International Workshop on Gallium Oxide and Related Materials (IWGO-6)
Room ESJ Concourse - Session IWGO-MoPI
Invited Poster Session

IWGO-MoPI-1 INVITED POSTER: Reliability of Ga_2O_3 Schottky Barrier Diodes, ***Md Hafijur Rahman****,* *Nahid Al-Mamun,* Penn State University*; Jian-Sian LI,* University of Florida, Gainesville*; Aman Haque, Douglas E. Wolfe,* Penn State University*; Fan Ren,* University of Florida, Gainesville

β-Ga_2O_3 is a leading ultra-wide bandgap semiconductor for next-generation power electronics due to its large bandgap (~4.8 eV) and high theoretical breakdown field (~8 MV/cm), enabling high-voltage, high-temperature operation. However, unresolved reliability issues under extreme electrothermal conditions limit its practical deployment. Here, we investigate the failure mechanisms of β-Ga_2O_3 Schottky barrier diodes (SBDs) under simultaneous forward bias and elevated temperature using in-situ transmission electron microscopy (TEM), enabling real-time observation of defect nucleation, evolution, and breakdown.

Experiments were performed using a MEMS-based heating and biasing platform integrated into the TEM, allowing controlled electrothermal stressing up to ~455 °C. Vertical β-Ga_2O_3 SBD lamellae were subjected to forward bias from 1–5 V. No structural changes were observed at ≤2 V (≤85 °C). At 3 V (185 °C), early degradation appeared as contrast variations indicating defect nucleation and localized strain. At ≥4 V (≥300 °C), rapid defect accumulation and severe structural degradation led to catastrophic failure.

The degradation process is driven by electrothermally induced vacancy cluster formation, producing significant compressive strain within the lattice. Increasing defect density promotes dislocations, stacking faults, and amorphization, primarily along (200) planes due to anisotropic thermal conductivity and low fault formation energy. Simultaneously, the Ni/Au Schottky contact degrades through interdiffusion and alloying, forming a metallic pool that penetrates the drift layer via defect-assisted pathways.

Elemental mapping reveals Ga enrichment and oxygen deficiency near the interface, indicating high vacancy concentration and compositional redistribution. The interaction between defect accumulation and metal diffusion generates localized stress fields that drive void formation, plastic deformation, and eventual cracking and delamination. These structural changes correlate with electrical degradation, including reduced forward current, increased on-resistance, lower turn-on voltage, and a significant drop in rectification ratio.

This study provides direct evidence that β-Ga_2O_3 SBD failure arises from a coupled process involving vacancy generation, defect evolution, and Schottky contact instability under electrothermal stress.

IWGO-MoPI-2 INVITED POSTER: Single-Event Transient Study of Ga_2O_3 Rectifiers, ***Ani Khachatrian****,* US Naval Research Laboratory*; Stephen Pearton, Fan Ren,* University of Florida*; Joel Hales,* Amentum*; Dale McMorrow,* US Naval Research Laboratory

Single-event effects (SEEs) studies were carried out on gallium oxide (Ga_2O_3) vertical rectifiers using ultrafast laser pulses. The Naval Research Laboratory (NRL) wide-bandgap pulsed-laser single-event effects (PL SEE) beamline consists of a tunable Optical Parametric Amplifier (OPA) that can generate ultrafast pulses across the UV-NIR spectrum, along with an imaging system for precise beam positioning. The laser pulse is focused onto a DUT to a sub-micron beam size using microscope objectives. The beamline is fully calibrated with online monitors and controllers for laser pulse energy and spot size, allowing for accurate modeling of charge deposition within the DUT's sensitive volume. The choice of laser wavelength depends on factors like device geometry and the semiconductor's bandgap. Two-photon absorption (TPA) technique at 350 nm laser wavelength was used to determine how the device transient response changes with deposited charge, bias, and the presence of defects. Pulsed-laser single-event measurements on Ga_2O_3 devices show that increased reverse bias and growth-related defects lead to enhanced single-event transients (SETs). This work demonstrates that the charge collection efficiency in the vertical Ga_2O_3 rectifier and the Ga_2O_3/ITO diode is near 100%. The shape of laser-induced SETs depends strongly on laser pulse energy, deposited charge distribution profile, bias, and the presence of growth-related defects. The SET decay time is most likely affected by both electrons tunneling into the hole-filled deep-level defect states and by the thermal emission of holes.

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IWGO-MoPI-3 INVITED POSTER: Nitrogen Precursor Selection for Controllable Doping in MOCVD Ga_2O_3, *William Brand,* ***Fikadu Alema****, Andrei Osinsky,* Agnitron Technology

Nitrogen is a promising deep acceptor dopant for β-Ga_2O_3 because of its low diffusivity, high thermal stability, and ability to compensate unintentional n-type conductivity in epitaxial layers and at film/substrate interfaces. However, the effectiveness and controllability of nitrogen doping by MOCVD depend strongly on the nitrogen precursor chemistry. In this work, nitrogen doping of β-Ga_2O_3 using different nitrogen sources is compared, including N_2O, NH_3/N_2, and NO/N_2. N_2O can act as both an oxygen source and a nitrogen source, but nitrogen incorporation is strongly dependent on growth temperature, pressure, and reactor conditions, making precise doping control challenging. NH_3/N_2 provides more direct control of nitrogen incorporation through the ammonia molar flow rate; however, it also introduces significant hydrogen at standard β-Ga_2O_3 growth temperatures, which may compensate the deep acceptor behavior of nitrogen. In comparison, NO/N_2 offers a hydrogen-lean alternative that enables controllable nitrogen incorporation while remaining compatible with conventional MOCVD growth conditions. Using NO/N_2, nitrogen concentrations up to ~6.5 × 10^{18} cm^{-3} were achieved, with N/H ratios as high as ~28, indicating substantially reduced hydrogen incorporation compared with NH_3/N_2-based doping, although the incorporation efficiency remains relatively low.

