Handbook of Visual Display Technology
Preface

This handbook grew out of an international graduate training program in visual displays – a new approach to postgraduate training for the display technologists of the future.

Leading edge international researchers and academics were invited to contribute, representing the knowledge supply chain from blue skies academic research through industrial design and development, to market analysis and creative content developers. Over a series of intensive one-week taught modules, these innovators helped deliver a stimulating and effective program which became known as DisplayMasters.

It soon became clear that, in addition to providing a novel educational program for new researchers in visual displays, this convergence of minds was providing a catalyst for networking and new collaborations throughout the professional community that was rapidly building around the delivery of the course modules.

It was through this community that discussions began around how best to capture the diversity of science and technology, engineering, human factors, ergonomics, market analysis, and economics of choice required to cover the scope of the subject comprehensively. While there were excellent texts available dealing with separate aspects of the field, including several focused on important display technologies, there was no core reference text that brought them all together. Hence, the project to develop this Handbook of Visual Display Technology was launched. The result is a major reference that covers the full range of subjects underpinning the field of display technology, a field which has become pivotal in our daily lives and in the impact of technology development and interaction.

The electronic display is our primary interface to the technological world. Through the screens of our desktop computers, interactive televisions, e-books, portable phones, and tablet devices, we are increasingly dependent upon the performance of the display interface to undertake our daily tasks, communicate with each other, and to consume our entertainment. This handbook presents the science behind the screen. With over 150 expert contributors from around the globe, this four-volume reference is a comprehensive and robust platform of knowledge for anyone involved in the research, design, development, marketing, and utilization of display systems.

A handbook of this scale is very much the result of the commitment and collaboration of a large number of people, and as Editors-in-Chief we would like to extend our gratitude to all of the contributors for their excellent work that constitutes the book, and in particular to the Editorial Board and Advisory Panel for their tireless input to the project. We would like to thank Dr. Anandan, President of the Society for Information Display, for his support and for kindly providing a Foreword which also serves as a comprehensive introduction to the handbook. Finally, we are indebted to Tom Spicer and Robin Rees of Canopus Academic Publishing for the excellent guidance, support, professionalism, and enthusiastic motivation.
they have provided throughout the project, without which it would not have been possible. We look forward to a continuing relationship with Canopus and Springer, through regular online updates of the handbook to ensure that it remains a live and comprehensive resource of the science behind the screen.

Janglin Chen, Wayne Cranton, and Mark Fihn
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I am honored to have been invited to write a Foreword to the *Handbook of Visual Display Technology*, a monumental work indeed! Display devices have changed the way we live, and the current generation is especially fortunate to be experiencing substantial changes in display technology. This book, to the best of my knowledge, is the first of its kind. The authors of the chapters in the *Handbook* are world experts, some of whom I have acquaintance with, engaged in R&D and the business of displays. The Editors have successfully met the challenge of selecting the best authors for the book.

From the stage of capturing the source image, through a CCD camera as an example, until the image is reproduced truthfully on a display device, all the steps along the way including image storage, image processing, image communication, video processing, display driving and finally the display itself are all vividly described by experts in their fields. As is required of a handbook, this book gives a clear account of the historical perspective of all display devices regardless of their obsolescence and commercial success. Directions for future research and suggestions for further reading are given along with exhaustive references at the end of every chapter. All major display technologies and display systems are discussed from microdisplay-size through to large TV-size and cinema-scale displays. The king of displays is the Liquid Crystal Display (LCD) and the book does full justice to its dominance. The reader will notice obvious overlap in some areas and this is unavoidable due to the nature of the scope of applications of displays.

As the title of the book contains the words “Visual Display,” it is most appropriate that Sect. 1 starts with the physics of light. Light is fundamental to display devices both for emissive and non-emissive displays. Definition and description of terms such as “coherence,” “interference,” “polarization,” “double refraction” and the like have direct relevance to visual displays. Section 2 follows in a natural sequence, dwelling on vision and perception. The neural network is well described with signals from 126 million photoreceptors reaching one million nerve fibers and finally leaving the eye to the brain. “Color vision” and “color blindness” have been described well.

Section 3 deals with image storage and manipulation. A good introduction to electronic imaging is outlined, tracing its historical development and illustrating the flow of image processing beginning with the capture of the source image. Video compression with various coding and encoding techniques is described and different video compression standards are outlined. The goal of digital color management, to maintain the color of the captured original image and render it truthfully on display device, is clearly emphasized. The perceptual rendering method that enables the colors in the source gamut to be scaled in to the destination gamut is interesting to read. Finally, the reliability and fidelity of image data as applied to medical imaging is well brought out. Currently, it is shown that six megapixel color resolution monitors are better than films. Applications in security such as facial recognition and fingerprint recognition are nicely illustrated.

