

Semiconductor Optoelectronic Devices Bhattacharya

The most up-to-date book available on the physics of photonic devices. This new edition of *Physics of Photonic Devices* incorporates significant advancements in the field of photonics that have occurred since publication of the first edition (*Physics of Optoelectronic Devices*). New topics covered include a brief history of the invention of semiconductor lasers, the Lorentz dipole method and metal plasmas, matrix optics, surface plasma waveguides, optical ring resonators, integrated electroabsorption modulator-lasers, and solar cells. It also introduces exciting new fields of research such as: surface plasmonics and micro-ring resonators; the theory of optical gain and absorption in quantum dots and quantum wires and their applications in semiconductor lasers; and novel microcavity and photonic crystal lasers, quantum-cascade lasers, and GaN blue-green lasers within the context of advanced semiconductor lasers. *Physics of Photonic Devices, Second Edition* presents novel information that is not yet available in book form elsewhere. Many problem sets have been updated, the answers to which are available in an all-new *Solutions Manual* for instructors. Comprehensive, timely, and practical, *Physics of Photonic Devices* is an invaluable textbook for advanced undergraduate and graduate courses in photonics and an indispensable tool for researchers working in this rapidly growing field.

First published in 1995, *The Engineering Handbook* quickly became the definitive engineering reference. Although it remains a bestseller, the many advances realized in traditional engineering fields along with the emergence and rapid growth of fields such as biomedical engineering, computer engineering, and nanotechnology mean that the time has come to bring this standard-setting reference up to date. New in the Second Edition 19 completely new chapters addressing important topics in bioinstrumentation, control systems, nanotechnology, image and signal processing, electronics, environmental systems, structural systems 131 chapters fully revised and updated Expanded lists of engineering associations and societies *The Engineering Handbook, Second Edition* is designed to enlighten experts in areas outside their own specialties, to refresh the knowledge of mature practitioners, and to educate engineering novices. Whether you work in industry, government, or academia, this is simply the best, most useful engineering reference you can have in your personal, office, or institutional library.

The technological progress is closely related to the developments of various materials and tools made of those materials. Even the different ages have been defined in relation to the materials used. Some of the major attributes of the present-day age (i.e., the electronic materials' age) are such common tools as computers and fiber-optic telecommunication systems, in which semiconductor materials provide vital components for various micro-electronic and optoelectronic devices in applications such as computing, memory storage, and communication.

The field of semiconductors encompasses a variety of disciplines. This book is not intended to provide a comprehensive description of a wide range of semiconductor properties or of a continually increasing number of the semiconductor device applications. Rather, the main purpose of this book is to provide an introductory perspective on the basic principles of semiconductor materials and their applications that are described in a relatively concise format in a single volume. Thus, this book should especially be suitable as an introductory text for a single course on semiconductor materials that may be taken by both undergraduate and graduate engineering students. This book should also be useful, as a concise reference on semiconductor materials, for researchers working in a wide variety of fields in physical and engineering sciences. Aimed primarily at the undergraduate students pursuing courses in semiconductor physics and semiconductor devices, this text emphasizes the physical understanding of the underlying principles of the subject. Since engineers use semiconductor devices as circuit elements, device models commonly used in the circuit simulators, e.g. SPICE, have been discussed in detail. Advanced topics such as lasers, heterojunction bipolar transistors, second order effects in BJTs, and MOSFETs are also covered. With such in-depth coverage and a practical approach, practising engineers and PG students can also use this book as a ready reference.

In two editions spanning more than a decade, The Electrical Engineering Handbook stands as the definitive reference to the multidisciplinary field of electrical engineering. Our knowledge continues to grow, and so does the Handbook. For the third edition, it has expanded into a set of six books carefully focused on a specialized area or field of study. Electronics, Power Electronics, Optoelectronics, Microwaves, Electromagnetics, and Radar represents a concise yet definitive collection of key concepts, models, and equations in these areas, thoughtfully gathered for convenient access. Electronics, Power Electronics, Optoelectronics, Microwaves, Electromagnetics, and Radar delves into the fields of electronics, integrated circuits, power electronics, optoelectronics, electromagnetics, light waves, and radar, supplying all of the basic information required for a deep understanding of each area. It also devotes a section to electrical effects and devices and explores the emerging fields of microlithography and power electronics. Articles include defining terms, references, and sources of further information. Encompassing the work of the world's foremost experts in their respective specialties, Electronics, Power Electronics, Optoelectronics, Microwaves, Electromagnetics, and Radar features the latest developments, the broadest scope of coverage, and new material in emerging areas.

