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Ultrawide bandgap (UWBG) semiconductors, with energy bandgaps (>4 eV), much wider than the conventional wide bandgap (WBG) of GaN (3.4 eV) and SiC (3.2 eV), represent an emerging new area of research covering a wide spectrum from materials, physics, devices, and applications. This new class of semiconductors has promising applications for future generations of RF and high-power electronics, as well as deep-UV optoelectronics, quantum electronics, and harsh-environment applications.

Compared to the development of traditional semiconductors such as Si and the III–Vs, and even the WBGs, all UWBG materials are relatively immature and still at a nascent stage. This Special Topic covers broad research subtopics on UWBG bulk crystals and substrate technologies, UWBG electronic and optoelectronic properties, UWBG power electronic devices, UWBG defect science and doping, UWBG low-dimensional structures and devices, UWBG carrier recombination dynamics, UWBG gate and passivation dielectrics, UWBG thermal properties and thermal engineering, and UV light emitting diodes and detectors.

Below are highlights from the collection of this Special Topic categorized by three representative UWBG material systems: AlGaN and related UWBG nitrides, gallium oxide (Ga_2O_3) and alloys, and diamond.

Aluminum gallium nitride ($Al_xGa_{1-x}N$) is an UWBG semiconductor possessing a bandgap that can be tuned from 3.4 to over 6 eV by controlling the Al composition x in the alloy. This permits the ready formation of heterostructures, which in addition to its direct bandgap and piezoelectric properties makes it a very versatile semiconductor material. Related nitrides, e.g., those containing B or Sc, likewise have intriguing properties. Over twenty papers on the UWBG nitrides appear in this Special Topic, indicating the large scope of vibrant research being conducted in the field today.

Several papers consider the growth, crystal structure, doping, and defects of AlGaN. For example, Kishimoto *et al.* examine the growth of an amorphous hole injection layer for p-type AlGaN,[1] and Pasayat *et al.* have achieved thick (>1 μm) AlGaN films grown on GaN-on-porous-GaN patterned substrates.[2] Yao *et al.* have utilized synchrotron x-ray topography to study the details of dislocations in AlN single crystals,[3] and a detailed study of vacancy defects in Si-doped $Al_{0.9}Ga_{0.1}N$ using positron annihilation measurements is presented by Prozheev *et al.*, where they determine that the charge state of the in-grown cation vacancy correlates with the carbon content.[4] The electrical properties of semi-polar (11–22) $Al_xGa_{1-x}N$ films with $x = 0.6$ and 0.8 are reported by Foronda *et al.*, who found that the resistivity for both compositions is impacted by compensation due to the formation of cation vacancy complexes.[5] Kaminska *et al.* conducted studies wherein PL and photoluminescence excitation (PLE) spectra determined that the bandgap of AlN depends on the growth substrate (Si or sapphire) due to lattice mismatch and the associated strain.[6] Theoretical work is reported by Pant *et al.* that calculates the alloy-disorder-limited electron mobility for AlGaN, with a minimum value of 136 $cm^2/V\,s$ including all scattering mechanisms, in good agreement with experiment.[7] Electrical and thermal transport in AlGaN and AlGaN heterostructures and superlattices are likewise studied by Muhin *et al.*[8] and Tran *et al.*,[9] respectively. Further, high-field impact ionization effects in GaN are reported by Ji and Chowdhury.[10]

Studies of UWBG nitrides other than AlGaN are also reported in this Special Topic. For example, Tran *et al.* have grown BAlN with

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over 20% B content by metalorganic chemical vapor deposition (MOCVD),[11] and the same group has conducted a nanoscale compositional analysis of similar films using atom probe tomography.[12] Additionally, Moser *et al.* have studied the dielectric properties and phonon modes of ScAlN using infrared spectroscopic ellipsometry.[13]