Section 4 traces the development of display drivers starting from direct drive and multiplex drive through to active matrix drive both for LCDs and OLEDs (Organic Light Emitting Diodes). Pixel drive circuits for LCDs and OLEDs are compared. For high content display
driving the recent “panel electronic system” is explained. The integration scheme for display controllers is emphasized. For driving large displays of 108” diagonal, the challenge in terms of line resistance and capacitance is explained with special reference to gate pulse distortion. The problem of image sticking as a result of the pulse distortion is outlined. System-on-glass technology for mobile display driving is covered, and display interfaces and display controllers for graphics are described. Under video processing, different de-interlacing methods employed for converting the interlaced fields received from the broadcast into the progressive fields necessary for operation of the display are described. The problem of “Motion Blur” is explained and the solution to this problem through the driving scheme is described. Addressing schemes starting from the Alt-Pleshko scheme to the active matrix driving scheme are sequentially described with distinct waveforms. Examples for TN (Twisted Nematic)-LCD, STN (Super Twisted Nematic)-LCD and TFT (Thin Film Transistor)-LCD driving are illustrated. With regard to LED backlight driving, the PWM (Pulse Width Modulation) driving of LEDs and local dimming of LEDs are also explained. This section on display driving is carefully structured and written well.

Section 5 focuses on display materials, TFTs and touch screen. The thermal expansion of glass, its stability against chemicals used in manufacturing and flatness requirements under high temperature processes are all well described. The use of Jade glass for OLEDs, and Gorilla glass for increased durability applications are emphasized. “Flexible glass” for ePaper applications is another interesting write-up under this section. Flatness, thinness and largeness are explained in the context of Gen 10 glass size. The subsection on a-Si:H and poly-silicon for TFTs for driving active matrix (AM) displays is written well. The device physics and fabrication of TFTs are well explained. Laser annealing for fabricating poly-silicon TFTs is clearly described. Drain field interference in TFTs and the solution to eliminate this through doping of adjacent regions is well illustrated. The display related characteristics of a-Si:H TFTs, polysilicon TFTs and organic TFTs are well elucidated and compared. The most recent and attractive oxide TFT technology is traced through its historic development and it is interesting to read that for 30 years, work on oxide TFTs was abandoned. Stability of oxide TFTs and charge mobility are reported. This section also comprises touch screen technology and this is exhaustively covered starting from sensor to controller to software driver to the computer. Resistive touch, capacitive touch, projected capacitive touch, in-cell touch, optical touch and camera based touch are all well explained, including the touch electronics.

Section 6 is exclusively devoted to Emissive Displays. Most emissive displays employ phosphors of either an inorganic or organic type. The book structures appropriately the topic on phosphors, before embarking on the actual emissive displays. Synthesis of phosphors and their application in CRTs, Vacuum Fluorescent Displays (VFDs), Field Emission Displays (FEDs), Plasma Display panels (PDPs) and inorganic electro-luminescent displays are all well described with emphasis on the demand placed by each display technology on the phosphor. AMOLEDs are described in terms of light emission from organic phosphors with the description of TFT technology dominating this section. Inclusion of LED as a main display completes the list of emissive displays.

Appropriately Sect. 7 is completely devoted to LCDs. This section is superbly done. The authors of this section have covered the subject matter in the greatest possible detail, tracing the history of liquid crystals (LCs), going through the physics and electro-optical properties of LCs, describing the exploitation of various modes of LCs in different type of LCD, explaining all display modes [namely, TN, STN, VAN (vertically aligned nematic), Pi-cell, PVA (patterned vertical alignment), MVA (multi-domain vertically aligned), PDLC (polymer
dispersed LC), FLC (Ferro-electric LC), blue-phase LC), outlining the fabrication steps, illustrating the driving methods, placing emphasis on Active Matrix TFT driving and finally LED backlighting. Applications for all the modes of LC have been well illustrated including the application of PDLC for “smart windows.” One observes after reading this section that there are still plenty of opportunities left for LCDs, in the improvement of optical transmission and simplification of the manufacturing process. For those who want to know the art of current mass manufacturing of LCDs, an excellent process flow is elucidated with the methods employed for each process. One interesting feature that the reader will be able to find is the correlation of LC display modes with the companies that use them in the mass manufacturing line. Under “device processing and testing of large scale TFTs” the illustrations are outstanding. Overall the past, present and future of LCDs are vividly described.

