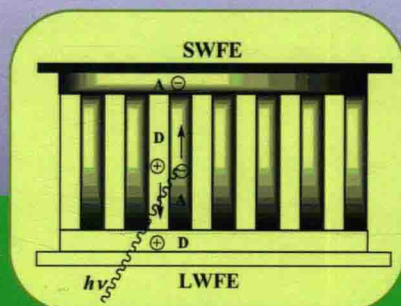


SECOND EDITION

Introduction to Organic Electronic and Optoelectronic Materials and Devices

Edited by
Sam-Shajing Sun
Larry R. Dalton



 **CRC Press**
Taylor & Francis Group

SECOND EDITION

Introduction to Organic Electronic and Optoelectronic Materials and Devices

Edited by

Sam-Shajing Sun

Norfolk State University, Norfolk, Virginia, USA

Larry R. Dalton

University of Washington, Seattle, Washington, USA



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2017 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed on acid-free paper
Version Date: 20160229

International Standard Book Number-13: 978-1-4665-8510-2 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Names: Sun, Sam-Shajing, editor. | Dalton, Larry R., editor.
Title: Introduction to organic electronic and optoelectronic materials and devices / edited by Sam-Shajing Sun and Larry R. Dalton.
Description: Second edition. | Boca Raton : Taylor & Francis, CRC Press, 2017. | Includes bibliographical references and index.
Identifiers: LCCN 2016008935 | ISBN 9781466585102 (hardcover : alk. paper)
Subjects: LCSH: Semiconductors--Materials. | Optoelectronics--Materials. | Organic semiconductors. | Organic compounds--Electric properties.
Classification: LCC TK7871 .I5847 2017 | DDC 621.36--dc23
LC record available at <http://lccn.loc.gov/2016008935>

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

Printed and bound in the United States of America by Publishers Graphics,
LLC on sustainably sourced paper.

SECOND EDITION

Introduction to
**Organic Electronic
and Optoelectronic
Materials and Devices**

Acknowledgments for the Second Edition

The acknowledgments for the first edition of this CRC textbook *Introduction to Organic Electronic and Optoelectronic Materials and Devices* also apply to this second edition with the following additions or changes:

The editor (Dr. Sam-Shajing Sun) thanks the authors of the four new chapters (Chapters 30 through 33) for their expertise, hard work, patience, and very valuable contributions, and co-editor, Dr. Larry Dalton, for his suggestions, reviews, and assistance. The editor particularly acknowledges and thanks Ashley Gasque (acquisition editor at CRC Press) for her enthusiasm toward the second edition of this textbook, Ed Curtis (project editor at CRC Press) for his guidance and assistance, and Vijay Bose (project manager at SPi Global) for typesetting the book.

The editor also acknowledges the U.S. Department of Defense (DOD), Department of Energy (DOE), and the National Science Foundation (NSF) for their support toward the research and/or educational efforts carried out by the editor on subjects related to this textbook.

Last but not least, the editor acknowledges his family (including his children: Marcia, Melanie, Matthew, and Jack) for their love and understanding.

Sam-Shajing Sun, PhD (editor)

*Center for Materials Research and Chemistry Department
PhD Program in Materials Science and Engineering
Norfolk State University
Norfolk, Virginia*

Acknowledgments for the First Edition

Professor Sam-Shajing Sun (editor) wishes to express his sincere appreciation and thanks to the following people and organizations whose contributions and/or assistances are critical and essential to the success of this textbook project.

