SID 2012 PREVIEW / BACKLIGHTING ISSUE

Information DISPLAY

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SOCIETY FOR INFORMATION DISPLAY

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April 2012
Vol. 28, No. 4

SID Honors Its Best and Brightest

Focus on Backlighting

LED LIGHT GUIDES EVOLVE BEYOND BACKLIGHTING

HOW LEDs HAVE CHANGED THE LCD INDUSTRY

A NOVEL MONOLITHIC-STRUCTURED 2-D BACKLIGHT DESIGN

SID 2012 HONORS AND AWARDS RECIPIENTS

PREVIEW OF UPCOMING BLOCKBUSTER SYMPOSIUM

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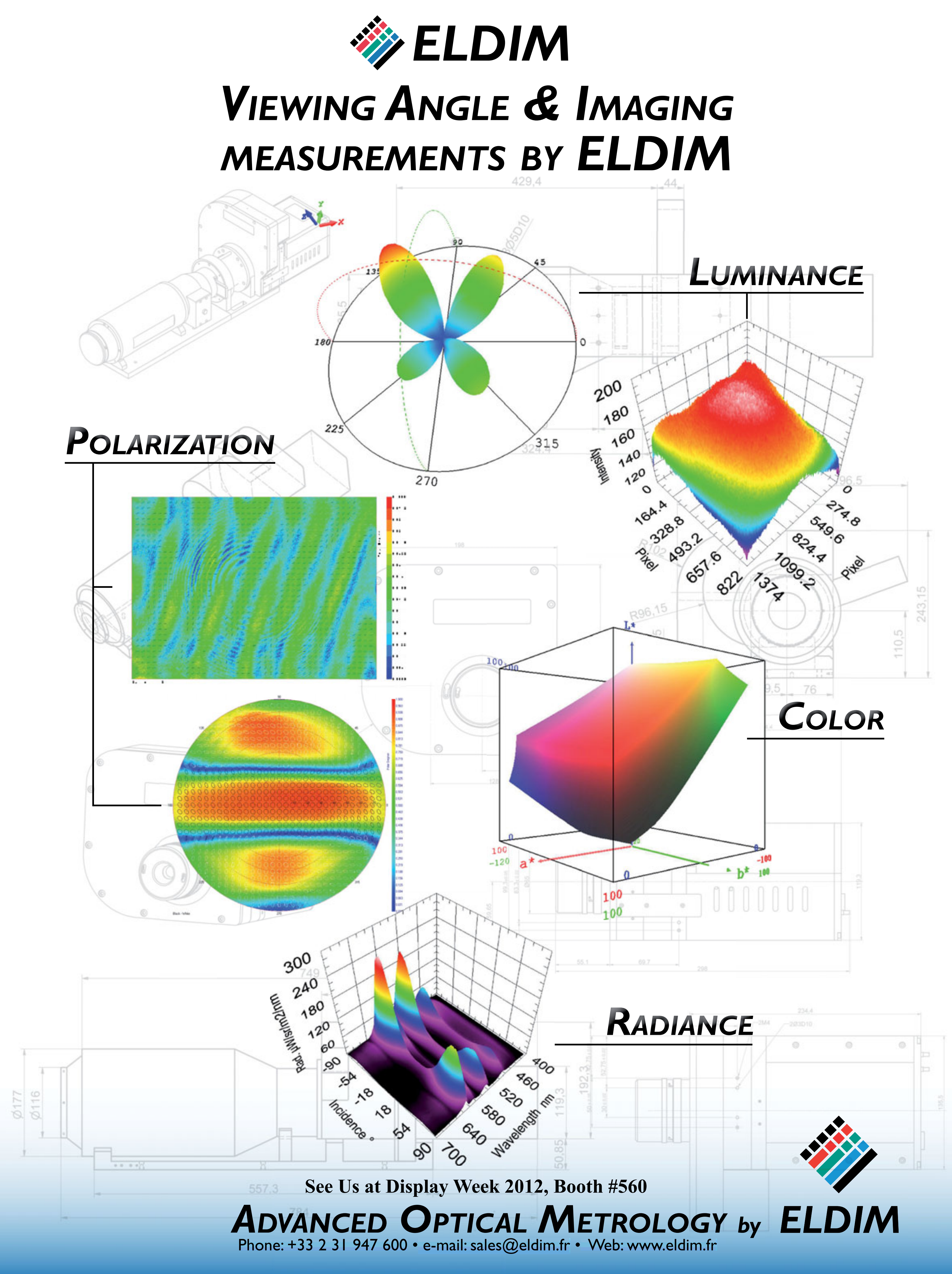
Plus

America Invents Act: What You Need to Know ... continued

Journal of the SID April Contents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SOCIETY FOR INFORMATION DISPLAY

Information DISPLAY

APRIL 2012
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ON THE COVER: *This year's winners of the Society for Information Display's Honors and Awards include* ***Dr. Jun Souk,*** *who will receive the Karl Ferdinand Braun Prize;* ***Dr. Tetsuo Tsutsui,*** *who will be awarded the Jan Rajchman Prize;* ***Mr. Adi Abileah,*** *who will receive the Otto Schade Prize;* ***Mr. Larry Tannas,*** *who will be awarded the Slottow–Owaki Prize; and* ***Dr. Webster Howard,*** *who will receive the Lewis & Beatrice Winner Award.*

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editorial

Supporting Students and Building Better Backlights

by Stephen Atwood

It's April, and within the next month classes at many colleges and universities will be over for the summer. Graduates will be looking for their first real industry jobs and undergrads will be seeking internships and summer work opportunities. Of those in the science and engineering fields, far too few will find places to work within the display industry. The reason is not because of slow growth, but rather because many display-industry companies do not make the effort to target their employee development strategies to students and recent grads. That's a missed opportunity because I have hired quite a few students in my career and many of them have become highly valued members of the industry.

Unfortunately, too few universities today offer specialized display-technology programs, so most new graduates either learn about display technology during internships or they must overcome a steep learning curve at their first new position before they can make meaningful contributions. I've often found it challenging to find qualified seasoned product engineers who have more than a passing knowledge of the fundamentals of LCDs, backlights, optics, and display electronics. In contrast, there is practically no mainstream high-tech product you can design today that does not require a display. In many cases, the display itself is a critical part of the product's differentiating identity, so those companies that can hire and train engineers with good display knowledge will find a competitive advantage in the marketplace. This is why most companies focus on hiring experienced candidates with many years of previous industry experience. By doing this, they get the benefit of the years of training and teaching that other businesses have already invested in that candidate. It's a good strategy, but obviously it has a limited reach. In fact, if we as industry leaders do not hire and teach new grads then eventually, surely within our career lifetimes, we will all run out of qualified candidates to hire.

So, consider the alternative: Student internships combined with mentoring programs can provide countless benefits for both the student and the supporting company. Students can learn the essential technical skills unique to each technology area from the original inventors and innovators. Companies can plant the seeds for their next generation of knowledge workers from the onset by instilling the right culture and values as well as the core technical disciplines required. I do not know what the statistics show, but I would be willing to bet that students who participate in successful internships are highly motivated to choose careers after graduation within the same industry and at the same companies that supported them as undergrads. That's loyalty, experience, like-minded culture, and high motivation, all instilled in a candidate who will be ready to make a difference in your company from the first day.

Not only does this partnership work both ways, but it also sends a valuable message to universities that display technology skills are a highly valued part of the science and technology curriculum. Universities care greatly about the marketability of their graduates and most will recognize the opportunities being offered and how they signal a need for more display-technology curriculum.

Beyond all this, giving back to the next generation through mentoring, teaching, and financial support is just the right thing to do. Many of my colleagues within our

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Executive Editor: Stephen P. Atwood
617/306-9729, satwood@azonix.com

Editor-in-Chief: Jay Morreale
212/460-9700, jmorreale@pcm411.com

Managing Editor: Jenny Donelan
603/924-9628, jdonelan@pcm411.com

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Samsung Announces LCD "Spinoff"

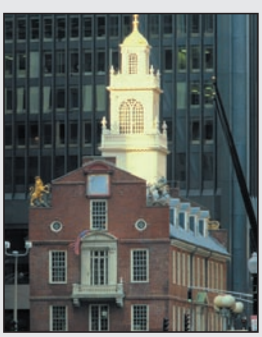
In February 2012, Samsung Electronics announced that its board had agreed to create a new and separate business entity based on the company's liquid-crystal-display (LCD) business. According to Samsung's announcement, factors spurring the move included rapid changes in the display market and the likelihood of OLEDs overtaking LCDs, as well as Samsung's desire to streamline decision-making and manage resources more efficiently.

Although the term "spinoff," used by Samsung in its announcement, often describes the creation of an independent company, the new Samsung entity, titled Samsung Display Co., will be a wholly owned subsidiary of Samsung Electronics. Among further measures under consideration, also stated in the Samsung announcement, is a merger with Samsung Mobile Display, which currently makes OLEDs and smaller devices. On March 15, shareholders approved the new company, with Samsung executive Dong-gun Park named to lead the firm as president, and initial funding of $848 million.

Samsung Electronics is currently the world's largest maker of flat panels, memory chips, and flat-screen televisions. For two reasons, a move of this kind is not unexpected, says Paul Semenza, analyst with market research firm DisplaySearch. "All LCD makers have been struggling, with six quarters of losses," he says. Most of these companies, he notes, are bound to be at least considering restructuring and cost-savings. The second reason involves the company's two-entity approach toward displays, with Samsung Electronics making large-area LCDs and Samsung Mobile Display making OLEDs and smaller devices. "This could be the first step toward some kind of consolidation," he says.

Consolidation does seem likely. LCD makers have been challenged in terms of profits over the last year and a half, and some experts are predicting that OLEDs will replace LCDs as the dominant display technology. Although it seems unlikely that Samsung is moving away from LCDs, particularly as it has a substantial investment in fabs across the world, combining the LCD and OLED divisions should allow the company to maximize the use of its resources and be ready to respond to market momentum in either direction.