One of the “hot topics” of today is ePaper-displays for eReaders. Section 8 deals with this subject, in addition to MEMS (Micro Electro-Mechanical System). Electro-phoretic displays dominate the market in eBooks and hence the focus on these display technologies is natural. Both vertical and in-plane electrophoretic displays along with “hybrid electrophoretic” displays are detailed. In addition, the prospects and potential of electro-wetting displays, electro-fluidic displays and reflective LCDs for application in ePaper displays, emphasizing reflectivity and response time, are well described. MEMS-based displays comprise DLP®, IMOD (Interferometric Modulator), Micro-shutter and TMOS (Time Multiplexed Optical Shutter) based displays. DLP technology is covered in the next section and the potential of all other MEMS-based displays are made clear in Sect. 8.

Another current hot topic is 3D, the subject of Sect. 9. As noted above, DLP is described in relation to 3D Cinema technology and this chapter is well written. 3D displays incorporating both active shutter glasses and passive shutter glasses are well described. Human factors, such as nausea and headaches, seem to be limiting the penetration of 3D TV and hence a sub-section is devoted to the human factors associated with viewing 3D images. Because of this limitation, the consumer trend is to go for auto-stereoscopic displays that do not require glasses. This part is well elucidated under “lenticular lens” and “parallax barrier.”

“Displays on the move” is an area dominated by many small-area displays involving various display technologies. A smooth presentation of the subject is given in Sect. 10, tracing the display technologies involved in mobile applications and the stringent demands satisfied by these technologies. The potential of OLEDs is well illustrated along with the current dominant LCD technology that has undergone custom designs for mobile applications. Power efficiency, which is critical for mobile displays is presented well, including the non-traditional approaches to power saving. Section 10 also deals with microdisplays, projection displays and head-mounted displays. The common element is the microdisplay which underpins these display systems. This section is very exhaustive and describes well the high resolution challenges relating to pixel sizes as small as 3–5 μm. The technologies covered under this section include LCoS (Liquid Crystal on Silicon), DLP, Polymer-OLEDs, Small molecule-OLEDs, and LCDs. For cinema scale projection systems, DLP cinema is stated to be the dominant technology with almost 30,000 screens in operation during 2010, and the chapter on DLP projection technology is well written. The applications of microdisplays in viewfinders, digital cameras and head-mounted systems are outlined.

There is a proliferation of display technologies and intense competition for many applications, making it difficult for consumers to select the display device that is suitable for a specific situation. There is a need to evaluate displays and a book of this type needs to dwell on the methods of measurement that truly capture the characteristics of displays. Section 11 of the
Handbook does precisely this. Various display parameters including luminance, contrast ratio, grayscale, viewing angle, color gamut, response time, spatial uniformity, etc., are all defined and the methods of measurement are described for various types of displays. It is interesting to read in this section that one of the shortcomings of display metrology is that judgment by human vision cannot be completely replaced by measurement.

Another unique and admirable aspect of the Handbook, seldom seen in works of this type, is the discussion of “market forecasts” and “preservation of our environment.” The final Sect. 12 deals with these aspects. Readers will be interested to see a question on the credibility of market forecasts and the narration of the author’s personal experience through several lessons. There is also a conclusion that the market forecast becomes simple because there is only one display (i.e., the LCD) that dominates all applications. The “Crystal Cycle,” and the “wave theory” of the 3D market forecast and 3D displays attempting for the past 60 years to come in to our lives will be of interest to readers. Finally the display industry is viewed in the context of a “green world” and suggestions are made for the recycling of the electronic waste emerging from various display technologies.

After scanning through the Handbook of Visual Display Technology, I feel that no engineering or science library can be without this book. It will be an asset for all companies engaged in display and display-related business. For researchers this book provides substantial guidelines for the future of display technology.

Dr. M. Anandan
President, Society for Information Display
Austin, TX
USA
Janglin Chen
Industrial Technology Research Institute
Taiwan

Janglin (John) Chen is a Vice President of Industrial Technology Research Institute (ITRI) in Taiwan, and the General Director of ITRI’s Display Technology Center. Prior to joining ITRI, Dr. Chen was a Research Fellow of Eastman Kodak Company in Rochester, New York, where he held many R&D managerial positions from 1982 to 2006, and is the author of sixty technical articles, and 33 issued US Patents. A native of Taiwan, Dr. Chen holds a Ph.D. degree from Polytechnic University in Brooklyn, New York (1982), and is a graduate of Senior Executive Program, Stanford University, CA. In ITRI, Dr. Chen and his staff focus on new display and advanced technology research, including flexible displays, substrates, metal oxide TFTs and electrowetting displays. Dr. Chen, an Associate Editor of IEEE/OSA Journal of Display Technology, is presently the Vice Chairman of Taiwan Display Union Association.
Wayne Cranton is Professor of Visual Technology at Nottingham Trent University, and Director of the Physical Sciences, Engineering and Computing Research Centre within the School of Science and Technology.

