Jiun-Haw Lee | David N. Liu | Shin-Tson Wu

Introduction to FLAT PANEL DISPLAYS

WILEY SID Series in **Display Technology**

Introduction to

FLAT PANEL DISPLAYS

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Flat Panel Displays (FPDs) are a frequent feature in our daily lives, used in mobile phones, laptop computers, desktop computer monitors and TVs. Several display technologies have been developed for FPDs, such as liquid crystal display (LCD), plasma display panel (PDP), light emitting diode (LED), organic light emitting device (OLED) and field emission display (FED).

Introduction to Flat Panel Displays describes the fundamental sciences behind each display technology: LCD, PDP, LED, OLED and FED including carbon nanotubes. It contains a comparative analysis of the different display technologies in which detailed overviews of each technology are linked together so as to provide a comprehensive reference for students and display engineers, alike. Solved problems as well as homework problems are provided in each chapter. Solutions are hosted on an accompanying website.

Senior undergraduate and graduate students taking courses in engineering, physics and chemistry will benefit from the systematic approach used throughout the book, which will help to prepare students for entry into a display profession. Display engineers, research scientists and technicians working on the development of flat panel display technology will also find this book an invaluable resource. Comparisons of the strengths and weaknesses of each of the display technologies will help professionals to decide which to use for their applications.

Features include:

- the classifications and specifications of display technologies as guidelines for developing a display and judging its performance;
- principles for designing color displays with good color saturation and wide color gamut;
- basic operating principles of thin-film transistors (TFTs) and their applications to state-of-the-art TFT-LCD and TFT-OLED;
- an overview of FED fundamentals comprising the physics of field emission, as well as FED structure and display mechanism.

Companion Website **www.wiley.com/go/leeflatpanel**

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The Society for Information Display (SID) is an international society which has the aim of encouraging the development of all aspects of the field of information display. Complementary to the aims of the society the Wiley–SID series is intended to explain the latest developments in information display technology at a professional level. The broad scope of the series addresses all facets of information displays from technical aspects through systems and prototypes to standards and ergonomics.

ISBN 978-0-470-51693-5

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John Wiley & Sons, Ltd

This edition first published 2008

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex,
PO19 8SQ, United Kingdom

Library of Congress Cataloging-in-Publication Data

Lee, Jiun-Haw.
Introduction to flat panel displays / by Jiun-Haw Lee,
David N. Liu, and Shin-Tson Wu.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-51693-5 (cloth)
1. Flat panel displays. I. Liu, David N. II. Wu, Shin-Tson. III. Title.
TK7882.I6L436 2008
621.3815′422—dc22

2008032204

A catalogue record for this book is available from the British Library.

ISBN: 978-0-470-51693-5 (H/B)

Set in 9/11pt Times by Integra Software Services Pvt. Ltd, Pondicherry, India
Printed in Great Britain by CPI Antony Rowe, Chippenham, Wiltshire

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Series Editor's Foreword

Article 2 of the bylaws of the Society for Information Display begins "*1. The purpose of SID shall be: a) To encourage the scientific, literary and educational advancement of information display and its allied arts and sciences...*". This book series was begun eleven years ago with the express object of extending that encouragement, which in the printed form amounted to publishing conference proceedings and a Journal of peer refereed papers, to the provision of a series of books which would satisfy the needs of scientists and engineers working in the wide and complex field of displays. More recently in 2006, we published "Fundamentals of Liquid Crystal Devices" by Deng-Ke Yang and Shin-Tson Wu (who – not coincidentally – is a co-author of this book). That book extended the readership because it was written primarily as a post graduate textbook.

This latest volume in the series extends that educational scope still further by describing the operating principles and the methods of fabrication of technologies used or of potential use in flat panel displays, their methods of addressing, systems aspects and the underpinning science. Although general books on flat panel displays have been published in the past, this is the first comprehensive flat panel display textbook to have been written at this academic level. Its readership and its use will extend far beyond post graduate courses as it offers in a single volume material of great value to practising industrial engineers and scientists across the whole range of flat panel technologies.

In my foreword, I usually provide a précis of the contents of a book, but the authors have done this so comprehensively that such an effort on my part would be superfluous. It merely remains for me to thank them for the great effort they have put into writing this book and wholeheartedly to commend it to our present and expanding readership.

Anthony C Lowe
Series Editor
Braishfield, UK.

About the authors

Jiun-Haw Lee

Jiun-Haw Lee received BSEE, MSEE and PhD degrees in electrical engineering in 1994, 1995 and 2000, respectively, all from National Taiwan University, Taipei, Taiwan. From 2000 to 2003 he was with the RiTdisplay Corporation as the director. In 2003 he joined the faculty of National Taiwan University in the Graduate Institute of Photonics and Optoelectronics and the Department of Electrical Engineering, where he is currently an associate professor. His research interests include organic light-emitting devices, display technologies and solid-state lighting.

