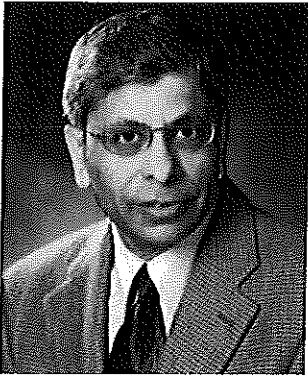


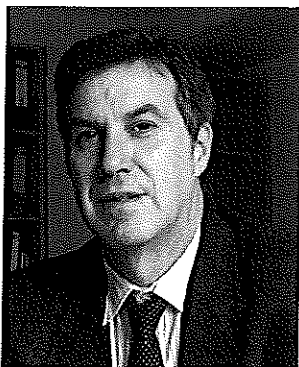
COMPREHENSIVE SEMICONDUCTOR SCIENCE AND TECHNOLOGY

Editors in Chief



Pallab Bhattacharya is the Charles M. Vest Distinguished University Professor of Electrical Engineering and Computer Science and the James R. Mellor Professor of Engineering in the Department of Electrical Engineering and Computer Science at the University of Michigan, Ann Arbor. He received the M. Eng. and Ph.D. degrees from the University of Sheffield, UK, in 1976 and 1978, respectively. Professor Bhattacharya was an Editor of the *IEEE Transactions on Electron Devices* and is Editor-in-Chief of *Journal of Physics D*. He has edited *Properties of Lattice-Matched and Strained InGaAs* (UK: INSPEC, 1993) and *Properties of III-V Quantum Wells and Superlattices* (UK: INSPEC, 1996). He has also authored the textbook *Semiconductor Optoelectronic Devices* (Prentice Hall, 2nd edition). His teaching and research interests are in the areas of compound semiconductors, low-dimensional quantum confined systems, nanophotonics and optoelectronic integrated circuits. He is currently working on highspeed quantum dot lasers, quantum dot infrared photodetectors, photonic crystal quantum dot devices, and spin-based heterostructure devices. From 1978 to 1983, he was on the faculty of Oregon State University, Corvallis, and since 1984 he has been with the University of Michigan. He was an Invited Professor at the Ecole Polytechnic Federale de Lausanne, Switzerland, from 1981 to 1982.

Professor Bhattacharya is a member of the National Academy of Engineering. He has received the John Simon Guggenheim Fellowship, the IEEE (EDS) Paul Rappaport Award, the Heinrich Welker Prize, the IEEE (LEOS) Engineering Achievement Award, the Optical Society of America (OSA) Nick Holonyak Award, the SPIE Technical Achievement Award, the Quantum Devices Award of the International Symposium on Compound Semiconductors, and the IEEE (Nanotechnology Council) Nanotechnology Pioneer Award. He has also received the S.S. Attwood Award, the Kennedy Family Research Excellence Award, and the Distinguished Faculty Achievement Award from the University of Michigan. He is a Fellow of the IEEE, the American Physical Society, the Institute of Physics (UK), and the Optical Society of America.



Roberto Fornari studied Solid State Physics at the University of Parma, Italy. He is presently director of the Leibniz Institute for Crystal Growth (IKZ) in Berlin and holds the Chair of Crystal Growth at the Physics Dept. of the Humboldt University Berlin (joint appointment). Before moving to Germany in 2003, he worked over twenty years as a research scientist at the Institute for Electronic and Magnetic Materials (MASPEC, later IMEM) of the Italian CNR where he led different research projects on growth and thermal processing of bulk III-V semiconductors, HVPE and MOVPE of Nitrides, characterization of semiconductors by electrical and optical techniques. He has authored/co-authored about 180 scientific papers, eight patents and different book chapters. He has edited books and proceedings on crystal growth and semiconductors physics and was subject editor of the *Encyclopedia of Materials* published by Pergamon Press in 2001. He is presently a member of the editorial board of the *Journal of Crystal Growth*, the *Crystal Research and Technology*, and the *Journal of Optoelectronics and Advanced Materials*.

He has been Chairman of the IUCr Commission for Crystal Growth and Characterization of Materials from 1999 to 2005 and then member till 2008. From 2001 to 2007 he served on the Executive Committee of the International Organization for Crystal Growth and is currently President of this organization.



Hiroshi Kamimura is currently a Senior Advisor to the Tokyo University of Science (TUS), and a guest professor of the Research Institute for Science and Technology at the TUS. He was awarded a Doctor of Science in Physics from the University of Tokyo in 1959. He worked at Bell-Telephone laboratories at Murray Hill, USA as a Member of Technical Staff from 1961 to 1964. In 1965 he became a lecturer, then an associate professor and a professor at the Department of Physics, Faculty of Science in the University of Tokyo. Between 1974 and 1975 he worked with Sir Nevill Mott as a guest scholar at Cavendish Laboratory in Cambridge, UK. In 1991 he retired from the University of Tokyo, and became a professor at the Department of Applied Physics, Faculty of Science at the TUS. His interests are in the theory of condensed matter physics and of materials science, in particular semiconductor physics, high temperature superconductivity and superionic conduction. He was President of the Physical Society of Japan between 1984 and 1985, and Chairman of IUPAP Semiconductor Commission between 1985 and 1990. He is an honorary fellow of the Institute of Physics, UK, a life-fellow of the American Physical Society, an emeritus professor of the University of the Tokyo and an emeritus professor of the Tokyo University of Science.