Wayne obtained his Ph.D. in Electrical and Electronic Engineering from the University of Bradford in 1995, following an investigation into the growth and characterisation of thin films for electroluminescent devices. He then moved to Nottingham Trent University to continue the work on materials for electroluminescent displays with the Thin Film and Displays Research Group. His research is concerned with the study of thin film materials for electronic displays, sensors, and light emitting devices. This has involved a number of collaborative applied research and development programmes on the deposition and processing of phosphors, dielectrics, and metal oxide semiconductors, with recent emphasis on the localised photonic processing of materials for low temperature fabrication of flexible electronics and displays. In 2001, Wayne was a founding partner of the DisplayMasters Inter-University Programme in the UK, which brought together display experts and students from around the globe and which became the catalyst for the collaborations resulting in the Handbook of Visual Display Technology.
Mark Fihn currently heads his own consulting company called VeritaVis, where he supports the flat panel display industry based on his expertise related to notebook PCs, Tablet PCs, touch technologies, the LCD TV market, and display related human factors, including high resolution and wide aspect ratios. Veritas et Visus is part of this consultancy, enabling Mark to reach a broader audience in association with his research activities. Prior to VeritaVis, Mark worked for 3 years at the market research firm DisplaySearch. He additionally participated for 15 years in computer system and LCD-related procurement at Texas Instruments and Dell Computer while living in the United States and Taiwan. He has been active in many display-related areas, most specifically in publicly championing industry-wide adoption of high resolution displays, notebook LCD standardization, and video sub-system integration. Mark was educated at St. Olaf College (Northfield, Minnesota), the American Graduate School of International Management, (Phoenix, Arizona); St. Edward’s University, (Austin, Texas), and in the University of Texas at Austin’s doctoral program in International Business. Most recently, Mark has been an active supporter and lecturer at the DisplayMasters degree program in the UK, contributing course lectureships at Cambridge University, Dundee University, and Nottingham Trent University.
Karlheinz Blankenbach has been with Pforzheim University since 1995 where he was one of the first professors of the newly established Technical Department. In 1998 he founded the Display Lab (http://www.displaylabor.de) which focuses on applied R&D on display systems, display driving and display metrology. In 2007 he was given an award by his university for outstanding and long-lasting research. The activities of Karlheinz and his team resulted in numerous projects funded by government and industry as well publications, talks and workshops.

Karlheinz started his industrial career in 1990 at AEG (a subsidiary of DAIMLER), Ulm, Germany where he developed display electronics and LCDs for public information systems as used in airports and railway stations. He holds an M.Sc. (Diplom) in Physics and a Ph.D. degree, both from the University of Ulm, Germany. He is head of the advisory board for the conference “ELECTRONIC DISPLAYS” (http://www.electronic-displays.de/), chairman of German Flat Panel Forum (http://www.displayforum.de/), speaker of the technical committee for Displays of VDE/ITG and chairman of the Steering Committee ADRIA (advanced displays research initiative, www.adria-network.org).
Stan Brotherton started his research career at the GEC, Hirst Research Laboratory, England, before taking a post-doctoral Research Fellowship at Southampton University in 1971. From there he moved to the Philips Research Laboratory, Redhill, England, where he was a Senior Principal Scientist, and he now works as an independent TFT Consultant. He has led a wide range of research projects investigating semiconductor devices, and related materials issues, where the devices have included MOSFETs and CCDs, power devices, and IR imaging devices. His most recent field of activity has been thin film transistors, within which he initiated the Philips research programme on poly-Si TFTs. Activity within this field has continued with consultancy contracts from a number of organisations.

