HL 48: ZnO: Devices

Time: Wednesday 10:15–13:30 Location: POT 151

HL 48.1 Wed 10:15 POT 151

Optimization of optical and electrical properties of room temperature deposited ZnO:X (X = Al, Ga, In) TCO electrodes — •Tobias Diez, Alexander Lajn, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig

Transparent conductive oxides (TCOs) are commercially exploited as electrodes in transparent electronics (e.g., transparent displays) and optoelectronic device applications (e.g., thin-film solar cells). Indium-tin-oxide (ITO) has the biggest market share, however, the increasing usage of TCOs in connection with the high indium price demands to establish alternatives. Doped ZnO is such a promising and cheap alternative to ITO. We deposited smooth, amorphous ZnO thin films on quartz glass and sapphire substrates at room temperature using pulsed laser deposition (PLD). To optimize the optical and electrical properties we measured transmittance and conductivity as a function of the oxygen pressure applied during PLD. Additionally, we investigated the influence of different group III dopants (Al, Ga, In) and their doping concentration on these thin film properties. For Al-doped ZnO the highest figure of merit ($T^{10}/R_s = 1.9 \cdot 10^{-3}\,\Omega^{-1}$) was found at an oxygen pressure of 0.002 mbar and a doping concentration of 3 %. Furthermore, we analyzed the impact of this optimized growth condition on the device performance of transparent metal-semiconductor field-effect transistors (MESFET) using highly conductive ZnO as source and drain electrodes.

HL 48.2 Wed 10:30 POT 151

Dynamic Properties of (Mg,Zn)O-based MESFETs — •Fabian J. Klüpfel, Alexander Lajn, Heiko Frenzel, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Abteilung Halbleiterphysik, Linnéstr. 5, 04103 Leipzig

Transparent electronics is an emerging technological field, in which oxide based transistors play a key role. Various materials have been used to fabricate transparent transistors, including ZnO, (In,Ga,Zn)O, SnO_2 and related compounds [1-4]. Besides the steady-state electrical characterization, dynamic properties of such devices have been studied using ring oscillators. However, this rather complex test structures are less suitable to investigate and identify the physical effects, which limit the working range in the frequency domain. We present dynamic measurements on single (Mg,Zn)O-based MESFETs with the gate materials Ag_xO, PtO_y and Au. A strong dependence of the dynamic properties on the gate material was observed. The usage of Ag_xO results in delayed response of the source-drain current even for frequencies below 1 kHz. For PtO_y and Au absence of such an effect was verified up to 1 Mhz. We attribute this difference to the diffusion of Ag into the channel material during device fabrication.

[1] K. Nomura et al. Science, 300, 1269 (2003)
[2] E. Fortunato, Thin Solid Films, 487, 205 (2005)
[3] Y. Ogo, Appl. Phys. Lett., 93, 032113 (2008)
[4] H. Frenzel et al., Adv. Mat., 10.1002/adma.201001375 (2010)

HL 48.3 Wed 10:45 POT 151

Carrier transport in nanocrystalline field-effect transistors: Impact of interface roughness and geometrical carrier trap — •Koshi Okamura and Horst Hahn — Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), 76021 Karlsruhe, Germany

Nanocrystalline field-effect transistors (FETs) inherently have a certain level of roughness at the semiconductor-dielectric interface, which originates from the size of building blocks, i.e., nanocrystals ranging from a few to a few tens of nanometers. This interface roughness is expected to act like carrier traps, significantly preventing induced carriers from being transported along the channel in nanocrystalline FETs. In this study, a simple numerical calculation is performed for nanoparticulate zinc oxide (ZnO) FETs on the basis of Shockley's gradual channel approximation with the induced carriers classified into two components: (1) fixed carriers located within a threshold depth d_{th} from the interface and (2) mobile carriers located away from d_{th}. This calculation clearly indicates that the mobile carrier concentration is strongly dependent on the level of interface roughness; and the field-effect mobility is directly reflected by the mobile carrier concentration, significantly decreasing by a factor of $3.9\text{x}10^{-1}$, $7.4\text{x}10^{-2}$, $3.0\text{x}10^{-2}$, $3.9\text{x}10^{-3}$, and $7.3\text{x}10^{-4}$ for d_{th} of 1, 5, 10, 30, and 40 nm, respectively. These findings reveal that an interface roughness as small as a few nanometers results in a decrease in field-effect mobility as large as an order of magnitude, which is in qualitative agreement with experimental results.

