Gallium Nitride Gan Physics Devices And Technology Devices Circuits And Systems

This book demonstrates to readers why Gallium Nitride (GaN) transistors have a superior performance as compared to the already mature Silicon technology. The new GaN-based transistors here described enable both high frequency and high efficiency power conversion, leading to smaller and more efficient power systems. Coverage includes i) GaN substrates and device physics; ii) innovative GaN -transistors structure (lateral and vertical); iii) reliability and robustness of GaN-power transistors; iv) impact of parasitic on GaN based power conversion, v) new power converter architectures and vi) GaN in switched mode power conversion. Provides single-source reference to Gallium Nitride (GaN)-based technologies, from the material level to circuit level, both for power conversions architectures and switched mode power amplifiers; Demonstrates how GaN is a superior technology for switching devices, enabling both high frequency, high efficiency and lower cost power conversion; Enables design of smaller, cheaper and more efficient power *supplies.*

This book provides an overview of compound semiconductor materials and their technology. After presenting a theoretical background, it describes the relevant material preparation technologies for bulk and thin-layer epitaxial growth. It then briefly discusses the electrical, optical, and structural properties of semiconductors, complemented by a description of the most popular characterization tools, before more complex hetero- and low-dimensional structures are discussed. A special chapter is devoted to GaN and related materials, owing to their huge importance in modern optoelectronic and electronic devices, on the one hand, and their particular properties compared to other compound semiconductors, on the other. In the last part of the book, the physics and functionality of optoelectronic and electronic device structures (LEDs, laser diodes, solar cells, field-effect and heterojunction bipolar transistors) are discussed on the basis of the specific properties of compound semiconductors presented in the preceding chapters of the book. Compound semiconductors form the back-bone of all opto-electronic and electronic devices besides the classical Si *electronics. Currently the most important field is solid state lighting with highly efficient LEDs emitting visible light. Also laser diodes of all wavelength ranges between mid-infrared and near ultraviolet have been the enabler for a huge number of unprecedented applications like CDs and DVDs for entertainment and data storage, not to speak about the internet, which would be impossible without optical data communications with infrared laser diodes as key elements. This book provides a concise overview over this class of materials, including the most important technological aspects for their fabrication and characterisation, also covering the most relevant devices based on compound semiconductors. It presents therefore an excellent introduction into this subject not only for students, but also for engineers and scientist who intend to put their focus on this field of science.*

Wide Bandgap Semiconductor Power Devices: Materials, Physics, Design and Applications provides readers with a single resource on why these devices are superior to existing silicon devices. The book lays the groundwork for an understanding of an array of applications and anticipated benefits in energy savings.

Authored by the Founder of the Power Semiconductor Research Center at North Carolina State University (and creator of the IGBT device), Dr. B. Jayant Baliga is one of the highest regarded experts in the field. He thus leads this team who comprehensively review the materials, device physics, design considerations and relevant applications discussed. Comprehensively covers power electronic devices, including materials (both gallium nitride and silicon carbide), physics, design considerations, and the most promising applications Addresses the key challenges towards the realization of wide bandgap power electronic devices, including materials defects, performance and reliability Provides the benefits of wide bandgap semiconductors, including opportunities for cost reduction and social impact

As a wide band-gap semiconductor, with large breakdown fields and saturation velocities, Gallium Nitride (GaN) has been increasingly used in high-power, high-frequency electronics and monolithic microwave integrated circuits (MMICs). At the same time, GaN also has excellent electromechanical properties, such as high acoustic velocities and low elastic losses. Together *with a strong piezoelectric coupling, these qualities make GaN ideal for RF MEMS resonators. Hence, GaN technology offers a platform for the seamless integration of low-loss, piezoelectric RF MEMS resonators with high power, high frequency electronics. Monolithic integration of MEMS resonators with ICs would lead to reduced parasitics and matching constraints, enabling high-purity clocks and frequency-selective filters for signal processing and high-frequency wireless communications. This thesis highlights the physics and resonator design considerations that must be taken into account in a monolithically integrated solution. We then show devices that achieve the highest frequency-quality factor product in GaN resonators to date (1.56 x 1013). We also highlight several unique transduction mechanisms enabled by this technology, such as the ability to use the 2D electron gas (2DEG) channel of High Electron Mobility Transistors (HEMTs) as an electrode for transduction. This enables a unique out-of-line switching capability which allowed us to demonstrate the first DC switchable solid-state piezoelectric resonator. Finally, we discuss the benefits of using active HEMT sensing of the* *mechanical signal when scaling to GHz frequencies, which enabled the highest frequency lithographically defined resonance reported to date in GaN (3.5 GHz). These demonstrated features sh*

Physics and Application

GaN-based Materials and Devices

Metallic Spintronic Devices

Gallium Nitride Materials and Devices

Handbook for III-V High Electron Mobility Transistor Technologies

23-25 January 2006, San Jose, California, USA

GaN Power Devices and Applications, provides an update on gallium nitride (GaN) technology and applications by leading experts. It includes detailed descriptions of the latest examples of GaN's usage in power supplies, lidar systems, motor drives, and space applications.