— Jenny Donelan



SID DISPLAY WEEK Boston 2012

Display Week 2012

SID International Symposium, Seminar & Exhibition

June 3–8, 2012

Boston Convention & Exhibition Center

Boston, Massachusetts, USA

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All photos courtesy of the Greater Boston Convention & Visitors Bureau

president's note

Display Week 2012 Steams into Boston

by Munisamy Anandan
President, Society for Information Display

As I prepare my last President's Note, it is April and about a month away from our annual Display Week event in Boston, Massachusetts, in the United States. Preparations for Display Week proceed in two areas: the exhibition and the technical symposium. Exhibition planning for the year commences immediately after each Display Week Exhibition in the spring. Preparation for the technical symposium and satellite conferences begins in earnest each January. For every Display Week Exhibition and Symposium, new features must be added in order to keep up with the changing needs of SID members and display-industry customers.

This year, on the technical symposium side, SID has added a one-day track for solid-state lighting. Interest in solid-state lighting has developed on a global scale, and displays offer an obvious hyperlink to this technology. In fact, the market demand for LEDs for LCD-TV backlighting took the lead over the market demand for LEDs in traditional lighting. Lighting is an integral part of displays; every display operates with lighting, whether ambient or built-in or self-emitting.

Solid-state lighting had penetrated only 11% of the global lighting market in 2011. But use of LED lighting is growing, and organic LEDs (OLEDs) also have great potential as lighting sources. SID has a strong background in both LED and OLED technology and, therefore, it is only logical for SID to exploit the technical and commercial aspects by focusing these technologies through a one-day new track at the symposium.

On the exhibit side, Display Week 2012 will have a new dedicated zone for exhibiting engineering/experimental prototypes of devices or systems that signal the future direction of displays. The I-Zone (Innovation Zone) is open to all universities, national laboratories, and small companies, and thus provides these institutions with a rare opportunity to demonstrate to the display community and the public what is on the horizon for display technology. SID volunteers have been working hard on this exciting new feature, and E Ink Corp., itself once a start-up with an important cutting-edge technology, is generously sponsoring the I-Zone.

My Station Is Coming Up

The train is approaching the station (my term as President of SID is almost up) and I am getting ready to step off, but I have a few words before I depart. The Society for Information Display (SID) is Number One in the world, attracting the best display technologists and showcasing the best in leading-edge research and development. I have made this statement at many gatherings because I truly believe in this institution, which has been built over the past 50 years by the hard work of volunteers and the SID leadership. My predecessors on the board, through their dedicated service, have led SID to this rank. Times are changing, and there is a definite need to add a business component to the society to augment our strong technical standing in the industry. We have been doing this in an incremental manner for our growth, being careful to preserve our fundamental mission while expanding our core reach into the industry at the same time.

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Display Week 2012

Photo courtesy of the Greater Boston Convention & Visitors Bureau

SID International Symposium, Seminar & Exhibition

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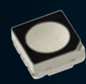

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guest editorial

Backlight-Unit Basics

by Adi Abileah

Flat-panel displays have come a long way in recent years. LCDs are the dominant technology today, and behind every LCD panel is a backlight. Even the newly developed transparent displays rely on illumination from behind. In this issue, we will present two papers on backlight technology, one describing the general direction of backlight units (BLUs) and the second showing state-of-the-art design considerations for a compact optical structure with local dimming.

There are two basic BLU concepts: (a) a cavity backlight with many light sources (*e.g.*, CCFLs or LEDs) distributed in the area, a reflector behind and diffusers above, and (b) an edge-illuminated light guide with light sources at the edge and optical elements on the light-guide surface to extract uniformly the light propagating along the cross section. In both cases, it is very important to have efficient light coupling and proper diffusers to obtain good uniformity and enhanced illumination.

Each BLU consists of (a) light sources (CCFL, LEDs), (b) light-distribution means (cavity reflectors or a light guide), (c) diffusers and light-shaping elements (BEF, holographic diffusers, DBEF), and (d) driving electronics for the light sources. When optimizing the BLU, all aspects have to be included. In the articles in this issue, we will touch on some of these aspects.

Until recently, the BLU light source of choice was the well-established cold-cathode fluorescent lamp (CCFL). Over the years, CCFLs have improved in efficiency (20–60 lm/W) and at the same time became thinner (*e.g.*, 2.8-mm outer diameter). This allowed thinner designs both in cavity mode and with edge illumination. The thin CCFLs match thinner light guides, with decent coupling efficiency. The CCFL also improved over time in terms of better gas mixtures and more robust hollow cathodes. And its total luminance, efficiency, and lifetime (*e.g.*, 30,000 hours) improved. Last, in mass production, they were also quite inexpensive.

Recently, LEDs have been taking over the backlight arena with higher efficacies (80–130 lm/W). As LEDs move into mass production, their prices are becoming competitive with CCFLs. LEDs are also penetrating into the area of general lighting (automotive, industrial, household).

The major breakthroughs in LED development have been (a) invention of blue LEDs. (b) light-extraction techniques from the emitting layer, and (c) development of white LEDs. The blue LED was the missing link needed to make multi-color arrays of LEDs. It was developed through the pioneering work of Dr. Shuji Nakamura form Nichia Japan.

The main leap-frog of luminance efficacy was performed when people realized that the LED theoretical maximum was very high (250 lm/W), but that the emitting layer had a very high index of refraction and the light was trapped internally. Surface interface techniques to extract the trapped light provided a significant improvement from the 20-lm/W range to the recently reported 150 lm/W. This represents amazing progress in just a few years. With commercial LEDs in the 80–130-lm/W range, we expect a fast penetration not only to backlights but also to general illumination, as presented in this issue's article, "Light Guides Evolve from Display Backlighting to General Illumination," by Brett Shriver of Global Lighting Technologies (GLT). Recent reports about LCD-TV trends show that more than 50% are using LED-based BLUs.

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2012 SID Honors and Awards

This year's winners of the Society for Information Display's Honors and Awards include ***Dr. Jun Souk,*** *who will receive the Karl Ferdinand Braun Prize for his pioneering work in the technology and product development of very-large-sized TFT-LCD TV panels;* ***Dr. Tetsuo Tsutsui,*** *who will be awarded the Jan Rajchman Prize for his pioneering contributions to OLED research, especially the insightful application of the micro-cavity effect in OLED devices;* ***Mr. Adi Abileah,*** *who will receive the Otto Schade Prize for his many outstanding contributions to the enhancement of the functional performance of displays, including contrast, brightness, viewing angle, gray-scale resolution, and stereoscopic imaging;* ***Mr. Larry Tannas,*** *who will be awarded the Slottow–Owaki Prize for his outstanding contributions to the education of students and engineers in the display field; and* ***Dr. Webster Howard,*** *who will receive the Lewis & Beatrice Winner Award for his outstanding and sustained services to SID.*

by Jenny Donelan

ONE POPULAR VIEW of scientists is that they spend all their time working by themselves in their laboratories. While the individuals honored by the Society for Information Display this year certainly spent a great deal of time working in laboratories, they did not do so alone. Leadership, mentoring, and the ability to inspire others are traits common to this year's winners. One researcher in Japan not only made important OLED discoveries, but inspired other scientists to study OLEDs so that great advances in this area took place in that country. Another engineer and scientist, although he had a busy career, took the time to teach classes for a span of more than 30 years at UCLA Extension and in private industry so that thousands of people who might not have otherwise learned about display technology became exposed to it.

Jenny Donelan *is the Managing Editor of* Information Display *Magazine. She can be reached at jdonelan@pcm411.com.*

Leadership is a key ingredient for any display discovery to come to fruition. Consider this year's Karl Ferdinand Braun Prize winner, Dr. Jun Souk, who was working to create a large-area LCD prototype at a time when most people thought it could not be done. He had to convince a team to believe in the project and help him carry it out. It was not glamorous work. "At that time," he says, "the equipment for liquid-crystal and module assembly processes was not available; therefore, we processed them manually, one by one, by hand. The liquid-crystal vacuum-filling process took 5 days, and we obtained a few good panels only after numerous failures." Through persistent effort and the willingness to work together to accomplish difficult tasks, Souk and his team played a part in clearing the way for the LCD market we now take for granted.

The SID Board of Directors, based on recommendations made by the Honors & Awards Committee, grants these annual awards based upon outstanding achievements and significant contributions to the display

The 2012 award winners will be honored at the SID Honors & Awards Banquet, which will take place Monday evening, June 4, 2012, during Display Week at the Boston Convention and Exhibition Center. Tickets cost $75 and must be purchased in advance – tickets will not be available on-site.

Visit **www.displayweek.org** for more information.

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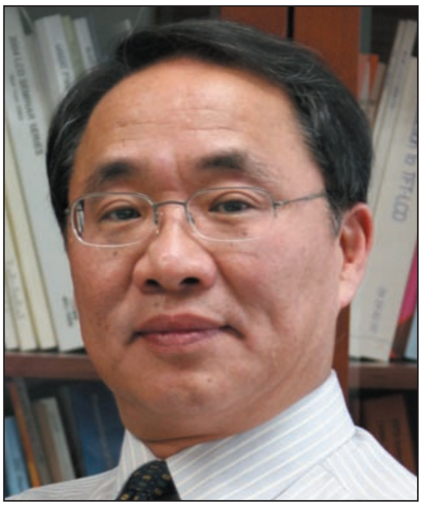

Dr. Jun Souk

Dr. Tetsuo Tsutsui

industry. This year's winners should take pride in this prestigious acknowledgment of their tremendous accomplishments.

This year's Honor and Awards recipients will be honored by the Society for Information Display during Display Week 2012 at the annual awards banquet to be held on Monday evening, June 4, prior to the Symposium. Tickets for this event are available in advance only by registering at www.displayweek.org.

Karl Ferdinand Braun Prize

This award is presented for an outstanding technical achievement in, or contribution to, display technology.

Dr. Jun Souk, SID member and Engineer/R&D Manager with Samsung Electronics, will receive the Karl Ferdinand Braun Prize "for his pioneering work in the technology and product development of very-large-sized TFT-LCD TV panels."