An additional advantage of NO/N_2 is its strong effect on the β-Ga_2O_3 growth rate. Introducing small NO flows together with O_2 increased the film growth rate by approximately 1.8–3.2× for both TEGa and TMGa precursors. This enhancement is attributed to NO-assisted oxidation chemistry, which promotes more efficient surface oxidation of Ga species. This work will also discuss how nitrogen-doped layers grown using these precursors can be used to suppress interface Si-related conduction in β-Ga_2O_3 field-effect transistors.

IWGO-MoPI-4 INVITED POSTER: Phase Transformation and Defect Evolution in Ge-Implanted β-Ga_2O_3(In Memory of Professor Stephen J. Pearton), ***Elaf Anber****, Daniel Foley,* Johns Hopkins University*; Andrew C. Lang,* US Naval Research Laboratory*; James Nathaniel,* Johns Hopkins University*; James L Hart,* US Naval Research Laboratory*; Marko J Tadjer, Karl D. Hobart,* Naval Research Laboratory*; Stephen Pearton,* University of Florida*; Mitra Taheri,* Johns Hopkins University

This contribution is dedicated to the memory of Professor Stephen J. Pearton, whose mentorship, scientific insight, and pioneering contributions to ion implantation and wide-bandgap semiconductors were instrumental to this work and continue to inspire the field.

Ion implantation is a critical technique for selective doping in β-Ga_2O_3 power electronic devices, yet the associated structural damage and recovery mechanisms remain incompletely understood. In this work, Ge ion implantation in β-Ga_2O_3 was investigated using advanced analytical electron microscopy, including scanning/transmission electron microscopy (S/TEM), electron energy-loss spectroscopy (EELS), precession electron diffraction (PED), and TopSpin strain analysis. Ge implantation produced a ~130 nm damaged region corresponding to the projected ion range and induced a complete phase transformation from β- to κ-Ga_2O_3 within the implanted layer. Rapid thermal annealing at 1150 °C in an O_2 atmosphere restored the β phase, although a thin (~17 nm) residual surface damage layer remained. EELS revealed persistent modifications to the oxygen electronic structure following annealing, while strain mapping indicated a residual tensile strain of approximately 0.5% extending beyond the implanted region, consistent with Ge diffusion into the bulk. These findings provide direct insight into implantation-induced phase transformations, defect recovery, and dopant redistribution in β-Ga_2O_3, offering guidance for optimizing ion implantation processes and post-implantation thermal treatments for high-performance Ga_2O_3 electronic devices.

IWGO-MoPI-5 INVITED POSTER: Prospect of Wide- and Ultrawide-Bandgap Semiconductors for Ultrahigh-Voltage Vertical Unipolar Power Switching, ***Franklin Nouketcha****, Aivars Lelis, Daniel Habersat, Ronald Green,* DEVCOM Army Research Laboratory*; Neil Goldsman,* ECE Department, University of Maryland, College Park

As new materials emerge for electronic applications, recent research has increasingly shifted toward wide-bandgap (WBG) and ultrawide-bandgap (UWBG) semiconductors because of their potential to enable high-power, high-voltage, high-frequency, high-temperature, and high-efficiency operation, thereby improving SWaP (Size, Weight, and Power) characteristics. Performance improvement in power electronic devices requires not only innovative device design but also careful material selection as material properties influence the resulting device characteristics. This work investigates the projected performance of selected WBG and UWBG semiconductors for high-voltage, vertical, unipolar power switching. The materials studied include silicon (Si), 4H silicon carbide (4H-SiC), gallium nitride (GaN), beta-gallium oxide (β-Ga_2O_3), diamond, and aluminum gallium nitride ($Al_xGa_{1-x}N$), and aluminum nitride (AlN). The study evaluates the breakdown voltage (V_{BR}) through avalanche-breakdown modeling based on impact ionization coefficients (IICs), and the specific on-state resistance ($R_{ON,SP}$) is determined by considering the incomplete ionization of dopant atoms and the dependence of carrier mobility on doping concentration and temperature.

The results show that, for a desired operating voltage, there is a unique combination of drift-region doping concentration and drift-layer thickness that maximizes the /$R_{ON,SP}$ ratio, referred to as the optimum trade-off ratio (OTR) [1]. The OTR, plotted as a function of V_{BR} at 300 K (Fig. 1a) and 500 K (Fig. 1b), depends strongly on both doping concentration and temperature. Higher OTR values are achieved in materials with a high dielectric constant, low IICs, low dopant ionization energies, and high carrier mobility. It is also observed that incomplete ionization is less severe for high-voltage devices because dopant ionization increases at lower doping concentrations. The greatest remaining challenges for vertical unipolar devices are the development of vertical substrates—feasible for SiC but still challenging for GaN and most UWBG materials—and background compensation [2], which limits the achievement of low doping concentrations in some materials.

[1] F. L. Nouketcha, A. Lelis, R. Green, and N. Goldsman, IEEE Trans. Electron Devices (2026)

[2] Y. Zhang and J. S. Speck, Semicond. Sci. Technol. 38, 119501 (2023)

Author Index

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