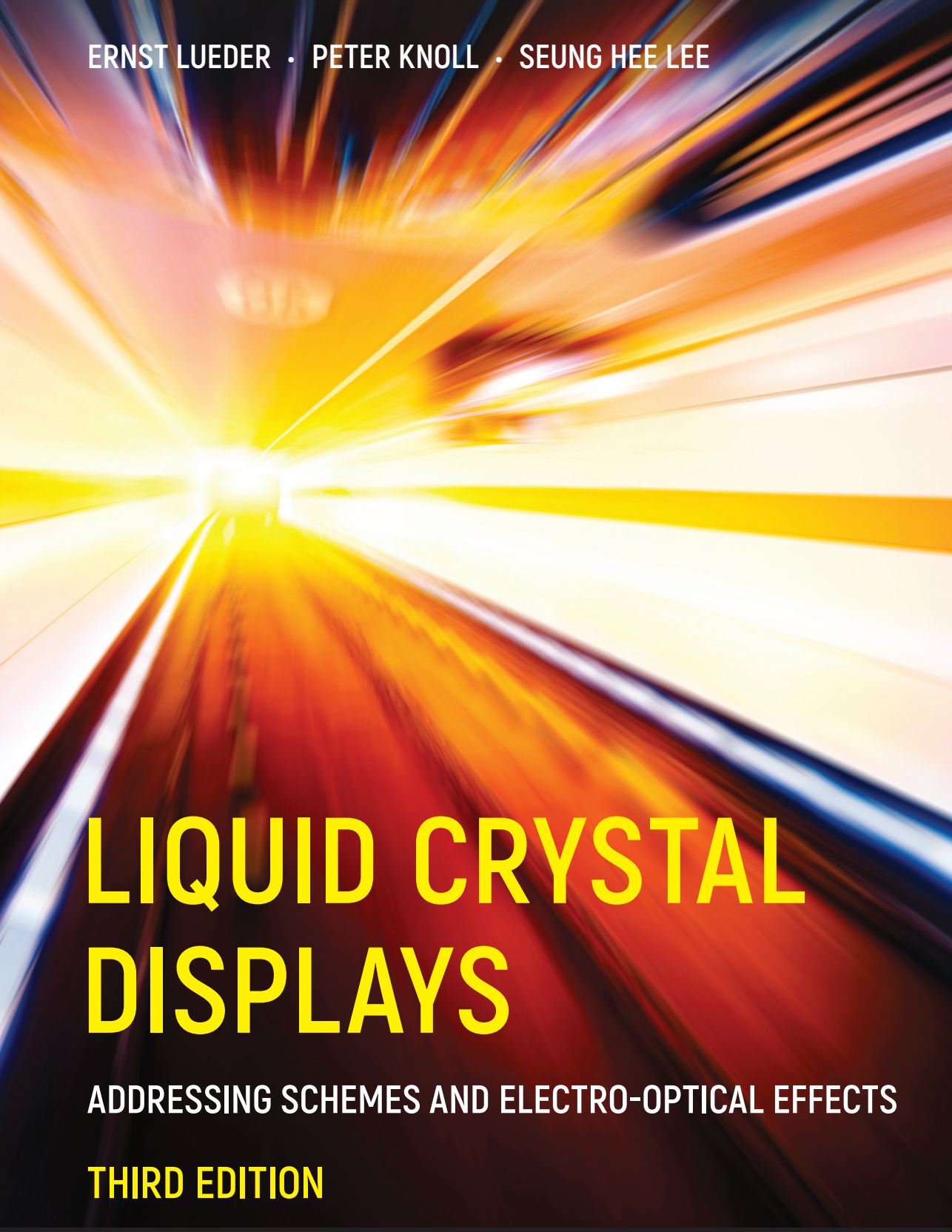
ERNST LUEDER · PETER KNOLL · SEUNG HEE LEE



LIQUID CRYSTAL DISPLAYS

ADDRESSING SCHEMES AND ELECTRO-OPTICAL EFFECTS

THIRD EDITION

SID Series in **Display Technology**

WILEY

Liquid Crystal Displays

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Liquid Crystal Displays

ADDRESSING SCHEMES AND ELECTRO-OPTICAL EFFECTS
THIRD EDITION

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To Helen

Whose assistance and patience made this book possible (Ernst Lueder)