Guided Wave Optics and Photonic Devices introduces readers to a broad cross-section of topics in this area, from the basics of guided wave optics and nonlinear optics to biophotonics. The book is inspired by and expands on lectures delivered by distinguished speakers at a three-week school on guided wave optics and

devices organized at the CSIR-Central Glass and Ceramic Research Institute in Kolkata in 2011. *An Introduction to Guided Wave Optics and Photonic Devices: Principles, Applications, and Future Directions* The book discusses the concept of modes in a guided medium from first principles, emphasizing the importance of dispersion properties in optical fibers. It describes fabrication and characterization techniques of rare-earth-doped optical fibers for amplifiers and lasers, with an eye to future applications. Avoiding complex mathematical formalism, it also presents the basic theory and operational principles of fiber amplifiers and lasers. The book examines techniques for writing fiber Bragg gratings, which are of particular interest for smart sensing applications. A chapter focuses on the fundamental principles of Fourier optics and its implementation in guided wave optics. In addition, the book explains the critical phenomena of soliton dynamics and supercontinuum generation in photonic crystal fiber, including its fabrication process and characteristics. It also looks at plasmonics in guided media and nonlinearity in stratified media—both key areas for future research. The last chapter explores the importance of lasers in biophotonic applications. Written by experts engaged in teaching, research, and development in optics and photonics, this reference brings together fundamentals and recent advances in one volume. It offers a valuable overview of the field for students and researchers alike and identifies directions for future research in guided wave and photonic device technology.

Starting from the basics of semiconductor lasers with emphasis on the generation of high optical output power the reader is introduced in a tutorial way to all key technologies required to fabricate high-power diode-laser sources. Various applications are exemplified.

From the Introduction: Nanotechnology and its underpinning sciences are progressing with unprecedented rapidity. With technical advances in a variety of nanoscale fabrication and manipulation technologies, the whole topical area is maturing into a vibrant field that is generating new scientific research and a burgeoning range of commercial applications, with an annual market already at the trillion dollar threshold. The means of fabricating and controlling matter on the nanoscale afford striking and unprecedented opportunities to exploit a variety of exotic phenomena such as quantum, nanophotonic and nanoelectromechanical effects. Moreover, researchers are elucidating new perspectives on the electronic and optical properties of matter because of the way that nanoscale materials bridge the disparate theories describing molecules and bulk matter. Surface phenomena also gain a greatly increased significance; even the well-known link between chemical reactivity and surface-to-volume ratio becomes a major determinant of physical properties, when it operates over nanoscale dimensions. Against this background, this comprehensive work is designed to address the need for a dynamic, authoritative and readily accessible source of information, capturing the full breadth of the subject. Its six volumes, covering a broad spectrum of disciplines including material sciences, chemistry, physics and life sciences, have been written and edited by an outstanding team of international experts. Addressing an extensive, cross-disciplinary audience, each chapter aims to cover key developments in a scholarly, readable and critical style, providing an indispensable first point of entry to the literature for scientists and technologists from interdisciplinary fields. The work focuses on the major classes of nanomaterials in terms of their synthesis, structure and applications, reviewing nanomaterials

and their respective technologies in well-structured and comprehensive articles with extensive cross-references. It has been a constant surprise and delight to have found, amongst the rapidly escalating number who work in nanoscience and technology, so many highly esteemed authors willing to contribute. Sharing our anticipation of a major addition to the literature, they have also captured the excitement of the field itself in each carefully crafted chapter. Along with our painstaking and meticulous volume editors, full credit for the success of this enterprise must go to these individuals, together with our thanks for (largely) adhering to the given deadlines. Lastly, we record our sincere thanks and appreciation for the skills and professionalism of the numerous Elsevier staff who have been involved in this project, notably Fiona Geraghty, Megan Palmer and Greg Harris, and especially Donna De Weerd-Wilson who has steered it through from its inception. We have greatly enjoyed working with them all, as we have with each other.