This book brings together recent research by scientists and device engineers working on both aggressively-scaled conventional transistors as well as unconventional high-frequency device concepts in the III-N material system. Device concepts for mm-wave to THz operation based on deeply-scaled HEMTs, as well as distributed device designs based on plasma-wave propagation in polarization-induced 2DEG channels, tunneling, and hot-carrier injection are discussed in detail. In addition, advances in the underlying materials science that enable these demonstrations, and advancements in metrology that permit the accurate characterization and evaluation of these emerging device concepts are also included. Targeting readers looking to push the envelope in GaN-based electronics device research, this book provides a current, comprehensive treatment of device concepts and physical phenomenology suitable for applying GaN and related materials to emerging ultra-high-frequency applications. Offers readers an integrated treatment of the state of the art in both conventional (i.e., HEMT) scaling as well as unconventional device architectures suitable for amplification and signal generation in the mm-wave and THz regime using GaN-based devices, written by authors that are active and widely-known experts in the field; Discusses both conventional scaled HEMTs (into the deep mm-wave) as well as unconventional approaches to address the mm-wave and THz regimes; Provides “vertically integrated” coverage, including materials science that enables these recent advances, as well as device physics & design, and metrology techniques; Includes fundamental physics, as well as numerical simulations and experimental realizations.

Since its inception in 1966, the series of numbered volumes known as Semiconductors and Semimetals has distinguished itself through the careful selection of well-known authors, editors, and contributors. The "Willardson and Beer" Series, as it is widely known, has succeeded in publishing numerous landmark volumes and chapters. Not only did many of these volumes make an impact at the time of their publication, but they continue to be well-cited years after their original release. Recently, Professor Eicke R. Weber of the University of California at Berkeley joined as a co-editor of the series. Professor Weber, a well-known expert in the field of semiconductor materials, will further contribute to continuing the series' tradition of publishing timely, highly relevant, and long-impacting volumes. Some of the recent volumes, such as Hydrogen in Semiconductors, Imperfections in III/V Materials, Epitaxial Microstructures, High-Speed Heterostructure Devices, Oxygen in Silicon, and others promise indeed that this tradition will be maintained and even expanded. Reflecting the truly interdisciplinary nature of the field that the series covers, the volumes in Semiconductors and Semimetals have been and will continue to be of great interest to physicists, chemists, materials scientists, and device engineers in modern industry.

Metallic Spintronic Devices provides a balanced view of the present state of the art of metallic spintronic devices, addressing both mainstream and emerging applications from magnetic tunneling junction sensors and spin torque oscillators to spin torque memory and logic. Featuring contributions from well-known and respected industrial and academic experts, this cutting-edge work not only presents the latest research and developments but also: Describes spintronic applications in current and future magnetic recording devices Discusses spin-transfer torque magnetoresistive random-access memory (STT-MRAM) device architectures and modeling Explores prospects of STT-MRAM scaling, such as detailed multilevel cell structure analysis Investigates spintronic device write and read optimization in light of spintronic memristive effects Considers spintronic research directions based on yttrium iron garnet thin films, including spin pumping, magnetic proximity, spin hall, and spin Seebeck effects Proposes unique solutions for low-power spintronic device applications where memory is closely integrated with logic Metallic Spintronic Devices aims to equip anyone who is serious about metallic spintronic devices with up-to-date design, modeling, and processing knowledge. It can be used either by an expert in the field or a graduate student in course curriculum.

Gallium Nitride Power Devices

High-Frequency GaN Electronic Devices

Physics of Semiconductor Devices

Physics, Technology, and Device Concepts

Power Electronics and Optoelectronic Devices

Principles and Simulation

Group III-Nitrides semiconductor materials, including GaN, InN, AlN, InGaN, AlGaN and AlInGaN, i.e. (Al, In, Ga)N, are excellent semiconductors, covering the spectral range from deep ultraviolet (DUV) to UV, visible and infrared, with unique properties very suitable for modern electronic and optoelectronic applications. Remarkable *breakthroughs have been achieved in recent years for research and development (R&D) in these materials and devices, such as high-power and high brightness UV-blue-green-white light emitting diodes (LEDs), UV-blue-green laser diodes (LDs), photo-detectors and various optoelectronics and electronics devices and applications. The Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura "for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources". Red and green diodes had been invented since 1960s-70s but without blue LED. Despite considerable efforts, the blue LED had remained a challenge for a long time. The success and inventions on GaN-based LEDs were revolutionary and benefiting for mankind. III-Nitrides-based industry has formed and acquired rapid developments over the world. Incandescent light bulbs lit the 20th century and the 21st century will be lit by LED lamps. Before this book, the editor has edited two books, III-Nitride Semiconductor Materials (2006) and III-Nitride Devices and Nanoengineering (2008), both published by ICP/WSP, in the fields of III-Nitride. The developments of these materials and devices are moving rapidly. Many data or knowledge, some even just published only recently, have been modified and needed to be upgraded. This new book, III-Nitride Materials, Devices and Nano-Structures as the third instalment, will cover the rapid new developments and achievements in the III-Nitride fields, particularly those made since 2009. Contents:General:Comprehensive Theoretical* *and Experimental Studies on III-Nitrides, Doping, Nano-Structures and LEDs (Jinmin Li, Zhiqiang Liu, Xiaoyan Yi and Junxi Wang)Waste Energy Harvesting Using III-Nitride Materials (E Ghafari, E Witkoske, Y Liu, C Zhang, X Jiang, A Bukowski, B Kucukgok, M Lundstrom; I T Ferguson and N Lu)III-Nitride Nanostructures for Intersubband Optoelectronics (C B Lim, A Ajay, J Lähnemann, D A Browne and E Monroy)GaN-Based Photodetectors (Ke Jiang, Xiaojuan Sun, Hang Song and Dabing Li)III-Nitride Materials:Single Crystal AlN: Growth by Modified Physical Vapor Transport and Properties (Honglei Wu and Ruisheng Zheng)Towards Understanding and Control of Nanoscale Phase Segregation in Indium-Gallium-Nitride Alloys (Yohannes Abate, Viktoriia E Babicheva, Vladislav S Yakovlev and Nikolaus Dietz)Investigating Structural and Optical Characteritics of III-Nitride Semiconductor Materials (Yi Liang, Xiaodong Jiang, Devki N Talwar, Liangyu Wan, Gu Xu and Zhe Chuan Feng)III-Nitride Devices and Nano-Structures:III-Nitride Nano-Structures and Improving the Luminescence Efficiency for Quantum Well LEDs (Peng Chen)Fabrication and Characterization of Green Resonant-Cavity Light-Emitting Diodes Prepared by Wafer Transfer Technologies (Shih-Yung Huang and Ray-Hua Horng)Nanotexturing Effects in GaN/InGaN Multi-Quantum-Wells LED Planar Structures (S J Xu)Group III-Nitride Nanostructures for Light-Emitting Devices and Beyond (Je-Hyung Kim, Young-Ho Ko and Yong-Hoon Cho) Readership: Scientists; material growers and evaluators; device design, processing engineers; postgraduate and graduate students in electrical &*