HL 48.4 Wed 11:00 POT 151

Covalent functionalization of ZnO nanowires — •Andreia da Rosa, Ney Moreira, and Thomas Frauenheim — BCCMS, University of Bremen, Am Fallturm 1, 28359, Bremen, Germany

Understanding the interaction of organic species with inorganic nanostructures constitutes a step forward in the development of semiconductor based biosensors. In this work we have used density functional theory to investigate ZnO-(1010) nanowire surfaces modified with substituted methane molecules (Me-X, with X= OH, NH2, SH, COOH, and CN). We have found three relevant mechanisms for surface stabilization: passivation of surface oxygen lone-pairs via dissociative chemisorption processes, electrostatic adsorbate-interations involving Zn surface sites and hydrogen bonding interactions involving oxygen surface sites. Covalent adsorbate-substrate interactions were found to play only a marginal role on the surface stabilization. Contradicting the usual chemical intuition, we have found no significant evidence for the formation of classical Lewis acid-base adducts on Zn surface sites. Finally we suggest that the functionalization with Me-COOH is also expected to be stable under ordinary laboratory conditions or in aqueous media.

HL 48.5 Wed 11:15 POT 151

Excitonic Transport in a ZnMgO/ZnO Quantumwell — •Martin Noltemeyer[1], Thomas Hempel[1], Jürgen Christen[1], Matthias Brandt[2], Michael Lorenz[2], Marius Grundmann[2], Andrey Polyakov[3], and Mikhail Stepovich[3] — [1]Institute of Experimental Physics, Otto-von-Guericke-Universität Magdeburg — [2]Institut fuer Experimentelle Physik II, Universität Leipzig — [3]Tsiolkovsky Kaluga State University, Russia

Using highly spectrally and ps-time resolved cathodoluminescence (CL) the excitonic transport in a c-oriented PLD grown ZnMgO/ZnO quantumwell (QW) of about $b = 4nm$ thickness is indirectly measured as a function of temperature ($T = 5K$-$180K$). In a first step, the initial exciton lifetime τ of the QW ($E_{QW}(5K) = 3.22eV$) is assigned by time resolved CL on the uncovered sample area. It decreases over one order of magnitude from $\tau(5K) = 3.75ns$ to $\tau(180K) = 0.38ns$. In a second step, the sample is excited by the pulsed e-beam in the center of a circular aperture ($d = 1.45\mu m$) in a completely light absorbing Ti-mask (thickness: 160nm). The analytic solution of the two-dimensional diffusion equation for this geometry is fitted to the initial decay of the CL with the given parameters $\tau(T)$ and $d(T)$. This directly gives the diffusion constant $D(T)$ which increases from $D(5K) = 0.25\ cm^2/s$ to $D(180K) = 1.4\ cm^2/s$. Using the Einstein-Relation, one can define an excitonic mobility that has a plateau around $\mu = 600\ cm^2/Vs$ at low T ($5K$-$12K$) with a decay at higher temperature following $\mu \propto T^{-\frac{2}{3}}$ which is close to scattering with Fröhlich-Interaction ($\mu \propto T^{-\frac{1}{2}}$).

HL 48.6 Wed 11:30 POT 151

First principles calculation of Auger recombination rates in ZnMgO — •Markus Heinemann and Christian Heiliger — I. Physikalisches Institut, Justus Liebig University Giessen, D-35392 Giessen, Germany

The variation of the band gap in $Zn_{1-x}Mg_xO$ with the Mg concentration x may open a channel for non-radiative recombination mechanisms. We use density functional theory to investigate the possibility of band-to-band Auger transitions in wurtzite $Zn_{1-x}Mg_xO$ alloys for $0 \leq x \leq 1$. Auger recombination rates for different Mg concentrations are computed by two different ways: (1) by interpolating the band structure and transition matrix elements from *ab initio* calculations of bulk ZnO, $Zn_{0.5}Mg_{0.5}O$, and MgO primitive cells, and (2) by using a supercell approach. We find that inter-band Auger recombination becomes possible at Mg concentrations $\gtrsim 50$ % where ZnMgO has not been reported to exist in a stable wurtzite phase.