Nanotechnology is a vital new area of research and development addressing the control, modification and fabrication of materials, structures and devices with nanometre precision and the synthesis of such structures into systems of micro- and macroscopic dimensions. Future applications of nanoscale science and technology include motors smaller than the diameter of a human hair and single-celled organisms programmed to fabricate materials with nanometer precision. Miniaturisation has revolutionised the semiconductor industry by making possible inexpensive integrated electronic circuits comprised of devices and wires with sub-micrometer dimensions. These integrated circuits are now ubiquitous, controlling everything from cars to toasters. The next level of miniaturisation, beyond sub-micrometer dimensions into nanoscale dimensions (invisible to the unaided human eye) is a booming area of research and development. This is a very hot area of research with large amounts of venture capital and government funding being invested worldwide, as such Nanoscale Science and Technology has a broad appeal based upon an interdisciplinary approach, covering aspects of physics, chemistry, biology, materials science and electronic engineering. Kelsall et al present a coherent approach to nanoscale sciences, which will be invaluable to graduate level students and researchers and practising engineers and product designers.

This book provides detailed fundamental treatment of the underlying physics and operational characteristics of most commonly used semi-conductor devices, covering diodes and bipolar transistors, opto-electronic devices, junction field-effect transistors, and MOS transistors. In addition, basic circuits utilising diodes, bipolar transistors, and field-effect transistors are described, and examples are presented which give a good idea of typical performance parameters and the associated waveforms. A brief history of semiconductor devices is included so that the student develops an appreciation of the major technological strides that have made today's IC technology possible. Important concepts are brought out in a simple and lucid manner rather than simply stating them as facts. Numerical examples are included to illustrate the concepts and also to make the student aware of the typical magnitudes of physical quantities encountered in practical electronic circuits. Wherever possible, simulation results are included in order to present a realistic picture of device operation. Fundamental concepts like biasing, small-signal models, amplifier operation, and logic circuits are explained. Review questions and problems are included at the end of each chapter to help students test their understanding. The book is designed for a first course on semiconductor devices and basic electronic circuits for the undergraduate students of electrical and electronics engineering as well as for the students of related branches such as electronics and communication, electronics and instrumentation, computer science and engineering, and information technology.

Optoelectronics and Optical Fiber Sensors is a comprehensive and well-organised book that covers wide aspects of optoelectronic processes, optoelectronic devices, mostly used optical fibers and optical fiber sensor systems including maximum technical discussions. The text

highlights the details of design, material selection and working processes as well as the limitations of various optoelectronic devices and fiber-optic sensor systems. Throughout the book, an attempt has been made to cover every important point related to this field from the fundamental concepts to the recent advancements as well as the future scope of the technical development in this exciting field. Primarily designed for a course of optoelectronics/optoelectronics and fiber optics/optical fiber sensor at both undergraduate and postgraduate levels in electrical and electronics engineering, electronics and communication engineering, electronics and instrumentation engineering and applied physics, it would also be appreciated by practising engineers and scientists who want to update the information related to the latest developments in this field. Key Features • Provides an enormous information regarding the optical interactions, processes, devices and various other related topics to enlarge the scope of the book. • Includes an in-depth presentation of important derivations to enhance the level of understanding. • Incorporates a considerable number of worked-out numericals to reinforce the understanding of the concepts. • Includes many pedagogical features such as chapterwise summary, exercises including probable problems and question bank and relevant references to provide a sound knowledge of various processes and systems.