In 2001, when Dr. Jun Souk and his team at Samsung Electronics introduced the first 40-in. TFT-LCD panel, 42-in. plasma displays were the dominant flat-panel TVs on the market and had only recently triumphed over CRTs. At the time, LCDs were not considered viable candidates for large-screen TVs because of the inherent poor switching characteristics of amorphous-silicon TFTs and the poor conduction lines in TFT backplanes. In addition, the processing equipment for the fabrication of liquid crystals on a large area was not available.

When asked why he proceeded with the 40-in. LCD panel despite conventional wisdom, Souk says it was a case of practice versus theory. His practice came from long industry experience with TFT-LCDs. Theories about large LCDs at that time were based on simulations and calculations and not on field experience with large-scale panels. "I firmly believed that 40-in. and larger LCD panels would be possible and planned this project for many years," says Souk.

"A 40-in. LCD is not a big TV now, but it was huge at that time and stunned many people," says Ki-Woong Whang, a professor at Seoul National University. Moreover, the LCD panel delivered high image quality with a wide viewing angle, 16-msec driving speed, and 72% color-saturation level. According to Lambent Consultancy's Tony Lowe, "to make even a prototype display of such a large size was regarded as a very brave step because even small [LCD] panels were only just beginning to be manufacturable at prices affordable by the market. This was really brave pioneering work."

Souk's work was not only brave but far-reaching and represented a critical breakthrough in the ascendency of LCDs in the display marketplace. In related work, he also pioneered wide-viewing-angle technologies for LCDs and investigated new types of LCD modes such as in-plane switching (IPS) and patterned-vertical-alignment (PVA) technologies for LCDs.

Souk began his academic career at Seoul National University, where he earned degrees in physics. He went on to earn his M.S. degree in material science from Drexel University and an honorary doctorate in science from Kent State University. He served in the display field for over 25 years, from the early stages of TFT-LCD research at IBM Research Center to the work in LCD-TV technology development at Samsung Electronics. He has returned to academia and is now a professor at Hanyang University. Souk has also authored and co-authored over 60 papers.

Jan Rajchman Prize

This award is presented for an outstanding scientific or technical achievement in, or contribution to, research on flat-panel displays.

Dr. Tetsuo Tsutsui, SID member and Senior Vice-President of CEREBA (Chemical Materials Evaluation and Research Base) will be awarded the Jan Rajchman Prize "for his pioneering contributions to OLED research, especially the insightful application of the micro-cavity effect in OLED devices."

Dr. Tetsuo Tsutsui has played a vital role in the development of organic light-emitting diodes (OLEDs), both in terms of research and in developing researchers. In the early 1990s, his group at Kyushu University invented and developed many of the key design features used in current OLED technology. Tsutsui was the first to invent and demonstrate a multiple heterojunction device, using three organic layers, for electron transport, hole transport, and light emission. He was also the first researcher to recognize the importance of the photonic structure in terms of controlling the color of light emission and the efficiency of light out-coupling.

Tsutsui says that his group started its OLED research in 1983. "We had no clear prospect for display applications in those days, but observing light emission from organic semiconductors was quite new and fascinating." When asked why he was initially attracted to the study of OLEDs, Tustsui says, "The Japanese people have a traditional seasonal custom called Hotarugari. In early summer, people wander by the riverside after sunset, watching the fire flies in the dark, beautiful landscape. We love the natural light of living things, and perhaps also the natural broadband light from organic molecules. I, and many other Japanese researchers, have certainly been very interested in producing artificial versions of natural lighting."

Tsutsui has shared his enthusiasm with others over the years. According to Ching Tang, the Doris Johns Cherry Professor of Chemical

Engineering at the University of Rochester, "Dr. Tsutsui, as an early pioneer and educator in the OLED research field, was responsible for training many OLED researchers in his laboratory." Some of those individuals went on to become the leading researchers and engineers in the OLED industry. "Indirectly," says Tang, "Dr. Tsutsui has contributed to the first commercialization of OLED displays in Japan through the work of his students embedded in many Japanese corporations, including Pioneer, Sanyo Electric, and TDK."

Dr. Tsutsui received his B.S. degree in applied chemistry from Kyushu University and his Ph.D. in materials science from the same university. He was a professor and then a dean at Kyushu University for many years. He has published more than 200 original and 50 review papers and is now a Professor Emeritus at Kyushu University.

Otto Schade Prize

The Otto Schade Prize is awarded for an outstanding scientific or technical achievement in, or contribution to, the advancement of functional performance and/or image quality of information displays.

Mr. Adi Abileah, SID Fellow and Chief Scientist with the Technology Group at Planar Systems, will receive the Otto Schade Prize "for his many outstanding contributions to the enhancement of the functional performance of displays, including contrast, brightness, viewing angle, gray-scale resolution, and stereoscopic imaging."

Adi Abileah

Although Adi Abileah grew up in a family of musicians, and played the French horn in both the Haifa Symphony Orchestra and the Israel Broadcast Orchestra, he always knew he wanted to pursue a career in physics. He began his studies at the Israel Institute of Technion, where he earned his B.Sc. degree in physics and then went on to earn his M.Sc. degree in plasma physics from Hebrew University in Jerusalem. Early in his career, he developed soil-mechanics density sensors based on gamma-ray reflections at the Negev Institute. He then worked at both Elscint (medical imaging) and Elbit (where he began focusing on avionics displays), then as the manager of the R&D Center of Electro-Optics Industries (EL-OP) in Haifa.

In 1987, he took a 1-year sabbatical at OIS (Optical Imaging Systems) in Michigan, USA, to learn about LCD technology, but ended up remaining there more than 10 years. He believes he was asked to stay because his background in avionics displays was helpful

2012 SID Fellow Awards

The grade of fellow is conferred annually upon SID members of outstanding qualifications and experience as scientists or engineers whose significant contributions to the field of information display have been widely recognized.

Nikhil Balram, *"For his pioneering contributions in the fields of video and image processing, integrating signal processing, visual perception, and semiconductor architectures."* Dr. Balram is President and CEO of Ricoh Innovations. He received his Ph.D. in electrical engineering from Carnegie-Mellon University.

Brian Berkeley, *"For his many advancements in the field of information display and contributions to display technology, including advancements in high-performance LCD driving technology."* Mr. Berkeley is Senior Vice-President for OLED Development at Samsung Mobile Display and President-Elect of the Society for Information Display. He received his B.S.E.E. from MIT and his M.S.E.E. from Carnegie-Mellon University.

Ho Kyoon Chung, *"For his contributions to the development and commercialization of AMOLED displays."* Dr. Chung is a professor with the Advanced Institute of Nanotechnology at Sungkyunkwan University. He holds a Ph.D. in electrical engineering from the University of Illinois, Urbana-Champaign.

Oh-Kyong Kwon, *"For his leading contributions to the research and development of LCDs, OLED displays, microdisplays, and system-on-panel technology."* Dr. Kwon is a professor with the Department of Electronic Engineering at Hanyang University. He received his Ph.D. in electrical engineering from Stanford University.

Hiap L. Ong, *"For his many significant contributions to the science and technology of LCDs, especially wide-viewing-angle twisted-nematic and multi-domain vertical-alignment LCDs."* Dr. Ong is President of Taiwan Kyoritsu Optronics Co. He earned his Ph.D. in physics from Brandeis University.

to the company. For his part, "OIS was a great place to learn about this type of displays – LCDs." After a year he became head of the optical group at OIS, where he developed. unique retardation film configurations for wide-viewing-angle AMLCDs. The work of his group also generated several structures used in avionics displays with special viewing-angle needs and yielded several patents. His contributions to backlight structures materialized when the patent was sold to 3M to make the brightness-enhancement film (BEF) used in many LCD products.

Abileah is notable not just for his research, but for his ability to mentor others. Says Sri Peruvemba, Chief Marking Officer at E Ink Holdings, "Adi Abileah has coached hundreds of hardware designers in the past two decades, resulting in better displays in numerous applications. Brian Schowengerdt, chair of the Display Systems committee of SID, says "Not only has Adi made direct and vital technical breakthroughs, he has also produced a powerful positive ripple effect in those working around him."

Abileah served at OIS until the company closed in 1998. Since that time he has worked at Planar Systems, where he is now Chief Scientist with the Technology Group. He has 34 U.S. patents, mostly related to displays and backlights, and has presented many technical papers and seminars at SID, SPIE, and OSA conferences.

Slottow–Owaki Prize

The Slottow–Owaki Prize is awarded for outstanding contributions to the education and training of students and professionals in the field of information displays.

Mr. Lawrence E. Tannas, Jr., SID Past-President, SID Fellow, and President of Tannas Electronics, will be awarded the Slottow–Owaki Prize "for his outstanding contributions to the education of students and engineers in the display field."

2012 SID Special Recognition Awards

Presented to members of the technical, scientific, and business community (not necessarily SID members) for distinguished and valued contributions to the information-display field.

Janglin Chen*, "For his leading contributions to the development of hybrid plastic substrates for flexible displays and electronics and for the development of rewritable and reusable electronic paper."* Dr. Chen is Vice President of ITRI (Industrial Technology Research Institute) and General Director of DTC (The Display Technology Center). He has a Ph.D. in polymer material from the Polytechnic Institute of New York.

Hyang Yul Kim*, "For contributions to the invention, product development, and commercialization of fringe-field-switching LCDs."* Dr. Kim is a Principal Engineer with Samsung Electronics Co. He has a Ph.D. in advanced organic materials from Chonbuk National University.

Seung-Hee Lee*, "For contributions to the invention, product development, and commercialization of fringe-field-switching LCDs."* Dr. S. H. Lee is a professor at Chonbuk National University. He received his Ph.D. in physics from Kent State University.

Seok-Lyul Lee*, "For contributions to the invention, product development, and commercialization of fringe-field-switching LCDs."* Mr. S. L. Lee is a senior manager at AU Optronics. He earned his M.S. degree in polymer/nanoscience technology from Chonbuk National University.