electronic engineering and materials engineering.
An up-to-date, practical guide on upgrading from silicon to GaN, and how to use GaN transistors in power conversion systems design This updated, third edition of a popular book on GaN transistors for efficient power conversion has been substantially expanded to keep students and practicing power conversion engineers ahead of the learning curve in GaN technology advancements. Acknowledging that GaN transistors are not one-to-one replacements for the current MOSFET technology, this book serves as a practical guide for understanding basic GaN transistor construction, characteristics, and applications. Included are discussions on the fundamental physics of these power semiconductors, layout, and other circuit design considerations, as well as specific application examples demonstrating design techniques when employing GaN devices. GaN Transistors for Efficient Power Conversion, 3rd Edition brings key updates to the chapters of Driving GaN Transistors; Modeling, Simulation, and Measurement of GaN Transistors; DC-DC Power Conversion; Envelope Tracking; and Highly Resonant Wireless Energy Transfer. It also offers new chapters on Thermal Management, Multilevel Converters, and Lidar, and revises many others throughout. Written by leaders in the power semiconductor field and industry pioneers in GaN power transistor technology and applications Updated with 35% new material, including three new chapters on Thermal Management, Multilevel Converters, Wireless Power, and Lidar Features practical

guidance on formulating specific circuit designs when constructing power conversion systems using GaN transistors A valuable resource for professional engineers, systems designers, and electrical engineering students who need to fully understand the state-of-the-art GaN Transistors for Efficient Power Conversion, 3rd Edition is an essential learning tool and reference guide that enables power conversion engineers to design energy-efficient, smaller, and more cost-effective products using GaN transistors.

Power devices are key to modern power systems, performing functions such as inverting and changing voltages, buffering and switching. Following a device-centric approach, this book covers power electronic applications, semiconductor physics, materials science, application engineering, and key technologies such as MOSFET, IGBT and WBG.

Gallium nitride (GaN) is an emerging technology that promises to displace silicon MOSFETs in the next generation of power transistors. As silicon approaches its performance limits, GaN devices offer superior conductivity and switching characteristics, allowing designers to greatly reduce system power losses, size, weight, and cost. This timely second edition has been substantially expanded to keep students and practicing power conversion engineers ahead of the learning curve in GaN technology advancements. Acknowledging that GaN transistors are not one-to-one replacements for the current MOSFET technology, this book serves as a practical *guide for understanding basic GaN transistor construction, characteristics, and applications. Included are discussions on the fundamental physics of these power semiconductors, layout and other circuit design considerations, as well as specific application examples demonstrating design techniques when employing GaN devices. With higher-frequency switching capabilities, GaN devices offer the chance to increase efficiency in existing applications such as DC–DC conversion, while opening possibilities for new applications including wireless power transfer and envelope tracking. This book is an essential learning tool and reference guide to enable power conversion engineers to design energy-efficient, smaller and more cost-effective products using GaN transistors. Key features: Written by leaders in the power semiconductor field and industry pioneers in GaN power transistor technology and applications. Contains useful discussions on device–circuit interactions, which are highly valuable since the new and high performance GaN power transistors require thoughtfully designed drive/control circuits in order to fully achieve their performance potential. Features practical guidance on formulating specific circuit designs when constructing power conversion systems using GaN transistors – see companion website for further details. A valuable learning resource for professional engineers and systems designers needing to fully understand new devices as well as electrical engineering students.*

Nitride Semiconductor Devices

Entrepreneurship in Power Semiconductor Devices, Power Electronics, and Electric Machines and Drive Systems

