAs coverage and growth temperature up to 425°C. A narrow dots size distribution was observed for 1.7 ML InAs coverage at a growth temperature of 400°C.

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Strain and critical thickness of the 2D→3D transition during GaSb/GaAs quantum dot growth — •Holger Eisele[1,2], Rainer Timm[1], Andrea Lenz[1], Lena Ivanova[1], and Mario Dähne[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenberstr. 36, D-10623 Berlin — [2]The University of Texas at Austin, Austin, TX 78712, USA

While for InAs/GaAs the critical thickness of 2D→3D transition is independent of the growth conditions within a small range of 1.5 – 1.8 monolayer (ML), for the GaSb/GaAs system extremely different values are reported up to now, ranging from about 0.5 ML to 4.0 ML. Therefore, we investigated differently grown GaSb/GaAs samples using cross-sectional scanning tunneling microscopy to study the amount of GaSb material in the wetting layer and the quantum dots. For these samples we found a critical thickness in the range of 1.0 ML to 1.5 ML of accumulated GaSb on the GaAs (001) surface. To support this experimental finding we calculated the strain energies of 1 ML InAs and GaSb on GaAs. Even if the lattice mismatch increases only from 7.2% (for InAs/GaAs) to 7.8% (for GaSb/GaAs), the strain energy is about 34% higher in the latter system due to the differences of the elastic moduli. Assuming similar surface energies for both systems, the critical thickness for the 2D→3D transition gets theoretically reduced by the same factor from about 1.65±0.15 ML for InAs to 1.2±0.1 ML for GaSb on GaAs.

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Electric field control of vertically tunnel coupled InP quantum dots — •Elisabeth Koroknay, Wolfgang-Michael Schulz, Robert Rossbach, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Stuttgart, Deutschland

Controllable interactions between coupled quantum dots (QD) are of great interest with regard to quantum information technology. Based on previous research on self organized QD single layers on (Al,Ga)InP barriers the self organized vertical alignment is investigated. The QDs grown by metalorganic vapour phase epitaxy are separated by a spacer layer of the corresponding barrier material. The first QD layer induces a strain field which has influences on the QD growth of the second layer. This influence was investigated by transmission elecron microscopy, atomic force microscopy and photoluminescence measurements. By controlling properly the amount of deposited material, asymmetric QD molecules can be grown, where the high energetic smaller sized QD is located above the low energetic larger sized QD. The electronic coupling between these QDs is achieved by a tunneling process of charge carriers. The influence of the barrier thickness on the tunneling probability can already be seen in ensemble PL measurements. In order to realize controllable interactions between the quantum dot layers, the tunnel coupling is varied by an electric field along the molecule axis. A n-i-schottky structure with the QD molecules in the intrinsic region is used to tilt the overall potential by applying an electric field. In this way the energy levels of the QDs can be tuned in and out of resonance.

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Structure of InAs/InGaAsP/InP Quantum Dots/Dashes — •Florian Genz[1], Andrea Lenz[1], Lena Ivanova[1], Rainer Timm[1], Udo W. Pohl[1], Dieter Franke[2], Harald Künzel[2], Holger Eisele[1], and Mario Dähne[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Germany — [2]Fraunhofer-Institut für Nachrichtentechnik, Heinrich-Hertz-Institut, Germany

Quantum dots or dashes in the InAs/InGaAsP/InP heterostructure system with emission wavelengths matching the absorption minimum of silica fibers (1.55 μm) are promising for semiconductor optical amplifiers for optical data transmission. To improve the device design and the preparation method, a detailed knowledge of the capped nanostructures is of high importance.

The size, shape, and density of InAs/InGaAsP quantum dots/dashes grown by metal organic vapor phase epitaxy were investigated with cross-sectional scanning tunneling microscopy (XSTM). We will present atomically resolved XSTM images of both the $(\bar{1}10)$ and the (110) cleavage surface showing a lateral decomposition of the quaternary InGaAsP matrix which may affect quantum dash development. The evolved nanostructures have lateral sizes of 14 to 33 nm base length along $[\bar{1}10]$ and of 7 to 17 nm along [110] while their heights are about 1.7 nm for the specific growth conditions applied. These structural results will be discussed under consideration of the growth conditions.