- CRC Press, Taylor & Francis Group, in particular, Mr. Taisuke Soda (now at McGraw-Hill) for his belief and enthusiasm to this project, Ms. Stephanie J. Morkert and Mr. Richard Tressider for their highly professional assistance, and Dr. S. Vinithan (at SPI) for typesetting the book.
- All contributing authors of this textbook for their expertise, hard work, patience, suggestions, and refereeing service to the project. The editor is fully aware of the challenges and sometimes formidable tasks of translating and presenting a relatively newly developed, complex, and sometimes debatable subject matter into an easily understandable and acceptable format for students and non-experts learning purpose.
- Coeditor Professor Larry R. Dalton. It is Professor Dalton's vision, leadership, and years of assistance/advice, including his assistance and advice to the editor that was very instrumental for the success of this project. Professor Sun also wishes to acknowledge and thank the support and/or contributions from the multi-university-involved Center on Materials and Devices for Information Technology Research (CMDITR, directed by Professor Dalton and sponsored by the National Science Foundation. Award number DMR-0120967).
- Professor Yang Yang at the University of California at Los Angeles, Professor Mikael Wasielewski at Northwestern University, Professor Jean-Luc Brédas at the Georgia Institute of Technology, and particularly, Professor Rudolph A. Marcus (Nobel Laureate, Chemistry, 1992) at the California Institute of Technology, and Professor Alan J. Heeger (Nobel Laureate, Chemistry, 2000) at the University of California at Santa Barbara, for their many helpful discussions with the editor on certain subjects/elements relevant to this book.
- Dr. Aloysius Hepp and Dr. Sheila Bailey (both at NASA Glenn Research Center) and Dr. Charles Lee (at DoD/AFOSR) for their years of support and assistance to the editor via research/educational grants (in particular, a NASA-sponsored Center for Research and Education in Advanced Materials [CREAM], award number NCC3-1035) focusing on subjects in this textbook.
- Last but not least, the editor's family (including his daughter, Marcia M. Sun) for their understanding and support to editor's numerous absences during "non-working" hours, including evenings, weekends, and holidays.

Preface to the Second Edition

All of the information given in the Preface of the first edition of this textbook, *Introduction to Organic Electronic and Optoelectronic Materials and Devices*, apply to this second edition as well, with the following additions:

Since the publication of the first edition in 2008, this textbook has been used and found very helpful in a number of senior-level undergraduate and graduate courses relevant to organic or polymeric electronic and optoelectronic materials and devices, such as a graduate-level course the editor has been teaching at Norfolk State University titled *Introduction to Organic Optoelectronic Materials and Devices* (MSE-660) in a materials science and engineering graduate program. Work on this second edition began as early as 2013, mainly due to recommendations and suggestions from the publisher (CRC Press/Taylor & Francis Group).

Compared to the first edition, the second edition mainly added four new chapters:

Chapter 30—Introduction to Organic Spintronic Materials and Devices

Chapter 31—Introduction to Organic Photo Actuator Materials and Devices

Chapter 32—Introduction to Organic Thermoelectric Materials and Devices

Chapter 33—Introduction to Computational Methods in Organic Materials

Additionally, Chapter 3, “Basic Electronic Structures and Charge Carrier Generation in Organic Optoelectronic Materials,” is modified and expanded with additional material, figures, and equations. Furthermore, some essential figures in several chapters are printed in color in this edition.

Sam-Shajing Sun, PhD (editor)

*Center for Materials Research and Chemistry Department
Norfolk State University
Norfolk, Virginia*

Larry R. Dalton, PhD (coeditor)

*Department of Chemistry
University of Washington
Seattle, Washington*

Preface to the First Edition

Electronic, photonic, and optoelectronic (OE) materials and devices, including, but not limited to, conducting and semiconducting materials used in transistors and integrated circuits (ICs), light-emitting diodes and display/lighting devices, solar cells, photo detectors, electro-optical devices, optoelectronic sensors, etc., have dramatically impacted the way humans live in the twentieth and twenty-first centuries. In OE devices, electrons and photons are used to generate, process, transmit, and store information at unprecedented rates and with ever-decreasing power requirements. Most of today's commercially available electronic and optoelectronic devices are fabricated from inorganic semiconductors and metal conductors. In the past several decades, however, research and development on organic/polymeric electronic and optoelectronic materials and devices has grown rapidly. Compared to their inorganic counterparts, emerging organic and polymeric optoelectronic materials have exhibited advantages such as improved speed, reduced power consumption, increased brightness (for displays), and improved processability leading to conformal and flexible devices and the potential for low-cost mass production. Plastic optoelectronic materials and devices are rapidly becoming a reality.

Though there are a number of specialized research review books relevant to selected topics of organic optoelectronic materials and devices, there are no books available covering the combined subjects of organic electronic and optoelectronic materials/devices suitable for classroom instruction at the senior college level or suitable for providing nonexperts a convenient introduction to this research discipline. It is the objective of this book to serve as a textbook suitable for senior undergraduate or graduate level courses for students majoring in materials science, physics, chemistry, chemical engineering, electrical engineering, optical engineering, or other information/energy-related science and engineering disciplines. This book is also suitable as a desk reference for scientists and engineers involved in research and development in the fields of telecommunications, computing, defense technologies, etc.