He has published ~120 papers on the physics and technology of silicon devices, and in 1989 he was awarded a DSc by London University for published work on deep level defects in silicon. He has presented numerous invited and contributed papers at major international conferences, and has been a regular contributor of specialist lectures for Masters degree courses at Southampton and Dundee Universities.
Jason Heikenfeld received the B.S. and Ph.D. degrees from the University of Cincinnati in 1998 and 2001, respectively. During 2001–2005 Dr. Heikenfeld co-founded and served as principal scientist at Extreme Photonix Corp. In 2005 he returned to the University of Cincinnati as a Professor of Electrical Engineering. Dr. Heikenfeld’s university laboratory, The Novel Devices Laboratory www.secs.uc.edu/devices, is currently engaged in electrofluidic device research for lab-on-chip, optics, and electronic paper. Dr. Heikenfeld has now launched his second company, Gamma Dynamics, which is pursuing commercialization of electrofluidic displays. Dr. Heikenfeld is a Senior member of the Institute for Electrical and Electronics Engineers, a Senior member of the Society for Information Display, and a member of SPIE. Dr. Heikenfeld is an associate editor of IEEE Journal of Display Technology, and an IEEE National SPAC Speaker on the topic of entrepreneurship.
Jon Peddie is a pioneer of the graphics industry, starting his career in computer graphics in 1962. After the successful launch of several graphics manufacturing companies, Peddie began Jon Peddie Associates in 1984 to provide comprehensive data, information and management expertise to the computer graphics industry. With those same goals in mind, he left JPA to form Jon Peddie Research in 2001 to provide a more customer intimate environment for clients, and to further explore the business of multimedia. Peddie lectures at numerous conferences on topics pertaining to graphics technology and the emerging trends in digital media technology. He is frequently quoted in trade and business publications, and contributes articles to numerous publications as well as appearing on CNN and TechTV. Peddie is also the author of several books and a contributor to Advances in Modeling, Animation, and Rendering. Jon Peddie is recognized as one of the leading analysts in the USA by AdWeek Magazine.
Peter Raynes joined the Royal Signals and Radar Establishment at Malvern in 1971, and moved to the Sharp Laboratories of Europe Ltd at Oxford in 1992, where he became Director of Research. He took up the Chair of Optoelectronics in the Department of Engineering Science at Oxford University in 1998, and in 2010 joined the Department of Chemistry, University of York, as a Leverhulme Emeritus Research Fellow. He has played a key role in developing liquid crystal displays to the pre-eminent position they hold today, with over 130 published papers and over 60 filed patent applications. He was responsible for two key device inventions (Supertwist LCD and defect-free Twisted Nematic LCD) which were both licensed to the world’s major manufacturers, are widely used in products and resulted in considerable royalties to QinetiQ. He has also contributed to several highly successful ranges of liquid crystal materials that resulted in Queen’s Awards for Technological Achievement in 1979 and 1992.

He was awarded the Rank Prize for Opto-electronics in 1980, the Paterson Medal of the Institute of Physics in 1986, the 2009 Jan Rajchman Prize and a Special Recognition Award in 1987 of the Society for Information Display, and the G W Gray Medal of the British Liquid Crystal Society in 2001. He is a Fellow of the Royal Society, the Institute of Physics and the Society for Information Display.
Jannick Rolland earned a Diploma from the Institut D’Optique in 1984, and MS (1985) and Ph.D. (1990) degrees in Optical Science from the University of Arizona. As a postdoctoral fellow in the Department of Computer Science at the University of North Carolina at Chapel Hill (UNC-CH), she started her work in head-worn display design and fabrication. Today her work focuses on freeform optics and compact eyeglass formats. With a strong interest in human perception, Dr. Rolland headed the UNC-CH Vision Research Group for Medical Displays (1992–1996). In 1996, she joined the College of Optics and Photonics at the University of Central Florida (1996–2008) where she built the Optical Diagnostics and Applications Laboratory (www.ODALab-spectrum.org). In 2009, she joined the Institute of Optics at the University of Rochester as the Brian J. Thompson (endowed) Professor of Optical Engineering and as Associate Director of the R.E. Hopkins Center for Optical Design and Engineering, together with joint appointments in the Department of Biomedical Engineering and in the Center for Visual Science. She serves the Institut d’Optique in Paris as invited Professor for their Pole Aquitaine in the Bordeaux region in an effort to help develop a new focus area in 3D scientific visualization and Augmented Reality. Professor Rolland served on the editorial board of the Journal Presence (MIT Press) (1996–2006), and as Associate Editor of Optical Engineering (1999–2004). She is a Fellow of the Optical Society of America and SPIE, a senior member of IEEE, and a member of SID. She is a Director at Large on the board of the Optical Society of America (2010–2012).
Advisory Panel

Thomas Coughlin
Coughlin Associates
USA

Matthew Forman
Create 3D
UK

Teresa Goodman
National Physical Laboratory
UK

Hideo Hosono
Tokyo Institute of Technology
Japan

Jyrki Kimmel
Nokia
Finland

Vasudevan Lakshminarayanan
University of Waterloo
Canada

Paul Lippens
Umicore
Belgium

Lesley Parry-Jones
Sharp Laboratories of Europe
UK

Robert Phares
Consultant
USA

David Rodley
University of Dundee
UK

Mervyn Rose
University of Dundee
UK

Kalluri Sarma
Honeywell International
USA

Graham Saxby
Consultant
UK

Ian Underwood
University of Edinburgh
UK

Tim Wilkinson
University of Cambridge
UK

Chris Williams
Logystyx
UK
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List of Contributors

Marc Albrecht
Institute of Microelectronics
Saarland University
Saarbruecken
Germany