Tapani Levola*, "For his outstanding technical accomplishments in advancing the science of diffractive optics related to near-to-eye display systems."* Dr. Levola is a principal hardware engineer at Microsoft. He has a Ph.D. in physics from the University of Joensuu.

Shigeaki Mizushima*, "For his leading contributions to the successful development of an 85-in. 8K × 4K-pixel TFT-LCD panel."* Dr. Mizushimi is Executive Director for Sharp Corp. He earned his Ph.D. in materials engineering at Osaka University.

Masayuki Sugawara*, "For his outstanding contributions to the development of an ultra-high-definition LCD based on his leadership in UHDTV system design."* Dr. Sugawara is an Executive Research Engineer for Science and Technical Research Laboratories, NHK. He was awarded his Ph.D. in electronic engineering from Tohoku University.

John Wager*, "For his pioneering contributions to the development of oxide TFTs."* Dr. Wager is a Professor in the College of Engineering at Oregon State University. He received his Ph.D. in electrical engineering from Colorado State University.

Lawrence E. Tannas, Jr.

Although he was trained and employed as an engineer and scientist, the career of Mr. Tannas demonstrates that he is also an educator at heart. He has clearly felt that it was important to reach out and train the next generation of information-display experts. "During my entire professional career, I have enjoyed my years as an engineer doing R&D in electronic information displays. But, perhaps, I enjoy, most of all, teaching," says Tannas.

Relatively few courses exist in the U.S. for undergraduates and graduates in the art and science of information display. For the last 30-plus years, Tannas has labored to fill this gap, teaching over 100 courses over this time period for UCLA Extension as well as private industry. "There are probably over 1000 graduates of these courses," says SID Past-President Erwin A. Ulbrich, Jr. Working through the LA Chapter of SID, Tannas, past Chapter President and current Chapter Director, also set up a Student Chapter at UCLA. In addition, he and his wife, Carol, have endowed a Chair devoted to Electronic Information Displays that has been awarded to Professor Yang Yang of the Materials Science and Engineering Department of the Henry Samueli School of Engineering and Applied Science at UCLA.

Tannas earned his B.S. and M.S. degrees in electrical engineering from UCLA. He worked on displays at GE Research Laboratories, Honeywell, Martin Marietta, Rockwell International, and Aerojet ElectroSystems before starting Tannas Electronics, a consultancy. He has been awarded 20 patents and patents pending and has developed and patented a successful, novel process to resize commercial-off-the-shelf LCDs by cutting and resealing them for custom applications in avionics, digital signs, etc. He has also written/edited two books and many technical articles and encyclopedia entries. The U.S. Government has awarded him a Certificate of Appreciation and Medallion for his pro bono services for DARPA, NSF, and the CIA. He is a Senior Member of IEEE and AIAA and other aircraft-oriented organizations, and as a private airplane owner holds FAA instrument, commercial, and flight instructor ratings. His flight-instructing years are consistent with his love of education.

Lewis & Beatrice Winner Award

This Lewis and Beatrice Award for Distinguished Service is awarded to a Society member for exceptional and sustained service to SID.

Dr. Webster Howard, SID Fellow, Jan Rajchman Prize recipient, and a consultant with Howard Consulting, will receive the Lewis & Beatrice Winner Award "for his outstanding and sustained services to SID."

Dr. Webster Howard has served SID in different capacities for more than 25 years. Among these are Technical Program Committee Chair, IDRC; Program Chair, IDRC; Associate Editor for JSID for over 10 years; member of SID Honors and Awards Committee for 4 years; Overseas Advisory committee member for many international conferences for over 10 years; Program Committee member in the Active-Matrix LCD subcommittee and Chair of the OLED Subcommittee; and a member of the SID Executive Committee for 10 years, including president for 2 years.

According to SID Past-President Paul Drzaic, "Dr. Howard epitomizes the very best of SID in many ways. He has been a steady contributor to the Society, and he is generous with his time and advice. Moreover, he has great credibility in societies outside of SID as well, and serves as an ambassador for SID in this way."

Howard received his B.S. degree from Carnegie-Mellon University and his A.M. and Ph.D. degrees from Harvard University, all in physics. He joined IBM as a research staff member and worked there for 12 years in semiconductor physics, including pioneering work on two-dimensional electron gases in Si inversion layers and on semiconductor superlattices. He later focused on display technology, managing projects in plasma displays, thin-film electroluminescence, CRTs, and thin-film transistor/liquid-crystal displays. The latter project led to the formation of DTI, the joint venture between IBM and Toshiba. After retiring from IBM, he worked at AT&T Global Manufacturing and Engineering and served as a consultant to the Display Research Department of AT&T Bell Laboratories. When AT&T/Lucent Technologies terminated its display activity in 1996, he joined eMagin Corp., where he led the development of a microdisplay technology based on organic light-emitting diodes on silicon. In 2002, he retired from eMagin as Chief Technology Officer and now serves as a consultant. ■

Dr. Webster Howard

The Society for Information Display is indebted to the following companies, who each donated $2000 to sponsor a prize:

Braun Prize	AU Optronics Corp.
Rajchman Prize	Sharp Corp.
Otto Schade Prize	Samsung Mobile Display
Slottow-Owaki Prize	Fujitsu, Ltd., and Dr. Tsutae Shinoda

Catch The Latest Cutting-Edge Display Technology

Don't miss the excitement when Display Week 2012 comes to Boston! Face off with the industry's latest and greatest developments at the SID International Symposium, Seminar and Exhibition – the premier display exhibition in North America.

From 3D and printed displays to tablet computers and solid-state lighting, you'll have a front-row seat for the coolest new and emerging information display technologies. This includes all things green: the industry is working to ensure that display manufacturing is as energy efficient as possible, while still turning out products with the size, resolution and performance that consumers are looking for. DisplayWeek assembles the strongest and broadest set of technical leaders in the display industry, in front of attendees representing the largest markets for the display industry. DisplayWeek is the best place to demonstrate advanced display technology, and publicize the value for licensing, selling or funding your technology. Be there when the puck drops June 3 - 8, 2012, at the Boston Convention and Exhibition Center. To exhibit or for more event information, visit: *http://www.displayweek.org*

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INNOVATION ZONE
"I-Zone"

New at Display Week 2012, the I-Zone will give attendees a glimpse of cutting-edge live demonstrations and prototypes of the display products of tomorrow. Researchers from companies, startups, universities, government labs, and independent research labs will demonstrate their prototypes or other hardware demo units for two days in a dedicated space in the main Exhibit Hall. The "Best Prototype at Display Week," to be selected by the I-Zone Committee, will be announced in Information Display magazine.

A Look Ahead at the 2012 Symposium

Plan your visit to Display Week 2012 with an advance look at some of the most exciting developments to be revealed in this year's technology sessions.

by Jenny Donelan

THE Society for Information Display's annual Symposium is the core of Display Week. The hundreds of papers presented each year represent the best of the most recent research and development in numerous areas of display technology. This year's Symposium, to be held in Boston, Massachusetts, June 5-8, will offer an enormous range of technical display-related presentations impossible to find at any other venue.

As in previous years, sessions are organized by subcommittees, whose members have chosen the most cutting-edge and informative papers in their chosen areas. Those areas include active-matrix devices, applications, applied vision, display electronics, display manufacturing, display measurement, display systems, emissive displays, flexible displays, liquid-crystal technology, OLEDs, projection, and touch and interactivity.

In addition to the above, SID has designated special topics of interest that are especially timely and important to our industry: 3-D, Green Technologies, Solid-State Lighting, and Flexible Electronics and Printed Displays. Attendees at Display Week 2012 will have the opportunity to gain comprehensive knowledge of each of these special topics not only by way of the presentations during the four-day technical symposium, but through the special Sunday Short Courses and Monday Seminars, and with a business perspective from the Business and Investors Conferences and the Market Focus Conferences.

***Jenny Donelan** is the Managing Editor of Information Display magazine. She can be reached at jdonelan@pcm411.com.*

The following session highlights are but a small portion of what awaits attendees at Display Week 2012. Come join us to find out what's happened in our industry over the past year, and what's going to happen next. See you in Boston!

Active-Matrix Devices: TFT Oxide Prepares to Go Mainstream

Two distinct themes emerged among this year's crop of active-matrix papers, according to subcommittee chair Russel Martin. The first involves the tremendous amount of work currently going into oxide semiconductors, which, as viable alternatives to amorphous-silicon TFTs, are moving from concept to manufacturing. The second is represented by very-high-resolution TV panels, including an 8K × 4K AMLCD. "These are just amazing leaps in high-end OLEDs and AMLCDs – the growth never stops," says Martin.

Among the oxide-TFT papers to watch for are "Implementation of 240-Hz 55-in. Ultra-Definition LCD Driven by a-IGZO semiconductor TFT with Copper Signal Lines" by Namyong Gong of LG Display and "Research, Development, and Application of Crystalline Oxide Semiconductor" by Jun Koyama of Semiconductor Energy Laboratory Co., Ltd. One of the most exciting papers will be "Development of Super Hi-Vision 8K × 4K Direct-View LCD for Next-Generation TV" by Takeshi Kumakura of Sharp Corp., a look at an 85-in. concept panel that is the world's first direct-view display for 8K × 4K resolution.

Applications: From Augmented Reality to Homeland Security

Applications represent that exciting stage of display development when theories and concepts become actual products. This year's applications papers range from stereoscopic and autostereoscopic displays to solid-state lighting to novel and emerging displays. One of the more interesting in the latter category is "Detection of Ionizing Radiation by Plasma-Panel Sensors: Cosmic Muons, Ion Beams, and Cancer Therapy," by Peter S. Friedman of Integrated Sensors LLC. Friedman's paper describes the plasma-panel sensor, a new radiation-detector technology based on plasma-display panels, which is being developed for a number of scientific and commercial applications, including homeland security, cancer treatments, and medical imaging. Also of interest is the paper "Sensing and Augmented-Reality Technologies for Mobile 3-D Platforms" by Chan Yuan of Sharp Laboratories of America, which describes algorithms that can enable novel user experiences by providing depth sensing for mobile devices. Possible 3-D and augmented-reality applications include gaming, tactical and situational awareness, scientific visualization, video surveillance, and robotics. The invited paper "Color-Accurate Monitors" by Adi Abileah of Planar will discuss the specifications for highly accurate color monitors as required by applications such as printing, graphic arts, photography, film-making and editing, medicine, art, and geospatial research. (Note: Abileah is being honored with SID's 2012 Otto Schade Prize for his contributions to display performance.)

