International Workshop on Gallium Oxide and Related Materials (IWGO-6)

Room ESJ 0202 - Session IWGO-MoM1

Plenary Session I

Moderator: Marko Tadjer, U.S. Naval Research Laboratory

8:00am **IWGO-MoM1-1 Breakfast**

8:45am **IWGO-MoM1-10 Welcome & Sponsor Thank Yous**

9:00am **IWGO-MoM1-13 PLENARY: Single Crystals and Wafers of β-Ga_2O_3, β-$(Al_xGa_{1-x})_2O_3$, and r-GeO2**, ***Zbigniew Galazka,*** Leibniz-Institut für Kristallzüchtung, Germany **INVITED**

Ultra-wide bandgap (UWBG) oxide materials attract a considerable scientific and technological attention in the research community to boost the development of next generation power devices capable of switching high voltages. The development chain includes single crystal growth, substrates preparation, homo- and heteroepitaxial film growth, device fabrication in different architectures, study of physical properties of obtained materials, and characterization of the devices. This requires a multidisciplinary approach interconnecting science and technology.

During this talk, I will overview melt growth methods applied for β-Ga_2O_3 and β-$(Al_xGa_{1-x})_2O_3$ single crystals [1-3], their structural quality, and wafers. I will also highlight epitaxial film growth of β-Ga_2O_3 and β-$(Al_yGa_{1-y})_2O_3$ on β-$(Al_xGa_{1-x})_2O_3$ substrates by Metal-Organic Vapor Phase Epitaxy (MOVPE) [4, 5]. Ultra-high purity β-Ga_2O_3 single crystals grown by the Czochralski method and their features will be described as well. Additionally, doping of Czochralski-grown β-$(Al_xGa_{1-x})_2O_3$ single crystals with different 4+ elements will reveal their impact on electrical conductivity at high Al content (>20 mol.%).

The discussion will also cover rutile-GeO_2 (r-GeO_2) single crystals grown by a modified Top-Seeded Solution Growth (TSSG) with prepared epi-ready wafers [6, 7].

Finally, a comparison of basic physical properties of the discussed β-Ga_2O_3, β-$(Al_xGa_{1-x})_2O_3$, and r-GeO_2 single crystals and wafers might be useful for further development directions.

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[1] Z. Galazka;J. Appl. Phys. 131 (2022) 031103.

[2] Z. Galazka; "Growth of bulk β-Ga_2O_3 single crystals" in "Comprehensive Semiconductor Science and Technology 2nd Ed.", Ed. R. Fornari, Elsevier (2025).

[3] Z. Galazka; IEEE Trans. Semicond. Manuf. 38 (2025) 796-802.

[4] S. Bin Anooz et al.; J. Phys. D: Appl. Phys. 59 (2026) 015308.

[5] S. Bin Anooz et al.; J. Vac. Sci. Technol. A 44 (2026) 032702.

[6] Z. Galazka et al.; J. Appl. Phys. 133 (2023) 035702.

[7] Z. Galazka et al.; Adv. Mater. Interfaces (2024) 2400122.

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9:45am **IWGO-MoM1-22 Plasma-Treatment Based (Near) Surface Doping of Semiconducting Oxides**, ***Oliver Bierwagen,*** Paul-Drude Institute for Solid State Electronics, Germany; *Piero Mazzolini,* University of Parma, Italy **INVITED**

The control of charge carrier concentration in (ultra-)wide bandgap oxide semiconductors usually involves the substitutional incorporation of foreign dopant atoms during growth or post growth by ion implantation or dopant in-diffusion. Above-room temperature growth or annealing processes are required for these approaches and often the dopant effect gets partially compensated by the formation of native point defects.

This talk will discuss a completely different approach based on two different room-temperature surface plasma treatments that induce free carrier systems in undoped (ultra-)wide bandgap oxide semiconductors.

In the first part, the creation of near-surface electron systems in *n*-type oxides, such as In_2O_3, SnO_2, and different polymorphs of Ga_2O_3 are discussed in detail. For example, the resulting electron systems in undoped κ-Ga_2O_3 exhibited an unprecedentedly high electron mobility above 25 cm^2/Vs at sheet/volume carrier concentrations around $2x10^{14}$ cm^{-2}/$4x10^{19}$ cm^{-3}, and a similar carrier system was induced in a semi-insulating Mg-doped β-Ga_2O_3 substrate. The thermal stability of these electron systems is discussed and a native-point-defect based doping mechanism is proposed. That the discussed feature can also be a bug, is further highlighted by the unintentional creation of an electron system during sputter deposition of a dielectric SiO_2 layer on a homoepitaxial β-Ga_2O_3 layer.

The creation and thermal stability of a surface hole system in the *p*-type oxide NiO is demonstrated in the second part and shown to be related to surface charge transfer doping.

The presented approaches may provide an easy way of scouting the charge-carrier-transport potential of novel oxide semiconductors before elaborating substitutional doping, and will be tested against further topical and novel oxide semiconductors.

The presented body of work has been accumulated over more than ten years and we acknowledge all contributors, including, Marko Perestjuk, Ivana Lapsanska, Carmine Borelli, Andrea Ardenghi, Theresa Berthold, Melanie Budde, Marcel Himmerlich, Christian Golz, Abbes Tahraoui.

10:10am **IWGO-MoM1-27 Lattice Defects in β-Ga_2O_3 Crystals and Power Devices**, *Yongzhao Yao,* ***Yukari Ishikawa,*** Mie University, Japan **INVITED**

Lattice defects in β-Ga_2O_3 significantly degrade the performance and reliability of Ga_2O_3-based devices. Establishing effective strategies to reduce such defects requires comprehensive knowledge of their three-dimensional spatial distribution as well as their structural characteristics. This information can be obtained through a combination of advanced characterization techniques, including transmission electron microscopy (TEM), phase-contrast microscopy, X-ray topography, and related X-ray imaging methods. In this work, we focus on the visualization and characterization of lattice defects and the evaluation of their impact on Ga_2O_3 power devices. We review recent results from our research group, where multiple X-ray imaging techniques—namely reflection and transmission X-ray topography (XRT), X-ray reticulography (XRR), and X-ray laminography (XRL)—have been employed to reveal structural defects such as dislocations, nano-voids, and domain boundaries in β-Ga_2O_3 crystals. Furthermore, reflection and transmission XRT has been extended to enable real-time observation of power devices under forward and reverse bias conditions (operando observation), allowing direct investigation of defect dynamics under external stimuli.

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