To Ernst Lueder

With many thanks to Ernst for the good and fruitful collaboration on bumpy roads (Peter Knoll)

To Dr. Minsu Kim

Whose assistance and discussion made this book possible (Seung Hee Lee)

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Series Editor's Foreword

The first edition of *Liquid Crystal Displays – Addressing Schemes and Electro-optic Effects* was one of the earliest to be published in the Wiley-SID series on display technology. It was also the first series volume to satisfy the need among the display community for a volume that not only covered the physics of liquid crystals and the electro-optic effects exploited in displays but also provided a comprehensive account of the techniques used to address them, including the then-dominant RMS multiplex modes as well as the device physics and operation of active matrix backplanes based on both amorphous and polycrystalline silicon. Through its best-selling first and second editions, it has become a comprehensive and trusted source of reference for display scientists and engineers. Although it is written at a technical level that is appropriate for a professional reference work, many advanced students have also found the book invaluable for its clear exposition of topics throughout LCD technology in a single volume.

In planning the current third edition of Professor Lueder's book, three major new chapters have been added in order to cover important technical advances that have emerged over the last 10 years. In Chapter 23, Professor Lueder expands on the comprehensive coverage of amorphous silicon and polycrystalline silicon backplanes given in earlier chapters by providing an account of the properties, processing and application of new semiconductor materials. Of these, transparent metal oxide semiconductors such as IGZO are most prominent and reflect the latest practice in the manufacture of premium professional and consumer LCDs. Advanced fabrication concepts, including printed backplanes and foldable displays using both inorganic and organic semiconductors, are also covered. Key structural issues that determine the performance of materials and devices are thoroughly discussed to provide an up-to-date account of recent advances in AM technology.

A constant trend in LCD applications has been the progress towards displays with higher resolution, complexity and image quality. FFS displays have become the LC technology of choice in mobile and high-resolution applications because of their favourable contrast and viewing angle properties, combined with lower power consumption, which results from their high aperture ratio, and their ease of integration with touch panels. They have also become commonplace in large panels, wherever the highest image quality is demanded. In Chapter 24 the inventor of the FFS display, Professor Seung Hee Lee, brings his unique depth of knowledge

to describe and analyse the structures, manufacture and performance of these devices. Professor Lee provides an accessible and authoritative account of FFS displays, which covers the many important variations of the technology including the use of positive and negative dielectric LC fluids, and different alignment geometries such as in the UFS mode. The various optimisations in performance available from these different modes are described and the underlying physics is carefully explained in each case.

As the application of flat panel displays expands into more and more areas, their capabilities are constantly being tested. In the final chapter, Professor Peter Knoll addresses the development of automotive displays in the widest context of instruments, entertainment systems and driver assistance. Focusing on the historical development of in-car systems and the ergonomics of the entire cockpit, Professor Knoll takes the reader through the rationale for the displacement of electromechanical instruments and the adoption of different display layouts and technologies, and provides an account of how LCD technology has competed with rival devices such as vacuum fluorescent, electroluminescent and, more recently, OLED panels. The capabilities of distinct display types drive their application in different areas. Improved displays also allow the realisation of new interaction modes through head-up and 3D displays, and their development and future prospects are fully covered.

In terms of units and total area, LCDs remain dominant in the flat panel display marketplace despite competition from OLEDs and other devices. They have shown remarkable resilience and adaptability in competing head-on in most aspects of performance, and the viewing angle, contrast, colour gamut and response speed have been transformed compared to early devices. As new generations of scientists and engineers exploit and improve LCDs, we hope that this volume will continue to inform and support their efforts.

Ian Sage
Malvern, UK

Foreword to the Second Edition

Since publication of the first edition of this book nine years ago, much has happened. Dominance of the CRT has been replaced by dominance of LCDs not only for computer monitors but also for television, control room and signage applications. The need for faster response, wider viewing angles, better colour rendition, thinner displays and lower energy consumption has motivated extraordinary developments, and this last decade has been one of unprecedented change. A fact known just to a few is that the first edition of this book was the Wiley-SID series' best seller. I am therefore delighted that Ernst Lueder has agreed to write a third edition.

