HL 57: Focussed Session: ZnO-based Semiconductors

Time: Thursday 14:00–18:00 Location: H17

Invited Talk HL 57.1 Thu 14:00 H17

Exploring Zinc Oxide: From band structure towards devices — •Bruno Meyer — 1. Physik. Institut, JLU Giessen, Giessen

One of the key issues in modern solid-state electronics is energy band engineering for design and fabrication of heterostructures and quantum wells. ZnO can be alloyed with MgO to form high quality single crystal MgxZn1-xO films with the Mg content up to 33 at %, while retaining the wurzite crystal structure. Alloying ZnO with MgO increases the direct bandgap of ZnO from 3.3 eV to about 4.0 eV (for 33% Mg incorporation). ZnO/ MgxZn1-xO forms type-I heterostructures, ideal for electrical and optical confinement. The small lattice mismatch and high bandgap ensure the effective use of MgxZn1-xO as a barrier layer for ZnO based heterostructures and quantum wells.

We report on the investigation of electronic and opto-electronic band structure effects of ZnO/MgZnO heterostructures grown on different polar and non-polar ZnO bulk substrates, and ZnO on GaN (AlGaN) templates where large conduction band offsets give rise to type II band alignment and band offsets can be tuned by the different heterovalent interfaces. From a substantially improved microscopic understanding of the electronic and opto-electronic properties of the ZnO-based quantum heterostructures one can expect to predict future device applications with complex designs such as field effect transistors and 2DEGs.

HL 57.2 Thu 14:30 H17

Magneto-optical properties of bound excitons in ZnO — •Benjamin Neuschl, Martin Feneberg, and Klaus Thonke — Institute of Quantum Matter, University of Ulm

High resolution, low temperature magneto-photoluminescence of ZnO single crystals is recorded in magnetic fields up to 28 Tesla. Full width at half maximum below 80 μeV for bound excitons and strong magnetic perturbation allow to observe rich splitting patterns of degenerate energy states and allow a unique insight into the magneto-optical properties of bound excitons. Interaction with excited rotor and valence band states of the hole involved are taken into account to obtain a perfect fit to the experimental data. By comparing the intensity dependence of the fine structure of single bound excitons at different temperatures and magnetic field orientations, we are able to clearly distinguish between donor and acceptor bound excitons, as well as between transitions assigned to ground or excited hole states.

HL 57.3 Thu 14:45 H17

Uniaxial stress dependent analysis of the optical and vibrational properties of high quality ZnO substrates — •Gordon Callsen[1], Markus R. Wagner[1], Ronny Kirste[1], Jan Schulze[1], Axel Hoffmann[1], Anna V. Rodina[2], and André Schleife[3] — [1]Technische Universität Berlin, Department of solid state physics, Hardenbergstr. 36, 10623 Berlin, Germany — [2]A. F. Ioffe Physico-Technical Institute, 194021 Sankt-Petersburg, Russia — [3]Friedrich-Schiller-Universität, Institut für Festkörpertheorie, Max-Wien-Platz 1, 07743 Jena, Germany

We analyze ZnO substrates from suppliers like Cermet, Crystek, Tokyo Denpa and UniWafer by PL and Raman measurements with strong focus on the observed uniaxial stress dependencies. Zero stress field PL measurements reveal varying energetic positions of the e.g. bound excitons and exciton-polaritons among the selection of ZnO substrates which indicates different built-in strain levels. Polarization dependent PL measurements under application of uniaxial stress yield different pressure coefficients for the full set of exciton-polaritons of all analyzed ZnO substrates. Therefore, different dependencies for the evolution of the A-C- and A-B-exciton-polariton-splitting under the influence of uniaxial stress are measured. First principal calculations which model the influence of uniaxial strain on the electronic band structure of ZnO allow detailed insight into the obtained PL results. Uniaxial stress dependent Raman measurements facilitate further comparison of the analyzed ZnO substrates based on their vibrational properties which are also directly influenced by the application of uniaxial stress.