Growth, Fabrication, Characterization and Performance
Linking Device Physics to High Voltage and High Frequency Circuit Design
Gallium Nitride Processing for Electronics, Sensors and Spintronics
Recent advances in the development of gallium nitride (GaN) high electron mobility transistor (HEMT) have shown promising results in the application of high frequency power conversion techniques. GaN transistors are emerging as a credible alternative to silicon (Si) devices in multiple power conversion applications. This is mainly because the characteristics of GaN offer higher electron mobility, electron velocity, and higher breakdown voltage compared to (Si) devices. In spite of the promising attributes offered by GaN devices, significant technological readiness level challenges remain, in order for the technology to be adopted pervasively into the market. These challenges relate to the reliability of the material both at the device-physics level, and at the circuit-implementation level. This thesis presents detailed studies on some of the circuit-level reliability phenomena affecting GaN technology. These studies will offer a better understanding of the limitations associated with GaN so that the technology's beneficial aspects can be leveraged. The first reliability investigation performed was related to a

comparison of two 600 V GaN HEMTs based on the same die, however packaged in two different configurations. In order to characterize the performance of the GaN HEMT, a realistic behavioral simulation model was developed in this thesis. The model takes into consideration both the static and dynamic characteristics of the HEMT including drain current variations with respect to gate voltage and drain voltage, ON resistance, intrinsic capacitances, and reverse recovery current and charge. The model was also integrated with values for the per-terminal parasitic package inductances. These values were obtained through empirical measurement. The modeled transistor was then simulated in a converter to analyze the overall performance of the system. Experimental results verified the results obtained by the model. This study thus presents a framework to project and assess the effect of each parasitic inductance on the performance of next generation GaN devices. In the second reliability study, the effect of gate-stress on the performance of normally-off GaN HEMT devices in a boost converter was investigated. The converter's efficiency, output voltage stability, and gate current were evaluated in order to scrutinize the failure mechanisms of pGaN gated lateral GaN devices under high gate stress. It was observed that the transient overshoot of the gate voltage during turn-on becomes switching frequency-dependent once the device has suffered sufficient degradation, leading to a marked decline in converter performance. This observation has not been reported in the previous literature. This improved understanding may allow *mitigation of degradation mechanisms in GaN at the fabrication, packaging, and circuit implementation level. The results of this thesis are beneficial in two ways. First it offers insights into the safe and reliable implementation of GaN devices at the circuits-level, thus obviating the need to trade device performance for device safety. Secondly, the gate-stressing investigation unveils degradation characteristics that are of critical importance to the design and fabrication of next generation GaN devices.*

Gallium Nitride (GaN) based high electron mobility transistors (HEMTs) outperform Gallium Arsenide (GaAs) and silicon based transistors for radio frequency (RF) applications in terms of output power and efficiency due to its large bandgap (~3.4 eV@300 K) and high carrier mobility property (1500 - 2300 cm^2/(V-s)). These advantages have made GaN technology a promising candidate for future high-power microwave and potential millimeter-wave applications. Current GaN HEMT models used by the industry, such as Angelov Model, EEHEMT Model and DynaFET (Dynamic FET) model, are empirical or semi-empirical. Lacking the physical description of the device operations, these empirical models are not directly scalable. Circuit design that uses the models requires multiple iterations between the device and circuit levels, becoming a lengthy and expensive process. Conversely existing physics based models, such as surface potential model, are computationally intensive and thus impractical for full scale circuit simulation and optimization. To enable efficient GaN-based RF circuit

design, computationally efficient physics based compact models are required. In this thesis, a physics based Virtual Source (VS) compact model is developed for GaN HEMTs targeting RF applications. While the intrinsic current and charge model are developed based on the Virtual Source model originally proposed by MIT researchers, the gate current model and parasitic element network are proposed based on our applications with a new efficient parameter extraction flow. Both direct current (DC) of drain and gate currents and RF measurements are conducted for model parameter extractions. The new flow first extracts device parasitic resistive values based on the DC measurement of gate current. Then parameters related with the intrinsic region are determined based on the transport characteristics in the subthreshold and above threshold regimes. Finally, the parasitic resistance, capacitance and inductance values are optimized based on the S-parameter measurement. This new extraction flow provides reliable and accurate extraction for parasitic element values while achieving reasonable resolutions holistically with both DC and RF characteristics. The model is validated against measurement data in terms of drain current, gate current and scattering parameter (S-parameter). This model provides simple yet clear physical description for GaN HEMTs with only a short list of model parameters compared with other empirical or physics based models. It can be easily integrated in circuit simulators for RF circuit design.

During the last 30 years, significant progress has been made to improve our understanding of gallium nitride and silicon carbide device structures, resulting in experimental demonstration of their enhanced performances for power electronic systems. Gallium nitride power devices made by the growth of the material on silicon substrates have gained a lot of interest. Power device products made from these materials have become available during the last five years from many companies. This comprehensive book discusses the physics of operation and design of gallium nitride and silicon carbide power devices. It can be used as a reference by practicing engineers in the power electronics industry and as a textbook for a power device or power electronics course in universities. Request Inspection Copy