Applied Vision: Seeing in 3-D

3-D is by far the biggest trend in applied-

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vision papers this year. "Almost half the papers are related to 3-D," says subcommittee chair Yi-Pai Huang. Of those, about 75% are related to 3-D perception and 3-D comfort, so there is a session devoted to each of these applied-vision aspects of 3-D.

Of particular note is a poster paper titled "Comparison of Simultaneous Measurement of Lens Accommodation and Convergence in Natural Vision and 3-D Vision" by Tomoki Shiomi of Nagoya University. The author's team set out to study the issue of lens accommodation and convergence, which is thought to be a major source of discomfort for people viewing 3-D imagery. The team invented a method to simultaneously measure accommodation and convergence and used it to measure them in both natural vision and 3-D vision. "This is something that has not been done before," says Huang. Surprisingly, the authors found very little difference between natural vision and 3-D vision in terms of accommodation and convergence, which suggests there could be another reason for viewer fatigue when viewing 3-D images.

Another paper to check out is "3-D Looks More Real and Is Funny: Comparing the Children's and Adults' 3-D-Related Experiences," by Viljakaisa Aaltonen of Nokia Research Center, which looks at users' experience of 3-D images. In the study, 80% of children said they would choose the 3-D format over 2-D, whereas only 26% of adults preferred 3-D. "The children want it but they do not have money to buy it," says Huang, adding that this bodes well for the future – if 3-D content and hardware providers can wait long enough for those kids to grow up and make money.

Display Electronics: LCD Panels Drive Tablet Innovations

Intra-panel interfaces were a popular topic for display-electronics papers this year, according to chair Taesung Kim, who attributes the interest to the rise of tablets, especially ultra-high-resolution varieties that require high-bandwidth interfaces. One session is devoted to intra-panel interfaces and leads off with the paper, "A 1.4-Gbps Intra-Panel Interface for Chip-on-Glass TFT-LCD Applications" by Dongmyung Lee of Samsung Electronics Co., Ltd.. Lee's paper describes a high-speed intra-panel interface with an enhanced reduced voltage differential signaling (eRVDS) scheme implemented in a 0.18-μm high-voltage CMOS process for chip-on-glass TFT-LCD applications. Measured results demonstrate a maximum data rate of 1.4 Gbps from a 1.8-V supply voltage with a WQXGA 60-Hz chip-on-glass TFT-LCD prototype panel.

Display Manufacturing: Oxide TFT and Roll-to-Roll Require New Processes

Much has been happening in display manufacturing this year. According to committee chair Don Carkner, trends for 2012 include new manufacturing options such as simulation and modeling and new processes such as replacing vacuum deposition with 3-D printing. Two other major trends are better performance and lower cost manufacturing for thin-film oxides, as exemplified in the paper "Manufacturing Issues for Oxide-TFT Technologies for Large-Sized AMOLED Displays" by Toshiaki Arai of Sony Corp., and the examination of substrates, including those that are thinner, lower cost, and flexible. Examples of papers in this category include "Flexible Hybrid Substrates of Roll-to-Roll Manufacturing for Flexible-Display Application" by Yung Hui Yeh of ITRI, "A 3-D Cover Glass for Mobile Devices" by Prakash Panda of Corning, and "Role of Glass in Manufacturing: The Next Generation of Advanced Displays" by Peter Bocko of Corning.

Display Measurement: How to Measure What's New

Researchers involved in display measurement face a never-ending challenge: as new display technologies emerge and develop, so must the methodologies used to measure them.
Two papers of note this year address issues prompted by relatively new technologies; in the first, Dupont looks at lifetime issues in terms of the demands of future OLED TVs. In the second, E Ink examines measurements for reflective technology.

In the paper, "Influence of TV Media Content on Display Lifetime and Image-Sticking Measurement Techniques" by Andrew Johnson of Dupont Displays," the author states that "both lifetime and image-sticking measurement techniques are well established but are somewhat uncharacteristic of actual TV usage" and proposes modifications that better represent actual usage demands from TV media. "I think this will be interesting and maybe a little controversial," says chair Tom Fiske.

Another paper of interest is "Viewing-Angle Measurements on Reflective e-Paper Displays" by Dirk Hertel of E Ink. Says Fiske, "The measuring of reflective displays is a tricky business because you should take into account the ambient-light geometry – whether it's a cloudy or a sunny day, whether you have lots of small point sources around the room or big luminaries. It's more complicated than pointing a photometer at a regular emissive display. The authors suggest some ways of zeroing in on particular lighting geometries to make measurements."

Display Systems: High-Speed Holographs

Two major trends in display systems are backlighting and 3-D. A 3-D related paper to watch for is "Real-Time Dynamic Holographic Display Based on a Liquid-Crystal Thin Film" by Hongyue Gao of Virginia Tech and Shanghai Jiao Tong University. The author describes a high-speed rewritable holographic technology that uses a liquid-crystal thin film without an applied electric field. The holographic response time is about 1 msec, and video displays have been achieved. Explains chair Brian Schowengerdt, "A high-resolution holograph is projected onto a film and it stays there until it is erased and replaced by the next image in the series. It provides the potential for a digital holographic display capable of full-speed motion video."

In the area of backlighting, the paper, "A High-Efficiency Wide-Color-Gamut Solid-State Backlight System for LCDs Using Quantum-Dot Enhancement Film" by Jason Hartlove of Nanosys outlines the use of narrow line-width red and green emission from quantum-dot enhancement film stimulated by high-efficiency blue LEDs. According to the author, "This drop-in-solution offers high brightness and good color uniformity at a cost far lower than RGB-LED LCDs or OLED systems."

Emissive Displays: Plasma Gains More Protection

Protective layers in plasma are once again a popular emissive displays topic this year, with six papers alone dedicated to the subject, according to Chair Yong-Seog Kim, who notes that these layers have the potential to reduce cost and increase luminous efficacy in PDPs. One such paper is "Development of MgCaO Protective Layer of Plasma Display Panels for Decreased Discharge Voltage" by

Takehiro Zukawa of Panasonic Plasma Display Co. Another exciting development is a 300-μm-thick plasma panel, as described in the paper, "Ultra-Thin Shadow-Mask PDP Fabricated by Vacuum In-line Sealing Technology" by Lanlan Yang of Southeast University.

An exciting late-news paper, also devoted **to plasma, is "Development of a 145-in.-.** Diagonal Super Hi-Vision Plasma-Display Panel" by Keiji Ishii of Japan Broadcasting Corporation (NHK), which describes the creation of prototype full-resolution Super-Hi-Vision (SHV) plasma-display panels (PDPs with 4320 scanning lines and over 33 million pixels).

Flexible Displays: A Range of Technologies Powers Flexible Displays

There were so many new developments in flexible displays this spring that an entire late-news session was added to feature the following three papers: "Oxide TFTs and Color-Filter-Array Technology for Flexible Top-Emission White-OLED Display" by Makoto Noda of Sony, "11.7-in. Flexible AMOLED Display Driven by a-IGZO TFTs on Plastic Substrate" by Hajime Yamaguchi of Toshiba Corp., and "Flexible Color Active-Matrix EP Display Using Low-Distortion OTFT Backplanes" by Paul Cain of Plastic Logic. Also of note is the paper "A 13.3-in. 200-dpi Flexible Electrophoretic Display Driven by OTFTs Manufactured Using High-Resolution Offset Printing" by Ryuto Akiyama of Sony Corp. Akiyama's work describes a very precise printing method used to achieve 5-μm resolution and ±2.2-μm overlay accuracy in organic thin-film transistors.

Liquid-Crystal Technology: Blue Phase Is Here to Stay

As in 2011, blue phase and alignment are the dominant topics for liquid-crystal displays this year. Research into blue-phase technology has continued with even more enthusiasm: last year there were nine blue-phase papers and this year there are 12. Highlighted papers in that category include "A Microsecond-Response Blue-Phase Liquid-Crystal Device by Yuan Chen and "Low-Voltage and Hysteresis-Free Blue-Phase LCD with Vertical Field Switching University of Central Florida" by Hui Chuan Cheng, both from the University of Central Florida. Both papers examine ways to optimize the performance of the promising blue-phase technology. Also of note is "Dual-Mode Reflective Cholesteric Display" by Rafael Zola of Kent State University (the winner of last year's JSID Outstanding Student Paper of the Year award on another topic). Zola's work describes a potential display in which the bistable mode is suitable for displaying static images. The monostable mode is suitable to display video-rate dynamic images.

OLEDs: Growing by Leaps and Bounds

OLEDs, which have had their ups and downs in terms of hype *vs.* reality, have definitely arrived. Overall, the key OLED themes for this year, according to chair Eric Forsythe, are (1) large-format displays, (2) high-resolution OLEDs for smartphones, (3) head-mounted displays, and (4) solid-state lighting. Without question, one of the highlights at Display Week this year will be the paper, "A 55-in. FHD OLED TV Employing New Tandem WOLEDs" by Chang-Wook Han of LG Display. Says Forsythe, "This TV certainly was the buzz at CES, and the paper will look at various technical aspects of achieving an OLED TV of this magnitude." An exciting late-news arrival, also centering on large format, is "Advanced Circular Polarizer by Using Coatable QWP Technology for Large-Sized OLED Display Applications" by Su Hyun Park of LG Display. This paper proposes the use of a circular polarizer to enhance contrast for outdoor applications where ambient luminance is high.

Projection: Pico-Projectors Poised to Become Hot Products

Projection co-chair Alan Sobel makes a bold statement about what's going on commercially in projection technology: "This will be the year of the pico-projectors," he says. "This technology is going to knock peoples' socks off. It's much better, it's more affordable, and this is the year that it's going to go big." In terms of papers at the Symposium, one notable trend, says Sobel, is the availability of green lasers, which have been challenging to manufacture. One such paper is "Watt-Level Compact Green-Laser Module for a Laser Display" by Chang-Qing Xu from McMaster University.