As with all books, the publisher, the editors, and the contributing authors have tried their best to make this textbook as informative, accurate, reliable, and nonbiased as possible. However, by no means is this book error-free or inclusive of every critical item. While the editors of this book are mainly responsible for the selection of topics/chapters, contributing authors, and the components/styles of the book, it is the contributing authors who are mainly responsible for the contents, opinions, and accuracy of each topic/chapter. Any comments, suggestions, or questions about this book (particularly those from course instructors/students) are welcomed and may be directed directly to the book editors or the contributing authors. It is hoped that the subsequent editions of this textbook could be further improved after instructional activities and feedbacks.

Sam-Shajing Sun, PhD (editor)

*Center for Materials Research and Chemistry Department
Norfolk State University
Norfolk, Virginia*

Larry R. Dalton, PhD (coeditor)

*Department of Chemistry
University of Washington
Seattle, Washington*

Editors

Sam-Shajing Sun, PhD, earned a BS in physical chemistry at Peking University (PKU) in China, an MS in inorganic/analytical/nuclear chemistry at California State University at Northridge (CSUN), and a PhD in organic/polymer/materials chemistry at the University of Southern California (USC). Dr. Sun's PhD dissertation (under the direction of Professor Larry R. Dalton) was titled "Design, Synthesis, and Characterization of Novel Organic Photonic Materials." After postdoctoral research experience at the Locker Hydrocarbon Institute (Director, George A. Olah), Dr. Sun joined the chemistry faculty of Norfolk State University (NSU) in 1998, was promoted to associate professor (with tenure) in 2002 and full professor in 2006. Since joining NSU, Dr. Sun has won a number of U.S. government research and educational grant awards in the field of optoelectronic polymers and is currently leading several research and education project focused on advanced optoelectronic and nanomaterials. Dr. Sun's main research interests and expertise are in the design, synthesis, processing, characterization, and modeling of novel polymers and thin-film devices for optoelectronic applications, particularly photovoltaic energy conversion.

Larry R. Dalton, PhD, BS (1965) and MS (1966) from the Honors College of Michigan State University and AM, PhD (1971) from Harvard University, is the George B. Kauffman Professor of Chemistry and Electrical Engineering and B. Seymour Rabinovitch Chair Professorship at the University of Washington, where he also directed the National Science Foundation, Science and Technology Center on Materials and Devices for Information Technology Research. Since 2002 he has received such awards as the 2006 IEEE/LEOS William Streifer Scientific Achievement Award, the 2003 Chemistry of Materials Award of the American Chemical Society, and the Quality Education for Minorities/Mathematics, Science, and Engineering Network 2005 Giants in Science Award. During this period, Professor Dalton was elected fellow of the American Association for the Advancement of Science and become a senior member of the IEEE (2006). His research interests focus on high-performance organic electro-optic materials and new sensor materials including metamaterials and silicon photonics. More information on Professor Dalton can be accessed at <http://depts.washington.edu/eooptic/>.

Contributors

Rabih O. Al-Kaysi

Department of Chemistry
University of California, Riverside
Riverside, California

Christopher J. Bardeen

Department of Chemistry
University of California, Riverside
Riverside, California

Kevin D. Belfield

Department of Chemistry
and
College of Optics and Photonics
University of Central Florida
Orlando, Florida

now at

College of Science
New Jersey Institute of Technology
Newark, New Jersey

Mykhailo V. Bondar

Institute of Physics
National Academy of Sciences (NAS) of
Ukraine
Kiev, Ukraine

Prasanna Chandrasekhar

Ashwin-Ushas Corporation
Marlboro, New Jersey

Antao Chen

Applied Physics Lab (APL)
University of Washington
Seattle, Washington

Jinghong Chen

Honeywell Electronic Materials
Sunnyvale, California

Liming Dai

Department of Chemical and Materials
Engineering
University of Dayton
Dayton, Ohio

now at

Department of Macromolecular Science and
Engineering
School of Engineering
Case Western Reserve University
Cleveland, Ohio

Arthur J. Epstein

Department of Physics
and
Department of Chemistry
Ohio State University
Columbus, Ohio

Antonio Facchetti

Department of Chemistry
and
Materials Research Center
Northwestern University
Evanston, Illinois