Preface

Semiconductors are at the heart of modern living. Almost everything we do, be it work, travel, communication, or entertainment, all depend on some feature of semiconductor technology. Though this domination has its roots in developments dating back 60 years, the progress has not been diminished by achievement, and the demands for improvements in performance continue to push manufacturing limits. As we enhance the performance of devices, we also extend the range of applications, exploiting what we have learned about older semiconductors to grow and process newer ones. Whereas once we were content to explore silicon chips for advanced electronics, and then gallium arsenide and other compound semiconductors for optoelectronics, we are now addressing critical issues in growth and processing of group III nitrides and silicon carbide for high-power, high-frequency, and high-temperature electronics and optoelectronics, with the objective of replacing fluorescent tubes and tungsten filaments in our homes and offices.

While the numerous applications of semiconductors are evident to most, less is known about the serendipitous evolution of basic semiconductor physics, which often paved the way to new device concepts. For example, in 2000 the Nobel prize for physics was awarded to Zhores Alferov and Herbert Kroemer for the development of the technology used today in satellite communication and cellular phones, and to Jack Kilby for the invention and development of the integrated circuit, the forerunner of the microchip and the pocket calculator. Further in 2009 Willard Boyle and George Smith shared the Nobel prize in physics for the invention of an imaging semiconductor circuit – ‘the CCD sensor’ – with Charles Kao for his groundbreaking research on the transmission of light in fibers for optical communication.

From the standpoint of chemistry and materials science, the prediction of semiconductor superlattices by Leo Esaki and Raphael Tsu in 1969 opened the tailor-made materials age, together with the development of the molecular beam epitaxy (MBE) and metal organic vapor phase epitaxy (MOVPE) techniques. These techniques paved the way for the realization of tailor-made semiconductor materials, in particular low-dimensional (two-, one-, and zero-dimensional) heterostructures which immediately became front runners in materials science. This frontier spirit of semiconductor research has led to the recent splendid realization of a one-atom thick layer of graphite, the so-called graphene, for which Andre Geim and Konstantin Novoselov received the 2010 Nobel prize in physics.

The discoveries of integer and fractional quantum Hall effects which were awarded the physics Nobel prize in 1985 (Klaus von Klitzing) and 1998 (Robert Laughlin, Horst Störmer and Daniel Tsui), respectively, are also undoubtedly among the most fascinating phenomena, not only in semiconductor physics, but also in the entire subject of condensed matter physics. The integer quantum Hall effect was originally discovered in Si-MOSFET (MOSFET, metal-oxide-semiconductor field-effect transistor), while the fractional quantum Hall effect was observed in very pure and atomically abrupt GaAs-AlGaAs heterostructures. As regards the theory of semiconductors from bulk to nanostructures, the advances in theoretical methodology and computer technology have been tremendous in the last few decades. In particular, predictions of new stable materials and device-worthy materials have contributed to remarkable progress in tailor-made materials and devices. The uniquely strong interplay between theory, experiment, chemistry, materials science, and technology has greatly contributed to the success of semiconductor-related fields.

The revolution in semiconductor science and technology did not happen by accident. It is based on a thorough understanding of the diverse science and technology of these fascinating materials, coupled with

astonishing facilities for controlling the crystallographic structure and purity. Progress has called for research by scientists and engineers from many disciplines, and the results of their efforts are documented in thousands of archival articles, patents, and licensed technologies. Those new to the subject blanch at the thought of assimilating even a small fraction of this immense knowledge base, and turn to the many specialist books that attempt to summarize specific aspects of the field. To date, there is no comprehensive work that covers the complete spectrum from fundamental semiconductor physics to design and manufacture devices which the physics predicted to be possible, and which are now actually fabricated by materials scientists. In this sense, a comprehensive work is different from an encyclopedia and a handbook. *Comprehensive Semiconductor Science and Technology* consists of much longer chapters, which contain extensive cross-references to other relevant information within the work and references to the vast available literature beyond the work. Each chapter may be partly tutorial so that graduate students can greatly benefit from its reading.

This comprehensive comprises six volumes, and has been broadly divided into three main sections:

Section 1: Physics/Fundamental Theory – Edited by Hiroshi Kamimura

Section 2: Chemistry/Preparation – Edited by Roberto Fornari

Section 3: Devices/Application – Edited by Pallab Bhattacharya

Each of these complementary sections will provide a complete description of one aspect of the whole, and will fuse together to give a comprehensive picture of the semiconductor world. The first section, which covers Volumes 1 and 2, is concerned with the fundamental physics of semiconductors, showing how the electronic properties and lattice dynamics change drastically when systems vary from bulk to a low-dimensional structure and further to an interface and to a nanometer size such as quantum dots. The section describes all the important characteristics of transport and optical properties. Further, this section includes many new topics such as spin effects, carbon crystalline systems such as graphene and nanotubes, ultrafast coherent optical phenomena, quantum information processing, etc., since the field of semiconductors continues to expand. Throughout Volumes 1 and 2, there is an emphasis on the full understanding of the underlying physics.