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15 min. break

HL 49.6 Fri 11:45 BEY 81

High and low density quantum dot arrays grown on prepatterned surfaces — •Tino Pfau, Aleksander Gushterov, and Johann-Peter Reithmaier — Technische Physik, INA, Universität Kassel, Heinrich–Plett-Str. 40, 34132 Kassel

Surface templates with nanoscale dimensions are developed for GaAs substrates based on electron beam lithography and wet-chemical etching in order to control the quantum dot position and to reduce the statistical size distribution of the dots in a self-assembled dot formation process. In comparison to dry etching, wet chemical etching avoids crystal damage and defect related non-radiative recombination processes should play a much smaller role. GaAs-templates with a hole density from 10^7 to 10^{10} cm^{-2} were overgrown by InAs to form quantum dots at the hole positions and characterized by scanning electron microscopy(SEM), atomic force microscopy(AFM) and photoluminescence measurements.

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Shape of InN quantum dots and nanostructures grown by

MOVPE — •S. Ploch[1], Ch. Meissner[1,2], M. Pristovsek[1], and M. Kneissl[1] — [1]TU Berlin, Institut für Festkörperphysik, EW 6-1, Hardenbergstr. 36, 10623 Berlin — [2]ISAS - Institute for Analytical Sciences, Albert-Einstein-Str. 9, 12489 Berlin

We report on the shape of InN quantum dots (QDs) grown on GaN/sapphire by MOVPE (metal organic vapour phase epitaxy) investigated by atomic force microscopy (AFM). The InN QDs were grown in a 100 mbar N_2 atmosphere, with a TMIn partial pressure of 0.17 Pa, a V/III ratio of 15,000 and a growth temperature between 480°C and 590 °C for 60 s. X-ray diffraction suggested pure relaxed InN. Only single large nanostructures and a low density are suitable for AFM investigations due to convolution with the AFM tip. Mesa shaped and cone like structures are observed. With increasing growth temperatures the cone type structures prevail. The mean height varies between 15 nm and 40 nm for mesa and 70 nm for conic structures. The mean diameter increases with increasing temperature from 70 nm at 550°C to 230 nm at 590°C for both structure types. The density is $2{\cdot}10^8/\mathrm{cm}^2$ over 560°C. The mesa type structures exhibit a hexagonal footprint, the cone's footprint is more distorted. The different structure types have different side facets. For both structures $\{1\bar{1}02\}$ and $\{\bar{1}102\}$ side facets dominate. No preferred facet polarity was observed for any facet. Two different explanations are possible for the different structures basing on a different growth rate caused by dislocations or a polarity inversion.

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Volmer-Weber growth of InN quantum dots by MOVPE — •Christian Meissner[1,2], Simon Ploch[1], Markus Pristovsek[1], and Michael Kneissl[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, EW6-1, 10623 Berlin — [2]ISAS - Institute for Analytical Sciences, Albert-Einstein-Str. 9, 12489 Berlin

We have investigated the growth of uncapped InN quantum dots (QDs) on GaN. The indium nitride QDs were grown on GaN/sapphire templates in a horizontal metal-organic vapour phase epitaxy reactor (MOVPE) at 100 mbar in a N_2 atmosphere. At a temperature of 520°C the growth time was varied between 5 s and 60 s. The precursor partial pressures were 0.5 Pa trimetylindium (TMIn) and 2500 Pa ammonia respectively. The InN material deposition during growth was investigated with in-situ spectroscopic ellipsometry (SE) and exsitu with atomic force microscopy (AFM) as well as X-ray diffraction (XRD).
A linear increase of the effective layer thickness, i. e. a constant growth rate of InN, was observed. At smallest growth time the surface is covered by only 0.9 ML of InN but still exhibits quantum dots with a density of $7 \cdot 10^{10}\,\mathrm{cm}^{-2}$ indicating Volmer-Weber growth mode. Further growth shows coalescence at a growth time beyond 20 s, with 50 nm in diameter and 4.9 nm high nanostructures. This diameter is consistent with the calculated coalescence diameter of 51 nm for the observed density of $7 \cdot 10^{10}\,\mathrm{cm}^{-2}$.

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The role of the spin-orbit interaction on the exchange coupling in lateral coupled quantum dots — •Fabio Baruffa[1], Peter Stano[2], and Jaroslav Fabian[1] — [1]Institute for Theoretical Physics - University of Regensburg — [2]Research Center of Quantum Information - Slovak Academy of Science, Bratislava

Direct exchange in coupled quantum dots is proposed as a means to manipulate spin qubits. In the presence of spin-orbit coupling the exchange is qualitatively changed: the total spin is no longer a good quantum number and chirality of the spins emerges. This is described by a new term in the Hamiltonian, the so called anisotropic exchange (proportional to the vector product of the two spins). We report systematic numerical and analytical calculations of both the direct and anisotropic exchange interactions, for realistic GaAs quantum dots, demonstrating the role of the Bychkov-Rashba and Dresselhaus spin-orbit coupling on the important two-electron interactions.

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