M. Fallahi

College of Optical Science
University of Arizona
Tucson, Arizona

Yongli Gao

Department of Physics and Astronomy
University of Rochester
Rochester, New York

Sebastian Gauza

College of Optics and Photonics
University of Central Florida
Orlando, Florida

Vladimir I. Gavrilenko

Center for Materials Research
Norfolk State University
Norfolk, Virginia

now at

VLEXCO L.L.C.
Newport News, Virginia

Xiong Gong

Institute for Polymers and Organic Solids
University of California, Santa Barbara
Santa Barbara, California

now at

Department of Polymer Engineering
University of Akron
Akron, Ohio

Peter Günter

Nonlinear Optics Laboratory
ETH Zurich—Swiss Federal Institute of
Technology
Zürich, Switzerland

Joel M. Hales

School of Chemistry and Biochemistry
Georgia Institute of Technology
Atlanta, Georgia

J.R. Heflin

Department of Physics
Virginia Polytechnic Institute and State
University
Blacksburg, Virginia

Jianhui Hou

Key Laboratory of Organic Solids
Institute of Chemistry
Chinese Academy of Sciences
Beijing, China

Sei-Hum Jang

Department of Materials Science and
Engineering
University of Washington
Seattle, Washington

Mojca Jazbinsek

Nonlinear Optics Laboratory
ETH Zurich—Swiss Federal Institute of
Technology
Zürich, Switzerland

Alex K.-Y. Jen

Department of Materials Science and
Engineering
University of Washington
Seattle, Washington

Taehyung Kim

Department of Chemistry
University of California, Riverside
Riverside, California

Arvind Kumar

Department of Chemistry and the Polymer
Program
University of Connecticut
Mansfield, Connecticut

Thein Kyu

Department of Polymer Engineering
University of Akron
Akron, Ohio

Yongfang Li

Key Laboratory of Organic Solids
Institute of Chemistry
Chinese Academy of Sciences
Beijing, China

Scott Meng

Department of Polymer Engineering
University of Akron
Akron, Ohio

Xianle Meng

Laboratory for Advanced Materials and
Institute of Fine Chemicals
East China University of Science and
Technology
Shanghai, China

Hatsumi Mori

Institute for Solid State Physics
University of Tokyo
Tokyo, Japan

and

Care Research for Evolutional Science and
Technology
Japan Science and Technology Agency
Saitama, Japan

Tammene Naddo

Department of Chemistry and Biochemistry
Southern Illinois University
Carbondale, Illinois

Yogesh Ner

Department of Chemistry and the Polymer
Program
University of Connecticut
Mansfield, Connecticut

Tho D. Nguyen

Department of Physics and Astronomy
University of Georgia
Athens, Georgia

Oksana Ostroverkhova

Department of Physics
Oregon State University
Corvallis, Oregon

Joseph W. Perry

School of Chemistry and Biochemistry
Georgia Institute of Technology
Atlanta, Georgia

Nasser Peyghambarian

College of Optical Science
University of Arizona
Tucson, Arizona

Joachim Piprek

NUSOD Institute
Newark, Delaware

Vladimir N. Prigodin

Department of Physics
Ohio State University
Columbus, Ohio

and

A.F. Ioffe Physico-Technical Institute
St. Petersburg, Russia

Liangti Qu

Department of Chemical and Materials
Engineering
University of Dayton
Dayton, Ohio

Mohd Faizul Mohd Sabri

Department of Electrical Engineering
University of Malaya
Kuala Lumpur, Malaysia

Suhana Mohd Said

Department of Electrical Engineering
University of Malaya
Kuala Lumpur, Malaysia

Henrik G.O. Sandberg

VTT Technical Research Center of Finland
Espoo, Finland

Jianmin Shi

Optical Electronics and Sensor Divisions
U.S. Army Research Laboratory
Adelphi, Maryland

Franky So

Department of Materials Science and
Engineering
University of Florida
Gainesville, Florida
now at

Department of Materials Science and
Engineering
North Carolina State University
Raleigh, North Carolina

Gregory A. Sotzing

Department of Chemistry and the Polymer
Program
University of Connecticut
Storrs, Connecticut

Geoffrey M. Spinks

ARC Centre of Excellence for Electromaterials
Science
University of Wollongong
Wollongong, New South Wales, Australia

Sam-Shajing Sun

Center for Materials Research and Chemistry
Department
Norfolk State University
Norfolk, Virginia