The following new sections have been added: fast blue phase materials, which have the sub-millisecond switching times required for 240Hz refresh rate TVs; multidomain VA cells for TV applications; the addressing requirements of VA cells to achieve TV speeds (which often requires parallel addressing); motion blur and its remedies and lastly, transfer techniques of TFTs fabricated at high temperature onto flexible substrates.

The sections on components for LCDs, flexographic printing, ink jet printing, surface properties for printing and cell building by lamination have been updated.

Thus the original purpose stated by Professor Lueder in his preface to the first edition – to condense into one volume all the basic information that is needed to understand the operation and the building of liquid crystal displays – will now be met by this third edition, which I am confident will see equal success.

Anthony Lowe
Braishfield, UK, 2009

Preface to the Third Edition

Without Dr. Ian Sage's initiative and steady support, the third edition would not have been realized. I am very grateful for the competent and always pleasant assistance he offered during the preparation of this edition.

I was very fortunate to have found two very capable co-authors for the third edition.

Prof. Seung Hee Lee of the Jeonbuk National University in South Korea is a pioneer of fringe-field switching, and he has contributed an outstanding chapter on this topic. While still working in private industry, he was twice awarded 'King of Invention', and at the Society for Information Display he won the Special Recognition Award and (in 2016) the Jan Rajchman Prize.

Prof. (Emeritus) Peter Knoll of Karlsruhe University in Germany played a leading role in the development of automotive displays as the head of the display laboratory at the Bosch Company. His knowledge of the evolution of car displays characterizes his prominent contribution to the third edition. His achievements culminated in the development of a night vision car display.

Ernst Lueder

Preface to the Second Edition

The second edition of *Liquid Crystal Displays* focuses on the latest LCDs with wide viewing characteristics, short optical response times and accelerated relaxation, the suppression of motion blur, thin LED backlights and printed layers replacing costly photolithography.

I very much appreciate the valuable suggestions by Dr. Tony Lowe, the editor of the Wiley SID series in Display Technology, and expert insights from my colleagues Dan Schott and Dr. Bob Melcher covering the wide area of current display activities. I am grateful for the diligent and skilled proofreading by Lyn Hicks and Kim Stringer. As in the first edition, I am greatly indebted to Heidi Schuehle for observantly and attentively typing the manuscript and to Rene Troeger for the accomplished and professional drawing of the figures.

Preface to the First Edition

The overriding purpose of this book, as further outlined in the Introduction (Chapter 1), is to condense in one single volume all the basic information that is needed to understand the operation and the building of liquid crystal displays. This requires a treatment of a wealth of electro-optical effects as well as a description of the rich variety of addressing schemes. The latter has not been done for more than a decade.

In the pursuit of this ambitious goal I was very fortunate to have a number of experts at my side who offered advice and assistance for writing this book. Dr. Tony Lowe, the editor of this SID-series, lent his experience in selecting the contents of this book and in focusing on special topics. His most valuable assistance is gratefully appreciated. Dr. Mike Lee from Imperial College in London enriched the chapters on addressing techniques with some most helpful suggestions and enlightening discussions. I am very grateful for his support. I am also indebted to my co-worker at Stuttgart University, Dr. Christoph Zeile, who contributed to the sections about electro-optical effects by numerous discussions and his helpful observations. I thank Mrs. Heidi Schuehle very much for typing the manuscript with competence and patience and for alerting me to various inconsistencies. Mr. Rene Troeger has skillfully drawn the figures for which I am very grateful.

Finally, I wish to thank John Wiley for their always pleasant cooperation as well as for the attractive production of the book.