Section 2, which covers Volumes 3 and 4, generally deals with technology of semiconductors. This includes a description of the main methods employed for the preparation of bulk single crystals and thin layers. It is shown that large single crystals may be conveniently grown from their melt, from solutions, or from the vapor phase, and that the thermodynamical properties of the semiconductors to be grown actually decide about the most appropriate method. The reader will also find some specific examples in the chapters devoted to bulk growth of silicon, wide-bandgap compounds, II–VI and III–V semiconducting compounds. In addition, Section 2 also contains reviews on thin film technology, in particular MBE and MOVPE. In particular, how a basic technology can be suited to preparation of semiconducting layers with tailored properties is discussed. Examples of advanced low-dimensional heterostructures and nanostructures are provided along with a specific chapter on integration of dissimilar materials. Additional chapters highlight the development of technologies for deposition of high-quality ferroelectric and high-K materials to be applied as memories and gate isolators, respectively. In addition to growth technology, Volumes 3 and 4 also include contributions regarding processing and characterization of semiconductors. The reader will find valuable information about the formation of shallow junctions in semiconductors, the fabrication of ohmic and Schottky contacts as well as several chapters describing the sophisticated methods used nowadays for investigating the physical and structural characteristics of substrates, films, and quantum structures.

Volumes 5 and 6, which correspond to Section 3, contain chapters on the physics, technology and application of devices, and circuits realized with diverse materials and heterostructure systems. The materials include Si/SiGe, GaAs-, and InP-based heterostructures, antimonides, GaN-, ZnO-, and SiC-based materials, graphene, HgCdTe, and materials for molecular electronics. Also included are carbon nanotubes and nanostructured materials for flexible and stretchable electronics. The chapters describe in detail the properties of high-speed, high-frequency, and high-power bipolar and field-effect transistors made with a variety of heterostructure systems, negative differential resistance devices, single electron transistors, and microelectromechanical system (MEMS)-based sensors. Several chapters describe the principles and properties of a wide variety of optoelectronic devices including photodetectors, solar cells, light emitting diodes, and lasers. Passive

photonic devices such as waveguides and filters are also included. The operating wavelength of these devices ranges from very short (ultraviolet) to very long (terahertz). The active region of some of these devices includes low-dimensional quantum-confined heterostructures such as quantum wells and quantum dots. Concepts such as the manipulation of slow and fast light and disordering of quantum structures for optoelectronic device integration are described in detail in a couple of chapters. The use of photonic crystals and microcavities in optical devices is elucidated. Electronics with molecules is included with a good description of the underlying physics. Finally, the physics, fabrication, and characteristics of spin-based electronic and optoelectronic devices, more commonly known as semiconductor spintronic devices, are described in a few chapters. Each chapter and topic is uniquely distinct, complete with the appropriate background material and references.

Pallab Bhattacharya, Roberto Fornari, and Hiroshi Kamimura

Contents of All Volumes

Volume 1

Physics and Fundamental Theory

Edited by Professor Hiroshi Kamimura, *Research Institute for Science and Technology, Tokyo University of Science, Tokyo, Japan*

- 1.01 Electrons in Semiconductors: Empirical and *ab initio* Pseudopotential Theories
- 1.02 *Ab initio* Theories of the Structural, Electronic, and Optical Properties of Semiconductors: Bulk Crystals to Nanostructures
- 1.03 Impurity Bands in Group-IV Semiconductors
- 1.04 Atomic Structures and Electronic Properties of Semiconductor Interfaces
- 1.05 Integer Quantum Hall Effect
- 1.06 Fractional Quantum Hall Effect and Composite Fermions
- 1.07 Spin Hall Effect
- 1.08 Ballistic Transport in 1D GaAs/AlGaAs Heterostructures
- 1.09 Thermal Conductivity and Thermoelectric Power of Semiconductors
- 1.10 Electronic States and Transport Properties of Carbon Crystalline: Graphene, Nanotube, and Graphite
- 1.11 Angle-Resolved Photoemission Spectroscopy of Graphene, Graphite, and Related Compounds
- 1.12 Theory of Superconductivity in Graphite Intercalation Compounds

Volume 2

Physics and Fundamental Theory

Edited by Professor Hiroshi Kamimura, *Research Institute for Science and Technology, Tokyo University of Science, Tokyo, Japan*

- 2.01 Electronic States and Transport in Quantum-Dots
- 2.02 Control Over Single Electron Spins in Quantum-Dots
- 2.03 Contact Hyperfine Interactions in Semiconductor Heterostructures
- 2.04 Semimagnetic Semiconductors
- 2.05 Optical Properties of Semiconductors
- 2.06 Light Emission from Silicon Nanoparticles and Related Materials
- 2.07 High-Density Excitons in Semiconductors
- 2.08 Magneto-Spectroscopy of Semiconductors
- 2.09 Bloch Oscillations and Ultrafast Coherent Optical Phenomena
- 2.10 Optically Controlled Semiconductor Spin Qubits and Indistinguishable Single Photons for Quantum Information Processing

Volume 3**Materials, Preparation, and Properties**

Edited by Dr Roberto Fornari, *Leibniz Institute for Crystal Growth, Berlin, Germany and Institute of Physics, Humboldt University, Berlin, Germany*

