Preface

With increased awareness of the adverse impact on the environment resulting from carbon emissions into the atmosphere, there is a growing demand for improving the efficiency of power electronic systems. Power semiconductor devices are recognized as a key component of all power electronic systems. It is estimated that at least 50 percent of the electricity used in the world is controlled by power devices. With the wide spread use of electronics in the consumer, industrial, medical, and transportation sectors, power devices have a major impact on the economy because they determine the cost and efficiency of systems. After the initial replacement of vacuum tubes by solid state devices in the 1950s, semiconductor power devices have taken a dominant role with silicon serving as the base material. These developments have been referred to as the *Second Electronic Revolution*.

In the 1970s, the power MOSFET product was first introduced by International Rectifier Corporation. Although initially hailed as a replacement for all bipolar power devices due to its high input impedance and fast switching speed, the silicon power MOSFET has successfully cornered the market for low voltage (<100 V) and high switching speed (>100 kHz) applications but failed to make serious inroads in the high voltage arena. This is because the on-state resistance of silicon power MOSFETs increases very rapidly with increase in the breakdown voltage. The resulting high conduction loss, even when using larger more expensive die, degrades the overall system efficiency.

The large on-state voltage drop for high voltage silicon power MOSFETs and the large drive current needed for silicon power bipolar transistors encouraged the development of the insulated gate bipolar transistor (IGBT) [1]. First commercialized in the early 1980s, the IGBT has become the dominant device used in all medium and high power electronic systems in the consumer, industrial, transportation, and military systems, and even found applications in the medical sector. The US Department of Energy has estimated that the implementation of IGBT-based variable speed drives for controlling motors is producing an energy savings of over 2 quadrillion btus per year, which is equivalent to 70 Giga-Watts of power. This energy savings eliminates the need for generating electricity from 70 coal-fired power-plants resulting in reducing carbon dioxide emissions by over one-Trillion pounds each year.

With on-going investments in renewable energy sources such as wind and solar power that utilize power semiconductor device in inverters, it is anticipated that there will be an increasing need for technologists trained in the discipline of designing and manufacturing power semiconductor devices. My recently published textbook [2] provides a comprehensive analysis of the basic power rectifier and transistor structures. This textbook has been complemented with a monograph on “Advanced Power Rectifier Concepts” to familiarize students and engineering professionals with structures that exhibit improved performance attributes.

This monograph introduces the reader to advanced power MOSFET concepts that enable improvement of performance of these transistor structures. For the convenience of readers, analysis of the basic transistor structures, with the same voltage ratings as the novel device structures, have been included in the monograph to enable comparison of the performance. As in the case of the textbook, analytical expressions that describe the behavior of the advanced power MOSFET structures have been rigorously derived using the fundamental semiconductor Poisson’s, continuity, and conduction equations in this monograph. The electrical characteristics of all the power MOSFETs discussed in this book can be computed using these analytical solutions as shown by typical examples provided in each section. In order to corroborate the validity of these analytical formulations, I have included the results of two-dimensional numerical simulations in each section of the book. The simulation results are also used to further elucidate the physics and point out two-dimensional effects whenever relevant. Due to increasing interest in the utilization of wide band-gap semiconductors for power devices, the book includes the analysis of silicon carbide structures.

In the first chapter, a broad introduction to potential applications for power devices is provided. The electrical characteristics for ideal power MOSFETs are then defined and compared with those for typical devices. The second and third chapters provide analyses of the planar DMOSFET structure and the trench-gate UMOSFET structure with 30-V blocking capability, which can be used as a benchmark for understanding the improvements achieved using the advanced device concepts. The analysis includes the on-resistance, the input capacitance, the gate charge, and the output characteristics.

The next four chapters are devoted to various advanced power MOSFET structures that allow improvement in the performance of devices with 30-V blocking capability. The fourth chapter discusses on the “Shielded Channel Planar Power MOSFET” structure, which allows a significant reduction in the gate charge while achieving a specific on-resistance close to that of the UMOSFET structure. The fifth chapter discusses the power CC-MOSFET structure, which utilizes the two-dimensional charge coupling effect to reduce the specific on-resistance by an order of magnitude. This structure is favorable for use as a synchronous rectifier in the sync-buck circuit topology used in voltage regulator modules for providing power to microprocessors in computers.

The next two chapters are devoted to high-voltage silicon device structures that utilize the charge-coupling concept to reduce the resistance of the drift region. In chapter six, the charge-coupling phenomenon is accomplished by using a graded doping profile in conjunction with an electrode embedded in an oxide coated trench to create the power GD-MOSFET structure. In chapter seven, the charge-coupling phenomenon is accomplished with adjacent p-type and n-type layers in the drift region to create the power SJ-MOSFET structure.

Chapter eight provides a detailed discussion of the body-diode within the various silicon power MOSFET structures. The body-diode can be used in place of the fly-back rectifier utilized in the H-bride circuit commonly used for motor control applications. It is demonstrated in this chapter that the judicious utilization of a Schottky contact within the power MOSFET cell structure can greatly improve the reverse recovery behavior of the body-diode.

Improvement in the performance of high voltage power MOSFET structures can also be achieved by replacing silicon with silicon carbide as the base material [3]. The much larger breakdown field strength for 4H-SiC allows increasing the doping concentration in the drift region by a factor of 200-times while shrinking the thickness of the drift region by one-order of magnitude. However, the silicon power MOSFET structure must be modified to shield the gate oxide from the much larger electric fields prevalent in silicon carbide to avoid rupture. In addition, the base region must be shielded to avoid reach-through breakdown. The on-resistance of these devices becomes limited by the channel resistance.

The final chapter provides a comparison of all the power MOSFET structures discussed in this book. The devices are first compared for the 30-V rating suitable for VRM applications and then with the 600-V rating suitable for motor control applications. In addition, the performance of all the devices is compared over a wide range of blocking voltages to provide a broader view.

I am hopeful that this monograph will be useful for researchers in academia and to product designers in the industry. It can also be used for the teaching of courses on solid state devices as a supplement to my textbook [2].

December, 2009 B. Jayant Baliga
Raleigh, NC

References

1. B.J. Baliga, “How the Super-Transistor Works”, Scientific American Magazine, Special Issue on ‘The Solid-State-Century’, pp. 34–41, January 22, 1988.
2. B.J. Baliga, “Fundamentals of Power Semiconductor Devices”, Springer Scientific, New York, 2008.
3. B.J. Baliga, “Silicon Carbide Power Devices”, World Scientific Press, Singapore, 2006.

http://www.springer.com/978-1-4419-5916-4

Advanced Power MOSFET Concepts
Baliga, B.J.
2010, XVI, 562 p., Hardcover
ISBN: 978-1-4419-5916-4