HL 57.4 Thu 15:00 H17

Dielectric passivated ZnO-based Schottky diodes — •Stefan Müller, Holger von Wenckstern, Zhipeng Zhang, Holger Hochmuth, Michael Lorenz, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Abteilung Halbleiterphysik, Linnéstr. 5, 04103 Leipzig

Vacuum-activated surface conduction (VASC) is a well known phenomenon of ZnO. Concerning ZnO-based devices, it can significantly reduce the parallel resistance of, e.g., Schottky diodes. Therefore, its formation must be suppressed to realize high quality, long-time stable devices. We have recently shown for the case of Au/ZnO Schottky-diodes, that dielectric passivation suppresses a VASC completely[1]. Here, we report on electrical and optical properties of passivated PdO_y/ZnO- and PtO_y/ZnO-Schottky diodes. The diodes were realized by reactive dc-sputtering of Pd and Pt, respectively, on nominally undoped ZnO thin films grown on a-plane sapphire substrate by pulsed laser deposition (PLD). On those Schottky-diodes a dielectric passivation, e.g. Al_2O_3 or $CaHfO_3$, was deposited by PLD at room temperature. For optical characterisation, we used depth-resolved cathodoluminescence and light beam induced current measurement, allowing the investigation of the lateral homogenity of the barrier potential on the μm-scale. Current-voltage- and capacitance-voltage-spectroscopy was measured in a temperature range from 10 K up to the point of thermic degradation and revealed that VASC does not play a role.

[1] H. von Wenckstern et al., J. Electron. Mater., DOI: 10.1007/s11664-009-0974-1

HL 57.5 Thu 15:15 H17

Excitation dynamics in ZnO random lasers — •Janos Sartor, Felix Eilers, Jonas Conradt, Cornelius Thiele, Claus Klingshirn, and Heinz Kalt — Angewandte Physik, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Random lasing is a phenomenon that appears in strongly scattering systems providing optical gain. In our work we investigate the spatial extent of laser modes in ZnO powders with grain sizes of the order of the emission wavelength. It has been shown that this material system is well suited for research on random lasing since the ZnO nanoparticles provide sufficient gain and scattering at the same time. Usually the emission of a random laser fluctuates too much to distinguish the vast amount of lasing modes. By reducing the volume of our random lasing medium to micro-sized structures we were able to reduce the number of modes as well, until only a few distinguishable modes remained. We observe the coexistence of strongly localized and extended modes and thus solve a longstanding discussion in current theoretical work. The mode extent is directly linked to the strength of the optical gain.

15 Min. Coffee Break

Invited Talk HL 57.6 Thu 15:45 H17

Interface Induced Gap States and ZnO Schottky Contacts — •Steven M. Durbin and Martin W. Allen — University of Canterbury, Christchurch, New Zealand

Practical aspects of fabricating Schottky contacts, such as lateral inhomogeneity, contaminants, and defects, can complicate the comparison of experimentally obtained barrier heights to theoretical predictions. The diode ideality factor η (which should approach unity for laterally homogeneous interfaces, after accounting for image force effects) is also strongly affected by the same issues, and correlations can be observed between barrier height and η when measuring large numbers of devices. ZnO could prove to be an interesting test case for evaluating various theoretical models, as it is significantly more ionic than most semiconductors, resulting in weaker Fermi pinning due to interface states. ZnO also does not require the removal of a native oxide layer for device processing, thereby avoiding often aggressive cleaning procedures. We have fabricated arrays of rectifying metal-ZnO contacts using bulk wafers and a wide variety of metals, using a technique which results in large barrier heights (typically > 0.8 eV) and low η (approaching the image force limit). Using the electrical characteristics of these diodes, we evaluate both Tung′s chemical bonding and Mönch′s metal induced gap states + electronegativity models, and discuss the limits of our current understanding of metal-ZnO interfaces.

HL 57.7 Thu 16:15 H17

Quantum confined Stark effect in ZnO/MgZnO quantum wells fabricated with different growth processes — •Marko Stölzel, Matthias Brandt, Alexander Müller, Michael Lorenz, Gabriele Benndorf, and Marius Grundmann — Uni-

versität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig, Germany

The properties of quantum wells (QWs) are very sensitive to the interface quality. Ideally, atomically flat interfaces are required to enclose a perfect square well. In the ZnO/MgZnO system the potential landscape changes into a triangular potential due to the electric polarization difference between both materials and the resulting electric field. The quantum confined stark effect (QCSE) is therefore expected to be observed in such heterostructures. Its presence and the related phenomena can be used as a criterion for the interface quality. In the present study QW-structures were grown by PLD directly on sapphire, on a ZnO buffer layer on sapphire and on O-polar ZnO single crystal substrates. The surface morphology was investigated by AFM. Structural quality was assessed by HR-XRD. All samples were grown pseudomorphically and in the step flow mode, excluding major influences from interface roughening.

The occurrence of the QCSE has been determined by intensity-dependent as well as time-resolved photoluminescence measurements. A redshift of the QW luminescence as well as an immense increase in the exciton lifetime is observed for high quality samples.