Another paper of note is "Submillisecond-Response Blue-Phase Liquid Crystal for Color-Sequential Projection Displays" by Sihui He from the University of Central Florida, which reports on the first attempt at using emerging blue-phase liquid-crystal (BPLC) technology for color-sequential projection displays. BPLC exhibits submillisecond response time, which is essential for suppressing the color breakup caused by field-sequential color displays. Both transmissive and reflective projectors with in-plane switching and vertical field-switching modes are discussed in the paper.

The projection sessions also enjoyed the addition of six late-news papers, ranging from "Micro-Mirror System-Level Synchronization Notes" by Sharon Hornstein of Maradin Technologies to "A Passive-Matrix Inorganic LED Array as a Projection Source" by Vincent Lee of Columbia University.

Touch Technology: Secrets Revealed

Choosing papers for the touch symposium can be difficult, according to subcommittee member Geoff Walker. "Touch is still very secretive," he explains. Some companies and researchers are reluctant to share their discoveries. Nonetheless, there are some interesting papers in this year's collection, including "An In-cell Capable Capacitive Touch-Screen Controller with 41-dB SNR and Integrated Display Driver IC for 480 × 864 LTPS Displays" by Murat Ozbas of Synaptics. This paper includes three major areas of focus, according to Walker: "What I call hybrid in-cell/on-cell, fast touches, and a high signal-to-noise ratio."

Also of interest is "High-Transmission Optically Matched Conductive Film with Sub-Wavelength Nano-Structures" by Kazuya Hayashibe of Sony Corp., in which the author describes how his team fabricated a very-low-internal-loss anti-reflection nano-structure (ARS) conductive film with over 99% high transmittance and sufficient surface resistance (270 Ω/□) that can be manufactured using roll-to-roll high-productivity methods and is suited for high-contrast touch screens.

The paper "Adding Proximity Detection to a Standard Analog-Resistive Touch-Screen" by Chaouki Rouaissia of Semtech Neuchatel Sarl is an example of doing something new (proximity sensing) with something old (analog-resistive), according to Walker. "They have made their resistive controller able to use the top electrode of the touch screen as a proximity sensor without changing anything in the sensor itself," he explains.

Possible applications could include a screen on your dashboard that lights up only as you reach your hand toward it.

Special Focus Areas: Green Technologies, Solid-State Lighting, and 3-D

Each year, the Society for Information Display designates special sessions to explore important and timely display topics. This year's sessions are Flexible Electronics and Printed Displays (covered in the February/March 2012 issue), Green Technologies, Solid-State Lighting, and 3-D.

There are 15 papers devoted to Green Technologies this year, with four sessions titled:

- Driving Methods for Low-Power Displays
- Low-Power Displays and Materials
- Green Optics for Display Systems
- Display Manufacturing: Novel Devices and Green Technology

Of particular interest is the paper "Low-Power High-Color-Gamut PenTile RGBCW Hybrid FSC-LCD" by Candice H. Brown Elliott of Nouvoyance, which describes technology with the potential for lower power consumption and higher color gamut than conventional local-dimming RGB-filtered LCD-TV panels. Another paper to note is "A Novel LCD Structure Using Transparent Polymers Free of Birefringence and Scattering Polymers Free of Wavelength Dependency" by Akihiro Tagaya of Keio University, which proposes a new LCD structure using a directional backlight and a scattering film.

Solid-State Lighting

Solid-state lighting promises to save energy and provide design flexibility. And it has offered backlighting manufacturers an opportunity to extend their expertise to general illumination applications, and thus expand their business. This year's symposium includes the following sessions:

- Solid-State-Lighting Applications,
- Four Solid-State Lighting Technology Sessions
- Lighting Devices
- Fabrication Processes and Solid-State Lighting.

Papers of note include: "From Backlight to Luminaire" by Tim Dekker of Philips Research Laboratories and "Commercialization of World's First All-Phosphorescent OLED Product for Lighting Application" by Takatoshi Tsujimura of Konica-Minolta Technology Center.

3-D

One trend in 3-D that has continued from last year is that there are a lot of sessions: 12 in all, including:

- Stereoscopic Display Applications
- Polarization-Based 3-D Displays
- Advances in 3-D Display Characterization
- Autostereoscopic 3-D Displays
- Advanced and 3-D Display Applications
- LC Lenses for 3-D
- Video Processing for 2-D/3-D
- 3-D and Multiview Projection Lens Design for 3-D Displays
- Volumetric, Lightfield, and Holographic Displays
- 3-D Comfort
- 3-D Perception.

One of the recent trends in 3-D noticed recently by chair Brian Schowengerdt is that "there has been a surge in papers addressing the creation and display of "light fields," which is a shift from the focus on stereoscopic display we have seen in the past. The goal is to accurately re-create in a digital display all elements of the light wavefronts that would emanate from real 3-D objects, including accurate focus cues. Holography is one core technology that can potentially create accurate light-fields – but a number of other technologies, such as volumetric displays, also provide good solutions." This year at Display Week, there is an emphasis on the full light-field ecosystem, from content capture and synthesis to display, with much of that work coming out of MIT, notes Schowengerdt. A keynote address by Ramash Raskar of MIT's Media Lab, entitled "Computational Displays: New Optimization for Interactive Lighting-Sensitive 3-D Displays" will discuss light-field encoding and decoding algorithms. Also from MIT, William Freeman will focus on light-field capture in his talk on "Computational Photography," while James Barabas will discuss the end of the pipeline in "Visual Perception and Holographic Displays." A related paper is "Envisioning a Light-Field Ecosystem" by Kurt Akeley of Lytro, who will present an overview of the full light-field process from capture with plenoptic cameras to 3-D displays capable of displaying light-fields.

Another item of interest, says Schowengerdt, is that Disney Research is presenting a paper on a volumetric 3-D technology at SID. "I don't think Disney has typically presented with us," says Schowengerdt. That paper is "A 3-D Volumetric Display Using a Rim-Driven Varifocal Beamsplitter and High-Speed DLP Backlit LCD" by Larry Smoot of Disney Research. ■

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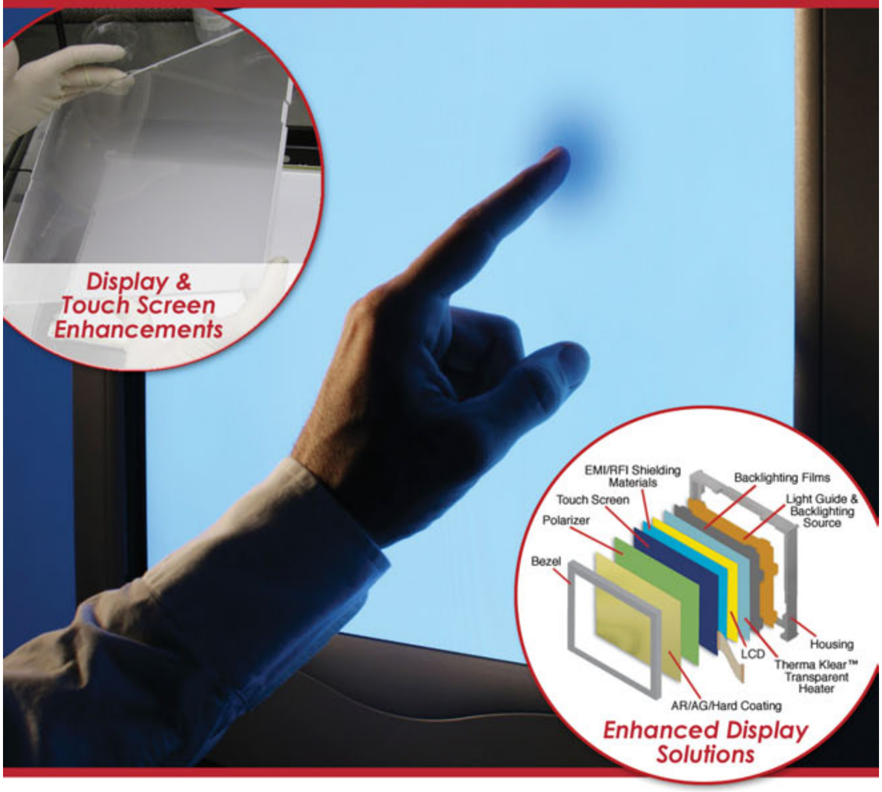

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How LEDs Have Changed the LCD Industry

LED backlighting has attracted a great deal of interest from the LCD industry over the last few years. The introduction of LED backlighting was not just a simple change to the panel structure; it affected the LCD industry in many ways, including product trends, economics, business strategies, and supply chains.

by Jimmy Kim and Paul Semenza

BEFORE THE BOOM of light-emitting-diode (LED) backlighting in the 2008–2009 time frame, TV makers used LEDs primarily to enhance the color gamut and contrast ratio of their products. This led to an increase in material costs, but makers expected the enhanced picture quality to add much more value to their products. However, they discovered that consumers were unwilling to pay a lot more money for picture quality. The penetration of LED backlighting did not increase, and most LCD TVs continued to use cold-cathode fluorescent lamps (CCFLs).

Eventually, the focus of LED backlighting for TV products shifted from picture quality to design. Makers focused on slim LED edge-backlit TVs. These were still more expensive than conventional CCFL-backlit TVs, but the price gap decreased significantly with the introduction of edge backlighting. Consumers were willing to pay more for design than for picture quality, and the penetration of LED backlighting started to increase.

What is the difference between these two cases? Picture quality is often thought of as a relative feature, valid only when compared to other products. Design is an absolute feature – no comparison is needed to see it. It seems that consumers will pay for an absolute benefit – LED backlighting showed that design can be a strong marketing tool in the TV market place. This trend toward design continues. At CES 2012, many companies exhibited narrow-bezel TVs and ultrabook models.

