HL 65: Focus Session (DS with HL): Oxide semiconductors I

Time: Thursday 9:30–12:45 Location: H 2032

Invited Talk HL 65.1 Thu 9:30 H 2032

Growth, properties and devices of gallium-oxide-based wide-gap semiconductors — •Shizuo Fujuta — Kyoto University, Kyoto, Japan

Recently, high-power devices with orthorhombic α-Ga_2O_3 have attracted increasing interest supported by solution-grown highly-crystalline substrates. However, orthorhombic crystals are rare in semiconductor family, hence there hardly are other semiconductors of the same crystal structure for alloys or multilayer structures with α-Ga_2O_3. On the other hand we have developed the growth of corundum-structured α-Al_2O_3, α-Ga_2O_3, α-In_2O_3 and their alloys achieving the band gap engineering from 3.8 to 8.8 eV, overcoming metastable phases of α-Ga_2O_3 and α-In_2O_3. For the growth we can apply a low-cost and environmental-friendly mist CVD method, which allowed highly-crystalline films as evidenced by FWHM of ω-scan XRD curves as small as <50 arcsec for α-Ga_2O_3 and <500 arcsec for others. The author will report crystal qualities, electrical properties, doping and preliminary device performances with MOS structures at the conference. In addition, alloying with transition-metal oxides such as α-Fe_2O_3 or α-Cr_2O_3 achieves addition of magnetic properties to semiconductors, as evidenced by magnetization hysteresis at >300K. This can also develop new multifunctional materials and devices with function engineering.

HL 65.2 Thu 10:00 H 2032

Growth-Kinetics Study and Doping the Group-III Sesquioxide β-Ga2O3 — •Patrick Vogt and Oliver Bierwagen — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5 - 7, 10117 Berlin, Germany

In the present talk, a comprehensive study of the growth-kinetics of β-Ga2O3 (-201) on Al2O3 (0001) is given. The growth was performed by plasma-assisted molecular beam epitaxy. Under ultra-high vacuum conditions atomic gallium and oxygen plasma were reacting amongst others to form β-Ga2O3. Besides the growth-kinetics studies for undoped Ga2O3 we also doped this material with tin. Under different growth conditions we investigated the carrier concentration depending on different growth parameters like growth temperature (Tgrowth) and metal fluxes, Ga and Sn flux, respectively.

This study shows the variation of the growth-rate depending on various growth-parameter such as the gallium beam equivalent pressure, Tgrowth and the oxygen flux. It turned out, that in the gallium-rich regime the formation of the volatile suboxide Ga2O reduce the growth-rate of β-Ga2O3 and result in an etching of the film when no oxygen is supplied. In order to investigate the carrier concentration of the Ga2O3 : Sn transport measurements were performed.

HL 65.3 Thu 10:15 H 2032

Au-Schottky contact on In2O3 single crystals — •Maryam Nazarzadehmoafi[1], Christoph Janowitz[1], Mattia Mulazzi[1], Stephan Machulik[1], Zbigniew Galazka[2], and Recardo Manzke[1] — [1]Institut für Physik, Humboldt Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany — [2]Leibniz Institut für Kristallzüchtung, Max Born Str. 2, 12489 Berlin, Germany

Au contacts on melt-grown-In2O3 (111) single crystals were studied using angle-resolved photoemission spectroscopy to monitor the band bending by core level and valence band spectra, with correction for the photovoltage effect. The measurement was performed through step-wise Au evaporation onto the (111) surface of In2O3 at room temperature (RT) as well as low temperature (LT). A small Schottky barrier on RT-samples and a larger one on LT-samples were observed. The comparison of the experimental barrier height with the predicted one from the Schottky-Mott rule shows a discrepancy. It implies that the complexity of the atomic structure of the present metal-semiconductor interface is beyond the applicability of the Schottky-Mott rule. The results indicate that an explicit reference to the surface electron accumulation layer is not necessary when discussing the Schottky character of the Au/In2O3 contact. In addition, the results reveal the epitaxial growth of Au on In2O3 and also the chemical reaction and formation of an Au-In alloy at RT.