Moving to devices, a number of transistor results are likewise reported. These include the use of plasma-deposited boron nitride (BN) as a gate dielectric in an AlGaN/GaN metal-insulator-semiconductor high electron mobility transistor (MISHEMT) by Yang *et al.*,[14] the temperature characteristics of AlGaN-channel metal-oxide- semiconductor high electron mobility transistors (MOSHEMTs) by Mollah *et al.*,[15] and studies of threshold voltage stability in GaN nanowire field effect transistors (FETs) by Ruzzarin *et al.*[16] Regarding heterostructures, band offsets between AlN and Al_2O_3 are reported by Fares *et al.*[17]

Finally, numerous reports of AlGaN-based optoelectronic devices are reported in this special issue. These include studies of carrier localization in AlGaN quantum wells by Frankerl *et al.*,[18] 233 nm deep AlGaN UV LEDs by Lobo-Ploch *et al.*,[19] recombination kinetics in UV-B LEDs by Ruschel *et al.*,[20] the space charge profile in polarization-doped cladding layers of UV-C laser diodes by Zhang *et al.*,[21] carrier dynamics near cracked GaN microwires in AlGaN multiple quantum wells by Finot *et al.*,[22] the reliability of UV-C LEDs on AlN/sapphire templates by Ruschel *et al.*,[23] and UV LEDs with a Mg-delta-doped AlGaN last barrier by Wang *et al.*[24]

Thus, a broad spectrum of novel material and device studies focused on UWBG AlGaN is presented in this special issue, and we sincerely hope that these new results are useful and gratifying to the reader.

β-Ga_2O_3 has an extremely large bandgap energy of 4.5 eV, and its bulk single crystals can be synthesized by melt growth methods. These two material features have promoted it to the mainstream of UWBG semiconductors. More than forty papers on Ga_2O_3 are reported in this Special Topic; this also indicates recent active research on it.

Several state-of-the-art epitaxial growth technologies for Ga_2O_3 and related materials are presented in this Special Topic. Mauze *et al.* conducted Sn doping in β-Ga_2O_3 thin films via plasma-assisted molecular beam epitaxy (MBE) and achieved a reasonable room-temperature electron mobility and a wide-range control of donor concentration.[25] Feng *et al.* demonstrated *in situ* Mg doping in β-Ga_2O_3 thin films during MOCVD growth.[26] They proposed that semi-insulating Mg-doped Ga_2O_3 epilayers can be used as energy barriers in power device structures. Goto *et al.* systematically studied structural properties of Ga_2O_3 thin films grown by halide vapor phase epitaxy as a function of growth temperature.[27] Grundmann *et al.* investigated $(AlGa)_2O_3$ alloy thin films in the corundum phase grown on r-plane sapphire substrates by pulsed laser deposition at various temperatures.[28]

There are still many unknown material properties for Ga_2O_3. Ghadi *et al.* systematically studied defect states in Si-doped β-Ga_2O_3 thin films grown by MOCVD by admittance spectroscopy and deep-level transient/optical spectroscopies.[29] Li *et al.* reported two articles on reverse current–voltage characteristics of β-Ga_2O_3 Schottky barrier diodes. They investigated the reverse leakage mechanisms based on traditional thermionic emission and thermionic field emission models.[30,31]

Prior to experimental studies, theoretical calculations have often been used to explore new material properties of semiconductors. Varley *et al.* surveyed donor dopants in $(AlGa)_2O_3$ alloys using first-principles density functional theory calculations.[32] They proposed that Si is the most efficient donor to achieve *n*-type conductivity in high Al-content $(AlGa)_2O_3$ alloys. Mu *et al.* theoretically investigated band alignments between $(AlGa)_2O_3$ and Ga_2O_3 for different crystal orientations.[33] Sharma and Singisetti simulated low-field electron transport in α-Ga_2O_3.[34] The peak electron mobility in α-Ga_2O_3 at room temperature was predicted to be $\sim$220 $cm^2/V\,s$ at a donor concentration of $1 \times 10^{15}\,cm^{-3}$.

