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Editorial

Micro- and Nanotechnology of Wide-Bandgap Semiconductors

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Gallium Nitride and Related Wide-Bandgap Semiconductors (WBS) have constantly received a great amount of attention in recent years. The main reason behind it is that several relevant high-power/high-frequency material parameters of semiconductors such as high breakdown field and low intrinsic carrier concentration, scale advantageously with bandgap. Semiconductor devices based on WBS allow for operation under extreme conditions, like high temperatures and electric fields. A huge range of wavelengths from IR to deep UV, enabling bandgap engineering together with excellent electron transport properties, makes nitrides attractive for electronic and optoelectronic devices as well. Today, nitride-based devices are widely used in high-performing radars (mainly 3D AESA), telecommunications (LTE-A, 5G), power electronic systems, light-emitting diodes and lasers. Despite substantial progress over the last twenty years, all these devices are still the subject of intense research to reach their full potential [1–4].

In this Special Issue, eight papers are published, covering various aspects of wide-bandgap semiconductor device technology, from substrates through epi-growth and semiconductor doping, to novel process modules for HEMTs, vertically integrated LEDs and laser diodes, and NWs-based nanoLEDs.

K. Grabianska et al. reported on the recent progress in bulk GaN technology achieved at Unipress, Poland [5]. Two processes, namely basic ammonothermal growth and halide vapor phase epitaxy have been thoroughly investigated and their advantages, disadvantages, and prospects discussed in detail. The authors suppose that within few years high-quality 2-in. truly bulk GaN substrates will be offered in large quantities, but today the main method for mass fabrication will be HVPE with Am-GaN crystals as seeds.

M. Stepniak et al. [6] investigated the process of selective-area metalorganic vapour-phase epitaxy (SA-MOVPE) of GaN and AlGaN/GaN hetereostructures intended for HEMT technology with bottom-up architecture. Excellent growth uniformity, appropriate structure profile, and precise control of compositional gradient were obtained. The applicability of the SA-MOVPE process in making GaN-based 3D nano- and microstructures for electroacoustic, electromechanic, and integrated optics devices and systems was discussed.

K. Sierakowski et al. [7] reported on high-pressure post-implant annealing of GaN at high temperatures. The thermodynamics of the process was discussed and its application for GaN processing was investigated in two aspects. First focused on GaN:Mg for p-type doping, second on GaN:Be treated as a case study for analysing mechanisms of dopant diffusion. Different configurations of the annealing process were studied in order to prevent GaN surface from decomposition. Mg activation exceeding 70% was reached together with electrical properties similar to those of MOVPE-doped GaN.

AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistors (MISHEMT) with a low-temperature epitaxy (LTE)-grown single crystalline AlN gate dielectric were demonstrated by M. Whiteside et al. [8]. Post-gate annealing effects were studied in detail showing considerable increase of 2DEG mobility and reduction of interface state density at the AlN/GaN interface after post-gate annealing. Consequently, important increase of extrinsic transconductance, reduction of reverse gate leakage, and suppression of drain current were reached in final LTE-AlN MISHEMT.

D. Gryglewski et al. proposed a novel approach to characterizing self-heating process in GaN-based HEMTs [9]. An advanced measurement system based on DeltaVGS method with implemented software enabling accurate determination of device channel temperature and thermal resistance was developed. Three types of GaN-based HEMTs were taken into consideration—commercially available GaN-on-SiC (CGH27015F and TGF2023-2-01) and GaN-on-Si (NPT2022) devices, as well as model GaN-on-Am-GaN HEMT [10]. The main advantage of the proposed approach is that it allows taking into account the self-heating effect of transistors during design of microwave devices and high-power amplifiers for systems using variable-envelope signals such as LTE-A and 5G radios.

Marcin Siekacz et al. demonstrate the applications of tunnel junctions (TJs) for new concepts of monolithic nitride-based multicolour light-emitting diode (LED) and laser diode (LD) stacks [11]. GaN-on-GaN epistructures under investigation were grown by plasma-assisted molecular beam epitaxy (PAMBE). A stack of four LDs operated at pulse mode with emission wavelength of 453 nm and two-colour (blue and green) LEDs were demonstrated. The presented design is a viable alternative to achieving III-nitride high-power pulse laser diodes for such applications such as gas sensing or LIDARs. The stack of multicolour LEDs interconnected by TJs is promising for white-colour, phosphorus-free LEDs and for LED array displays. The use of TJs simplifies the electrical connections to buried LED structures, eliminating the need of p-type contacts application.

The two next paper addressed the topic of GaN-based nanowires, promising building blocks for future generation of electronic and optoelectronic devices. These nanostructures facilitate, for instance, the integration of GaN-based devices with Si electronics. Additionally, complicated heterostructures can be grown in the form of NWs with a crystallographic quality not achievable in the case of comparable planar hetereostructures for nanoLED.

M. Sobanska et al. made use of Kelvin probe force microscopy to assess the polarity of GaN nanowires (wurtzite structures) grown by plasma-assisted Molecular Beam Epitaxy on Si (111) substrates [12]. They showed that uniformity of the polarity of GaN nanowires critically depends on substrate processing prior to the growth. Several methods of surface preparation were investigated, and their results indicated that reversal of nanowires' polarity can be prevented by growing them on a chemically uniform substrate surface, particularly on in situ formed SiN_x or ex situ deposited AlOy buffers.

Anna Reszka et all. [13] reported on growth, optical and electrical properties of GaN/AlGaN Nanowire LEDs fabricated on Si (111) substrates by plasma-assisted molecular beam epitaxy (PAMBE). No catalyst was used to induce the nucleation of the NWs. The nanowire LEDs included three GaN quantum wells in the area of the p–n junction. The research focused on the influence of switching the growth polarity. Spatially and spectrally resolved cathodoluminescence spectroscopy and imaging, e-beam-induced current microscopy, the nano-probe technique, and scanning electron microscopy were used for structural analysis, and complemented by photo- and electro-luminescence characterization. The interpretation of the experimental data was supported by the results of numerical simulations of the electronic band structure. Their results proved that intentional polarity inversion between the n- and p-type parts of NWs is a potential path towards the development of efficient nanoLED NW structures.

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