Primary goal of this book is to provide a cohesive description of the vast field of semiconductor quantum devices, with special emphasis on basic quantum-mechanical phenomena governing the electro-optical response of new-generation nanomaterials. The book will cover within a common language different types of optoelectronic nanodevices, including quantum-cascade laser sources and detectors, few-electron/exciton quantum devices, and semiconductor-based quantum logic gates. The distinguishing feature of the present volume is a unified microscopic treatment of quantum-transport and coherent-optics phenomena on ultraspace- and time-scales, as well as of their semiclassical counterparts.

Reflecting rapid growth in research and development on organic/polymeric electronic and photonic materials and devices, Introduction to Organic Electronic and Optoelectronic Materials and Devices provides comprehensive coverage of the state-of-the-art in an accessible format. The book presents fundamentals, principles, and mechanisms complemented by examples, experimental data, and more than 600 figures, more than 500 equations, about 70 tables, more than 150 exercise questions, and more than 1500 reference citations.

This book provides a comprehensive treatment of the design and applications of optoelectronic devices. Optoelectronic devices such as light emitting diodes (LEDs), semiconductor lasers, photodetectors, optical fibers, and solar cells, are important components for solid state lighting systems, optical communication systems, and power generation systems. Optical fiber amplifiers and fiber lasers are also important for high power industrial applications and sensors. The applications of optoelectronic devices were first studied in the 1970's. Since then, the diversity and scope of optoelectronic device research and applications have been steadily growing. Optoelectronic Devices is self-contained and unified in presentation. It can be used as an advanced textbook by graduate students and practicing engineers. It is also suitable for non-experts who wish to have an overview of optoelectronic devices and systems. The treatments in the book are detailed enough to capture the interest of the curious reader and complete enough to provide the necessary background to explore the subject further.

This authoritative account of electronic and optoelectronic devices covers the fundamental principles of operation, and, uniquely, their circuit applications too.

A rigorous guide providing a unified, multidisciplinary treatment of the fundamentals of optical and optoelectronic nanostructures.

Held in Sao Paulo, Brazil, from September 6 - September 9, 2010, the mission of the 25th Symposium on Microelectronics Technology and Devices ζ SBMicro2010 was to share ideas

and to point to new directions for future research and development. SBMicro offers researchers and practitioners a unique opportunity to share their perspectives with those interested in the various aspects of microelectronics. This issue of ECS Transactions continues the SBMicro tradition of being a premier forum for the presentation of leading edge research on process, devices, sensors and integrated circuit technology.

The first true "introduction" to semiconductor optoelectronic devices, this book provides an accessible, well-organized overview of optoelectronic devices that emphasizes basic principles. Coverage begins with an optional review of key concepts— such as properties of compound semiconductor, quantum mechanics, semiconductor statistics, carrier transport properties, optical processes, and junction theory— then progress gradually through more advanced topics. The "Second Edition" has been both updated and expanded to include the recent developments in the field.

Organized as a mini-encyclopedia of infrared optoelectronic applications, this long awaited new edition of an industry standard updates and expands on the groundbreaking work of its predecessor. Pioneering experts, responsible for many advancements in the field, provide engineers with a fundamental understanding of semiconductor physics and the technical information needed to design infrared optoelectronic devices. Fully revised to reflect current developments in the field, *Optoelectronics: Infrared-Visible-Ultraviolet Devices and Applications, Second Edition* reviews relevant semiconductor fundamentals, including device physics, from an optoelectronic industry perspective. This easy-reading text provides a practical engineering introduction to optoelectronic LEDs and silicon sensor technology for the infrared, visible, and ultraviolet portion of the electromagnetic spectrum. Utilizing a practical and efficient engineering approach throughout, the text supplies design engineers and technical management with quick and uncluttered access to the technical information needed to design new systems.

In this fifth edition all chapters have been revised and updated. The chapters on Polymer and Fiber Integrated Optics, Optical Amplifiers, Micro-Optical-Electro-Mechanical Devices, and Photonic and Microwave Wireless Systems are completely new. Problems help the students to deepen their knowledge.

This is a textbook for undergraduate (and graduate) Electrical engineering students. It starts with the Quantum theory, continuing to intrinsic and doped semiconductors, p-n junctions and optoelectronics. Bipolar transistors, FETs, and Integrated Circuit fabrication are covered. While the material is easily understandable, there is emphasis on depth-of-knowledge, and appreciation of engineering principles.

