

DS 34: Focused Session: Oxide semiconductors I (joint session with HL)

Time: Thursday 9:30–12:45

Location: H 2032

Invited Talk

DS 34.1 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 -Ga₂O₃ 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 -Ga₂O₃. On the other hand we have developed the growth of corundum-structured α -Al₂O₃, α -Ga₂O₃, α -In₂O₃ and their alloys achieving the band gap engineering from 3.8 to 8.8 eV, overcoming metastable phases of α -Ga₂O₃ and α -In₂O₃. 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 -Ga₂O₃ 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 -Fe₂O₃ or α -Cr₂O₃ 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.

DS 34.2 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 (T_{growth}) 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, T_{growth} 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.

DS 34.3 Thu 10:15 H 2032

Au-Schottky contact on In₂O₃ single crystals — ●MARYAM NAZARZADEHMOAFI¹, CHRISTOPH JANOWITZ¹, MATTIA MULAZZI¹, STEPHAN MACHULIK¹, ZBIGNIEW GALAZKA², and RECARDO MANZKE¹ — ¹Institut für Physik, Humboldt Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany — ²Leibniz 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.

DS 34.4 Thu 10:30 H 2032

Schottky contacts and pn-heterojunctions on heteroepitaxial

In₂O₃ 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 In₂O₃ are promising materials for a new generation of transparent electronic devices. While the properties of highly tin-doped In₂O₃ (ITO) for use as a transparent conductive oxide (TCO) are well investigated, interest in the semiconducting properties of In₂O₃ 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 ZnCo₂O₄ [2]. To optimize the performance of the rectifying contacts different approaches were used: By introducing a Mg-doped In₂O₃ layer, the reverse current was decreased by several orders of magnitude since Mg acts as an acceptor in In₂O₃ 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)

DS 34.5 Thu 10:45 H 2032

Temperature-dependent thermal conductivity in Mg-doped and undoped β -Ga₂O₃ bulk-crystals — ●MARTIN HANDWERG^{1,2}, RÜDIGER MITDANK¹, ZBIGNIEW GALAZKA³, and AND SASKIA F. FISCHER¹ — ¹AG Neue Materialien, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — ²Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — ³Leibniz Institute for Crystal Growth, Max-Born-Strasse 2, 12489 Berlin, Germany

Transparent semiconducting insulators like Ga₂O₃ are important materials for high power electronics and optoelectronics. For β -Ga₂O₃ 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 -Ga₂O₃ bulk crystals, which have a thickness of 200 μ m and 800 μ m. At room temperature the thermal conductivity along the [100]-direction in Mg-doped electrical insulating and undoped semiconducting β -Ga₂O₃ is confirmed as 13 ± 1 Wm⁻¹K⁻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 Handweg *et al.*, 2014, SST, accepted (arXiv 1407 4272)

30 min. break.

Invited Talk

DS 34.6 Thu 11:30 H 2032

BaSnO₃; 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 BaSnO₃ has been reported to possess electron mobilities as high as 320 cm²V⁻¹s⁻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 BaSnO₃, and use this information to explain why La-doped BaSnO₃ possesses all the qualities needed to be the next generation *n*-type TCO.

DS 34.7 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.

DS 34.8 Thu 12:15 H 2032

Dopant clustering in p-type transparent semiconducting Cr₂O₃: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 Cr₂O₃: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.

DS 34.9 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 cm²/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 N₂ 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 $1 \times 10^{17} - 3 \times 10^{18} \text{ cm}^{-3}$ and Hall mobilities ranging from 10 to 20 cm²/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)