He Tian

Laboratory for Advanced Materials and
Institute of Fine Chemicals
East China University of Science and
Technology
Shanghai, China

Van-Tan Truong

Maritime Platforms Division
Defence Science and Technology Organisation
Melbourne, Victoria, Australia

Gordon G. Wallace

ARC Centre of Excellence for Electromaterials
Science
University of Wollongong
Wollongong, New South Wales, Australia

Shu Wang

Key Laboratory of Organic Solids
Institute of Chemistry
Chinese Academy of Science
Beijing, China

Philip G. Whitten

ARC Centre of Excellence for Electromaterials
Science
University of Wollongong
Wollongong, New South Wales, Australia

Xiaomei Yang

Department of Chemistry and Biochemistry
Southern Illinois University
Carbondale, Illinois

Yang Yang

Department of Materials Science and
Engineering
University of California
Los Angeles, California

Sheng Yao

Department of Chemistry
and
College of Optics and Photonics
University of Central Florida
Orlando, Florida

Ling Zang

Department of Chemistry and Biochemistry
Southern Illinois University
Carbondale, Illinois

now at

Department of Chemistry
University of Utah
Salt Lake City, Utah

Cheng Zhang

Center for Materials Research and Chemistry
Department
Norfolk State University
Norfolk, Virginia

now at

Department of Chemistry and Biochemistry
South Dakota State University
Brookings, South Dakota

Lingyan Zhu

Department of Chemistry
University of California, Riverside
Riverside, California

Weihong Zhu

Laboratory for Advanced Materials and
Institute of Fine Chemicals
East China University of Science and
Technology
Shanghai, China

Contents

Acknowledgments for the Second Edition.....	ix
Acknowledgments for the First Edition.....	xi
Preface to the Second Edition.....	xiii
Preface to the First Edition.....	xv
Editors.....	xvii
Contributors.....	xix
Chapter 1 Introduction to Optoelectronic Materials.....	1
<i>Nasser Peyghambarian and M. Fallahi</i>	
Chapter 2 Introduction to Optoelectronic Device Principles.....	25
<i>Joachim Piprek</i>	
Chapter 3 Basic Electronic Structures and Charge Carrier Generation in Organic Optoelectronic Materials.....	47
<i>Sam-Shajing Sun</i>	
Chapter 4 Charge Transport in Conducting Polymers.....	101
<i>Vladimir N. Prigodin and Arthur J. Epstein</i>	
Chapter 5 Major Classes of Organic Small Molecules for Electronics and Optoelectronics.....	143
<i>Xianle Meng, Weihong Zhu, and He Tian</i>	
Chapter 6 Major Classes of Conjugated Polymers and Synthetic Strategies.....	189
<i>Yongfang Li and Jianhui Hou</i>	
Chapter 7 Low Energy Gap, Conducting, and Transparent Polymers.....	225
<i>Arvind Kumar, Yogesh Ner, and Gregory A. Sotzing</i>	
Chapter 8 Conjugated Polymers, Fullerene C ₆₀ , and Carbon Nanotubes for Optoelectronic Devices.....	251
<i>Liangti Qu, Liming Dai, and Sam-Shajing Sun</i>	
Chapter 9 Introduction of Organic Superconducting Materials.....	277
<i>Hatsumi Mori</i>	
Chapter 10 Molecular Semiconductors for Organic Field-Effect Transistors.....	299
<i>Antonio Facchetti</i>	

Chapter 11	Polymer Field-Effect Transistors.....	331
	<i>Henrik G.O. Sandberg</i>	
Chapter 12	Organic Molecular Light-Emitting Materials and Devices	363
	<i>Franky So and Jianmin Shi</i>	
Chapter 13	Polymer Light-Emitting Diodes: Devices and Materials	387
	<i>Xiong Gong and Shu Wang</i>	
Chapter 14	Organic and Polymeric Photovoltaic Materials and Devices.....	415
	<i>Sam-Shajing Sun and Cheng Zhang</i>	
Chapter 15	Organic Molecular Nonlinear Optical Materials and Devices	435
	<i>Mojca Jazbinsek and Peter Günter</i>	
Chapter 16	Polymeric Second-Order Nonlinear Optical Materials and Devices.....	483
	<i>Sei-Hum Jang and Alex K.-Y. Jen</i>	
Chapter 17	Organic and Polymeric Third-Order Nonlinear Optical Materials and Device Applications	529
	<i>Joel M. Hales and Joseph W. Perry</i>	
Chapter 18	Organic Multiphoton Absorbing Materials and Devices	589
	<i>Kevin D. Belfield, Sheng Yao, and Mykhailo V. Bondar</i>	
Chapter 19	Organic and Polymeric Photorefractive Materials and Devices	625
	<i>Oksana Ostroverkhova</i>	
Chapter 20	Organic/Metal Interface Properties	657
	<i>Yongli Gao</i>	
Chapter 21	Single-Molecule Organic Electronics and Optoelectronics.....	681
	<i>Ling Zang, Xiaomei Yang, and Tammene Naddo</i>	
Chapter 22	Introduction to Nonvolatile Organic Thin-Film Memory Devices.....	723
	<i>Yang Yang</i>	
Chapter 23	Introduction to Organic Electrochromic Materials and Devices.....	735
	<i>Prasanna Chandrasekhar</i>	

