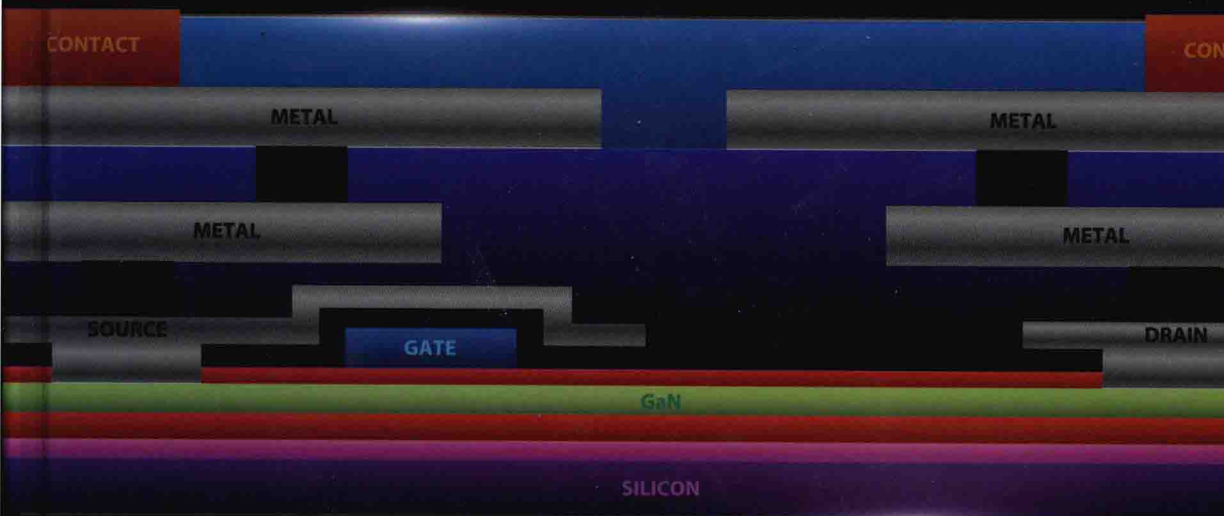
GaN Transistors for Efficient Power Conversion



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WILEY

GaN TRANSISTORS FOR EFFICIENT POWER CONVERSION

Second Edition

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Efficient Power Conversion Corporation, El Segundo, California, USA

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GaN TRANSISTORS FOR EFFICIENT POWER CONVERSION

In memory of Eric Lidow,
the original power conversion pioneer.

Foreword

It is well established that the CMOS inverter and DRAM are the two basic building blocks of digital signal processing. Decades of improving inverter switching speed and memory density under Moore's Law has unearthed numerous applications that were previously unimaginable. Power processing is built upon two similar functional building blocks: power switches and energy storage devices, such as the inductor and capacitor. The push for higher switching frequencies has always been a major catalyst for performance improvement and size reduction.

Since its introduction in the mid-1970s, the power MOSFET, with its greater switching speed, has replaced the bipolar transistor. To date, the power MOSFET has been perfected up to its theoretical limit. Device switching losses can be reduced further with the help of soft-switching techniques. However, its gate drive loss is still excessive, limiting the switching frequency to the low hundreds of kilohertz in most applications.

The recent introduction of GaN, with much improved figures of merit, opens the door for operating frequencies well into the megahertz range. A number of design examples are illustrated in this book and other literatures, citing impressive power density improvements of a factor of 5 or 10. However, I believe the potential contribution of GaN goes beyond the simple measures of efficiency and power density. GaN has the potential to have a profound impact on our design practice, including a possible paradigm shift.

Power electronics is interdisciplinary. The essential constituents of a power electronics system are switches, energy storage devices, circuit topology, system packaging, electromagnetic interactions, thermal management, EMC/EMI, and manufacturing considerations. When the switching frequency is low, these various constituents are loosely coupled. Current design practices address these issues in piecemeal fashion. When a system is designed for a much higher frequency, the components are arranged in close proximity, to minimize undesirable parasitics. This invariably leads to unwanted electromagnetic coupling and thermal interaction.

This increasing intricacy between components and circuits requires a more holistic approach, concurrently taking into account all electrical, mechanical, electromagnetic and thermal considerations. Furthermore, all operations should be executed correctly, both spatially and temporally. These challenges prompt circuit designers to pursue a more integrated approach. For power electronics, integration needs to take place at the functional level or the subsystem level whenever feasible and practical. These integrated modules then serve as the basic building blocks of further system integration. In this manner, customization can be achieved using standardized building blocks, in much the same way as digital electronics systems. With the economy of scale in manufacturing, this will bring significant cost reduction in power electronics equipment and unearth numerous new applications previously precluded due to high cost.

GaN will create fertile ground for research and technological innovations for years to come. Dr. Alex Lidow mentions in this book that it took thirty years for the power MOSFET to reach its current state of maturity. While GaN is still in an early stage of development, a few technical challenges require immediate attention. These issues are recognized by the authors and are addressed in this book.

1. High dv/dt and high di/dt render most of the commercially available gate drive circuits unsuitable for GaN devices, especially for the high-side switch. Chapter 3 offers many important insights in the design of the gate drive circuit.
2. Device packaging and circuit layout are critical. The unwanted effects of parasitics need to be contained. Soft-switching techniques can be very useful for this purpose. A number of important issues related to packaging and layout are addressed in detail in Chapters 4–6.
3. High-frequency magnetic design is also critical. The choice of suitable magnetic materials becomes rather limited when the switching frequency goes beyond 2–3 MHz. Additionally, more creative high-frequency magnetics design practice should be explored. Several recent publications suggest design practices that defy the conventional wisdom and practice, yielding interesting results.
4. The impact of high frequency on EMI/EMC has yet to be explored.

Dr. Alex Lidow is a well-respected leader in the field. Alex has always been in the forefront of technology and a trendsetter. While serving as the CEO of IR, he initiated GaN development in the early 2000s. He also led the team in developing the first integrated DrMOS and DirectFET®, which are now commonly used to power the new generation of microprocessors and many other applications.

This book is a gift to power electronics engineers. It offers a comprehensive view, from device physics, characteristics, and modeling to device and circuit layout considerations and gate drive design, with design considerations for both hard switching and soft switching. Additionally, it further illustrates the utilization of GaN in a wide range of emerging applications.

It is very gratifying to note that three of the four authors of this book are from CPES, joining with Dr. Lidow in an effort to develop this new generation of wide-band-gap power switches – presumably a game-changing device with a scale of impact yet to be defined.

Dr. Fred C. Lee
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University Distinguished Professor, Virginia Tech

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