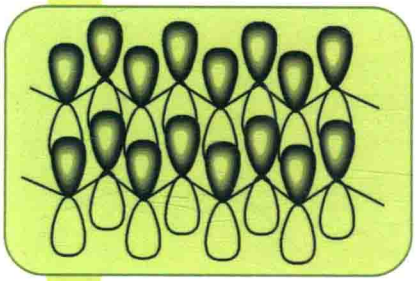

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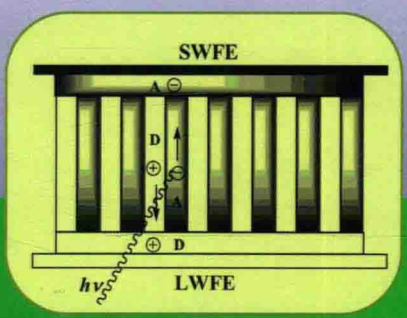
Larry R. Dalton



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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.

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

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Acknowledgments for the First Edition

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- 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).
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- 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.

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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.

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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 Amercian 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/.

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Contents

1 Introduction to Optoelectronic Materials

Nasser Peyghambarian and M. Fallahi

CONTENTS

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