__Paul Semenza__ is Senior Vice-President, Analyst Services for DisplaySearch. He can be reached at paul.semenza@displaysearch.com. __Jimmy Kim__ is Senior Analyst, Display Materials and LEDs, at DisplaySearch.

Value Creation for LCD Makers

LED backlighting allowed panel and set makers to add more value to their products and lower the rate at which panel and set prices were dropping. By comparing LCD panel-area prices with LED penetration into large-area-LCD panel shipments (Fig. 1), it

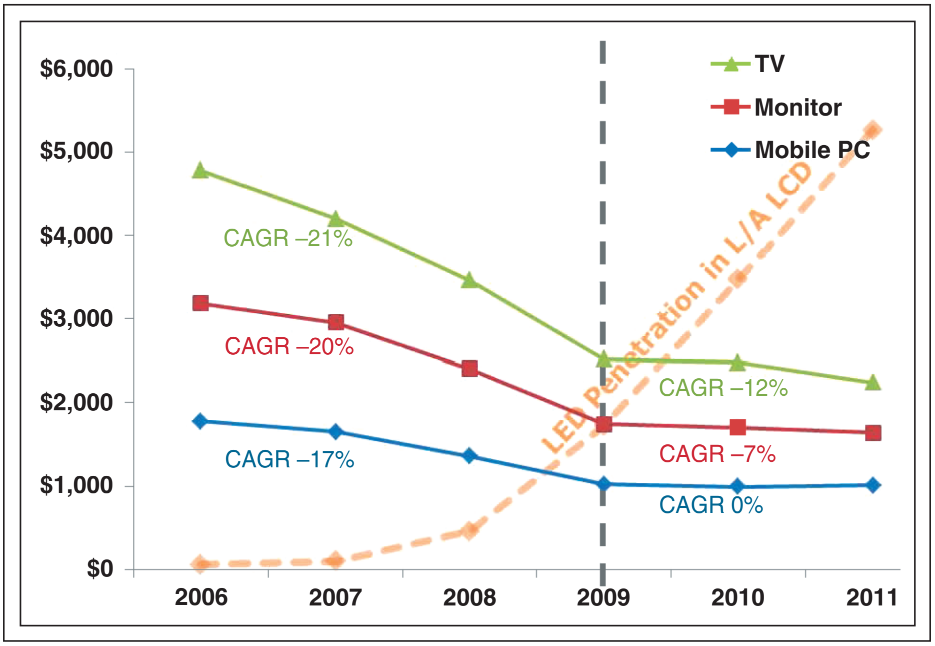

__Fig. 1:__ LCD panel prices fell rapidly until 2009, when LED penetration began to increase. Source: DisplaySearch, Quarterly Worldwide FPD Shipment and Forecast Report and Quarterly Large-Area TFT LCD Shipment Report. (Note: CAGR is the Compound Annual Growth Rate).

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can be seen that panel prices stabilized after the 2009 boom in LED edge-backlit TVs. TV makers began filling their product lines with LED-backlit models after that time. The intention was to increase, or at the least maintain, total revenue in the event that prices continued to drop sharply in the display industry.

Revolution in the LCD Business Model

A more fundamental change resulting from the LED-backlighting boom in the LCD industry relates to the structure of the supply chain. The clearest example of this is the emerging open-cell business model (in which LCD makers ship panels without backlights), which is shifting value in the LCD supply chain from panel makers to set makers and has been accelerated by the introduction of LED backlighting.

The origin of the open-cell business model dates back to 2005. As shipments of large-sized LCD TVs increased, the cost of the large numbers of CCFL tubes and inverters became a concern. With increasing panel size and resolution, as well as the introduction of 120/240-Hz frame rates, the luminance requirement for backlighting increased. This made decreasing the number of CCFLs even more difficult, so panel and set makers focused on reducing the costs related to inverters.

Some set makers focused on the overlap of power components in TV sets and LCD modules. The switching-mode power supply (SMPS) in a TV set provides 24 V DC from a 100 to 240 V AC current supply. The inverter in the LCD module converts the 24 V DC back to AC current at more than 1000 V. This duplication can be eliminated by combining the inverter and SMPS into one power board, the so-called integrated power board (IP board), saving cost and increasing efficiency.

The IP board became part of the power supply of the TV set, so set makers could use LCD modules without inverters, which meant that the value of the backlighting started to shift from panel makers to set makers. However, IP boards did not lead to broad use of the open-cell model; only a few Taiwanese makers supplied open cells to set makers. Set makers did not want to expand the IP board business to an open-cell business entirely, and only accepted IP boards for a limited number of models.

The adoption of LEDs in backlights simplified the electrical circuitry, and the open-cell business began to accelerate after the increase of LED penetration in 2009. Many panel makers increased shipments of open cells. According to DisplaySearch's research, open cells accounted for 25% of LCD-TV panel shipments in 2011, and the share will nearly double in 2012.

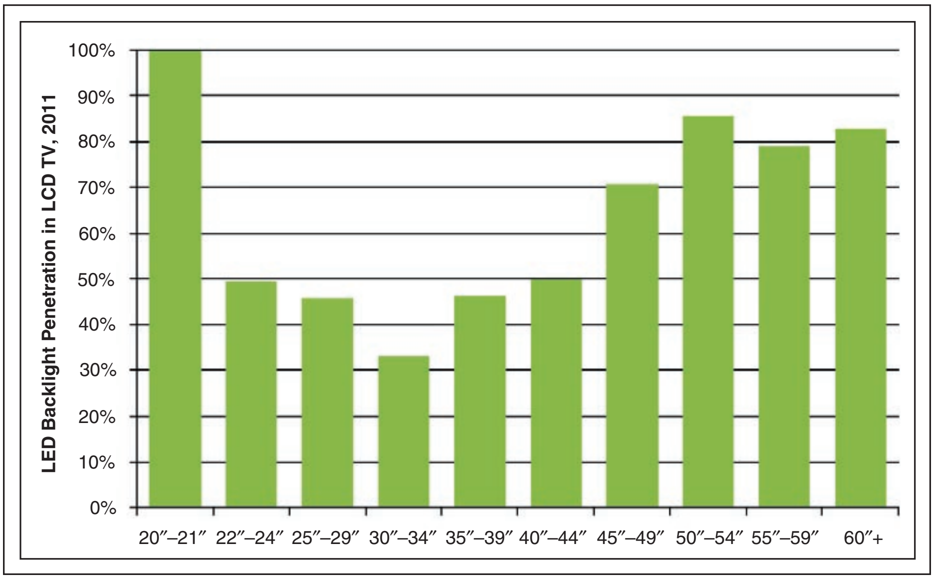

Fig. 2: In 2011, the share of LED backlights used in LCD TVs reached 46%, but the penetration was lowest in the highest volume size, 32 in. Source: DisplaySearch, Quarterly Advanced Global TV Shipment and Forecast Report.

What Happened after 2009?

For set makers, lack of expertise in CCFLs was the main obstacle to moving more quickly to the open-cell model. CCFLs contain mercury, which makes them hard to control under even slight temperature changes. Set makers were not as experienced in dealing with CCFLs as panel makers and they faced quality issues if they used open-cell panels. LEDs changed this situation.

There was less of a gap in LED experience between set makers and panel makers, and LED performance and operation were better understood by set makers than the performance and operation of CCFLs. As a result, LED backlighting successfully accelerated the open-cell business. Panel makers clearly had reason to be concerned about the open-cell model, as they realized that it reduced the value of the product they delivered, and some resisted in providing such panels. However, the panel surplus that developed in mid-2010 forced some panel makers into the open-cell model because they needed to supply open-cell panels in order to maintain business with set makers that requested them for their LED-backlight models.

Another factor was that the slowdown in demand during 2011 resulted in large LCD inventories. Because LCD modules are custom products (mainly due to the backlights), inventories for different customers are not interchangeable, so panel makers have had difficulty reducing inventories. Open cell models have wider compatibility than LCD modules, thus they create the potential for better inventory control, which can help improve the profitability of panel makers. Thus, some panel makers determined that the open-cell model could benefit them and, as a result, have even been increasing open-cell CCFL-backlit panels.

How LEDs Are Changing TV-Set Design

The earliest LED backlight designs used direct lighting, in which a large number of LEDs are mounted behind the display. These failed to gain market share due to high cost, despite their excellent image quality and ability to perform local dimming. Samsung moved to adopt edge-mounted LED backlights and had significant early success, in large part due to the fact that the edge-lit LED backlights enabled extremely thin set designs, in some cases less than 10 mm.

Edge-lit LED backlights allow the set maker to reduce the number of LEDs by concentrating them along the edges. This

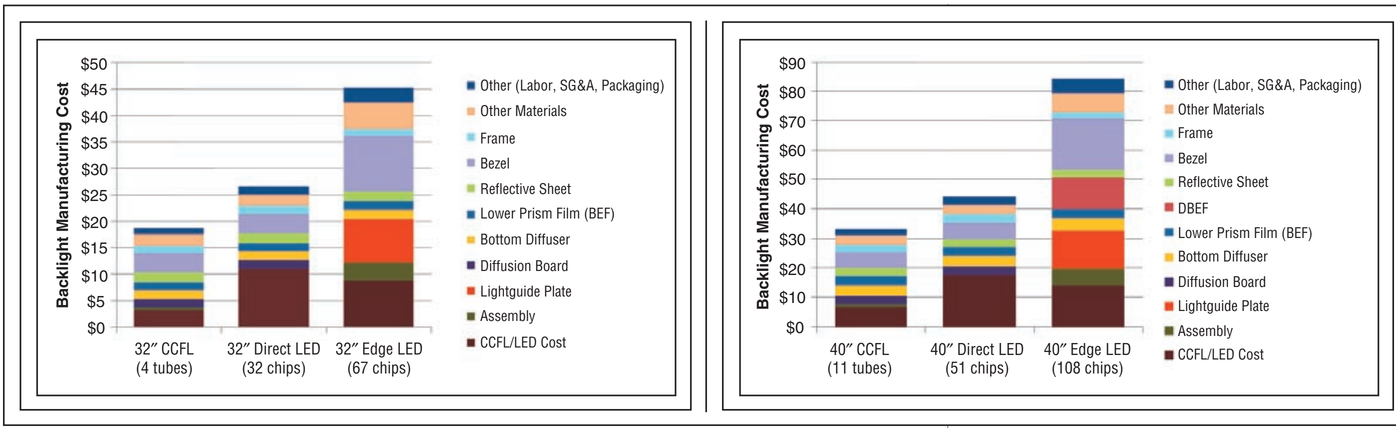

Fig. 3: New, low-cost direct-lit LED backlight designs for LCD TVs are expected to be close to the manufacturing cost for equivalent CCFL backlights, as shown for 32-in. (left) and 40-in. (right) sizes. These designs are significantly cheaper than the edge-lit designs, due to the elimination of the light-guide plate as well as light-enhancement films and reduction in mounting and assembly costs for 40-in. units. Source: DisplaySearch, DisplaySearch Quarterly LED & CCFL Backlight Cost Report.

happened first on all four edges, then moved to two and eventually to a single short edge. Set makers have continued to struggle with an LED premium that many consumers are unwilling to pay for and with continuing rapid erosion of retail prices. In 2011, LED-backlit units accounted for 46% of LCD TVs (Fig. 2).