Karl Amundson
E Ink Corporation
Cambridge, MA
USA

Sarah Atkinson
Human Factors Research Group
Department of Mechanical, Materials and Manufacturing Engineering
University of Nottingham
Nottingham
UK

Keith J. Baker
Glasgow Caledonian University
Glasgow, Scotland
UK

Norman Bardsley
Bardsley Consulting
Danville, CA
USA

David Barnes
BizWitz LLC
Georgetown, TX
USA

Frank Bartels
Bartels Mikrotechnik GmbH
Dortmund
Germany

Karl G. Baum
Qmetrics Technologies
Rochester, NY
USA

Philip W. Benzie
Department of Engineering Science
University of Oxford
Oxford
UK

Bruce Berkoff
LCD TV Association
Beaverton, OR
USA

Charles A. Bishop
C.A.Bishop Consulting Ltd
Shepshed, Nr. Loughborough
Leicestershire
UK

Ion Bita
Qualcomm MEMS Technologies
San Jose, CA
USA

Karlheinz Blankenbach
Display Lab
Pforzheim University
Pforzheim
Germany

Francesco Bloisi
CNR-SPIN and Dipartimento di Scienze Fisiche
Università di Napoli “Federico II”
Naples
Italy
Marina Bloj  
Bradford School of Optometry and Vision Sciences  
University of Bradford  
Bradford  
UK

Barry G. Blundell  
School of Computing and Mathematical Sciences  
Auckland University of Technology  
Auckland  
New Zealand

Peter L. Bocko  
Glass Technologies Group  
Corning Incorporated  
Corning, NY  
USA

Philip Bos  
Liquid Crystal Institute & Chemical Physics Program  
Kent State University  
Kent, OH  
USA

Gary Boyd  
3M Optical Systems Division  
3M Center  
St. Paul, MN  
USA

Alejandro L. Briseno  
Polymer Science and Engineering  
Conte Research Center  
University of Massachusetts  
Amherst, MA  
USA

S. D. Brotherton  
TFT Consultant  
Forest Row  
UK

Margaret Brown  
Microvision Inc.  
NE Redmond, WA  
USA

Carl V. Brown  
School of Science and Technology  
Nottingham Trent University  
Nottingham  
UK

Ozan Cakmakci  
Optical Research Associates  
Optical Solutions Group of Synopsys, Inc.  
Pasadena, CA  
USA

Jim Chase  
HDMI Licensing, LLC  
Sunnyvale, CA  
USA

Feng Chen  
University of Waterloo  
Waterloo, ON  
Canada

K. C. Cheng  
Manufacturing Technology Center  
AU Optronics Corporation  
Taichung, Taiwan

Hua-Chi Cheng  
Display Technology Center  
Industrial Technology Research Institute (ITRI)  
Hsinchu, Taiwan  
PRC

Vien Cheung  
School of Design  
University of Leeds  
Leeds  
UK
Chris Chinnock  
Insight Media  
Norwalk, CT  
USA

David Coates  
R2Tek  
Culham Innovation Centre  
Abingdon  
UK

Jennifer Colegrove  
Emerging Display Technologies  
DisplaySearch  
Santa Clara, CA  
USA

Harry J. Coles  
Centre of Molecular Materials for Photonics and Electronics  
Department of Engineering  
University of Cambridge  
Cambridge  
UK

Tom Coughlin  
Coughlin Associates  
Atascadero, CA  
USA

Carol Crawford  
Microchip Technology Inc  
Chandler, AZ  
USA

Andreas Elschner  
Heraeus Clevios GmbH  
Leverkusen  
Germany

Steve J. Elston  
Department of Engineering Science  
University of Oxford  
Oxford  
UK

Yongchang Fan  
Division of Electronic Engineering and Physics  
University of Dundee  
Nethergate, Dundee  
UK

Johan Feenstra  
Liquavista BV  
Eindhoven, AG  
The Netherlands

Sunzida Ferdous  
Polymer Science and Engineering  
Conte Research Center  
University of Massachusetts  
Amherst, MA  
USA

Mark Fihn  
Veritas et Visus  
Temple, TX  
USA

A. J. Flewitt  
Electrical Engineering Division  
Cambridge University  
Cambridge  
UK

Matthew C. Forman  
Create 3D  
Sheffield  
UK

Christine Garhart  
College of Optometry  
University of Missouri  
St. Louis, MO  
USA

Andrew Garrard  
Consultant  
UK
Gerhard Gassler
Samtel Electron Devices GmbH
Ulm
Germany

J. W. Goodby
Department of Chemistry
University of York
York
UK

Teresa Goodman
National Physical Laboratory
Teddington, Middlesex
UK

Alok Govil
Qualcomm MEMS Technologies
San Jose, CA
USA

Andreas Grimm
Fujitsu Semiconductor Europe GmbH
Graphic Competence Center
Neuried
Germany

