HL 38: ZnO I

Time: Thursday 10:00–13:00 Location: H17

HL 38.1 Thu 10:00 H17

Photoluminescence of vanadium-implanted and annealed ZnO thin films — •Michael Lorenz[1], Heidemarie Schmidt[1], Carsten Ronning[2], Sven Müller[2], Mariana Ungureanu[1], Gabriele Benndorf[1], and Marius Grundmann[1] — [1]Universität Leipzig, Institut für Experimentelle Physik II, Leipzig, Germany — [2]Georg-August-Universität Göttingen, II. Physikalisches Institut, Göttingen, Germany

Within our search for multifunctional ferromagnetic and semiconducting ZnO-based thin film material for spintronic applications we have implanted 250 keV ^{51}V-ions into PLD-grown, about 700 nm thin ZnO films on a-plane sapphire. The implantation was done either at 300°C or at room temperature and several annealings up to 900°C were done after implantation. Low-temperature photoluminescence spectra taken before and after implantation and after annealing show remarkable changes of the intensities of excitonic peaks (UV) and the green defect-related band (VIS) with the implantation fluence and the annealing temperature. Interestingly, after high-temperature annealing the UV / VIS intensity ratio increases with increasing V-implantation fluence. In contradiction to the V-implanted samples, some reference films implanted with Ar-ions show a strong quenching of the excitonic luminescence, as found earlier also for Mn-doped ZnO [1]. This points to a different incorporation of V, Ar, Mn, and Co into the ZnO lattice.

Funded within BMBF Young Scientists Group Nanospintronics.

[1] M. Diaconu, H. Schmidt et. al., Thin Solid Films 486 (2005) 117.

HL 38.2 Thu 10:15 H17

Origin of the near-band-edge photoluminescence in ZnO nanorods realised by vapour phase epitaxy and aqueous chemical growth — •C. Bekeny[1], B. Hilker[1], L. Wischmeier[1], T. Voss[1], B. Postels[2], A. Mofor[2], Andrey Bakin[2], and A. Waag[2] — [1]IFP, University of Bremen, P.O Box 330440, 28334 Bremen — [2]IHT, TU Braunschweig, P.O Box 3329, 38023 Braunschweig

Well established high temperature growth techniques like the vapour-liquid-solid (VLS: 1100°C) and vapour-phase-epitaxy (VPE: 800°C) have been successfully optimized while the low-temperature aqueous chemical growth (ACG: 90°C) is being extended to yield large-scale high quality ZnO nanorods. Here, a detailed and systematic photoluminescence (PL) study is presented to understand the microscopic processes responsible for the near-band-edge (NBE) emission in nanorods obtained from these processes. For the ACG samples, the as-grown nanorods show relatively broad NBE emission (15meV) attributed to the presence of large donor densities. After annealing in various atmospheres at ˜800°C, a significant reduction of the linewidth (˜4meV) and even the appearance of relatively sharp excitonic transitions is explained by the drastic reduction of the donor density. In contrast, the as-grown VPE and VLS samples exhibit well-resolved and sharp peaks resulting from exciton-related transitions. There is a shift in the room-temperature PL peak for VLS and VPE samples and is shown to result from contributions of the free exciton peak, its first and second order phonon replicas and not due to quantum confinement and or laser heating as assumed in literature.

HL 38.3 Thu 10:30 H17

The influence of entropy on the capture cross-section determination in ZnO — Heidemarie Schmidt, Maria Wiebe, •Beatrice Dittes, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstrasse 5, D-04103 Leipzig, Germany

ZnO has great potential for optoelectronic and spintronic applications. Deep level transient spectroscopy (DLTS) has been used to probe the parameters of deep defects in intrinsically n-type conducting, magnetic ZnO [1]. Different groups report on thermal activation energies ranging from 0.12 eV up to 0.6 eV below the conduction band minimum and an abnormally large variation of the capture cross section σ. As shown for other material systems with deep defects exhibiting a Meyer-Neldel Rule (MNR) behavior [2], the large variation of σ is an artifact of an incorrect analysis of DLTS data. Using DLTS data we show that also deep electron defects in ZnO exhibit the MNR behavior. Electron and hole defects in the same material system have to fit along the same MNR line. Therefore, the established isokinetic temperature will also help to fully understand deep hole defects in ZnO.