HL 57.8 Thu 16:30 H17

Einfluss der Exzitonen-Phononen-Wechselwirkung auf das Absorptionsverhalten von MgZnO — •Maciej Neumann[1], Gerhard Gobsch[1], Rüdiger Goldhahn[1], Thomas A. Wassner[2], Bernhard Laumer[2] und Martin Eickhoff[3] — [1]Technische Universität Ilmenau, Institut für Physik, PF 100565, Ilmenau 98684 — [2]Technische Universität München, Walter Schottky Institut, Garching D-85748 — [3]Justus-Liebig-Universität Giessen, I. Physikalisches Institut, Giessen

Die Verbindungshalbleiter ZnO und MgZnO sind bekannt für ihre hohen Exzitonenbindungsenergien sowie die starke Polarität der Bindung. Diese Eigenschaften spiegeln sich in den Absorptionsspekten wider und können nicht allein durch das von Elliott abgeleitete Modell wiedergegeben werden. Die vorliegende Studie untersucht den Einfluss der Exzitonen-Phononen-Kopplung auf die Absorptionseigenschaften auf Basis der Analyse der dielektrischen Funktion (DF). Dazu wurden hexagonale $Mg_xZn_{1-x}O$-Schichten mit Mg-Konzentrationen von $x = 0$ bis $x = 0.23$ mittels plasmaunterstützter Molekularstrahlepitaxie auf Saphir-Substraten gewachsen und durch spektroskopische Ellipsometrie sowie Photolumineszenzspektroskopie (PL) untersucht. Die Beiträge von Exzitonen, coulombverstärkten Interbandübergängen sowie Exzitonen-Phonen-Komplexen auf die DF wird analysiert. Dies liefert die Bandlücke bei Raumtemperatur und zeigt, dass der Beitrag durch die Exzitonen-Phononen-Wechselwirkung nicht vernachlässigt werden kann. Der Vergleich mit der PL weist eine schwache Stokes-Verschiebung durch Lokalisierung der Exzitonen auf.

HL 57.9 Thu 16:45 H17

Growth and Characterization of Hetero- and Homoepitaxial ZnO/ZnMgO Quantum Wells. — •Bernhard Laumer[1], Thomas A. Wassner[1], Fabian Schuster[1], Martin Stutzmann[1], and Martin Eickhoff[2] — [1]Walter Schottky Institut, Technische Universität München, Am Coulombwall 3, 85748 Garching — [2]I. Physikalisches Institut, Justus-Liebig-Universität, Heinrich-Buff-Ring 16, 35392 Gießen

In this study, $ZnO/Zn_{1-x}Mg_xO$ single quantum wells (SQW) with different well widths have been grown by plasma-assisted molecular beam epitaxy on c-plane sapphire as well as on c-plane (O-face) bulk ZnO crystals. For heteroepitaxy on c-plane sapphire, a MgO/ZnO double buffer has been introduced to overcome the large lattice mismatch. Reflection high energy electron diffraction was used for in-situ growth monitoring and atomic force microscopy for ex-situ investigation of the sample morphology. The rms roughness of both hetero- and homoepitaxial SQW samples ranges from 0.2 to 0.4 nm, indicating the presence of well-defined and abrupt heterointerfaces. The optical properties of the quantum well structures were investigated by photoluminescence spectroscopy (PL). At 4.2 K, excitonic emission from the SQW is observed, that blue shifts for decreasing well width due to enhanced quantum confinement. As shown by temperature-dependent PL measurements, this emission line can be attributed to excitons localized at potential fluctuations of the SQW due to fluctuations of the barrier height or well width. At higher temperatures a second peak emerges that is attributed to free excitons.

HL 57.10 Thu 17:00 H17

Structural defect bound excitons in ZnO — •Markus R. Wagner[1], Gordon Callsen[1], Jan-Hindrik Schulze[1], Martin Kaiser[1], Ronny Kirste[1], Axel Hoffmann[1], Martin Noltemeyer[2], Anna V. Rodina[3], Stefan Lautenschläger[4], Sebastian Eisermann[4], and Bruno K. Meyer[4] — [1]TU Berlin, Inst. für Festkörperphysik, 10623 Berlin — [2]OvGU Magdeburg, Inst. für Exp. Physik, 36106 Magdeburg — [3]A.F. Ioffe Physico-Technical Inst., 194021 St.-Petersburg, Russia — [4]JLU Giessen, I. Physikalisches Inst., 35592 Giessen

Excitons bound to structural defects are a common feature of many semiconductor materials. In ZnO the narrow transition line in luminescence and absorption at 3.333eV is a typical example for this category of excitons. In this contribution we present a comprehensive study of defect bound excitons under the influence of external magnetic and stress fields. The defect centers are identified as neutral donor states with low activation energies despite of their much larger localization energies. Time resolved photoluminescence reveals a significant discrepancy compared to the Rashba-like behavior of the shallow bound excitons. This difference is further supported by the quantitative analysis of the pressure coefficients under the influence of uniaxial stress. The excitation channels of the defect bound excitons are compared with those of the I4 to I9 lines by PLE measurements. Monochromatic CL images provide insights into the microscopic nature of these transitions. Possible defect models for the deeply bound excitons will be discussed.

