Wide Bandgap Devices and Power Conversion Systems—Part II

WIDE bandgap (WBG) semiconductors have arisen as a key enabling technology for modern power conversion systems, achieving unpresented levels of efficiency, power density, and performance. Such advances are supported by extensive research efforts at the power device, power system, and application levels and are aimed at having a major impact in our industry and daily lives. In this context of special relevance of WBG technology, this "Special Section on Wide Bandgap Devices and Power Conversion Systems" of IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS intends to present to the community the state-of-the-art research progresses in this area.

This Special Section has attracted great attention from both academia and industry, achieving more than 40 accepted papers that were divided into two parts: Part I was published in October 2017, including 19 papers, whereas Part II is being published in the this issue with 21 papers. This part contains relevant research results focused on the semiconductor devices [items 1) and 2) in the Appendix] and their packaging [item 3) in the Appendix]; modeling [items 4) and 5) in the Appendix] and performance evaluation [items 6) and 7) in the Appendix]; new gate drivers [items 8–11) in the Appendix]; as well as developments on key applications such as new data center power supplies [items 12) and 13) in the Appendix], dc microgrid concepts [item 14) in the Appendix] and dc-dc power supplies [item 15) in the Appendix]; automotive [item 16) in the Appendix], aircraft [item 17) in the Appendix], and renewable energy systems [items 18) and 19) in the Appendix]; and wireless power transfer [items 20) and 21) in the Appendix] systems.

New WBG power devices are the core of modern power systems, and consequently, significant attention has been paid to them. In item 1) in the Appendix, boron-doped gate oxide is proposed to improve the electrical properties of 4.5-kV SiC planar MOSFETs, achieving an increase of inversion channel mobility and a reduction of specific on-resistance. Complementary to this, in item 2) in the Appendix, a review of GaN-on-Si technology is provided, proposing new structures for Gan-based E-mode hybrid metal oxide semiconductor heterojunction field effect transistor (MOS-HFET) and lateral diodes with promising results aimed at realizing cost-effective full-GaN single-chip power ICs. To take the most of WBG devices, in item 3) in the Appendix, an SiC half-bridge module is designed following a hybrid packing method and tested through a synchronous buck converter, achieving improved switching behavior, thanks to the reduced stray inductances.

In order to design high performance systems taking advantage of WBG devices, several research lines have focused on modeling and the evaluation of conduction and switching performance of WBG semiconductors. In item 4) in the Appendix, a nonsegmented PSpice circuit model of GaN HEMTs is proposed that is capable of modeling both static and dynamics characteristics. Similarly, in item 5) in the Appendix, a refined model for SiC MOSFET is provided, relying on datasheet values. Both papers provide useful tools for designers to enable system optimization and reduce design complexity and development time. In item 6) in the Appendix, an extensive analysis of short-circuit behavior of medium-voltage GaN HEMTs and MISHEMTs is provided using both physics-based simulations and experimental measurements, and providing important results for the design of protection circuits. Finally, in item 7) in the Appendix, a double pulse tester focused on the accurate evaluation of GaN devices by reducing parasitic effects is proposed.

Due to the special switching characteristics of WBG devices, the design of gate driver circuits to maximize their performance and minimize stray elements is essential. In Item 8) in the Appendix, an active gate driver capable of controlling *di/dt* and *dv/dt* during transitions is proposed to achieve optimum switching trajectories, significantly reducing current and voltage overshoots. In item 9) in the Appendix, a GaN enhanced-mode high electron mobility transistor (E-HEMT) gate driver focusing on high immunity and low jitter for special applications requiring high precision and low noise while using high-speed semiconductors is proposed. In item 10) in the Appendix, cross-talk issues and half-bridge configurations using SiC devices are deeply analyzed, and a gate driver using magnetic coupling is proposed to achieve cross-talk suppression. Finally, item 11) in the Appendix is focused on the detection of the cross-turn-on inside power modules, and several protection methods are proposed and tested experimentally.

WBG devices enable the design of high performance converters with significant advantages in terms of performance, efficiency, and power density, which are of great interest in a wide range of applications. Following this aim, item 12) in the Appendix proposes the design of an *LLC* converter for data centers taking advantage of GaN devices, leading to a 1-MHz implementation with 97.6% peak efficiency and 900-W/in^3 power density. In item 13) in the Appendix, a three-phase power factor corrector rectifier using SiC devices is presented. The proposed topology reduces the number of required devices, allowing a cost-effective and high-performance implementation.

Modern dc grid designs require highly efficient power conversion to be considered as a sustainable option. In item 14) in the Appendix, a 98.3% efficiency bidirectional dc–dc converter featuring GaN devices is detailed, whereas item 15) in the Appendix details the design of an isolated dc–dc converter achieving 98.8% efficiency at 50% load and 7-kw/l power density using GaN devices and optimized magnetic components.

Relevant industries such as automotive, aerospace, and renewable energy are taking advantage of the benefits of WBG devices. In item 16) in the Appendix, an SiC-based 6.6-kW bidirectional on-board charger is detailed, featuring a

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variable dc-link voltage architecture and a high-frequency operation with 96% efficiency and 37 W/in^3. Further pushing output power and power density, item 17) in the Appendix presents a 50-kW SiC-based three-phase voltage-source inverter for aerospace applications achieving 26 kW/kg. In this paper, the switching conditions are carefully studied and designed to achieve robust operation and 97.91% efficiency at 100 kHz.

Photovoltaic systems also benefit from the benefits of SiC devices. The research conducted in item 18) in the Appendix details the switching characterization and short-circuit protection for 1200 V SiC MOSFETs with special emphasis on the topology used for PV systems, whereas item 19) in the Appendix details the design and experimental verification of a 60-kW PV inverter achieving a remarkable 99.2% peak efficiency and 3-kW/kg power density.

Finally, the development of new applications such as wireless power transfer systems is being enhanced by the use of WBG technology. In item 20) in the Appendix, a high-frequency zero voltage switching (ZVS) multiresonant converter for inductive power transfer is designed using GaN HFET devices, achieving 93% efficiency, whereas item 21) in the Appendix proposes the use of GaN devices to build a multifrequency wireless power transfer inverter that achieves higher performance and versatility than the state-of-the-art single-frequency inverters.

In summary, this Part II of this "Special Section on Wide Bandgap Devices and Power Conversion Systems" covers broad research areas related to wide bandgap devices and their applications and complements those research results published in Part I. The guest editors hope that this Special Section helps establish the state-of-the-art of WBG devices and power conversion systems and helps envision future devices, systems, and applications to bring industrial electronics to a new and exciting era of innovation.

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Appendix
Related Work

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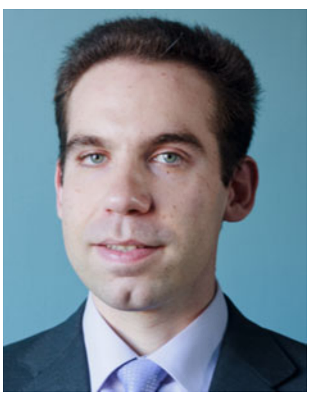

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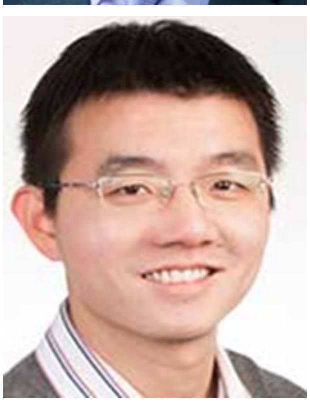

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