Evgeni Gusev
Qualcomm MEMS Technologies
San Jose, CA
USA

Michael J. Hayford
Optical Research Associates
Optical Solutions Group of Synopsys, Inc.
Pasadena, CA
USA

Monika Hedrich
Bradford School of Optometry and Vision Sciences
University of Bradford
Bradford
UK

Jason Heikenfeld
Novel Devices Laboratory
School of Electronics and Computing Systems
University of Cincinnati
Cincinnati, OH
USA

Harald Hirschmann
Merck KGaA
Performance Materials Business Unit Liquid Crystals
Darmstadt
Germany

Hyungki Hong
Department of Visual Optics
Seoul National University of Science and Technology
Nowong-gu, Seoul
South Korea

Hideo Hosono
Frontier Research Center & Materials and Structures Laboratory
Tokyo Institute of Technology
Japan

Andreas Hudak
Display Lab
Pforzheim University
Pforzheim
Germany

Hsin Hung Li
Manufacturing Technology Center
AU Optronics Corporation
Taichung, Taiwan

Scott Janus
Visual and Parallel Computing Group
Intel Corporation
Folsom, CA
USA
Michael Jentsch
Display Lab
Pforzheim University
Pforzheim
Germany

Alan D. Jones
Consultant
Salisbury, Wilts
UK

Lesley Parry Jones
Sharp Laboratories of Europe Limited
Oxford
UK

Cliff Jones
ZBD Displays Ltd
Malvern, Worcestershire
UK

Tobias Jung
Institute of Microelectronics
Saarland University
Saarbruecken
Germany

Adam Kerin
Intel Corp
Santa Clara, CA
USA

Jyrki Kimmel
Nokia Research Center
Tampere
Finland

Adrian H. Kitai
McMaster University
Hamilton, ON
Canada

Kiyoshi Kiyokawa
Cybermedia Center
Osaka University
Toyonaka, Osaka
Japan

Melanie Klasen-Memmer
Merck KGaA
Performance Materials
Business Unit Liquid Crystals
Darmstadt
Germany

Hagen Klauk
Max Planck Institute for Solid State Research
Stuttgart
Germany

Davor Kovačec
Xylon d.o.o.
Zagreb
Croatia

M. R. Krames
Soraa, Inc.
Fremont, CA
USA

Vasudevan Lakshminarayanan
School of Optometry and Departments of Physics and Electrical Engineering
University of Waterloo
Waterloo, Ontario
Canada
and
Michigan Center for Theoretical Physics
University of Michigan
Ann Arbor, MI
USA

Lance Lamont
Microchip Technology Inc
Chandler, AZ
USA

Kars-Michiel H. Lenssen
Philips Research
HTC34-51
Eindhoven, AE
The Netherlands
Wen-yi Lin  
Manufacturing Technology Center  
AU Optronics Corporation  
Taichung, Taiwan

Paul Lippens  
UMICORE – Thin Film Products  
Olen  
Belgium

David N. Liu  
Display Technology Center  
Industrial Technology Research Institute (ITRI)  
Hsinchu, Taiwan  
ROC

Lenny Lipton  
Lipton IP  
Los Angeles, CA  
USA

Feng Liu  
Polymer Science and Engineering  
Conte Research Center  
University of Massachusetts  
Amherst, MA  
USA

Mark E. Lucente  
Consultant  
Austin, TX  
USA

Wilfried Lövenich  
Heraeus Clevios GmbH  
Leverkusen  
Germany

Ruiqing Ma  
Universal Display Corporation  
Ewing, NJ  
USA

Sid Madhavan  
Microvision Inc.  
NE Redmond, WA  
USA

Kathleen Maher  
Jon Peddie Research  
Tiburon, CA  
USA

Avtar Singh Matharu  
Department of Chemistry  
Green Chemistry Centre of Excellence  
University of York  
UK

Bernard Mendiburu  
VP Innovation  
VolfoNi  
Los Angeles, CA  
USA

David W. Monk  
Engineering and Mathematical Sciences  
City University London and European Digital Cinema Forum  
London  
UK

Stephen M. Morris  
Centre of Molecular Materials for Photonics and Electronics  
Department of Engineering  
University of Cambridge  
Cambridge  
UK

N. J. Mottram  
Department of Mathematics and Statistics  
University of Strathclyde  
Glasgow  
UK
Uwe Muehlfeld
AKT Display Products
Applied Materials GmbH & Co. KG
Alzenau
Germany

Oliver Nachbaur
Advanced Low Power Solutions
Display Power
Texas Instruments Deutschland GmbH
Freising
Germany