- 3.01 Bulk Crystal Growth of Semiconductors: An Overview
- 3.02 Bulk Growth of Crystals of III–V Compound Semiconductors
- 3.03 Fundamentals and Engineering of the Czochralski Growth of Semiconductor Silicon Crystals
- 3.04 Growth of $\text{Cd}_{0.9}\text{Zn}_{0.1}\text{Te}$ Bulk Crystals
- 3.05 Sublimation Epitaxial Growth of Hexagonal and Cubic SiC
- 3.06 Growth of Bulk GaN Crystals
- 3.07 Growth of Bulk AlN Crystals
- 3.08 Growth of Bulk ZnO
- 3.09 Organometallic Vapor Phase Epitaxial Growth of Group III Nitrides
- 3.10 ZnO Epitaxial Growth
- 3.11 Nanostructures of Metal Oxides
- 3.12 Molecular Beam Epitaxy: An Overview
- 3.13 Growth of Low-Dimensional Semiconductors Structures

Volume 4**Materials, Preparation, and Properties**

Edited by Dr Roberto Fornari, *Leibniz Institute for Crystal Growth, Berlin, Germany and Institute of Physics, Humboldt University, Berlin, Germany*

- 4.01 Integration of Dissimilar Materials
- 4.02 Ion Implantation in Group III Nitrides
- 4.03 Contacts to Wide-Band-Gap Semiconductors
- 4.04 Formation of Ultra-Shallow Junctions
- 4.05 New High- K Materials for CMOS Applications
- 4.06 Ferroelectric Thin Layers
- 4.07 Amorphous and Glassy Semiconducting Chalcogenides
- 4.08 Scanning Tunneling Microscopy and Spectroscopy of Semiconductor Materials
- 4.09 Atomic Resolution Characterization of Semiconductor Materials by Aberration-Corrected Transmission Electron Microscopy
- 4.10 Assessment of Semiconductors by Scanning Electron Microscopy Techniques
- 4.11 Characterization of Semiconductors by X-Ray Diffraction and Topography
- 4.12 Electronic Energy Levels in Group-III Nitrides
- 4.13 Organic Semiconductors

Volume 5**Devices and Applications**

Edited by Professor Pallab Bhattacharya, *Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI, USA*

- 5.01 SiGe/Si Heterojunction Bipolar Transistors and Circuits
- 5.02 Silicon MOSFETs for ULSI: Scaling CMOS to Nanoscale
- 5.03 GaAs- and InP-Based High-Electron-Mobility Transistors
- 5.04 High-Speed InP-Based Heterojunction Bipolar Transistors
- 5.05 Negative Differential Resistance Devices and Circuits
- 5.06 GaN-Based Transistors for High-Frequency Applications
- 5.07 GaN- and SiC-Based Power Devices

- 5.08 Silicon Single Electron Transistors Operating at Room Temperature and Their Applications
- 5.09 Electronics with Molecules
- 5.10 Electronic and Optoelectronic Properties and Applications of Carbon Nanotubes
- 5.11 Micro- and Nanostructured Semiconductor Materials for Flexible and Stretchable Electronics
- 5.12 MEMS-Based Sensors
- 5.13 III-V Compound Avalanche Photodiodes
- 5.14 Disordering of Quantum Structures for Optoelectronic Device Integration
- 5.15 Quantum-Well Lasers and Their Applications
- 5.16 Quantum Cascade Lasers
- 5.17 Slow and Fast Light in Quantum-Well and Quantum-Dot Semiconductor Optical Amplifiers

Volume 6

Devices and Applications

Edited by Professor Pallab Bhattacharya, *Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI, USA*

- 6.01 III-Nitride-Based Short-Wavelength Ultraviolet Light Sources
- 6.02 Nitride-Based LEDs and Superluminescent LEDs
- 6.03 Electronic and Optoelectronic Devices Based on Semiconducting Zinc Oxide
- 6.04 Molecular Beam Epitaxy of HgCdTe Materials and Detectors
- 6.05 Quantum-Well Infrared Photodetectors and Arrays
- 6.06 InAs/(In)GaSb Type II Strained Layer Superlattice Detectors
- 6.07 Terahertz Detection Devices
- 6.08 Amorphous and Nanocrystalline Silicon Solar Cells and Modules
- 6.09 Quantum-Dot Lasers: Physics and Applications
- 6.10 High-Performance Quantum-Dot Lasers
- 6.11 Quantum-Dot Infrared Photodetectors
- 6.12 Photonic Crystal Microcavity Light Sources
- 6.13 Photonic Crystal Waveguides and Filters
- 6.14 Spintronic Devices Based on Semiconductors
- 6.15 Spin-Based Semiconductor Heterostructure Devices
- 6.16 Spin-Polarized Transport and Spintronic Devices