The characterization and precisely controlled building of atomic-scale multilayers have been the subject of intensive R&D worldwide. Nanometric structures based on III-V semiconductors have attracted particular attention. Since 1970, around 15,000 papers have been published in all, of which 10,000 have appeared in the last 6 years. The resulting improved materials control is enabling engineers to achieve major improvements in the performance of microelectronic and optoelectronic devices such as QW lasers, tunnelling devices, modulators, switches and photodetectors. In this book, the large volume of research results which have accumulated is evaluated and distilled down to a useful, manageable concentration of up-to-date knowledge for electronic engineers and solid-state physicists. This has been carried out by an invited international team of over 50 specialists under the editorship of Professor Bhattacharya with support from INSPEC, who also compiled the subject index. There are 40 individually-written, self-contained modules ("Datareviews"), each specially commissioned to fit into a pre-determined structure. Subjects reviewed in depth include historical perspective, theory, epitaxial growth and doping, structure (e.g. X-ray

bringing them up to speed on new discoveries and commercial applications. It provides specific technical applications of key processes such as laser diodes, LEDs, and very high temperature electronic controls on engines, focusing on doping, etching, oxidation passivation, growth techniques and more.

The topic of this monograph is the physical modeling of heterostructure devices. A detailed discussion of physical models and parameters for compound semiconductors is presented including the relevant aspects of modern submicron heterostructure devices. More than 25 simulation examples for different types of Si(Ge)-based, GaAs-based, InP-based, and GaN-based heterostructure bipolar transistors (HBTs) and high electron mobility transistors (HEMTs) are given in comparison with experimental data from state-of-the-art devices.

This book introduces some alternative methods for enhancing the performance of In(Ga)As/GaAs-based quantum dot infrared photodetectors (QDIPs). In(Ga)As/GaAs-based QDIPs and focal plane array (FPA) cameras have wide application in fields such as military and space science. The core of the study uses a combination of quaternary $\text{In}_{0.21}\text{Al}_{0.21}\text{Ga}_{0.58}\text{As}$ and GaAs spacer as a capping layer on In(Ga)As/GaAs quantum dots in the active region of the detector structure. For the purposes of optimization, three types of samples growths are considered with different capping thicknesses. The results presented include TEM, XRD and photoluminescence studies that compare combination barrier thickness and its effect on structural and optical properties. Compressive strain within the heterostructure, thermal stability in high temperature annealing, spectral response, shifts in PL peaks peak, and responsivity and detectivity are all considered. The results also present a narrow spectral width that was obtained by using InAs QDs which is very useful for third generation FPA camera application. The book details effect of post-growth rapid thermal annealing on device characteristics and methods to enhance responsivity and peak detectivity. The contents of this book will be useful to researchers and professionals alike.

Optoelectronic devices impact many areas of society, from simple household appliances and multimedia systems to communications, computing, spatial scanning, optical monitoring, 3D measurements and medical instruments. This is the most complete book about optoelectromechanic systems and semiconductor optoelectronic devices; it provides an accessible, well-organized overview of optoelectronic devices and properties that emphasizes basic principles.

Semiconductor Optoelectronic Devices

This book is devoted to optical semiconductor devices and their numerous applications in telecommunications, optoelectronics, and consumer electronics-areas where signal processing or the transmission of signals across fiber optic cables is paramount. It introduces a new generation of devices that includes optical modulators, quantum well (QW) lasers, and photodiodes and explores new applications of more established devices such as semiconductor lasers, light-emitting diodes, and photodiodes. Mitsuo Fukuda examines the material properties, operation principles, fabrication, packaging, reliability, and applications of each device and offers a unique industrial perspective, discussing everything engineers and scientists need to know at different phases of research, development, and production. This guide to the state-of-the-art of optical semiconductor devices: * Helps you choose the right device for a given application. * Covers important performance data such as temperature and optical feedback noise in lasers. * Highlights epitaxial growth techniques and fabrication for each device. * Features one hundred figures and an extensive bibliography. * Provides a clear and concise treatment, unencumbered by excessive theory Optical Semiconductor Devices is

an essential resource for engineers and researchers in telecommunications and optoelectronics, equipment designers and manufacturers, and graduate students and scholars interested in this rapidly evolving field.