From its excellent electrical properties originated from the extremely large bandgap, Ga_2O_3 field effect transistors (FETs) and diodes have been actively developed for power switching and RF applications. Gong *et al.* fabricated high-performance vertical NiO/β-Ga_2O_3 *p–n* heterojunction diodes without any electric field managements.[35] Moser *et al.* discussed current status and future prospects of β-Ga_2O_3 RF FETs.[13] Zheng *et al.* simulated and experimentally demonstrated nanoscale β-Ga_2O_3 vibrating channel transistors that can integrate RF mechanical motion with electrical output current through electrostatic and transistor gating effects.[36] Budde *et al.* grew *p*-SnO layers on *n*-Ga_2O_3 (−201) substrates by MBE and fabricated vertical *p–n* heterojunction diodes.[37]

Diamond is a fascinating semiconductor with exceptional physical properties such as an ultrawide bandgap (5.5 eV), a high breakdown electric field, an outstanding thermal conductivity, and high carrier mobilities. Even if *n*-type and *p*-type doping of diamond epilayers grown by plasma enhanced chemical vapor deposition are available, this material is still facing research challenges to be fully exploited in next generation electronics. Fifteen original papers dealing with diamond material properties and devices are reported in this UWBG Special Topic.

Several papers tackle one of the current major issues of diamond: the realization of large size substrates. Different strategies are addressed such as diamond layer transfer, heteroepitaxy, and "mosaic" wafer. For example, Fukumoto *et al.*[38] demonstrate the possibility to directly bond diamond and semiconductor substrates using NH_3/H_2O_2 cleaning. Kim *et al.*[39] grow 1-in. free-standing (001) diamond layers on a (11–20) (a-plane) sapphire substrate with an Ir buffer layer, opening new opportunities for power electronics applications. Mehmel *et al.*[40] propose a strategy to reduce dislocation density using overgrowth on hole arrays made in heteroepitaxial diamond substrates. Hanada *et al.*[41] achieve a high yield uniformity in pseudo-vertical diamond Schottky barrier diodes fabricated on half-inch mosaic single-crystal wafers, with some Schottky barrier diodes able to sustain high electric field strength ($\sim$5 MV/cm).

Defects and doping are still likewise important topics. In this context, Araujo *et al.*[42] report a comprehensive study on the dislocation generation mechanisms in heavily boron-doped diamond epilayers, establishing conditions to grow dislocation-free boron-doped diamond epilayers on undoped substrates. Lloret *et al.*[43] propose a strategy to perform selectively boron-doped homoepitaxial diamond growth for electronic devices.

Fundamental transport studies are focusing on the high mobility of carriers in diamond. Konishi *et al.*[44] reported the highest recorded mobility-lifetime product of 0.2 cm^2/V at low temperature in high-purity synthetic diamond, and Grivickas *et al.*[45] investigated the carrier recombination and diffusion in high-purity diamond after electron irradiation and annealing.

Concerning devices, important results on diamond-based FETs have been reported. Lee *et al.*[46] proposed a new hybrid self-aligned

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MIS–MESFET architecture, while Zhang *et al.*[47] studied the electrical performances of a yttrium/Al_2O_3/H-terminated diamond FET. Regarding metal–oxide–semiconductor (MOS) structures, Liu *et al.*[48] investigated the fixed charges in Al_2O_3/H-terminated diamond MOS capacitors and Zhang *et al.*[49] implemented the high-temperature conductance method to study the Al_2O_3/B-doped diamond interface states. Moreover, Mirabedini *et al.*[50] reported a first-principles study of the structural and electronic properties of 2D layer (graphene and h-BN)/hydrogen-terminated diamond (100) heterostructures.

Finally, Hatano *et al.*[51] invented a fiber-coupled quantum diamond sensor for simultaneous thermometry and magnetometry applications, and Shimaoka *et al.*[52] reported ultrahigh conversion efficiency of betavoltaic cell using diamond p–n junction, having an efficiency close to the theoretical Shockley–Queisser efficiency limit.

In summary, this Special Topic provides an opportunity for the reader to get a glimpse of the recent advancements in UWBG materials, physics, and devices. Despite being in its early years, tremendous progress has been made in this research field exploiting the fascinating properties of UWBG semiconductors. We hope this collection of articles can serve as a platform to stimulate more research interest and thus further advance the potential advantages of UWBGs for future applications.

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DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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