Robert M. Nally
CRO, Innovative Card Scanning, Inc
Plano, TX
USA

C. J. P. Newton
Hewlett-Packard Laboratories
Bristol
UK

Peter J. Opdahl
Ito Corporation
Chuo-ku, Tokyo
Japan

Daniel K. Van Ostrand
Research and Development
Uni-Pixel Displays, Inc.
The Woodlands, TX
USA

Robert Earl Patterson
Air Force Research Laboratory
Wright-Patterson AFB, OH
USA

Marcia Payne
Outrider Technologies, LLC
Lexington, KY
USA

Jon Peddie
Jon Peddie Research
Tiburon, CA
USA

Robert Phares
Display Sourcing & Service LLC
Knoxville, TN
USA

Alfred Poor
HDTV Almanac
Perkasie, PA
USA

Ismo Rakkolainen
School of Information Sciences
University of Tampere
Tampere
Finland

Ram Ramakrishnan
Uni-Pixel Displays, Inc.
The Woodlands, TX
USA

Peter Raynes
Department of Chemistry
University of York
York
UK

David Redinger
3M Company
St. Paul, MN
USA

Stephan Reichelt
SeeReal Technologies GmbH
Dresden
Germany

Markus Römer
Inova Semiconductors GmbH
Munich
Germany
Jannick P. Rolland  
Institute of Optics  
University of Rochester  
Rochester, NY  
USA

Mervyn Rose  
Division of Electronic Engineering and Physics  
University of Dundee  
Nethergate, Dundee  
UK

Per Rudquist  
Department of Microtechnology and Nanoscience  
Chalmers University of Technology  
Göteborg  
Sweden

Kalluri R. Sarma  
Honeywell  
Phoenix, AZ  
USA

Graham Saxby  
University of Wolverhampton (retired)  
West Midlands  
UK

Axel Schindler  
Institute for System Theory and Display Technology  
University of Stuttgart  
Stuttgart  
Germany

Brian T. Schowengerdt  
Department of Mechanical Engineering  
Human Photonics Laboratory, and Human Interface Technology Laboratory  
University of Washington  
Seattle, WA  
USA

Markus Schu  
3D Impact Media  
R&D Technology Center  
Munich  
Germany

Eric J. Seibel  
Department of Mechanical Engineering  
Human Photonics Laboratory, and Human Interface Technology Laboratory  
University of Washington  
Seattle, WA  
USA

Ian Sexton  
Imaging and Displays Research Group  
De Montfort University  
Leicester  
UK

Sarah Sharples  
Human Factors Research Group  
University of Nottingham  
Nottingham  
UK

Jack Silver  
School of Engineering and Design  
Wolfson Centre for Materials Processing  
Brunel University  
Uxbridge, Middlesex  
UK

Eugen Stamate  
Risø DTU  
Technical University of Denmark  
Roskilde  
Denmark

David Steven  
Optovise Ltd  
Roslin, Edinburgh  
UK
<table>
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<td>Andrew Stubbings</td>
<td>Itron UK Limited</td>
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<td></td>
<td>Great Yarmouth, Norfolk</td>
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<td></td>
<td>UK</td>
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<tr>
<td>Phil Surman</td>
<td>Imaging and Displays Research Group</td>
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<td>De Montfort University</td>
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<tr>
<td>Bernd Szyszka</td>
<td>Department of Large Area Coating</td>
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<td>Fraunhofer Institute for Surface Engineering and Thin Films (IST)</td>
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Thomas Wirschem  
High Speed Data Path Division  
National Semiconductor  
Santa Clara, CA  
USA

Robert Withnall  
School of Engineering and Design and  
Wolfson Centre for Materials Processing  
Brunel University  
Uxbridge, Middlesex  
UK

W. B. Wu  
Manufacturing Technology Center  
AU Optronics Corporation  
Taichung, Taiwan

Chihao Xu  
Institute of Microelectronics  
Saarland University  
Saarbruecken  
Germany

Yoshitaka Yamamoto  
Display Technology Laboratories  
Corporate R & D Group  
Sharp Corporation  
Tenri, Nara  
Japan

Geun Young Yeom  
Advanced Materials Science and Engineering  
Sungkyunkwan University  
Suwon  
South Korea

Hidefumi Yoshida  
Display Engineering Laboratories  
Corporate R & D Group  
Sharp Corporation  
Tenri, Nara  
Japan

Ross Young  
SVP Displays  
LEDs and Lighting  
IMS Research  
Austin, TX  
USA

Kaichang Zhou  
Gamma Dynamics  
Cincinnati, OH  
USA

Enrico Zschau  
SeeReal Technologies GmbH  
Dresden  
Germany