HL 96: Focus Session: Semiconductor Nanophotonics - Characterization on the Atomic Scale

For a detailed understanding of complex semiconductor nano- and heterostructures as well as the physics of devices based on them, a systematic determination and correlation of the structural, chemical, electronic, and optical properties on a nanometer or atomic scale is essential. This session brings the atomic structural and chemical imaging using cross-sectional scanning tunneling microscopy, advanced X-ray diffraction, and ultra-high resolution transmission electron microscopy together with the nanoscopic mapping of the optical and electronic properties using scanning transmission microscopy cathodoluminescence spectral imaging. Even more challenging is the atomic scale characterization directly during the epitaxial growth, made possible using in situ scanning tunneling microscopy during MBE growth and in situ synchrotron X-ray studies during metal-organic chemical vapor deposition. (Organizers: Jürgen Christen, Magdeburg University, and Holger Eisele, TU Berlin)

Time: Friday 9:30–12:45 Location: ER 164

Topical Talk HL 96.1 Fri 9:30 ER 164
Atomic Resolution Transmission Electron Microscopy of III-Nitride Nanostructues — •M. Albrecht[1], T. Schulz[1], T. Markurt[1], T. Remmele[1], A. Duff[2], J. Neugbauer[2], V. Grillo[3], J.-L. Rouviere[4], C. Nennstiel[5], and A. Hoffmann[5] — [1]Leibniz-Institut für Kristallzüchtung, Berlin, Germany — [2]Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany — [3]CNR NANO S3, Modena, Italy — [4]CEA/INAC, Grenoble, France — [5]TU Berlin, Institut für Festkörperphysik Berlin, Germany

The influence of compositional fluctuations on carrier localization in III-Nitride base alloys is an ongoing debate. Despite huge efforts in theory and experiment it is still controversial whether the In distribution in an InGaN quantum well is truly random or if small In enriched clusters are present. The progress in aberration corrected transmission electron microscopy offers new possibilities to study alloy fluctuations at atomic scale and with high precision. In this presentation we will summarize recent results obtained by aberration corrected transmission electron microscopy and scanning transmission electron microscopy. We will show that local strain fluctuations can be measured wit 1.5 pm precision. This allows even statistical alloy fluctuations and static atomic displacements to be analyzed in real space. We revise approaches to analyze alloy fluctuations from tetragonal lattice distortions. Our results on the alloy distribution of InGaN quantum wells are compared to optical properties measured by cathodoluminescence, photoluminescence excitation and time resolved photoluminescence.

Topical Talk HL 96.2 Fri 10:00 ER 164
A cathodoluminescence study of a UV detector based on GaN Quantum Discs built in a single nanowire — •Luiz Zagonel[1] and Mathieu Kociak[2] — [1]Laboratorio Nacional de Nanotecnologia (LNNano), Centro Nacional de Pesquisa em Energia e Materiais (CNPEM), 13083-970, Campinas, Brasil — [2]Laboratoire de Physique des Solides/CNRS, Université Paris-Sud

We report the spectral imaging in the UV to visible range with nanometer scale resolution of closely packed GaN/AlN quantum disks in individual nanowires using an improved custom-made cathodoluminescence system. We demonstrate the possibility to measure full spectral features of individual quantum emitters as small as 1 nm and separated from each other by only a few nanometers and the ability to correlate their optical properties to their size, measured with atomic resolution. The direct correlation between the quantum disk size and emission wavelength provides evidence of the quantum confined Stark effect leading to an emission below the bulk GaN band gap for disks thicker than 2.6 nm. With the help of simulations, we show that the internal electric field in the studied quantum disks is smaller than what is expected in the quantum well case. We show evidence of a clear dispersion of the emission wavelengths of different quantum disks of identical size but different positions along the wire. This dispersion is systematically correlated to a change of the diameter of the AlN shell coating the wire and is thus attributed to the related strain variations along the wire. The present work opens the way both to fundamental studies of quantum confinement in closely packed quantum emitters and to characteriza- tions of optoelectronic devices presenting carrier localization on the nanometer scale.

Topical Talk HL 96.3 Fri 10:30 ER 164
Lattice parameter accomodation at the GaAs Nanowire to Silicon (111) substrate interface after Ga-assisted MBE growth — •Ullrich Pietsch[1], Andreas Biermanns[1], Anton Davydok[1], Steffen Breuer[2], Achim Trampert[2], and Lutz Geelhaar[2] — [1]Festkörperphysik, 57068 Universität Siegen — [2]Paul-Drude Institut für Festkörperelektronik, 10117 Berlin

We report on x-ray and TEM studies revealing the mechanism of lattice parameter accommodation of GaAs nanowires (NWs) grown on Si [111] substrate by Ga-assisted MBE. We show that the lattice mismatch between NW and substrate is released by a large procentage immediately after the beginning of NW growth through the inclusion of misfit dislocations. For thick NWs, the interface is rough preventing complete relaxation, whereas the release is nearly complete for thin NWs because the interface is flat. Using a nanosized x-ray beam and synchrotron radiation we could measure the residual strain and the phase composition of individual NWs. We find that even neighbouring NWs grown on the same sample under the same conditions differ significantly in their phase structure. Comparing the strains measured at a set of short nanowires of different height we are able to quantify the residual strain field close to the NW to substrate interface. It decays much faster along the interface compared to decay along the growth direction.

