Organic Light-Emitting Devices

SPRINGER SCIENCE+BUSINESS MEDIA, LLC

Joseph Shinar
Editor

Organic Light-Emitting Devices

A Survey

With 158 Illustrations

AIP PRESS

Springer

Joseph Shinar
Ames Laboratory
USDOE and Department of
Physics and Astronomy
Iowa State University
Ames, IA 50011
USA
shinar@ameslab.gov

Library of Congress Cataloging-in-Publication Data
Organic light-emitting devices : a survey / editor, Joseph Shinar.
p. cm.
Includes bibliographical references and index.

1. Light emitting diodes. 2. Polymers Electric properties. I. Shinar, Joseph.
TK787.89.L53 O73 2002
621.3815′22 dc21 2001049272

ISBN 978-1-4419-2960-0 ISBN 978-0-387-21720-8 (eBook)
DOI 10.1007/978-0-387-21720-8

Originally published by Springer-Verlag New York, Inc in 2004
Softcover reprint of the hardcover 1st edition 2004

9 8 7 6 5 4 3 2 1

www.springer-ny.com

Preface

This volume on organic light-emitting devices (OLEDs) has been written to serve the needs of the beginning researcher in this area as well as to be a reference for researchers already active in it.

From their very beginning, OLEDs, which include both small-molecular- and ploymer-based devices, were recognized as a promising display technology. As the dramatic improvements in the devices unfolded over the past two decades, the investment of research and development resources in this field grew exponentially. The fascination with these devices is due to several potential advantages: (1) Relative ease and low cost of fabrication, (2) their basic properties as active light-emitters (in contrast to liquid-crystal displays, which are basically polarizing filters requiring a backlight), (3) flexibility, (4) transparency, and (5) scalability. Once the performance of red-to-green OLEDs approached and then exceeded that of incandescent bulbs and fluorescent lights, it became clear that they are serious candidates for general solid-state lighting technology, competing directly with inorganic LEDs. Hence, while inorganic LEDs are the dominant solid-state lighting devices at present, OLEDs are expected to gradually replace the inorganic devices in more and more niche areas. Finally, OLEDs are attracting considerable attention as building blocks for some types of molecular electronic devices, and, most recently, for spintronic devices. In short, although their introduction into commercial products began only a few years ago, the breadth of their impact is widening rapidly.

The first reports of electroluminescence (EL) from an organic material can be traced back to 1907, and the first actual OLED, based on anthracene, was fabricated in 1963. However, it was not a thin-film device, and the operating voltage was extremely high. After years of efforts to improve its performance, interest in the subject waned. The breakthroughs that led to the exponential growth of this field and to its first commercialized products can be traced to two poineering papers. The 1987 paper by Tang and Van Slyke demonstrated that the performance of green-emitting thin film OLEDs based on the small organic molecule tris(8-hydroxy quinoline) Al (Alq_3) is sufficiently promising to warrant extensive research on a wide variety of thin film OLEDs. The 1990 paper by Bradley, Friend, and coworkers described the first ploymer OLED (PLED), which was based on poly(*p*-phenylene vinylene) (PPV), and demonstrated that such devices warrant close scrutiny as well. Since then, the competition between small-molecular OLEDs and PLEDs continues in parallel with the overall dramatic developments of this field. This volume has tried to mirror this competition by devoting comparable attention to these two subfields.

The first chapter provides an introduction to the basic physics of OLEDs and surveys the various topics and challenges in this field. It includes a description of the basic optical and transport processes, the materials used in some of the OLEDs that have studied extensively to date, the performance of various blue-to-red OLEDs, and a brief outlook.

Chapters 2 through 4 are devoted to small-molecular OLEDs. Chapter 2 focuses on design concepts for molecular materials yielding high performance small molecular OLEDs, including the recent developments in electrophosphorescent devices. Chapter 3 focuses on the degradation processes affecting Alq_3, which is arguably the small molecular device material that has been studied in more detail than any other. Chapter 4 is devoted to organic microcavity light emitting diodes, providing a review of the geometrical effects of the OLED geometry on its performance.