Reflecting changes in the field in the ten years since the publication of the first edition, *The Handbook of Photonics, Second Edition* explores recent advances that have affected this technology. In this new, updated second edition editor Mool Gupta is joined by John Ballato, strengthening the handbook with their combined knowledge and the continued contributions of world-class researchers. New in the Second Edition: Information on optical fiber technology and the economic impact of photonics Coverage of emerging technologies in nanotechnology Sections on optical amplifiers, and polymeric optical materials The book covers photonics materials, devices, and systems, respectively. An introductory chapter, new to this edition, provides an overview of photonics technology, innovation, and economic development. Resting firmly on the foundation set by the first edition, this new edition continues to serve as a source for introductory material and a collection of published data for research and training in this field, making it the reference of first resort.

This updated, second edition textbook provides a thorough and accessible treatment of semiconductor lasers from a design and engineering perspective. It includes both the physics of devices as well as the engineering, designing and testing of practical lasers. The material is presented clearly with many examples provided. Readers of the book will come to understand the finer aspects of the theory, design, fabrication and test of these devices and have an excellent background for further study of optoelectronics.

The advent of microelectromechanic system (MEMS) technologies and nanotechnologies has resulted in a multitude of structures and devices with ultra compact dimensions and with vastly enhanced or even completely novel properties. In the field of photonics it resulted in the appearance of new paradigms, including photonic crystals that exhibit photonic bandgap and represent an optical analog of semiconductors and metamaterials that have subwavelength features and may have almost arbitrary values of effective refractive index, including those below zero. In addition to that, a whole new field of plasmonics appeared, dedicated to the manipulation with evanescent, surface-bound electromagnetic waves and offering an opportunity to merge nanoelectronics with all-optical circuitry. In the field of infrared technologies MEMS and nanotechnologies ensured the appearance of a new generation of silicon-based thermal detectors with properties vastly surpassing the conventional thermal devices. However, another family of infrared detectors, photonic devices based on narrow-bandgap semiconductors, has traditionally been superior to thermal detectors. Literature about their micro and nanophotonic enhancement has been scarce and scattered through journals. This book offers the first systematic approach to numerous different MEMS and nanotechnology-based methods available for the improvement of photonic infrared detectors and points out to a path towards uncooled operation with the performance of cryogenically cooled devices. It is shown that a vast area for enhancement does exist and that photonic devices can readily keep their leading position in infrared detection. The various methods and approaches described in the book are also directly applicable to different other types of photodetectors like solar cells, often with little or no modification.

Optoelectronics has become an important part of our lives. Wherever light is used to transmit information, tiny semiconductor devices are needed to transfer electrical current into optical signals and vice versa. Examples include light emitting diodes in radios and other appliances, photodetectors in elevator doors and digital cameras, and laser diodes that transmit phone calls through glass fibers. Such optoelectronic devices take advantage of sophisticated interactions between electrons and light. Nanometer scale semiconductor structures are often at the heart of modern optoelectronic devices. Their shrinking size and increasing complexity make computer simulation an important tool to design better devices that meet ever rising

performance requirements. The current need to apply advanced design software in optoelectronics follows the trend observed in the 1980's with simulation software for silicon devices. Today, software for technology computer-aided design (TCAD) and electronic design automation (EDA) represents a fundamental part of the silicon industry. In optoelectronics, advanced commercial device software has emerged recently and it is expected to play an increasingly important role in the near future. This book will enable students, device engineers, and researchers to more effectively use advanced design software in optoelectronics. *

Provides fundamental knowledge in semiconductor physics and in electromagnetics, while helping to understand and use advanced device simulation software * Demonstrates the combination of measurements and simulations in order to obtain realistic results and provides data on all required material parameters * Gives deep insight into the physics of state-of-the-art devices and helps to design and analyze of modern optoelectronic devices

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