Index

Contributors to Volume 1

H. Aoki <i>University of Tokyo, Tokyo, Japan</i>	Chapter 1.05 p. 175
J. R. Chelikowsky <i>University of Texas, Austin, TX, USA</i>	Chapter 1.01 p. 1
W. R. Clarke <i>University of New South Wales, Sydney, NSW, Australia</i>	Chapter 1.08 p. 279
J. Deslippe <i>University of California at Berkeley and Lawrence Berkeley National Laboratory, Berkeley, CA, USA</i>	Chapter 1.02 p. 42
M. Eto <i>Keio University, Yokohama, Japan</i>	Chapter 1.03 p. 77
Y. Iye <i>University of Tokyo, Kashiwa, Chiba, Japan</i>	Chapter 1.10 p. 359
J. K. Jain <i>The Pennsylvania State University, University Park, PA, USA</i>	Chapter 1.06 p. 210
H. Kamimura <i>Tokyo University of Science, Tokyo, Japan</i>	Chapter 1.03 p. 77
Y. Kangawa <i>Kyushu University, Fukuoka, Japan</i>	Chapter 1.04 p. 113
C.-T. Liang <i>National Taiwan University, Taipei, China</i>	Chapter 1.08 p. 279
S. G. Louie <i>University of California at Berkeley and Lawrence Berkeley National Laboratory, Berkeley, CA, USA</i>	Chapter 1.02 p. 42
S. Murakami <i>Tokyo Institute of Technology, Tokyo, Japan</i>	Chapter 1.07 p. 222
N. Nagaosa <i>University of Tokyo, Tokyo, Japan</i>	Chapter 1.07 p. 222
T. Nakayama <i>Chiba University, Chiba, Japan</i>	Chapter 1.04 p. 113
T. Sato <i>Tohoku University, Sendai, Japan</i>	Chapter 1.11 p. 383
K. Shiraishi <i>University of Tsukuba, Ibaraki, Japan</i>	Chapter 1.04 p. 113

M. Y. Simmons <i>University of New South Wales, Sydney, NSW, Australia</i>	Chapter 1.08 p. 279
Y. Takada <i>University of Tokyo, Kashiwa, Chiba, Japan</i>	Chapter 1.12 p. 410
T. Takahashi <i>Tohoku University, Sendai, Japan</i>	Chapter 1.11 p. 383
I. Terasaki <i>Nagoya University, Nagoya, Japan</i>	Chapter 1.09 p. 326

Contributors to Volume 2

M. Cardona <i>Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany</i>	Chapter 2.05 p. 125
J. A. Gaj <i>University of Warsaw, Warszawa, Poland</i>	Chapter 2.04 p. 95
Y. Hirayama <i>Toboku University, Sendai, Japan</i>	Chapter 2.03 p. 68
Y. Kanemitsu <i>Kyoto University, Kyoto, Japan</i>	Chapter 2.06 p. 196
M. Kuwata-Gonokami <i>University of Tokyo, Tokyo, Japan</i>	Chapter 2.07 p. 213
K. Leo <i>Technische Universität Dresden, Dresden, Germany</i>	Chapter 2.09 p. 343
V. Lyssenko <i>Technische Universität Dresden, Dresden, Germany</i>	Chapter 2.09 p. 343
N. Miura <i>University of Tokyo, Kasbiwa, Chiba, Japan</i>	Chapter 2.08 p. 256
Y. V. Nazarov <i>Delft University of Technology, Delft, The Netherlands</i>	Chapter 2.01 p. 1
S. Tarucha <i>University of Tokyo, Tokyo, Japan</i>	Chapter 2.02 p. 23
Y. Tokura <i>NTT Basic Research Laboratories, Kanagawa, Japan</i>	Chapter 2.02 p. 23
Y. Yamamoto <i>Stanford University, Stanford, CA, USA</i>	Chapter 2.10 p. 400
P. Y. Yu <i>University of California, Berkeley, CA, USA</i>	Chapter 2.05 p. 125

Contributors to Volume 3

O. V. Avdeev <i>Nitride Crystals Ltd., Saint-Petersburg, Russia</i>	Chapter 3.07 p. 282
A. Bakin <i>Technical University Braunschweig, Braunschweig, Germany</i>	Chapter 3.10 p. 368
O. Bierwagen <i>University of California, Santa Barbara, CA, USA</i>	Chapter 3.13 p. 523
T. Yu Chemekova <i>Nitride Crystals Ltd., Saint-Petersburg, Russia</i>	Chapter 3.07 p. 282
L. Chow <i>University of Central Florida, Orlando, FL, USA</i>	Chapter 3.11 p. 396
B. Dai <i>MEMC Electronic Materials, St. Peters, MO, USA</i>	Chapter 3.03 p. 81
R. F. Davis <i>Carnegie Mellon University, Pittsburgh, PA, USA</i>	Chapter 3.09 p. 339
E. Diéguez <i>Universidad Autónoma de Madrid, Madrid, Spain</i>	Chapter 3.04 p. 170
P. S. Dutta <i>Rensselaer Polytechnic Institute, Troy, NY, USA</i>	Chapter 3.02 p. 36
M. Enachi <i>Technical University of Moldova, Chisinau, Republic of Moldova</i>	Chapter 3.11 p. 396
B. Feigelson <i>US Naval Research Laboratory, Washington, DC, USA</i>	Chapter 3.06 p. 232
R. Fornari <i>Leibniz Institute for Crystal Growth, Berlin, Germany</i>	Chapter 3.01 p. 1
S. Franchi <i>CNR-IMEM Institute, Parma, Italy</i>	Chapter 3.12 p. 480
P. Frigeri <i>CNR-IMEM Institute, Parma, Italy</i>	Chapter 3.12 p. 480
S. Ganschow <i>Leibniz Institute for Crystal Growth, Berlin, Germany</i>	Chapter 3.08 p. 302
F. Hatami <i>Humboldt-Universität zu Berlin, Berlin, Germany</i>	Chapter 3.13 p. 523
H. Helava <i>Helava Systems Inc., Deer Park, NY, USA</i>	Chapter 3.07 p. 282