Efficient power conversion is essential to face the continuously increasing energy consumption of our society. GaN based vertical power field effect transistors provide excellent performance figures for power-conversion switches, due to their capability of handling high voltages and current densities with very low area consumption. This work focuses on a vertical trench gate metal oxide semiconductor field effect transistor (MOSFET) with conceptional advantages in a device fabrication preceded GaN epitaxy and enhancement mode characteristics. The functional layer stack comprises from the bottom an n+/n--drift/p-body/n+-source GaN layer sequence. Special attention is paid to the Mg doping of the p-GaN body layer, which is a complex topic by itself. Hydrogen

passivation of magnesium plays an essential role, since only the active (hydrogen-free) Mg concentration determines the threshold voltage of the MOSFET and the blocking capability of the body diode. Fabrication specific challenges of the concept are related to the complex integration, formation of ohmic contacts to the functional layers, the specific implementation and processing scheme of the gate trench module and the lateral edge termination. The maximum electric field, which was achieved in the pn-junction of the body diode of the MOSFET is estimated to be around 2.1 MV/cm. From double-sweep transfer measurements with relatively small hysteresis, steep subthreshold slope and a threshold voltage of 3 - 4 V a reasonably good Al2O3/GaN interface quality is indicated. In the conductive state a channel mobility of around 80 - 100 cm2/Vs is estimated. This value is comparable to device with additional overgrowth of the channel. Further enhancement of the OFF-state and ON-state characteristics is expected for optimization of the device termination and the high-k/GaN interface of the vertical trench gate, respectively. From the obtained results and dependencies key figures of an area efficient and competitive device design with thick drift layer is extrapolated. Finally, an outlook is given and advancement possibilities as well as technological limits are discussed.

Materials, Applications and Reliability

Gallium Nitride-based HEMTs for Microwave Power and Noise

GaN Microelectromechanical System Resonators
Physics, Applications, and Reliability
GaN Power Devices and Applications
GaN and ZnO-based Materials and Devices

Addresses a Growing Need for High-Power and High-Frequency Transistors Gallium Nitride (GaN): Physics, Devices, and Technology offers a balanced perspective on the state of the art in gallium nitride technology. A semiconductor commonly used in bright light-emitting diodes, GaN can serve as a great alternative to existing devices used in microelectronics. It has a wide band gap and high electron mobility that gives it special properties for applications in optoelectronic, high-power, and high-frequency devices, and because of its high off-state breakdown strength combined with excellent on-state channel conductivity, GaN is an ideal candidate for switching power transistors. Explores Recent Progress in High-Frequency GaN Technology Written by a panel of academic and industry experts from around the globe, this book reviews the advantages of GaN-based material systems suitable for high-frequency, high-power applications. It provides an overview of the semiconductor environment, outlines the fundamental device physics of GaN, and describes GaN materials and device structures that are needed for the next stage of microelectronics and optoelectronics. The book details the development of radio frequency (RF) semiconductor devices and circuits, considers the current challenges that the industry now faces, and examines future trends. In addition, the authors: Propose a design in which multiple LED stacks can be

connected in a series using interband tunnel junction (TJ) interconnects Examine GaN technology while in its early stages of high-volume deployment in commercial and military products Consider the potential use of both sunlight and hydrogen as promising and prominent energy sources for this technology Introduce two unique methods, PEC oxidation and vapor cooling condensation methods, for the deposition of high-quality oxide layers A single-source reference for students and professionals, Gallium Nitride (GaN): Physics, Devices, and Technology provides an overall assessment of the semiconductor environment, discusses the potential use of GaN-based technology for RF semiconductor devices, and highlights the current and emerging applications of GaN.

With the dawn of Gallium Oxide (Ga2O?) and Aluminum Gallium Nitride (AlGaN) electronics and the commercialization of Gallium Nitride (GaN) and Silicon Carbide (SiC) based devices, the field of wide bandgap materials and electronics has never been more vibrant and exciting than it is now. Wide bandgap semiconductors have had a strong presence in the research and development arena for many years. Recently, the increasing demand for high efficiency power electronics and high speed communication electronics, together with the maturity of the synthesis and fabrication of wide bandgap semicon-ductors, has catapulted wide bandgap electronics and optoelectronics into the mainstream.Wide bandgap semiconductors exhibit excellent material properties, which can potentially enable power device operation at higher efficiency, higher temperatures, voltages, and higher switching speeds than current Si technology. This edited volume will serve as a useful reference for researchers in this

field — newcomers and experienced alike.This book discusses a broad range of topics including fundamental transport studies, growth of high-quality films, advanced materials characterization, device modeling, high frequency, high voltage electronic devices and optical devices written by the experts in their respective fields. They also span the whole spectrum of wide bandgap materials including AlGaN, Ga2O?and diamond.

This book is based on nearly a decade of materials and electronics research at the leading research institution on the nitride topic in Europe. It is a comprehensive monograph and tutorial that will be of interest to graduate students of electrical engineering, communication engineering, and physics; to materials, device, and circuit engineers in research and industry; to all scientists with a general interest in advanced electronics.

The AlInGaN and ZnO materials systems have proven to be one of the scientifically and technologically important areas of development over the past 15 years, with applications in UV/visible optoelectronics and in high-power/high-frequency microwave devices. The pace of advances in these areas has been remarkable and the wide band gap community relies on books like the one we are proposing to provide a review and summary of recent progress.

Nitride Semiconductor Technology

Modeling Gallium-nitride Based High Electron Mobility Transistors

Gallium Nitride-enabled High Frequency and High Efficiency Power Conversion

Technology of Gallium Nitride Crystal Growth

GaN Transistors for Efficient Power Conversion
Wide Bandgap Semiconductor Power Devices

This book discusses the important technological aspects of the growth of GaN single crystals by HVPE, MOCVD, ammonothermal and flux methods for the purpose of free-standing GaN wafer production.