[1] M. Diaconu, H. Schmidt, H. Hochmuth, M. Lorenz, H. v. Wenckstern, G. Biehne, D. Spemann, M. Grundmann, Sol. Stat. Comm. 137, 417 (2006).

[2] J. A. M. AbuShama et al., Appl. Phys. Lett. 87, 123502 (2006).

HL 38.4 Thu 10:45 H17

The anisotropy of the dielectric function of ZnO films. — •Chris Sturm, Rüdiger Schmidt-Grund, Tsvetan Chavdarov, Bernd Rheinländer, Holger Hochmuth, Michael Lorenz, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig

In the last years, the tensor of the optical dielectric function (DF) of ZnO has been of much interest. Many properties of this tensor are still unknown. We report on the influence of the film thickness and film crystallographic orientation on this dielectric tensor. The a-plane and m-plane ZnO films were deposited on r-plane and m-plane sapphire, respectively, by Pulsed Laser Deposition. The m-plane and a-plane orientation of the ZnO films permits the determination of the two independent components of the dielectric tensor ($\varepsilon_\perp$ and $\varepsilon_\parallel$). The thicknesses of the ZnO films in the different samples vary in a range $(30 - 600)$ nm. The samples were studied by Generalized Spectroscopic Ellipsometry in the energy range $(1,0 - 4,5)$ eV. The DF was obtained with help of a layer stack model and model dielectric function analysis. The DF in the band-gap region is dominated by free excitons. Comparing the DF of m-plane and a-plane ZnO films with each other, a blue shift of the exciton peak energy was found for the a-plane ZnO films. A blue shift and an increasing line broadening of the exciton peaks with decreasing film thickness were found for both film orientations. This behavior is attributed mainly to strain effects since thickness non-uniformity, free charge carrier and surface overlayer effects can be excluded as responsible for the blue shift and the line broadening.

HL 38.5 Thu 11:00 H17

Depletion layer spectroscopy on bulk and thin film ZnO — •H. von Wenckstern, H. Schmidt, G. Biehne, R. Pickenhain, M. Lorenz, and M. Grundmann — Universität Leipzig, Fakultät für Physik, Linnéstrasse 5, 04103 Leipzig

Experimental investigations of deep defects in ZnO (especially the characterization of minority traps) are scanty. Hole traps with $E_t \sim 150$ meV and 280 meV, respectively, were found by deep level transient spectroscopy (DLTS) for N^+ implanted ZnO crystals [1], however, systematic investigations are necessary to conclude on the macroscopic origin of these defects. Minority and majority carrier traps in bulk ZnO and epitaxial PLD ZnO thin films are investigated by means of depletion layer spectroscopy. For that, high-speed Pd/ZnO Schottky diodes [2], *pn* hetero- or *pn* homojunctions [1] are prepared and investigated for temperatures ranging from 20 K to 330 K. The density (N_t) and thermal activation energy (E_t) of shallow majority carrier defects, and N_t, E_t, and the capture cross section σ of deep majority and minority carrier traps are discussed.

[1] H. von Wenckstern, R. Pickenhain, H. Schmidt, M. Brandt, G. Biehne, M. Lorenz, M. Grundmann and G. Brauer, Appl. Phys. Lett. **89**, 092122 (2006).

[2] H. von Wenckstern, G. Biehne, R. A. Rahman, H. Hochmuth, M. Lorenz, and M. Grundmann, Appl. Phys. Lett. **88**, 092102 (2006).