Dr Lee is a member of the IEEE, OSA, MRS and SPIE. He received the Exploration Research Award of Pan Wen Yuan Foundation and Lam Research Award in both 2005 and 2006. He has published over 40 journal papers, 100 conference papers and 20 issued patents.

David N. Liu

David N. Liu has been the director of the Strategic Planning Division in the Display Technology Center (DTC) of the Industrial Technology Research Institute (ITRI) since 2006. He worked on IC and field emission displays at ERSO (Electronics Research and Service Organization)/ITRI and Bellcore (Bell Communication Research) from 1983 to 1996. He started his research and development work on plasma display panels at Acer Peripheral Inc. and AUO from 1996 to 2002. After his service at AUO, he was in charge of the flat panel display technology division in ERSO/ITRI until 2006.

Dr Liu received his PhD degree in electrical engineering from New Jersey Institute of Technology in 1992. He has over 45 issued patents, 18 published papers and a contributed chapter of the *Semiconductor Manufacturing Handbook* (McGraw-Hill, 2005). He also successfully developed field emission displays, plasma display panels and flat panel displays followed by the receipt of many awards from ITRI, Photonics Industry and Technology Development Association, Administration Bureau of Science Base Industry Park and the Ministry of Economic Affairs (MOEA). He was also a recipient of the Outstanding Project Leader Award from MOEA in 2006.

Shin-Tson Wu

Shin-Tson Wu is a PREP professor at the College of Optics and Photonics, University of Central Florida (UCF). Prior to joining UCF in 2001, Dr Wu worked at Hughes Research Laboratories (Malibu, California) for 18 years. He received his PhD in physics from the University of Southern California (Los Angeles) and BS in physics from National Taiwan University (Taipei).

Prof. Wu has co-authored four books: *Fundamentals of Liquid Crystal Devices* (Wiley, 2006), *Introduction to Microdisplays* (Wiley, 2006), *Reflective Liquid Crystal Displays* (Wiley, 2001) and *Optics and Nonlinear Optics of Liquid Crystals* (World Scientific, 1993), six book chapters, over 300 journal publications and 75 issued and pending patents.

Prof. Wu is a fellow of the IEEE, OSA, SID and SPIE. He is a recipient of the SPIE G.G. Stokes award, SID Jan Rajchman Prize, SID Special Recognition Award, SID Distinguished Paper Award, Hughes team achievement award, Hughes Research Laboratories outstanding paper award, UCF Distinguished Researcher Award and UCF Research Incentive Award. He was the founding editor-in-chief of the IEEE/OSA *Journal of Display Technology*.

Preface

Flat panel displays (FPDs) are everywhere in our daily lives: mobile phones, notebooks, monitors, TVs, traffic signals and electronic signage are a few examples. Several FPD technologies, such as liquid crystal displays (LCDs), plasma display panels (PDPs), light-emitting diodes (LEDs), organic light-emitting devices (OLEDs) and field emission displays (FEDs), have been developed. They coexist because each technology has its own unique properties and applications.

However, due to the diversity of display materials and operating mechanisms, there has not been a textbook covering the fundamental physics of such a wide spectrum of display technologies. There are books dedicated to a specific display technology or book chapters covering different display technologies. This book is intended as a textbook for senior undergraduate and graduate students with a wide variety of backgrounds, such as electrical engineering, electronics, material science, applied physics and optical engineering. It can also be used as a reference book for engineers and scientists working in display industries. Parts of the material in this book and its organization follow the course 'Introduction to display technologies', which has been taught by Jiun-Haw Lee in the Graduate Institute of Photonics and Optoelectronics (GIPO) and Department of Electrical Engineering, National Taiwan University (NTU), Taipei, Taiwan, since 2003.

This book introduces basic operation principles and underlying physics for thin-film transistors (TFTs) LCDs, PDPs, LEDs, OLEDs and FEDs in each chapter. The LCD is a nonemissive display. From the electrical viewpoint, each pixel is a light switch driven by a TFT. To reduce leakage current of the capacitor, the liquid crystal material should have a high resistivity. Moreover, to achieve a high contrast ratio, most direct-view TFT LCDs require two absorption-type sheet polarizers. These polarizers not only reduce the light efficiency but also limit the LCD's viewing angle. Therefore, phase compensation films are required for wide-view LCDs. In contrast, the PDP is an emissive display. It can be considered as consisting of millions of miniature fluorescent lamps on a single panel. LEDs and OLEDs are electroluminescent devices with crystallized semiconductors and amorphous organic materials, respectively. Compared with liquid crystal materials which are also organic compounds, OLED materials should exhibit a low resistivity to reduce ohmic losses. A FED is a type of flat cathode ray tube, which has all the advantages of this mature technology.