Gallium-Nitride-based high electron mobility transistor (HEMTs) technology is increasingly finding space in high voltage (HV) and high frequency (HF) circuit application domains. The superior breakdown electric field, high electron mobility, and high temperature performance of GaN HEMTs are the key factors for its use as HV switches in converters and active components of RF-power amplifiers. Designing circuits in both application regimes requires accurate compact device models that are grounded in physics and can describe the non-linear terminal characteristics. Currently available compact models for HEMTs are empirical and hence are lacking in physical description of the device, which becomes a handicap in understanding key device-circuit interactions and in accurate estimation of device behavior in circuits. This thesis seeks to develop a physics-based compact model for GaN HEMTs from first principles which can be used as a design tool for technology optimization to identify device-performance bottlenecks on one hand and as a tool for circuit design to investigate the impact of behavioral nuances of the device on circuit performance, on the other. Part of this thesis consists of demonstrations of the capabilities of the model to accurately predict device characteristics such as terminal DC- and pulsed-currents, charges, small-signal S-parameters, large-signal switching characteristics, load-pull, source-pull and power-sweep, inter-modulation-distortion and noise-figure of both HV- and RF-devices. The thesis also aims to tie device-physics concepts of carrier transport and charge distribution in GaN HEMTs to circuit-design through circuit-level evaluation. In the HV-application regime benchmarking is conducted against switching characteristics of a GaN DC-DC converter to understand the impact of device capacitances, field plates, temperature and charge-trapping on switching slew rates. In the RF-application regime validation is done against the large-signal characteristics of GaN-power amplifiers to study the output-power, efficiency and compression characteristics as function of class-of-operation. Noise-figure of low-noise amplifiers is tested to estimate the contributions of device-level noise sources, and validation against switching frequency and phase-noise characteristics of voltage-controlled oscillators is done to evaluate the noise performance of GaN HEMT technology. Evaluation of model-accuracy in determining the conversion-efficiency of RF-converters and linearity metrics of saturated non-linear amplifiers is carried out.

The key contribution of this work is to provide a tool in the form of a physics-based compact model to device-technology-engineers and circuit-designers, who can use it to evaluate the potential strengths and weaknesses of the emerging GaN technology.

The unique materials properties of GaN-based semiconductors have stimulated a great deal of interest in research and development regarding nitride materials growth and optoelectronic and nitride-based electronic devices. High electron mobility and saturation velocity, high sheet carrier concentration at heterojunction interfaces, high breakdown field, and low thermal impedance of GaN-based films grown over SiC or bulk AlN substrates make nitride-based electronic devices very promising. The chemical inertness of nitrides is another key property.This volume, written by experts on different aspects of nitride technology, addresses the entire spectrum of issues related to nitride materials and devices, and it will be useful for technologists, scientists, engineers, and graduate students who are working on wide bandgap materials and devices. The book can also be used as a supplementary text for graduate courses on wide bandgap semiconductor technology.

GaN is considered the most promising material candidate in next-generation power device applications, owing to its unique material properties, for example, bandgap, high breakdown field, and high electron mobility. Therefore, GaN power device technologies are listed as the top priority to be developed in many countries, including the United States, the European Union, Japan, and China. This book presents a comprehensive overview of GaN power device technologies, for example, material growth, property analysis, device structure design, fabrication process, reliability, failure analysis, and packaging. It provides useful information to both students and researchers in academic and related industries working on GaN power devices. GaN wafer growth technology is from Enkris Semiconductor, currently one of the leading players in commercial GaN wafers. Chapters 3 and 7, on the GaN transistor fabrication process and GaN vertical power devices, are edited by Dr. Zhihong Liu, who has been working on GaN devices for more than ten years. Chapters 2 and 5, on the characteristics of polarization effects and the original demonstration of AlGaN/GaN heterojunction field-effect transistors, are written by researchers from Southwest Jiaotong University. Chapters 6, 8, and 9, on surface passivation, reliability, and package technologies, are edited by a group of researchers from the Southern University of Science and Technology of China.

Thermal Management of Gallium Nitride Electronics

17th International Workshop on the Physics of Semiconductor Devices 2013

Sources, Detectors, Advanced Materials, and Light-matter Interactions
Effects of Gate Stress and Parasitic Package Inductance on the Reliability of GaN HEMTs
Vertical GaN and SiC Power Devices
III-Nitride Semiconductors and Their Modern Devices

This is the first book to be published on physical principles, mathematical models, and practical simulation of GaN-based devices. Gallium nitride and its related compounds enable the fabrication of highly efficient light-emitting diodes and lasers for a broad spectrum of wavelengths, ranging from red through yellow and green to blue and ultraviolet. Since the breakthrough demonstration of blue laser diodes by Shuji Nakamura in 1995, this field has experienced tremendous growth worldwide. Various applications can be seen in our everyday life, from green traffic lights to full-color outdoor displays to high-definition DVD players. In recent years, nitride device modeling and simulation has gained importance and advanced software tools are emerging. Similar developments occurred in the past with other semiconductors such as silicon, where computer simulation is now an integral part of device development and fabrication. This book presents a review of modern device concepts and models, written by leading researchers in the field. It is intended for scientists and device engineers who are interested in employing computer simulation for nitride device design and analysis.

This book highlights recent advances and applications in terahertz (THz) technology, addressing advanced topics such as THz biomedical imaging, pattern recognition and tomographic reconstruction for THz biomedical imaging by machine learning and artificial intelligence, THz imaging radars for autonomous vehicle applications, and THz imaging systems for security and surveillance. It also discusses theoretical, experimental, established and validated empirical work on these topics.

