Sunday Afternoon, January 15, 2023

PCSI
Room Redondo - Session PCSI-SuA

Novel Device Characterization

Moderator: Holger Eisele, Otto-von-Guericke-Universität

4:00pm **PCSI-SuA-1 Welcome and Opening Remarks***,*

4:05pm **PCSI-SuA-2 Electroemission Spectroscopy of GaN-Based Diodes – Revealing the Inner Working of LEDs and More!***, **Jim Speck**,* University of California Santa Barbara **INVITED**

In this talk, we introduce the technique of electroemission spectroscopy (EES) and its application to GaN-based LEDs.The technique is based on electron emission from p-GaN surfaces that have been cessiated to realize negative electron affinity (NEA).For LEDs the p-GaN surface is exposed through open apertures in a grid metal contact.We have developed this technique to measure electron emission into vacuum that are the result of (i) three-body Auger nonradiative recombination (n2p process (assuming n ≈p, scaling as n3)), trap-assisted Auger recombination (TAAR, n2 process); and electron overflow.

In this talk we review the evolution of the EES technique as applied to LEDs and reference p-n and p-i-n diodes.We review four different techniques that have identified the first conduction band upper valley (UV1) at 0.9 eV above the CBM.We show evidence for the next upper valley (UV2) at 1.7 eV above the CBM.Additionally, we review systematic measurements to assure that the emitted electrons from the p-GaN surface are indeed a result of processes occurring at the internal diode junction.

Recently we have performed EES measurement on electrically driven InGaN/GaN commercial blue c-plane (peak wavelengths λ = 465 nm) light emitting diode (LED) with 60 nm of p-GaN on top of the active region (this is relatively thin p-GaN).The signal-to-noise ratio of semiconductor peaks is improved on the thin p-GaN LED due to reduced loss of electrons en route to emission into vacuum during transit through the thin p-GaN.This further proves that hot electrons are generated in the bulk region and not by light or other hot electron generation mechanisms at the surface.Using square root of the light output power as a proxy for the active region carrier density, n, the hot electron integrated peak intensity is shown to be proportional to n3 and, thus, is directly attributed to a 3-body Auger process.Since there are significant Auger recombination currents even at low injection current densities, it is expected that Auger recombination current will dominate over radiation recombination and Shockley–Read–Hall (SRH) currents at higher current densities.

4:45pm **PCSI-SuA-10 Characterization of Semiconductor Nanostructures using Ultra-high Resolution STEM-CL***, **Gordon Schmidt**, J. Christen, F. Bertram,* Otto-von-Guericke-University Magdeburg, Germany **INVITED**

For a comprehensive understanding of complex semiconductor heterostructures and the physics of devices based on them, a systematic determination and correlation of the structural, chemical, electronic, and optical properties on a nanometer scale is essential. Luminescence techniques belong to the most sensitive, non-destructive methods of semiconductor research. The combination of luminescence spectroscopy – in particular at liquid He temperatures – with the high spatial resolution of a scanning transmission electron microscope (STEM) as realized by the technique of low temperature cathodoluminescence microscopy in a STEM (STEM-CL), provides a unique, extremely powerful tool for the optical nano-characterization of quantum structures.

Typical results, which will be presented, include the nm-scale analysis of group III-V semiconductor nanostructures visualizing the enormous capability of STEM-CL characterization.

The direct identification of the emission of a two-dimensional electron gas (2DEG) in a lateral GaN/AlN/AlGaN heterostructure field-effect transistor (HFET) will be shown.The characteristic emission of the 2DEG channel is observed on the low-energy side of the dominating donor-bound exciton luminescence. Beside this spectral fingerprint, the exact local origin of the 2DEG CL is verified to be close to the GaN/AlN interface. Due to the superposition of several possible recombination channels in the near-band-edge spectral region, this local verification is essential for the unambiguous identification of the 2DEG luminescence. The transport of the generated excess minority carriers (i.e. holes) into the 2DEG region leads to an intensity onset of the 2DEG emission already 60 nm below the GaN/AlN interface (already in the GaN drift region).

Single dot spectroscopy by means of low temperature STEM-CL provides a detailed insight into the energy structure of individual quantum dots (QDs) and directly correlates those properties with the real structure on a nanoscale. We characterize the vertical and lateral transfer of carriers within a 7-fold layer stack with high-density InP quantum dots grown via Stranski-Krastanov mode. We observe a characteristic change of the excitonic emission lines during scanning across an individual InP QD in a lateral CL linescan. This reveals the change of the numbers of excess carriers reaching the dot - i.e. altering the quantum dot population. The shift of emission energies visualize the renormalization of the ground-state energy of the single dot and the intensity ratio of the excitonic recombinations verifies this change in occupation.

5:25pm **PCSI-SuA-18 Optimizing Tof-SIMS Depth Profiles of Semiconducting Heterostructures***, **Jan Tröger**,* University of Münster, Germany*; R. Kersting, B. Hagenhoff,* Tascon GmbH, Germany*; D. Bougeard,* University of Regensburg, Germany*; H. Riemann, N. Abrosimov,* Institute for Crystal Growth Berlin, Germany*; J. Klos, L. Schreiber,* RWTH Aachen University, Germany*; H. Bracht,* University of Münster, Germany

In order to meet the demand for increased performance with progressive miniaturization, microelectronic components are being developed into multilayer structures with increasing complexity. Since the material composition, the layer thickness and the diffusion behavior between the individual layers have a sensitive effect on both the performance and the service life of the components, such a development is only possible through analytical monitoring of the materials properties on an atomistic scale.

A suitable analytical method to investigate semiconductor multilayer structures is Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS). The particular strength of the method is the possibility to determine all elements including their isotopes. In addition, the information depth of only about 0.5 nm (< 3 monolayers) makes SIMS a very surface-sensitive tool. By sputtering it becomes possible to obtain the composition of materials in deeper layers.

In this presentation we focus on optimizing ToF-SIMS depth profiling of semiconductor heterostructures. As model system, we investigate while varying sputter parameters a state-of-the-art Molecular Beam Epitaxy (MBE) grown multilayer structure consisting of ultra-thin layers with 2 nm in thickness. We measure atomic concentration profiles and use an error function based description model to quantify layer thicknesses as well as interface sharpness. Using this approach the multilayer structure is well resolved. The optimized instrumental setting for high depth resolution in ToF-SIMS profiling is applied to analyze a MBE grown SiGe/^{28}Si/SiGe heterostructure. The strained and isotopically purified 28Si layer of this structure represents a Quantum Well that has been proven to be an excellent host for an electrostatically defined electron spin qubit [1].

[1] Struck, T.; Hollmann, A.; Schauer, F.; Fedorets, O.; Schmidbauer, A.; Sawano, K.; Riemann, H.; Abrosimov, N. V.; Cywiński, ; Bougeard, D.; Schreiber, L. R. Low-frequency spin qubit energy splitting noise in highly purified 28Si/SiGe. npj Quantum Information 2020, 6, 2056–6387.

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