HL 38.6 Thu 11:15 H17

Cathodoluminescence study of ZnO and $Zn_{1-x}Mg_xO$ nanopillars on different substrates — •Martin Schirra, Anton Reiser, Raoul Schneider, Günther Prinz, Klaus Thonke, and Rolf Sauer — Institut für Halbleiterphysik, Universität Ulm, D-89069 Ulm

ZnO nanopillars are potential candidates for future sensor and optoelectronic devices. Any application calls for optimal structural and optical properties of such pillars. In the present study *single* nanopillars, mainly grown by the vapor-liquid-solid process, were investigated by spatially resolved cathodoluminescence in a scanning electron microscope (SEM-CL) at low temperatures (10K) and low acceleration voltages (2kV).
In order to achieve at the same time high SEM resolution and CL

sensitivity, a new concept was realized based on a field-emitter type SEM and light collection by a glass fiber. ZnO nanopillars on sapphire substrate exhibit free and bound exciton recombination with narrow linewidths indicating high purity and high crystal quality. ZnO nanopillars on a GaN template show broad luminescence in the near-band edge region due to the incorporation of Ga into the pillars. Corresponding Ga concentrations are estimated. Nanopillars grown homoepitaxially on a ZnO thin film show mainly two donor bound exciton lines with narrow linewidths which are presumably related. Ternary $Zn_{1-x}Mg_xO$ nanopillars are also grown by the vapor-liquid-solid process. Incorporation of Mg into the ZnO matrix is demonstrated by blue-shifts of the luminescence, and the Mg concentration is determined.

15 min. break

HL 38.7 Thu 11:45 H17

A Zincoxide Microwire Laser — •Christian Czekalla, Andreas Rahm, Jörg Lenzner, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstr. 5, 04103, Leipzig, Germany

We report the observation of stimulated emission from hexagonally shaped zinc oxide (ZnO) microcrystals observed by spatially resolved photoluminescence (PL) and high excitation spectroscopy. The structures were synthesized by thermal evaporation of a pressed ZnO-graphite target at ambient pressure. They show a high PL signal under low excitation conditions. Under high optical excitation, the observed PL spectra show an additional peak at 3,15 eV. This is most probably related to an inelastic exciton-exciton scattering process (P-band). The gain reported for ZnO [1] cannot overcome the high losses caused by the short distance of the mirrors. Hence, ZnO microwires per se cannot be expected to act as a cavity for the emitted light. However, stimulated emission as a result of single pass gain will be demonstrated. A superlinear dependency of the peak intensity on the excitation and the observed spectral narrowing indicate lasing with a threshold of 150 kW/cm^2.
[1] Y. Chen *et al*, Appl. Phys. Lett. **78**, 11 (2001).

HL 38.8 Thu 12:00 H17

Luminescence properties of ordered ZnO single crystal nanorod arrays — •Huijuan Zhou, Markus Wissinger, Johannes Fallert, Robert Hausschild, Felix Stelzl, Mario Hauser, Claus Klingshirn, and Heinz Kalt — Institut für angewandte Physik, Universität Karlsruhe (TH), Karlsruhe, Germany

ZnO is an important material for blue/ultraviolet (UV) light emitting diode or laser diode. The practical application depends to great extend on the crystal quality of ZnO. By a controlled vapor phase transportation growth method we have recently fabricated high quality ordered ZnO nanorod arrays, which may be promising candidates for UV emitting devices. The ZnO nanorods are [0001] oriented single crystals with diameter of 250-300 nm and length of 2.5-4.7 μm, perpendicularly grown on GaN substrate.

The luminescence properties of the nanorods are studied extensively. Low temperature measurements show well separated bound exciton and free A-exciton emission in the UV region of the spectra, indicating high sample quality. By using the combination of a confocal microscopy and a 50 fs Ti:Sapphire laser, time resolved micro-photoluminescence (μ-TRPL) spectra are measured on single nanorods. Power dependent measurements demonstrate lasing behavior of the rods.