This unique new resource provides a comparative introduction to vertical Gallium Nitride (GaN) and Silicon Carbide (SiC) power devices using real commercial device data, computer, and physical models. This book uses commercial examples from recent years and presents the design features of various GaN and SiC power components and devices. Vertical verses lateral power semiconductor devices are explored, including those based on wide bandgap materials. The

abstract concepts of solid state physics as they relate to solid state devices are explained with particular emphasis on power solid state devices. Details about the effects of photon recycling are presented, including an explanation of the phenomenon of the family tree of photon-recycling. This book offers in-depth coverage of bulk crystal growth of GaN, including hydride vapor-phase epitaxial (HVPE) growth, high-pressure nitrogen solution growth, sodium-flux growth, ammonothermal growth, and sublimation growth of SiC. The fabrication process, including ion implantation, diffusion, oxidation, metallization, and passivation is explained. The book provides details about metal-semiconductor contact, unipolar power diodes, and metal-insulator-semiconductor (MIS) capacitors. Bipolar power diodes, power switching devices, and edge terminations are also covered in this resource.
Proceedings of SPIE present the original research papers presented at SPIE conferences and other high-quality conferences in the broad-ranging fields of optics and photonics. These books provide prompt access to the latest innovations in research and technology in their respective fields. Proceedings of SPIE are among the most cited references in patent literature.

Materials, Physics, Design, and Applications
Compound Semiconductors
Gallium Nitride and Silicon Carbide Power Devices
Gallium Nitride Electronics
Gallium Nitride (GaN)
Wide Bandgap Semiconductor Electronics And Devices

Entrepreneurship in Power Semiconductor Devices, Power Electronics, and Electric Machines and Drive Systems introduces the basics of entrepreneurship and a methodology for the study of entrepreneurship in electrical engineering and other engineering fields. Entrepreneurship is considered here in three fields of electrical engineering, viz. power semiconductor devices, power electronics and electric machines and drive systems, and their current practice. It prepares the reader by providing a review of the subject matter in the three fields, their current status in research and development with analysis aspect as needed, thus allowing readers to gain self-sufficiency while reading the book. Each field's emerging applications, current market and future market forecasts are introduced to understand the basis and need for emerging startups. Practical learning is introduced in: (i) power semiconductor devices entrepreneurship through the prism of 20 startups in detail, (ii) power electronics entrepreneurship through 28 startup companies arranged under various application fields and (iii)

electric machines and drive systems entrepreneurship through 15 startups in electromagnetic and 1 in electrostatic machines and drive systems. The book: (i) demystifies entrepreneurship in a practical way to equip engineers and students with entrepreneurship as an option for their professional growth, pursuit and success; (ii) provides engineering managers and corporate-level executives a detailed view of entrepreneurship activities in the considered three fields that may potentially impact their businesses, (iii) provides entrepreneurship education in an electrical engineering environment and with direct connection and correlation to their fields of study and (iv) endows a methodology that can be effectively employed not only in the three illustrated fields of electrical engineering but in other fields as well. This book is for electrical engineering students and professionals. For use in undergraduate and graduate courses in electrical engineering, the book contains discussion questions, exercise problems, team and class projects, all from a practical point of view, to train students and assist professionals for future entrepreneurship endeavors.

This book focusses on III-V high electron mobility transistors (HEMTs) including basic physics, material used, fabrications details, modeling, simulation, and other important aspects. It initiates by describing principle of operation, material systems and material technologies followed by description of the structure, I-V characteristics, modeling of DC and RF parameters of AlGaN/GaN HEMTs. The

book also provides information about source/drain engineering, gate engineering and channel engineering techniques used to improve the DC-RF and breakdown performance of HEMTs. Finally, the book also highlights the importance of metal oxide semiconductor high electron mobility transistors (MOS-HEMT). Key Features Combines III-As/P/N HEMTs with reliability and current status in single volume Includes AC/DC modelling and (sub)millimeter wave devices with reliability analysis Covers all theoretical and experimental aspects of HEMTs Discusses AlGaN/GaN transistors Presents DC, RF and breakdown characteristics of HEMTs on various material systems using graphs and plots
The book "Nitride Semiconductor Technology" provides an overview of nitride semiconductors and their uses in optoelectronics and power electronics devices. It explains the physical properties of those materials as well as their growth methods. Their applications in high electron mobility transistors, vertical power devices, LEDs, laser diodes, and vertical-cavity surface-emitting lasers are discussed in detail. The book further examines reliability issues in these materials and puts forward perspectives of integrating them with 2D materials for novel high-frequency and high-power devices. In summary, it covers nitride semiconductor technology from materials to devices and provides the basis for further research.