HL 65.4 Thu 10:30 H 2032

Schottky contacts and pn-heterojunctions on heteroepitaxial In_2O_3 thin films grown by pulsed laser deposition — •Daniel Splith, Florian Schmidt, Steffen Lanzinger, Stefan Müller, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Leipzig, Germany

Oxide semiconductors like In_2O_3 are promising materials for a new generation of transparent electronic devices. While the properties of highly tin-doped In_2O_3 (ITO) for use as a transparent conductive oxide (TCO) are well investigated, interest in the semiconducting properties of In_2O_3 for the investigation of material properties and application in devices arose recently. In order to create devices like diodes or field-effect transistors, the creation of a space charge region is required, which can be done either by a Schottky contact (SC) or a pn-junction.

In this contribution we discuss the fabrication of rectifying contacts based on SCs [1] and pn-heterojunctions with an amorphous *p*-type oxide like NiO or $ZnCo_2O_4$ [2]. To optimize the performance of the rectifying contacts different approaches were used: By introducing a Mg-doped In_2O_3 layer, the reverse current was decreased by several orders of magnitude since Mg acts as an acceptor in In_2O_3 and therefore increases the width of the space charge region. Also, a tin doped back contact layer was employed in order to decrease the series resistance of the contacts. Further, different substrates were used to investigate the influence of the crystal quality on the rectifying properties.

[1] H. von Wenckstern *et al.*, APL Mat. 2, 046104 (2014)
[2] F.-L. Schein *et al.*, Appl. Phys. Lett. 104, 022104 (2014)

HL 65.5 Thu 10:45 H 2032

Temperature-dependent thermal conductivity in Mg-doped and undoped β-Ga_2O_3 bulk-crystals — •Martin Handwerg[1,2], Rüdiger Mitdank[1], Zbigniew Galazka[3], and Saskia F. Fischer[1] — [1]AG Neue Materialien, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH,Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [3]Leibniz Institute for Crystal Growth, Max-Born-Strasse 2, 12489 Berlin, Germany

Transparent semiconducting insulators like Ga_2O_3 are important materials for high power electronics and optoelectronics. For β-Ga_2O_3 only little information exist concerning the thermal properties, especially the thermal conductivity λ. Here, the thermal conductivity is measured by applying the electrical 3ω-method on Czochralski-grown β-Ga_2O_3 bulk crystals, which have a thickness of 200 μm and 800 μm. At room temperature the thermal conductivity along the [100]-direction in Mg-doped electrical insulating and undoped semiconducting β-Ga_2O_3 is confirmed as 13 ± 1 $Wm^{-1}K^{-1}$ for both crystals [1]. The phonon contribution of λ dominates over the electron contribution below room temperature. The observed function $\lambda(T)$ is in accord with phonon-phonon-Umklapp scattering and the Debye-model for the specific heat at $T \gtrsim 90$ K which is about 0.1 fold of the Debye-temperature θ_D. Here a detailed discussion of the phonon-phonon-Umklapp scattering for $T < \theta_D$ is carried out. The influence of point defect scattering is considered for $T < 100$ K.

[1] Martin Handwerg et al. , 2014, SST, accepted (arXiv 1407 4272)

30 min. break.

Invited Talk HL 65.6 Thu 11:30 H 2032

$BaSnO_3$; The next generation of transparent conducting oxide? — •David Scanlon — Department of Chemistry, University College London, UK — Diamond Light Source Ltd., Harwell, UK.

La-doped cubic perovskite $BaSnO_3$ has been reported to possess electron mobilities as high as 320 $cm^2\,V^{-1}\,s^{-1}$ for carrier concentrations of 8×10^{19} cm^{-3}, comparable to the very best transparent conducting oxides (TCOs). In this presentation we will examine the electronic structure and defect chemistry of $BaSnO_3$, and use this information to explain why La-doped $BaSnO_3$ possesses all the qualities needed to be the next generation $n-$type TCO.