D. Klimm <i>Leibniz Institute for Crystal Growth, Berlin, Germany</i>	Chapter 3.08 p. 302
M. S. Kulkarni <i>MEMC Electronic Materials, St. Peters, MO, USA</i>	Chapter 3.03 p. 81
O. Lupan <i>University of Central Florida, Orlando, FL, USA</i>	Chapter 3.11 p. 396
Yu N. Makarov <i>Nitride Crystals, Inc., Richmond, VA, USA</i>	Chapter 3.07 p. 282
E. N. Mokhov <i>Nitride Crystals Ltd., Saint-Petersburg, Russia</i>	Chapter 3.07 p. 282
S. S. Nagalyuk <i>Nitride Crystals Ltd., Saint-Petersburg, Russia</i>	Chapter 3.07 p. 282
T. Paskova <i>Kyma Technologies, Inc., Raleigh, NC, USA</i>	Chapter 3.06 p. 232
M. G. Ramm <i>Helava Systems Inc., Deer Park, NY, USA</i>	Chapter 3.07 p. 282
D. Schulz <i>Leibniz Institute for Crystal Growth, Berlin, Germany</i>	Chapter 3.08 p. 302
A. S. Segal <i>STR Group – Soft-Impact Ltd., Saint-Petersburg, Russia</i>	Chapter 3.07 p. 282
L. Seravalli <i>CNR-IMEM Institute, Parma, Italy</i>	Chapter 3.12 p. 480
M. Syväjärvi <i>Linköping University, Linköping, Sweden</i>	Chapter 3.05 p. 202
I. M. Tiginyanu <i>Academy of Sciences of Moldova, Chisinau, Republic of Moldova</i>	Chapter 3.11 p. 396
G. Trevisi <i>CNR-IMEM Institute, Parma, Italy</i>	Chapter 3.12 p. 480
V. V. Ursaki <i>Academy of Sciences of Moldova, Chisinau, Republic of Moldova</i>	Chapter 3.11 p. 396
V. V. Voronkov <i>MEMC Electronic Materials, St. Peters, MO, USA</i>	Chapter 3.03 p. 81
A. Waag <i>Technical University Braunschweig, Braunschweig, Germany</i>	Chapter 3.10 p. 368
R. Yakimova <i>Linköping University, Linköping, Sweden</i>	Chapter 3.05 p. 202
A. I. Zhmakin <i>AF Ioffe Physical Technical Institute, Saint-Petersburg, Russia</i>	Chapter 3.07 p. 282

Contributors to Volume 4

B. Chen <i>National Institute for Materials Science (NIMS), Ibaraki, Japan</i>	Chapter 4.10 p. 308
K. Das <i>Tuskegee University, Tuskegee, AL, USA</i>	Chapter 4.03 p. 44
Y. Dong <i>The Ohio State University, Columbus, OH, USA</i>	Chapter 4.03 p. 44
P. F. Fewster <i>Panalytical Research Centre, Sussex Innovation Centre, Brighton, UK</i>	Chapter 4.11 p. 357
M. Frumar <i>University of Pardubice, Pardubice, Czech Republic</i>	Chapter 4.07 p. 206
B. Frumarova <i>Institute of Macromolecular Chemistry, Academy of Sciences of the Czech Republic, Prague, Czech Republic</i>	Chapter 4.07 p. 206
P. Gorai <i>University of Illinois at Urbana–Champaign, Urbana, IL, USA</i>	Chapter 4.04 p. 86
B. Grandidier <i>Institut d'Electronique, de Microelectronique et de Nanotechnologie, Lille, France</i>	Chapter 4.08 p. 262
T. F. Kuech <i>University of Wisconsin – Madison, Madison, WI, USA</i>	Chapter 4.01 p. 1
L. Lazzarini <i>CNR-IMEM Institute, Parma, Italy</i>	Chapter 4.10 p. 308
K. Leo <i>Technische Universität Dresden, Dresden, Germany</i>	Chapter 4.13 p. 448
B. Lüssem <i>Technische Universität Dresden, Dresden, Germany</i>	Chapter 4.13 p. 448
J. H. Melby <i>Carnegie Mellon University, Pittsburgh, PA, USA</i>	Chapter 4.03 p. 44
D. W. Palmer <i>University of Exeter, Exeter, UK</i>	Chapter 4.12 p. 390
S. J. Pearton <i>University of Florida, Gainesville, FL, USA</i>	Chapter 4.02 p. 25
S. J. Pennycook <i>Oak Ridge National Laboratory, Oak Ridge, TN, USA</i>	Chapter 4.09 p. 287