HL 57.11 Thu 17:15 H17

Charge states of a hydrogen defect (3326 cm^{-1} line) in ZnO — •Frank Herklotz, Eduard Lavrov, and Jörg Weber — Technische Universität Dresden, 01062 Dresden, Germany

Hydrogen in ZnO is a common impurity that strongly influences its electrical and optical properties, in particular, via formation of shallow donor states [1,2].
An IR absorption study of a H-related defect resulting in a local vibrational mode (LVM) at 3326 cm^{-1} [3] is presented. We observed that a sub band-gap illumination results in the appearance of an IR absorption line at 3358 cm^{-1} at the expense of the 3326 cm^{-1} signal. The results of isotope substitution experiments strongly reveal that the two signals are LVMs of the same defect in different charge states. From the energy of the sub band-gap light it is concluded that this defect has a deep level in the band-gap. Data on thermal stability as well as the transition between the different charge states at different temperatures are also presented. The microscopic nature of the defect will be discussed.

[1] C.G. Van de Walle, Phys. Rev. Lett. 85, 1012 (2000)
[2] E.V. Lavrov, F. Herklotz, C.G. Van de Walle, Phys. Rev. B 79, 165210 (2009).
[3] M.D. McCluskey, S.J. Jokela, K.K. Zhuravlev, P.J. Simpson, and K.G. Lynn, Appl. Phys. Lett. 81, 3807 (2002).

HL 57.12 Thu 17:30 H17

Spin Coherence in ZnO — •Christoph Schwark[1], Vera Klinke[1], Gernot Güntherodt[1], Matthias Althammer[2], Sebastian T.B. Goennenwein[2], Matthias Opel[2], Rudolf Gross[2], Thomas Wassner[3], Martin S. Brandt[3], and Bernd Beschoten[1] — [1]Physikalisches Institut IIA, RWTH Aachen University, Aachen, and JARA - Fundamentals of Future Information Technology, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Walter Schottky Institut, Technische Universität München, Garching, Germany

ZnO is a promising candidate for future spintronic applications due to its wide bandgap and small spin-orbit coupling. Using time resolved Faraday rotation experiments, we have studied the spin dephasing time T_2^* as a function of temperature in epitaxial ZnO thin films. Two sets of samples were investigated: one set of ZnO films was deposited on sapphire substrates via pulsed laser deposition, the other was grown using plasma-assisted molecular beam epitaxy. At 10 K, we observe spin dephasing times in excess of 20 ns, surpassing all previously reported values in ZnO bulk single crystals and thin films [1]. We will discuss the correlation between the spin dephasing time observed experimentally and the crystalline quality, as well as the evolution of T_2^* with temperature.

Financial support by DFG through SPP 1285 and by HGF through VISel - Virtual Institute of Spin Electronics is gratefully acknowledged.

[1] Gosh *et al.*, Appl. Phys. Lett **86**, 232507 (2005).

HL 57.13 Thu 17:45 H17

Majority and minority carrier traps in a n - type ZnO thin film — •Matthias Schmidt, Martin Ellguth, Holger v. Wenckstern, Rainer Pickenhain, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Leipzig, Germany

The majority of the published deep level transient spectroscopy (DLTS) data on defects in ZnO stems from energy levels in the upper third of the ZnO band gap. This is due to the p doping difficulty and the wide band gap. Only few reports on DLTS studies using pn junctions for the investigation of hole traps in the vicinity of the valence band exist.

In this work we investigated defects present in a ZnO thin film grown by pulsed laser deposition on a two side polished a-plane sapphire substrate. Space charge regions (SCR) were provided by Pd Schottky contacts. We employed standard DLTS for the detection of majority carrier traps, e.g. E3. Using the double DLTS technique, we observed the Poole Frenkel effect for the E3 deep level. Hole traps were studied by minority carrier spectroscopy, a DLTS technique, where instead of the voltage pulse a UV LED pulse illuminates the sample from the back such that electron hole pairs are created. Due to the electric field at the Schottky barrier, the electrons drift towards the bulk and the holes into the SCR. In doing so, hole traps are filled during the pulse and hole emission is observed by DLTS. These experiments revealed the existence of a deep level approx. 430 meV above the valence band.