Ernst Lueder
Scottsdale, Arizona, 2000

About the Authors

Ernst Lueder was born in 1932. At his graduation from high school he was awarded the 'Scheffel'-prize for literary achievements. In 1962 he received his doctorate in electrical engineering, and in 1966 his Habilitation, which qualified him to teach theoretical electrical engineering. From 1968 to 1971 he worked for Bell Telephone Laboratories in Holmdel, New Jersey, USA, undertaking research into the design of miniaturized filters and communication systems, especially in thin film technology. He established laws for optimizing the dynamic range and the signal-to-noise ratio of two-ports.

In 1971 he was appointed a full professor at the Department of Electrical Communications, and was named Director of the Institute of Network and Systems Theory at Stuttgart University. He specialized in the design of hybrid thin and thick film circuits, the development of sensors, thin film transistors and flat panel liquid crystal displays, in the synthesis of circuits, in the theory of communication systems and in the optimization of systems. From spring 1991 he also headed a new DM80 million laboratory for the fabrication of flat panel displays. Research activities in this laboratory include TFT- and MIM-addressed TN, PDLC and GH displays, as well as bistable FLC and PSCT displays.

He retired in 1999. He was a member of the IEEE, and became an IEEE Fellow in 1985. As a member of the German Society for Information Technology, ITG, he was for two years a member of the society's board of directors. He served in the Scientific Advisory group for the Heinrich-Hertz Institute in Berlin, and was chairman of this group for four years.

Starting in 1994 he participated as a member of the SID board of directors, as a director of the Mid-Europe chapter, and as vice-president for Europe. Further, he was a member of the SPIE, ISHM, FKTG, the German society for broadcast and television technology and the New York Academy of Sciences (NYAS). In 1991 he was awarded the order of merit 1st Class of the Federal Republic of Germany, and in 1998 he became a Fellow of SID and in 2009 received SID's Slottow-Owaki Award.

During his career and retirement Professor Lueder has authored more than 200 publications on LCDs, network and system theory and optimization, and sensors and electro-optical signal processing.

Seung Hee Lee received his BS degree in Physics from Jeonbuk National University in 1989 and his PhD from the Physics Department of Kent State University in 1994. In 1995, he joined the LCD division of Hyundai Electronics (later named HYDIS Co.), where he did research on development of wide-viewing-angle TFT-LCDs with new liquid crystal devices until August 2001. During that time, he made a big contribution to the invention and commercialization of new wide-viewing-angle technology called 'fringe-field switching (FFS)' and introduced the FFS device to the public in Asia Display '98, SID & IDW '99, SID '01, and IDMC '02 for the first time.

In addition, his team has investigated unique and fundamental electro-optic performances of the FFS mode depending on electrode structure, cell parameters, and sign of LC's dielectric anisotropy via journal and conference proceedings, and filed many key patents. His team proved the FFS mode was the only mode that can show high transmittance, low operating voltage, fast response time, wide viewing angle and pressure-resistant characteristics simultaneously, suggesting that the FFS mode can be applied to all kinds of high-end and high-image-quality TFT-LCDs.

In September 2001, he became professor in Department of Polymer Nano Science and Technology of Jeonbuk National University. Since then, he has worked on the development of new electro-optic materials and devices for displays and photonics. He was awarded 'King of Invention' twice while he was in industry. He has also received several major awards, such as the 'SID Fellow' in 2008, the 'SID Special Recognition Award' in 2012, and the 'Merck Award-Major' from the Korean Information Display Society in 2013, and the 'Jan-Rajchman Prize' in 2016.

Peter Michael Knoll was employed at Robert Bosch GmbH, Karlsruhe, Germany, from 1980 until his retirement in 2006. He is now a retired Associate Professor for Driver Assistance Systems and associated Human Machine Interaction at the KIT, formerly University of Karlsruhe, Germany.

He was head of the Bosch Companies Laboratory for Car Displays from 1980 until 1995; General Manager at ADT Inc. (Applied Display-Technology GmbH), Stuttgart, Germany, until 1999; Vice President Development New Products, Driver Assistance systems Business Unit, Robert Bosch GmbH, Leonberg, Germany, until 2007; Associate Professor for Display Technologies, Faculty of Electrical Engineering University of Karlsruhe, Germany, from 1988 to 2009; and Associate Professor for Automotive Information Systems, Driver Assistance Systems at the KIT, Germany, until 2013.