15 min. break

HL 48.7 Wed 12:00 POT 151

Light emitting diodes based on ZnO — •Julian Benz, Christian Reindl, Stefan Lautenschläger, Sebastian Eisermann, Torsten Henning, Peter J. Klar, and Bruno K. Meyer — I. Physikalisches Institut, Justus-Liebig-Universität, Heinrich-Buff-Ring 16, 35392 Giessen

The oxide semiconductor zinc oxide (ZnO) is due to its wide band-gap potentially of interest for applications in blue and UV optoelectronic devices. The availability of crystalline ZnO substrates of different orientations offers new possibilities in this respect. However, before optoelectronic devices fully based on ZnO can be realized, one has to overcome the problem of p-type doping. A possible way to circumvent this problem is the use of p-GaN/n-ZnO heterostructures. In the last few years considerable progress has been made in the development of p-type ZnO. Doping with nitrogen is used in Giessen. We report on current-voltage characteristics and electroluminescence measurements of GaN/ZnO heterostructures and ZnO/ZnO:N homojunctions.

HL 48.8 Wed 12:15 POT 151

Optical spin orientation by linearly polarized light in ZnO — •Vera Klinke[1], Christoph Schwark[1], Christian Weier[1], Gernot Güntherodt[1], Matthias Althammer[2], Sebastian T.B. Goennenwein[2], Matthias Opel[2], Rudolf Gross[2], and Bernd Beschoten[1] — [1]Physikalisches Institut II A, RWTH Aachen University, Aachen, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

Optical absorption of circularly polarized light is well known to yield spin-polarized electrons. Recently, some of us have demonstrated that electron spin polarization can even be generated with high efficiency by absorption of linearly polarized light in InGaAs for laser energies near its fundamental band gap [1]. This method allows to selectively excite in-plane or out-of-plane spins. The excitation mechanism, however, has not been fully understood. We extend our studies to unintentionally doped ZnO samples. For laser excitation energies far below the band gap, we can resonantly spin-polarize donor bound excitons with linearly polarized light excitation. Surprisingly, the observed Faraday rotation for linearly polarized excitation can even be 10 times larger than for circularly polarized excitation.

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[1] K. Schmalbuch *et al., arXiv:1008.0157, Phys. Rev. Lett. (in press)*

HL 48.9 Wed 12:30 POT 151

Piezoelectric properties of ZnO and (Zn,Mg)O- microstructures — •Christina A. Fobbe[1], Irina Laubenstein[1], Marcel Ruth[1], Manuel H. W. Bader[1], Alexander M. Bernhart[2], Mark R. Kaspers[2], Christian A. Bobisch[2], Rolf Moeller[2], and Cedrik Meier[1] — [1]University of Paderborn, Experimental Physics & CeOPP, Warburger Str. 100, 33098 Paderborn — [2]University of Duisburg-Essen, Faculty of Physics, Lotharstr. 1, 47057 Duisburg

Zinc oxide (ZnO) is a highly attractive material for piezoelectric applications. The usage of ZnO crystals in applications such as sensors and actuators has already been demonstrated. *Ab-initio* calculations have shown that the piezoelectric constant for magnesium oxide (MgO) exceeds the value for bulk ZnO [1].

We present investigations of the piezoelectric properties of $Zn_{1-x}Mg_xO$-microstructures with different Mg concentrations in comparison to binary ZnO-microstructures. For these experiments ZnO based microstructure devices have been fabricated on hydrothermally grown ZnO samples as well as on (Zn,Mg)O-epilayers grown by plasma-assisted molecular beam epitaxy (MBE).