HL 38.9 Thu 12:15 H17

Nitrogen related centres in ammonia treated ZnO — •Joachim Sann[1], Jan Stehr[1], Albrecht Hofstätter[1], Detlev M. Hofmann[1], Bruno K. Meyer[1], Anja Neumann[2], Miriam Plana[2], Martin Lerch[2], Ute Haboeck[3], Axel Hoffmann[3], and Christian Thomsen[3] — [1]I. Physikalisches Institut, Justus-Liebig-Universität-Giessen, Heinrich-Buff-Ring16, — [2]Institut für Chemie, Technische Universität Berlin, Straße des 17. Juni 135, — [3]Institut für Festkörperphysik, Technische Universität Berlin, Hardenberg Str. 36

Ammonia (NH_3) is rather frequently used for the p-type doping of ZnO due to its higher chemical reactivity compared to other gases like N_2. We investigated the formation of defects in ZnO that has been subjected to heat treatments in ammonia atmosphere by photoluminescence, electron paramagnetic resonance and Raman spectroscopy. For annealing temperatures of about 550 °C we found Zn interstitials and Zn interstitial - nitrogen complex centres. We relate the Zn interstitials to the I_{3a} excitons and the complex centres to a recombination at 3.193 eV. For annealing temperatures of about 650 °C we find the N centres substituting oxygen. The incorporation of nitrogen is evident from Raman spectroscopy where the N related modes are observed.

HL 38.10 Thu 12:30 H17

Zeitaufgelöste Photolumineszenz-Spektroskopie an undotierten und Cr-dotierten ZnO Nanopartikeln — •Lars Schneider[1], Gerd Bacher[1], Wei Jin[2] und Markus Winterer[2] — [1]Werkstoffe der Elektrotechnik, Universität Duisburg-Essen — [2]Institut für Verbrennung und Gasdynamik, Universität Duisburg-Essen

ZnO ein viel versprechender Kandidat für optoelektronische Anwendungen im UV und verspricht Ferromagnetismus bei Raumtemperatur. Wir präsentieren zeitaufgelöste und zeitintegrierte Photolumineszenzmessungen an undotierten und Cr-dotierten ZnO Nanopartikeln. Die Tieftemperaturspektren der undotierten Partikel werden durch mehrere schmale Linien dominiert, die der Rekombination freier und gebundener Exzitonen und ihrer Phononreplika zugeschrieben werden. Die schmale Linienbreite (FWHM) von 2.9 meV ist ein Hinweis für die gute optische Qualität der Nanopartikel, die selbst bei Raumtemperatur eine ausgeprägte, bandkantennahe Emission ermöglicht. Eine Analyse der Zerfallskonstanten erlaubt die Bestimmung charakteristischer Rekombinationszeiten donator- und akzeptorgebundener sowie freier Exzitonen. Für Cr-dotierte ZnO-Nanopartikel konnte eine ähnlich gute optische Qualität festgestellt werden. EELS- und EXAFS-Messungen zeigen eindeutig den Einbau von Cr in die Gitterstruktur des ZnO. Magnetolumineszenz-Messungen zeigen allerdings keinen signifikanten Einfluss der magnetischen Ionen auf die magnetooptischen Eigenschaften des ZnO. Dies lässt sich mit Hilfe von XANES- und EXAFS-Messungen erklären, die zeigen, dass Chrom als Cr3+ nicht substitutionell in das Wurtzit-Gitter eingebaut wird.

HL 38.11 Thu 12:45 H17

Cathodoluminescence study of ZnO layers grown on GaN — •Raoul Schneider, Martin Schirra, Anton Reiser, Günther Prinz, Rolf Sauer, and Klaus Thonke — Institut für Halbleiterphysik, Universität Ulm, D-89069 Ulm

Growth of ZnO layers on GaN substrates benefits from the small lattice mismatch of the two materials. We report on cathodoluminescence studies of ZnO layers grown by a modified CVD process on GaN templates deposited on sapphire substrates. The measurements were performed in a field-emitter type scanning electron microscope (FE-SEM) at low temperature and low acceleration voltages resulting in high spatial resolution below 80nm. A versatile detection system has been developed, which allows us to record single CL spectra, line scans and monochromatic CL images. Line scans across the GaN/ZnO interface reveal relaxation of strain and incorporation of Ga from the template into the ZnO layer. Monochromatic CL images of the edge and of the surface show a homogeneous distribution of the near band edge luminescence apart from single defects. First results of micro-Raman measurements are compared to the CL results.