The purpose of this workshop is to spread the vast amount of information *available on semiconductor physics to every possible field throughout the scientific community. As a result, the latest findings, research and discoveries can be quickly disseminated. This workshop provides all participating research groups with an excellent platform for interaction and collaboration with other members of their respective scientific community. This workshop's technical sessions include various current and significant topics for applications and scientific developments, including • Optoelectronics • VLSI & ULSI Technology • Photovoltaics • MEMS & Sensors • Device Modeling and Simulation • High Frequency/ Power Devices • Nanotechnology and Emerging Areas • Organic Electronics • Displays and Lighting Many eminent scientists from various national and international organizations are actively participating with their latest research works and also equally supporting this mega event by joining the various organizing committees.*

Gallium-Nitride (GaN) II

Iii-nitride Materials, Devices And Nano-structures

Physics, Devices, and Technology

Emerging Trends in Terahertz Solid-State Physics and Devices

Physics Based Virtual Source Compact Model of Gallium-nitride High Electron Mobility Transistors

Power GaN Devices

Semiconductor spintronics is expected to lead to a new generation of transistors, lasers and integrated magnetic sensors that can be used to create ultra-low power, high speed memory, logic and photonic devices. Useful spintronic devices will need materials with practical magnetic ordering temperatures and current research points to gallium and aluminium nitride magnetic superconductors as having great potential. This book details current research into the properties of III-nitride semiconductors and their usefulness in novel devices such as spin-polarized light emitters, spin field effect transistors, integrated sensors and high temperature electronics. Written by three leading researchers in nitride semiconductors, the book provides an excellent introduction to gallium nitride technology and will be of interest to all reseachers and industrial practitioners wishing to keep up to date with developments that may lead to the next generation of transistors, lasers and integrated magnetic sensors.

Thermal Management of Gallium Nitride Electronics outlines the technical approaches undertaken by leaders in the community, the challenges they have faced, and the resulting advances in the field. This book serves as a one-stop reference for compound semiconductor device researchers tasked with solving this engineering challenge for future material systems based on ultra-wide bandgap semiconductors. A number of perspectives are included, such as the growth methods of nanocrystalline diamond, the materials integration of polycrystalline diamond through wafer bonding, and the new physics of thermal transport across heterogeneous interfaces. Over the past 10 years, the book's authors have performed pioneering experiments in the integration of nanocrystalline diamond capping layers into the fabrication process of compound semiconductor devices. Significant research efforts of integrating diamond and GaN have been reported by a number of groups since then, thus resulting in active thermal management options that do not necessarily lead to performance derating to avoid self-heating during radio frequency or power switching operation of these devices. Self-heating refers to the increased channel temperature caused by increased energy transfer from electrons to the lattice at high power. This book chronicles those breakthroughs. Includes the fundamentals of thermal management of wide-bandgap semiconductors, with historical context, a review of common heating issues, thermal transport physics, and characterization methods Reviews the latest strategies to overcome heating issues through materials modeling, growth and device design strategies Touches on emerging, real-world applications for thermal management strategies in power electronics

This book addresses material growth, device fabrication, device application, and commercialization of energy-efficient white light-emitting diodes (LEDs), laser diodes, and power electronics devices. It begins with an overview on basics of semiconductor materials, physics, growth and characterization techniques, followed by detailed discussion of advantages, drawbacks, design issues, processing, applications, and key challenges for state of the art GaN-based devices. It includes state of the art material synthesis techniques with an overview on growth technologies for emerging bulk or free standing GaN and AlN substrates and their applications in electronics, detection, sensing, optoelectronics and photonics. Wengang (Wayne) Bi is Distinguished Chair Professor and Associate Dean in the College of Information and Electrical Engineering at Hebei University of Technology in Tianjin, China. Hao-chung (Henry) Kuo is Distinguished Professor and Associate Director of the Photonics Center at National Chiao-Tung University, Hsin-Tsu, Taiwan, China. Pei-Cheng Ku is an associate professor in the Department of Electrical Engineering & Computer Science at the University of

Michigan, Ann Arbor, USA. Bo Shen is the Cheung Kong Professor at Peking University in China.

All recent developments of nitrides and of their technology are gathered here in a single book, with chapters written by world leaders in the field.

Vertical Gallium Nitride PowerDevices: Fabrication and Characterisation

Nitride Semiconductors and Devices

Modern Power Electronic Devices

Handbook of GaN Semiconductor Materials and Devices

This timely monograph addresses an important class of semiconductors and devices that constitute the underlying technology for blue lasers. It succinctly treats structural, electrical and optical properties of nitrides and the substrates on which they are deposited, band structures of nitrides, optical processes, deposition and fabrication technologies, light-emitting diodes, and lasers. It also includes many tables and figures detailing the properties and performance of nitride semiconductors and devices.

Gallium Nitride (GaN)Physics, Devices, and TechnologyCRC Press

This book presents the first comprehensive overview of the properties and fabrication methods of GaN-based power transistors, with contributions from the most active research groups in the field. It describes how gallium nitride has emerged as an excellent material for the fabrication of power transistors; thanks to the high energy gap, high breakdown field, and saturation velocity of GaN, these devices can reach breakdown voltages beyond the kV range, and very high switching frequencies, thus being suitable for application in power conversion systems. Based on GaN, switching-mode power converters with efficiency in excess of 99 % have been already demonstrated, thus clearing the way for massive adoption of GaN transistors in the power conversion market. This is expected to have important advantages at both the environmental and economic level, since power conversion losses account for 10 % of global electricity consumption. The first part of the book describes the properties and advantages of gallium nitride compared to conventional semiconductor materials. The second part of the book describes the techniques used for device fabrication, and the methods for GaN-on-Silicon mass production. Specific attention is paid to the three most advanced device structures: lateral transistors, vertical power devices, and nanowire-based HEMTs. Other relevant topics covered by the book are the strategies for normally-off operation, and the problems related to device reliability. The last chapter reviews the switching characteristics of GaN HEMTs based on a systems level approach. This book is a unique reference for people working in the materials, device and power electronics fields; it provides interdisciplinary information on material growth, device fabrication, reliability issues and circuit-level switching investigation.