L. M. Porter <i>Carnegie Mellon University, Pittsburgh, PA, USA</i>	Chapter 4.03 p. 44
M. Riede <i>Technische Universität Dresden, Dresden, Germany</i>	Chapter 4.13 p. 448
J. Robertson <i>Cambridge University, Cambridge, UK</i>	Chapter 4.05 p. 132
G. Salviati <i>CNR-IMEM Institute, Parma, Italy</i>	Chapter 4.10 p. 308
E. G. Seebauer <i>University of Illinois at Urbana–Champaign, Urbana, IL, USA</i>	Chapter 4.04 p. 86
T. Sekiguch <i>National Institute for Materials Science (NIMS), Ibaraki, Japan</i>	Chapter 4.10 p. 308
K. van Benthem <i>University of California, Davis, CA, USA</i>	Chapter 4.09 p. 287
A. R. Virshup <i>Carnegie Mellon University, Pittsburgh, PA, USA</i>	Chapter 4.03 p. 44
T. Wagner <i>University of Pardubice, Pardubice, Czech Republic</i>	Chapter 4.07 p. 206
R. Wördenweber <i>Forschungszentrum Jülich, Jülich, Germany</i>	Chapter 4.06 p. 177

Contributors to Volume 5

A. Agarwal <i>Cree Inc., Durham, NC, USA</i>	Chapter 5.07 p. 299
J.-H. Ahn <i>Sungkyunkwan University, Suwon, Korea</i>	Chapter 5.11 p. 499
Ph. Avouris <i>IBM TF Watson Research Center, Yorktown Heights, NY, USA</i>	Chapter 5.10 p. 480
S. K. Banerjee <i>University of Texas at Austin, Austin, TX, USA</i>	Chapter 5.02 p. 52
S. Barik <i>Blueglass Ltd., Silverwater, NSW, Australia</i>	Chapter 5.14 p. 584
P. R. Berger <i>The Ohio State University, Columbus, OH, USA</i>	Chapter 5.05 p. 176
M. Buda <i>National Institute for Material Physics, Bucharest-Magurele, Romania</i>	Chapter 5.14 p. 584
S.-W. Chang <i>University of Illinois at Urbana-Champaign, Urbana, IL, USA</i>	Chapter 5.17 p. 724
S. L. Chuang <i>University of Illinois at Urbana-Champaign, Urbana, IL, USA</i>	Chapter 5.17 p. 724
S. Dey <i>Texas Instruments, Inc., Dallas, TX, USA</i>	Chapter 5.02 p. 52
L. Fu <i>The Australian National University, Canberra, ACT, Australia</i>	Chapter 5.14 p. 584
A. W. Ghosh <i>University of Virginia, Charlottesville, VA, USA</i>	Chapter 5.09 p. 383
Y. B. Gianchandani <i>University of Michigan, Ann Arbor, MI, USA</i>	Chapter 5.12 p. 527
A. Gutierrez-Aitken <i>Northrop Grumman Space Technology, Redondo Beach, CA, USA</i>	Chapter 5.04 p. 114
M. M. Hayat <i>University of New Mexico, Albuquerque, NM, USA</i>	Chapter 5.13 p. 560
T. Hiramoto <i>University of Tokyo, Tokyo, Japan</i>	Chapter 5.08 p. 340
C. Jagadish <i>The Australian National University, Canberra, ACT, Australia</i>	Chapter 5.14 p. 584

D.-H. Kim <i>University of Illinois at Urbana–Champaign, Urbana, IL, USA</i>	Chapter 5.11 p. 499
P. K. Kondratko <i>University of Illinois at Urbana–Champaign, Urbana, IL, USA</i>	Chapter 5.17 p. 724
A. Matsudaira <i>University of Illinois at Urbana–Champaign, Urbana, IL, USA</i>	Chapter 5.17 p. 724
L. J. Mawst <i>University of Wisconsin–Madison, Madison, WI, USA</i>	Chapter 5.15 p. 626
S. McNamara <i>University of Louisville, Louisville, KY, USA</i>	Chapter 5.12 p. 527
U. K. Mishra <i>University of California, Santa Barbara, CA, USA</i>	Chapter 5.06 p. 242
K. Miyaji <i>University of Tokyo, Tokyo, Japan</i>	Chapter 5.08 p. 340
S. Mokkaṃpati <i>The Australian National University, Canberra, ACT, Australia</i>	Chapter 5.14 p. 584
R. Paiella <i>Boston University, Boston, MA, USA</i>	Chapter 5.16 p. 683
T. Palacios <i>Massachusetts Institute of Technology, Cambridge, MA, USA</i>	Chapter 5.06 p. 242
A. Ramesh <i>The Ohio State University, Columbus, OH, USA</i>	Chapter 5.05 p. 176
J.-S. Rieh <i>Korea University, Seoul, South Korea</i>	Chapter 5.01 p. 1
J. A. Rogers <i>University of Illinois at Urbana–Champaign, Urbana, IL, USA</i>	Chapter 5.11 p. 499
T. Suemitsu <i>Toboku University, Sendai, Japan</i>	Chapter 5.03 p. 84
H. H. Tan <i>The Australian National University, Canberra, ACT, Australia</i>	Chapter 5.14 p. 584
N. Tansu <i>Lehigh University, Bethlehem, PA, USA</i>	Chapter 5.15 p. 626
J. C. Tsang <i>IBM T J Watson Research Center, Yorktown Heights, NY, USA</i>	Chapter 5.10 p. 480
Y. Wu <i>Transphorm Inc., Goleta, CA, USA</i>	Chapter 5.07 p. 299