Coffee Break (15 min)

Topical Talk HL 96.4 Fri 11:15 ER 164
Atomic imaging of binary and quaternary semiconductor nanostructures by cross-sectional STM — •Andrea Lenz — Technische Universität Berlin, Berlin, Germany

In cross-sectional STM (XSTM) experiments typically layered semiconductor samples are cleaved in an ultrahigh vacuum system, laying bare an atomically clean cleavage surface. Therewith buried nanostructures can be analyzed with atomic resolution, providing access to their spatial structure and stoichiometry as it also appears in devices.

This contribution will focus first on the atomic structure of binary InAs submonolayer depositions on GaAs(001), demonstrating that the InAs is not located within a single atomic plane, but segregated along growth direction. In addition, the segregation along growth direction is determined in detail by the analysis of the local lattice parameter. Both demonstrate that the strain-induced segregation processes occurring during overgrowth defines the resulting nanostructures. Second, the atomic composition of quaternary InGaAsP layers grown latticed matched on InP(001) is analyzed at both the (110) and the (-110) cleavage surfaces, together yielding two different phase separation effects on different length scales: a formation of columnar structures with widths of some tens of nm and a CuPt-like ordering on the atomic scale. The latter can be identified at the (-110) cleavage surface by alternating brighter and darker atomic rows aligned along the [110] direction, with a periodicity along the [001] growth direction of two lattice constants, as well as by atomic chains of similar brightness oriented along the [-112] and [1-12] directions at the (110) cleavage surface.

Invited Talk HL 96.5 Fri 11:45 ER 164
Atomistic insights and controls for compound semiconductor growth by STMBE: STM obseration during MBE growth — •Shiro Tsukamoto — Anan National College of Technology

High density arrays of quantum dots (QDs) can easily be grown without any need for nano-patterning. These self-assembled QDs are strong candidates for advanced semiconductor laser and quantum devices. However, the precise physical mechanism of self-assembly is not understood, which hampers control over QD size, density and distribution for particular applications. This prototypical self-assembly system also

presents very general challenges for growth modeling over scales from atomic dimensions to hundreds of nanometers. Here we show dynamic images of InAs QD formation on GaAs(001) obtained using a unique scanning tunneling microscope (STM) placed within a molecular beam epitaxy (MBE) growth chamber: STMBE. These elucidate the mechanism of QD nucleation, demonstrating directly that not all deposited In is initially incorporated into the lattice, hence providing a large supply of material to rapidly form QDs via islands containing tens of atoms and Kinetic Monte Carlo (KMC) simulations based on first-principles calculations show that alloy fluctuations in the InGaAs wetting layer (WL) are crucial in determining nucleation sites. [1]S.Tsukamoto and N.Koguchi, J.Cryst.Growth 201, 118 (1999). [2]S.Tsukamoto, et. al., Small 2, 386 (2006). [3]T.Konishi and S.Tsukamoto, Nano.Res.Lett. 5, 1901 (2010); Surf.Sci. 605, L1 (2011).[4]T.Toujyou and S.Tsukamoto, Phys.Stat.Sol. (c) 8, 402 (2011); Nano.Res.Lett. 5, 1930 (2010); Surf.Sci. 605, 1320 (2011).

Invited Talk HL 96.6 Fri 12:15 ER 164

In situ synchrotron x-ray studies during metal-organic chemical vapor deposition of semiconductors — •Carol Thompson[1,2], Matthew J. Highland[2], Edith Perret[2], Marie-Ingrid Richard[3], Paul H. Fuoss[2], Stephen K. Streiffer[2], and G. Brian Stephenson[2] — [1]Northern Illinois Univ., DeKalb, IL, USA — [2]Argonne National Lab., Argonne, IL, USA — [3]Universite Paul Cezanne Aix-Marseille, Marseille, France

In-situ, time-resolved techniques provide valuable insight into the complex interplay of surface structural and chemical evolution occurring during materials synthesis and processing of semiconductors. Our approach is to observe the evolution of surface structure and morphology at the atomic scale in real-time during metal organic vapor phase deposition (MOCVD) by using grazing incidence x-ray scattering and x-ray fluorescence, coupled with visible light scattering. Our vertical-flow MOCVD chamber is mounted on a 'z-axis' surface diffractometer designed specifically for these studies of the film growth, surface evolution and the interactions within a controlled growth environment. These techniques combine the ability of x-rays to penetrate a complex environment for measurements during growth and processing, with the sensitivity of surface scattering techniques to atomic and nanoscale structure. In this talk, we outline our program and discuss examples from our in-situ and real-time x-ray diffraction and fluoresence studies of InN, GaN, and InGaN growth on GaN (0001). Work supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under contract DE-AC02-06CH11357.