HL 65.7 Thu 12:00 H 2032

Nitrogen doping in tin dioxide thin film grown by chemical vapor deposition — •Jie Jiang, Yinmei Lu, Benedikt Kramm, and Bruno K Meyer — I. Physics Institute, Justus-Liebig-University Giessen, Giessen, Germany

As a direct band gap semiconductor, tin dioxide (SnO2) is a promising candidate for next generation ultraviolet light emitting diodes (LEDs) and photo detectors, due to its large band gap of 3.6 eV, and high carrier mobility of about 250 cm2/Vs at room temperature. An essential step to fabricate SnO2-based optoelectronic devices is to obtain high quality p-type SnO2 films. Nitrogen could be an excellent p-type dopant in SnO2 owing to its suitable electronegativity and ion size, high solubility limit, and non-toxicity. At the same time, only a few experimental investigations were performed on N-doped SnO2. For this reason, we deposit the N-doped SnO2 thin films on c-sapphire substrates via chemical vapor deposition (CVD), using SnI2 powder and O2 and NH3 gas as source materials. Both undoped and N-doped samples are annealed at different temperature for a short time using a rapid thermal processing. The crystal structure, electrical properties and optical properties of the films were measured and investigated by X-ray diffraction (XRD), Hall effect measurements, optical transmittance, secondary ion mass spectrometry (SIMS) and X-ray photoelectron spectroscopy (XPS), respectively. The effect of short-time annealing on structural, optical and electrical properties is also analyzed.

HL 65.8 Thu 12:15 H 2032

Dopant clustering in p-type transparent semiconducting Cr_2O_3:Mg — •Karsten Fleischer, David Caffrey, Leo Farrell, Emma Norton, Daragh Mullarkey, Elisabetta Arca, and Igor V. Shvets — School of physics and Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN), Trinity College Dublin, Dublin 2, Ireland

We present an analysis of the Raman spectra of p-type transparent conducting Cr_2O_3:Mg grown by various techniques including spray pyrolysis (SP), pulsed laser deposition (PLD), molecular beam epitaxy (MBE) and reactive magnetron sputtering (RMS). The best performing films show a distinct broad range Raman signature related to defect-induced vibrational modes not seen in stoichiometric, undoped material. Our comparative study demonstrates that Raman spectroscopy can quantify unwanted dopant clustering in the material at high Mg concentrations, while also being sensitive to the Mg incorporation site. By correlating the Raman signature to the electrical properties of the films, growth processes can be optimised to give the best conducting films and the local defect structure for effective p-type doping can be studied.

HL 65.9 Thu 12:30 H 2032

Annealing effects on electrical properties of room-temperature deposited zinc oxynitride thin films — •Anna Reinhardt, Heiko Frenzel, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Semiconductor Physics Group

Amorphous oxide semiconductors have attracted much attention as channel material for thin-film transistors (TFT) due to their comparatively large electron mobility (> 10 cm^2/Vs) achieved already by low-temperature fabrication. In order to further increase channel mobilities while maintaining the stability of oxide-based TFTs the alloying of ZnO by nitrogen was suggested [1].

We have investigated the electrical properties of semiconducting zinc oxynitride (ZnO_xN_y) thin films depending on annealing temperature and doping. Therefore we conducted annealing experiments in air and N_2 atmosphere up to 400°C. The ZnO_xN_y thin films were deposited on glass substrates by reactive radio-frequency magnetron sputtering of a metallic zinc target at room-temperature. Electrical properties were examined using the four-probe van der Pauw technique. The as-deposited films show n-type semiconducting behaviour with carrier concentrations of $1 \times 10^{17} - 3 \times 10^{18}$cm^{-3} and Hall mobilities ranging from 10 to 20 cm^2/Vs. With increasing annealing temperature the resistivity decreases whereas the mobility increases. In addition, possible structural changes due to annealing were analyzed using x-ray diffraction.

[1] Y. Ye *et al.*, J. Appl. Phys., 106, 074512 (2009)