Contributors to Volume 6

A. Adibi <i>Georgia Institute of Technology, Atlanta, GA, USA</i>	Chapter 6.13 p. 509
H. Altug <i>Boston University, Boston, MA, USA</i>	Chapter 6.12 p. 486
G. Ariyawansa <i>Georgia State University, Atlanta, GA, USA</i>	Chapter 6.07 p. 265
K. Balakrishnan <i>University of South Carolina, Columbia, SC, USA</i>	Chapter 6.01 p. 1
D. Basu <i>University of Michigan, Ann Arbor, MI, USA</i>	Chapter 6.15 p. 563
C. R. Becker <i>University of Illinois at Chicago, Chicago, IL, USA</i>	Chapter 6.04 p. 128
P. Bhattacharya <i>University of Michigan, Ann Arbor, MI, USA</i>	Chapter 6.10, 6.15 p. 385, 563
W. Bowen <i>University of Michigan, Ann Arbor, MI, USA</i>	Chapter 6.03 p. 101
E. Cagin <i>University of Michigan, Ann Arbor, MI, USA</i>	Chapter 6.03 p. 101
T. N. Casselman <i>EPIR Technologies Inc., Bolingbrook, IL, USA</i>	Chapter 6.04 p. 128
K. K. Choi <i>US Army Research Laboratory, Adelphi, MD, USA</i>	Chapter 6.05 p. 160
A. A. Eftekhari <i>Georgia Institute of Technology, Atlanta, GA, USA</i>	Chapter 6.13 p. 509
D. Englund <i>Stanford University, Stanford, CA, USA</i>	Chapter 6.12 p. 486
C. Ertler <i>University of Regensburg, Regensburg, Germany</i>	Chapter 6.16 p. 615
J. Fabian <i>University of Regensburg, Regensburg, Germany</i>	Chapter 6.16 p. 615
C. H. Grein <i>EPIR Technologies Inc., Bolingbrook, IL, USA</i>	Chapter 6.04 p. 128

S. Guha <i>United Solar Ovonic LLC, Troy, MI, USA</i>	Chapter 6.08 p. 308
M. Holub <i>Naval Research Laboratory, Washington, DC, USA</i>	Chapter 6.15 p. 563
A. Khan <i>University of South Carolina, Columbia, SC, USA</i>	Chapter 6.01 p. 1
S. Krishna <i>University of New Mexico, Albuquerque, NM, USA</i>	Chapter 6.06 p. 229
S. G. Matsik <i>Georgia State University, Atlanta, GA, USA</i>	Chapter 6.07 p. 265
Z. Mi <i>McGill University, Montreal, QC, Canada</i>	Chapter 6.10 p. 385
B. Momeni <i>Georgia Institute of Technology, Atlanta, GA, USA</i>	Chapter 6.13 p. 509
S. Ohya <i>University of Tokyo, Tokyo, Japan</i>	Chapter 6.14 p. 540
A. G. U. Perera <i>Georgia State University, Atlanta, GA, USA</i>	Chapter 6.07 p. 265
J. Phillips <i>University of Michigan, Ann Arbor, MI, USA</i>	Chapter 6.03 p. 101
E. Plis <i>University of New Mexico, Albuquerque, NM, USA</i>	Chapter 6.06 p. 229
J. B. Rodriguez <i>Université Montpellier 2, Montpellier, France</i>	Chapter 6.06 p. 229
D. Saha <i>Indian Institute of Technology, Bombay, Mumbai, India</i>	Chapter 6.15 p. 563
S. Sivananthan <i>University of Illinois at Chicago, Chicago, IL, USA</i>	Chapter 6.04 p. 128
P. M. Smowton <i>Cardiff University, Cardiff, UK</i>	Chapter 6.09 p. 353
A. Sobiesierski <i>Cardiff University, Cardiff, UK</i>	Chapter 6.09 p. 353
M. Soltani <i>Georgia Institute of Technology, Atlanta, GA, USA</i>	Chapter 6.13 p. 509
A. D. Stiff-Roberts <i>Duke University, Durham, NC, USA</i>	Chapter 6.11 p. 452
Y.-K. Su <i>National Cheng Kung University, Tainan, Taiwan, China</i>	Chapter 6.02 p. 28
M. Tanaka <i>University of Tokyo, Tokyo, Japan</i>	Chapter 6.14 p. 540
J. Vuckovic <i>Stanford University, Stanford, CA, USA</i>	Chapter 6.12 p. 486
W. Wang <i>University of Michigan, Ann Arbor, MI, USA</i>	Chapter 6.03 p. 101

B. Yan <i>United Solar Ovonix LLC, Troy, MI, USA</i>	Chapter 6.08 p. 308
J. Yang <i>United Solar Ovonix LLC, Troy, MI, USA</i>	Chapter 6.08 p. 308
S. Yegnanarayanan <i>Georgia Institute of Technology, Atlanta, GA, USA</i>	Chapter 6.13 p. 509
I. Žutić <i>University at Buffalo, SUNY, Buffalo, NY, USA</i>	Chapter 6.16 p. 615