Chapter 24 An Introduction to Conducting Polymer Actuators 755
Geoffrey M. Spinks, Philip G. Whitten, Gordon G. Wallace, and Van-Tan Truong

Chapter 25 Organic Liquid Crystal Optoelectronic Materials and Devices..... 787
Sebastian Gauza

Chapter 26 Organic and Polymeric Photonic Band Gap Materials and Devices 815
Scott Meng and Thein Kyu

Chapter 27 Introduction to Polymer Photonics for Information Technology 841
Antao Chen

Chapter 28 Organic Low-Dielectric Constant Materials for Microelectronics 867
Jinghong Chen

Chapter 29 Self-Assembly of Organic Optoelectronic Materials and Devices 889
J.R. Heflin

Chapter 30 Introduction to Organic Spintronic Materials and Devices 911
Tho D. Nguyen

Chapter 31 Introduction to Organic Photo Actuator Materials and Devices..... 957
Lingyan Zhu, Taehyung Kim, Rabih O. Al-Kaysi, and Christopher J. Bardeen

Chapter 32 Introduction to Organic Thermoelectric Materials and Devices 985
Suhana Mohd Said and Mohd Faizul Mohd Sabri

Chapter 33 Introduction to Computational Methods in Organic Materials..... 1023
Vladimir I. Gavrilenko

Index..... 1043

1 Introduction to Optoelectronic Materials

Nasser Peyghambarian and M. Fallahi

CONTENTS

1.1	Introduction	1
1.2	Types of Optoelectronic Materials	2
1.2.1	Semiconductors.....	2
1.2.1.1	Basic Concepts in Semiconductors.....	2
1.2.1.2	p–n Homojunctions and Heterojunctions.....	4
1.2.1.3	Alloy Semiconductors, Quantum Wells, and Strained Quantum Wells.....	5
1.2.1.4	Light Absorption and Emission in Semiconductors	9
1.2.1.5	Semiconductor LEDs and Lasers.....	10
1.2.2	Optical Glass.....	10
1.2.3	Electro-Optic Materials	12
1.2.4	Organic and Polymeric Materials.....	14
1.3	Waveguiding Principles for Optoelectronic Materials	14
1.3.1	Waveguiding in Semiconductors	16
1.3.2	Waveguiding in Glass–Ion-Exchange Glass and Optical Fibers	17
1.3.3	Waveguiding in EO Materials Like LiNbO_3	18
1.3.4	Silica-on-Silicon Waveguides	18
1.3.5	Waveguiding in Organic Materials.....	20
1.4	Challenges and Recent Developments.....	21
1.4.1	Material Fabrication and Compatibility	21
1.4.2	Heterogeneous Integration	21
	Exercise Questions	23
	List of Abbreviations.....	23
	References.....	24

Abstract: This chapter summarizes the principles of optoelectronic materials. Four classes of materials, including inorganic semiconductors; glassy materials; electro-optic crystals, such as lithium niobate (LiNbO_3); and organic and polymeric materials, are reviewed. Waveguiding approaches in these four classes of materials are also reviewed and some current examples provided. Finally some of the challenges in optoelectronic materials including compatibility issues, hybrid materials, and integration between different types of materials are discussed.

1.1 INTRODUCTION

Since the early 1980s the field of integrated optics and optoelectronics has experienced very rapid growth. Today optical technologies are extensively used in a wide range of applications such as telecommunications, medical, and security systems. Lasers and other photonic components are