Chapters 5 through 9 are devoted to various PLEDs. Chapter 5 provides an extensive review of devices based poly(*p*-phenylene vinylene), which has been studied more than any other light-emitting polymer. Chapter 6 is devoted to the dominant effects of polymer morphology on device performance. Chapter 7 is devoted to studies of the transient EL in PPV-based PLEDs, which exhibit EL spikes and have provided considerable insight into details of carrier dynamics in these devices. Chapter 8 reviews the extensive work on EL of polyparaphenylenes (PPPs), which in 1993 were the first reported blue-light emitting polymers. Although other blue-light emitting polymers have been developed since then, notably polyfluorenes and phenyl-substituted polyacetylenes, PPPs were studied extensively and provided extensive insight into light-emitting polymers in general and blue emitters in particular. Chapter 9 reviews direct and alternating current light-emitting devices based on pyridine-containing conjugated polymers. In particular, it describes the symmetrically-configured AC light-emitters (SCALE) devices and discusses their potential. Finally, Chapter 10 focuses on polyflurorene-based PLEDs which developed during the past six years and are perhaps the most promising blue devices, and consequently provide a basis for full-color PLED-based displays.

In spite of the fast pace of developments on OLEDs, it is hoped that the topics provided in this volume will be valuable as tutorials for the beginning resercher and as a desktop reference for the advanced researcher for some time to come.

Joseph Shinar
Ames, IA, February, 2003

Contents

Contributors

Editor:
Joseph Shinar, Ames Laboratory – USDOE & Department of Physics and Astronomy, Iowa State University, Ames, IA

Chapter 1:
Joseph Shinar, Ames Laboratory – USDOE & Department of Physics and Astronomy, Iowa State University, Ames, IA
Vadim Savvateev, 3M Corporate Research Center, St. Paul, MN

Chapter 2:
Chihaya Adachi, Department of Photonics Materials Science, Chitose Institute of Science & Technology (CIST), Chitose, Japan
Tetsuo Tsutsui, Department of Materials Science and Technology, Graduate School of Engineering Sciences, Kyushu University, Kasuga, Fukuoka, Japan

Chapter 3:
Fotis Papadimitrakopoulos, Department of Chemistry and Institute of Materials Science, University of Connecticut, Storrs, CT
Baocheng Yang, Department of Chemistry and Institute of Materials Science, University of Connecticut, Storrs, CT
Keith Higginson, Triton Systems Inc., Chelmsford, MA
D. Laurence Thomsen III, NASA Landley Research Center, Hampton, VA

Chapter 4:
Ananth Dodabalapur, Department of Electrical and Computer Engineering, Microelectronics Research Center, The University of Texas at Austin, Austin, TX

Chapter 5:
Neil C. Greenham, Cavendish Laboratory, Cambridge University, Cambridge, UK
Richard H. Friend, Cavendish Laboratory, Cambridge University, Cambridge, UK

Chapter 6:
Yang Yang, Department of Material Science and Engineering, University of California, Los Angeles, CA
Yijian Shi, Department of Materials Science and Engineering, University of California, Los Angeles, CA
Jie Liu, General Electric Global Research, Niskayuna, NY

Chapter 7:
Aharon Yakimov, GE Global Research Center, Niskayuna, NY 12309
Vadim Savvateev, 3M Corporate Research Center, St. Paul, MN
Dan Davidov, Racah Institute of Physics, The Hebrew University, Jerusalem, Israel

Chapter 8:
Stefan Tasch, Institut für Festkorpephysik, Technische Universitt Graz, Austria
Wilhelm Graupner, Austriamicrosystems AG, Schloss Premstaetten, Austria
Guenther Leising, Institut für Festkorpephysik, Technische Universität Graz, Austria

Chapter 9:
Arthur J. Epstein, Department of Physics, Department of Chemistry, and Center for Materials Research, The Ohio State University, Columbus, OH
D. Gebler, The Ohio State University, Columbus, OH
Y. Z. Wang, The Ohio State University, Columbus, OH

Chapter 10:
Paul A. Lane, Draper Laboratory, Cambridge, MA