In this book, both basic physics and practical issues (such as material requirements, device configurations, fabrication methods and driving techniques) of different display technologies are addressed. Each display technology is at a different development stage; some are more mature than others. Generally speaking, they are still advancing so rapidly that it is difficult to keep up with the technological advancements. Thus, in this introductory book we have decided to emphasize the fundamental science and only highlight the key technological advancements of each technology.

Another objective of this book is to provide background knowledge for readers from interdisciplinary fields to stimulate new ideas. Since display technologies cover very broad scientific spectra, any breakthrough from any aspect may result in substantial progress in this industry. Sometimes there is not only competition but also cooperation among different display technologies. For example, LCDs and LEDs are distinct technologies for different display applications. However, LEDs can be also used as

backlights for LCDs. As a result, the color gamut is widened, the dynamic contrast ratio is enhanced and power consumption is reduced. After reading this book, one may expect to have a whole picture of display technologies from scientific, technical and engineering viewpoints. There are different kinds of technologies suitable for different sizes (ranging from smaller than an inch to more than a hundred inches in diagonal measurement) and applications (such as outdoor, indoor and mobile displays). Furthermore, this book may serve as a stepping stone to more advanced research and development.

The organization of this book is as follows. Chapter 1 introduces the classifications and specifications of display technologies, which are guidelines for developing a display and judging performance. Applications suitable for different technologies (LCD, PDP, LED, OLED and FED) are also illustrated. Displays are used to produce or reproduce color images. In Chapter 2 we introduce the stages of color formation from a scientific viewpoint. Then, the chromaticity diagram is used to quantitatively describe colors. Finally, one can use the background of color science to engineer the color performance of a display. Chapter 3 describes the TFTs based on semiconductor material, which are used to drive LCDs and OLEDs. Since this is an introductory textbook, some basic semiconductor physics are first introduced, which is also useful knowledge for Chapter 6. Material aspects of amorphous silicon and polycrystalline silicon are discussed. Then, device structures and their performances are introduced. Finally, driving techniques and circuits for LCDs and OLEDs are demonstrated. Emerging TFT technologies, such as organic and oxide TFTs, are briefly discussed.

In Chapter 4 we begin with basic liquid crystal compound structures, mixture formulations and their physical properties, and then extend the discussion to device structures and display characteristics. Three major LCDs are introduced: transmissive, reflective and transflective. Most modern LCDs are of the transmissive type. However, these displays might be washed out by direct sunlight. In contrast, reflective displays work well under sunlight but are not readable in dark ambient. To retain the good images of a transmissive display while keeping good sunlight readability, transflective LCDs have been developed.

Chapter 5 gives an overview of PDP fundamentals. We begin with a discussion of the physics of a gas discharge, covering the reactions of gas discharges and I–V characteristics. DC PDP and AC PDP panels as well as surface discharge and vertical discharge approaches are introduced. The panel process technologies and useful process approaches are also described. Finally, we discuss system techniques with cell operation and driving mechanism.

Semiconductor LEDs are discussed in Chapter 6. We start from the material system because this determines the emission wavelength. Electrical properties of LEDs, typically p–n junctions, and corresponding optical characteristics are then discussed. The fabrication process is introduced, which highlights the practical electrical, optical and thermal issues. Finally, applications of LEDs for displays are described.

Chapter 7 describes OLEDs, with fabrication processes and operation principles similar to LCDs and LEDs, respectively. The chapter starts from the material aspect. Opto-physical processes in an organic material are introduced. Electrical injection and transport in organic materials are then described. Device structures and fabrication are then discussed. One serious disadvantage of an OLED is its short lifetime; this issue is also addressed. In Chapter 8 an overview of FED fundamentals is provided. We begin by discussing the physics of field emission, covering the field enhancement and vacuum mechanism. FED structure, display mechanism and various emitters are introduced. The advantages and disadvantages of using low- and high-voltage phosphor are compared. The panel process technology and useful process approaches are also described. Finally, system techniques are discussed.

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Acknowledgements

Jiun-Haw Lee would like to thank his colleagues Profs. I-Chun Cheng, Chih-I Wu, Jian-Jang Huang, Yuh-Renn Wu, Hoang-Yan Lin and Ding-Wei Huang of GIPO, NTU, for many helpful discussions. Mr Jia-Xing Lin of ITRI is gratefully acknowledged for kindly providing useful information about TFT technologies. Dr Lee is also grateful to his students in NTU and Dr Zhibing Ge of the University of Central Florida, who helped to prepare drawings, references, homework problems and examples, together with providing valuable remarks and comments from a reader's perspective.

David N. Liu is grateful to his colleagues in ITRI and AUO for useful discussions, and Ted Knoy for his professional proofreading. In particular, he would like to express his gratitude to his wife Janice for her patience and support during the period of writing the book.

Shin-Tson Wu is deeply indebted to his present and former group members at the University of Central Florida for their numerous technical contributions, and to Chi-Mei Optoelectronics for the funding support. He is grateful to his wife Cho-Yan for spiritual support during the writing of the book.

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