The piezoelectric properties of the devices were investigated by applying an external electric field using a UHV-four-probe scanning tunneling microscope (STM). This way, we were able to reproduce the literature value of bulk ZnO and report on the results obtained for (Zn,Mg)O samples.

[1] G. Chambaud et al., Chem. Phys. 352, 147 (2008)

HL 48.10 Wed 12:45 POT 151

Synthesis and characterization of micro scaled free standing c-oriented piezoelectric ZnO needles — •Sören Kaps, Arnim Schuchardt, Yogendra Kumar Mishra, and Rainer Adelung — Functional Nanomaterials, Institute for Materials Science, University of Kiel, Kaiserstraße 2, 24143 Kiel

The combination of a piezoelectric and a magnetostrictive material on a microscopic scale allows the creation of magnetoelectric (ME) composites with a very high ME effect. For magnetic field sensors a freestanding ME composite has the advantage that no clamping of the composite is necessary and therefore no hindering of the deformation can occur. Since the preferred growth direction of ZnO is the c-axis which is also piezoelectric active and hence it becomes a potential candidate for building freestanding ME composites. The controlled growth and the piezoelectric properties of ME composites are highly important to realize ME composites by coating the ZnO with a magnetostrictive material. In the present work free standing ZnO needles with variable dimensions, have been synthesized by conventional vapor liquid solid (VLS) and a newly introduced flame transport synthesis (FTS) approach. The effect of different ZnO structures on piezoelectric properties will be discussed. Further the piezoelectric properties will be related to the electronic properties and it will be shown how reliable conductivity measurements can give a hint on the quality of the obtained structures.

HL 48.11 Wed 13:00 POT 151

Electrical properties of 1D to 3D ZnO nanostructures synthesized by flame transport synthesis approach — •Arnim Schuchardt, Sören Kaps, Yogendra Kumar Mishra, Ingo Paulowicz, and Rainer Adelung — Functional Nanomaterials, Institute for Material Science, Faculty of Engineering, Christian-Albrechts-University, Kaiserstraße 2, 24143 Kiel Germany

Due to the piezoelectricity and the strong tendency to grow self organised in one or two dimensional structures with high aspect ratios, ZnO has obtained huge interest for the application in nanogenerators. With a simple flame transport method self organised ZnO-structures with dimensions ranging from nm up to mm were synthesised. In first experiments to investigate the piezoelectric properties of ZnO rods, these rods where deformed periodically by a PZT piezo actuator including a simultaneous measurement of the voltage. The electrical properties of ZnO structures synthesised by the flame transport method and the influence of the metallic contacts will be shown and discussed. The occurrence of Schottky contacts in between the ZnO structures and the metallic contacts will be elaborated in more detail. With respect to the generator applications, the change of the electrical conductivity under normal and bended state for a ZnO rod was performed and preliminary results will be discussed. Apart from ZnO rods, electrical properties of 3-dimensional complex flexible network of ZnO nanostructures will also be discussed.

HL 48.12 Wed 13:15 POT 151

Trap-related behavior of charge carrier transport in transparent conductive oxides — •Marlis Ortel and Veit Wagner — School of Engineering and Science, Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany

Recently significant progress was made in the field of wet-chemically processed metal oxide semiconductors. Even though these materials are amorphous they show high mobility values of up to 100 cm2/Vs. Furthermore metal oxide semiconductors are transparent due to their large band gap. The combination of both properties makes these materials important for applications such as transparent electronics.

However TCO-based devices often show hysteresis and stress-related threshold voltage shift, which is not acceptable in many applications. In this work the charge carrier transport in TCO-based transistors is analyzed. The semiconductor is wet-chemically deposited from a precursor solution and thermally converted into ZnO. The hysteresis and bias stress in these layers are attributed to trapping of charges. The observed threshold voltage shifts are strongly affected by charge carrier density, electric field strength, temperatures and ambient gases. To gain detailed information about the local threshold voltage shift within the channel is obtained via 4-probe setup. This setup includes two electrodes in the conducting channel which enable the determination of the potential in the channel while stressing the device and thus yield valuable information if charge density or electric field strength is more important. The analysis yields, among others, especially a strong influence of the electric field strength on the observed bias stress.