In 2012, set makers are introducing a new, low-cost direct LED backlight design, targeting CCFL designs with similar thickness and cost (although lower brightness) in the key 32-in. size. Bigger LED emitter chips are used, but in fewer numbers. In some cases, the LED packages include a lens structure on their surface to improve optical performance.

While they require brighter and thus more expensive LEDs, these new designs eliminate the need for the light-guide plate (LGP) and diffuser used in edge-lit designs and for brightness-enhancement film. By running at lower brightness, they can approach cost parity with CCFL backlights (Fig. 3). However, these sets are thicker than edge-lit varieties. In many markets, LED-backlit LCD TV has become associated with slim designs, so thicker set designs could run the risk of confusing consumers.

Ultimate Impact of LEDs on the LCD Industry

The introduction of LED backlighting has changed the pricing, value chain, and structure of the LCD industry, as well as influencing LCD-TV product designs and marketing. The LED has brought significant performance improvements to LCD TV, enabling it to stem the growth of plasma TV and putting it in a good position to compete with OLED TV. But LEDs have also contributed to the shift in power in the industry, as panel manufacturing moves to more of a foundry business model.

Regardless of the changes in industry structure, LED backlights are now on a path to dominate all LCDs used in PCs and TVs (Fig. 4), particularly as manufacturing costs for LED chips continue to fall and environmental regulations banning the mercury found in fluorescent tubes take force in more countries. The long-term challenge for LED backlights will be to optimize the efficiency of converting point sources to area lighting. ■

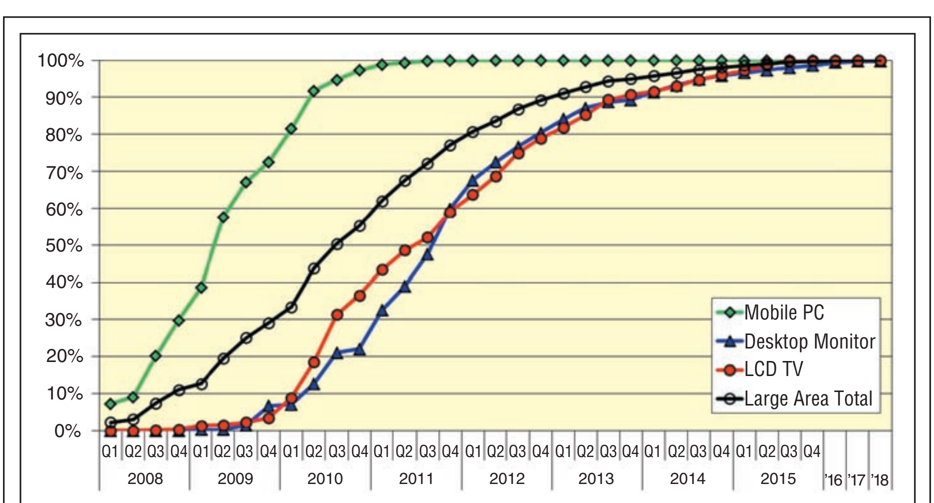

Fig. 4: After passing 50% penetration of the LCD-TV market in the second half of 2011, LED backlights are expected to increasingly dominate large-area (9.1-in.-diagonal and larger) LCD backlights, with adoption by LCD monitors now growing rapidly. Source: DisplaySearch Quarterly LED & CCFL Backlight Cost Report.

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An Interview with Avnet Embedded's Director of Display Solutions and the President of Display Logic USA

As the global distributor of electronic components and value-added embedded and display products, Avnet Embedded, a division of Avnet, Inc., has a team of experts that offer turn-key support of hardware and custom integration for any application involving visual performance. *Information Display* sat down with Andrew Blum, Director of Display Solutions for Avnet Embedded, and one of Avnet's LED-backlighting partners, Keith Morton, President of Display Logic USA, to discuss current trends in the world of LCD backlighting technology and the impact it is having in the marketplace today.

Andrew Blum

***Information Display (ID)*:** **What is the current state of LCD backlighting?**
Andrew Blum (AB): Since LCDs do not produce light themselves, the majority of LCD technologies require a light source that projects through the LCD to produce a viewable image. Recently, we've seen advancements in backlighting technologies that have often made it possible for customers to now use an LCD panel in applications where it might have been impossible with older technology – either due to power, heat, durability, or visual performance. Avnet is able to offer value-added services around backlighting, which allow customers to maintain brightness and performance for far less power and heat.

***ID*:** **How has LCD backlighting evolved throughout the years?**
AB: Traditional LCD backlighting involved cold-cathode fluorescent lamps (CCFLs). Although other technologies existed, CCFLs emerged as the standard for many years. CCFLs were either placed directly behind an LCD (direct backlighting) or along one or more edges with a light guide to direct the light output through the LCD (edge lit). There were both pros and cons with CCFL backlighting, but the change to LED backlighting was mainly due to these common issues with CCFLs:

- CCFLs require high-voltage AC power and a separate, complex device known as an inverter to turn them on.
- Inefficient and high voltage can contribute to EMI issues in an assembly.
- CCFLs used in displays are generally long, thin, and fragile, requiring special mechanical support.
- CCFLs require a lot of power to produce a specified brightness; thus, they also generate a lot of heat.
- They have poor/difficult dimming characteristics and require a complex backlight control inverter.
- They require warm-up time to achieve full brightness.
- They are susceptible to the effects of temperature extremes – especially in cold climates.
- CCFLs contain mercury; not considered an environmentally friendly product.

***ID*:** **What is today's LCD backlighting technology?**
AB: Today, backlighting technology is made up primarily of light-emitting diodes (LEDs). These low-voltage two-pin devices have replaced CCFLs. With improved color LED options, phosphor coatings, and thermal management, there are now greater options for high-brightness LEDs (HBLEDs) that operate at lower power levels and have longer life. LED backlighting involves the addition of LEDs that can be built into strips or rail configurations for edge lighting or installed as banks of LEDs directly behind an LCD panel to replace older CCFL technology and provide the required light source. White LEDs are the primary light source for LCD backlighting today. They are unique in that white light is achieved by using a colored LED, coated with phosphor.

***ID*:** **What are the advantages of LED backlighting?**
AB: There are many advantages to LED backlighting, including:

- The ability to achieve usable brightness levels with low power draw and less heat generated.
- The ability to achieve higher brightness levels at more reasonable power and heat levels.
- Instant-on functionality at full brightness with no warm-up time.
- LEDs are small, low profile, and thin; thus, LCDs and LCD-based products can be both thinner and lighter.
- LEDs easily meet ROHS directives, no hazardous material such as mercury found in CCFLs.
- LEDs are low-voltage DC-devices; most EMI issues are resolved because there is no complex DC-AC inverter required.
- They require a simple DC driver solution
- LEDs are more durable and can easily meet the most stringent of shock and vibration specifications with little additional mechanical measures required.

Today, all LCD manufacturers have already switched, or plan to switch, to LED-backlit LCDs.

ID**: What is causing the widespread adoption of LED backlighting in the industry?**

AB: There are a number of factors that can be seen as contributors to the widespread and rapid adoption of LED backlighting in the industry. The widespread implementation of LED backlighting in consumer products, improvements in LED performance, and price parity with CCFL are the most significant.

Brightness versus power and backlight life specifications developed to the point where they met and now exceed those of CCFL backlighting. CCFL backlight life was generally stated at 50,000 hours, at which the brightness level would be half of what it originally was. Today 50,000 hours for LED backlighting is common, with many LCD makers offering up to 100,000 hours specifications.

ID**: What challenges can customers expect when implementing LED backlighting?**

AB: Although the technical and process improvements of LED manufacturing have sped the adoption of the LED-backlit technology, it is important to note that the end result is still a process that is not capable of producing highly consistent LEDs.

Keith Morton (KM): The main issue that often does not surface until after the implementation of an LED-backlit LCD involves the consistency of the LED components and therefore the entire backlight system. There are variations in the previously mentioned phosphor coating that impacts the light output and color-temperature consistency between LEDs. Additionally, variations in the diode portion of an LED result in a wide range in turn-on or forward voltage, making it difficult to control the brightness range of an LCD.

Operating temperature is another issue to be aware of. Almost all LCD manufacturers specify their backlight performance at an ambient temperature of 25°C, and CCFLs do not suffer greatly when run at hotter temperatures. This is not true for LED backlights, which can suffer large decreases in brightness and lifespan when brought up to the full operating temperature of an LCD. These issues are significant because they affect the brightness, efficiency, and lifetime of LED backlighting, making it difficult to control the specification of an LED-backlit LCD.

ID**: How do Avnet and its partners help customers navigate these challenges?**

KM: One way LCD manufacturers compensate for difference in LEDs is to arrange them in multiple strings in which each string's current is individually controlled. This method helps reduce the variations in LED-backlight brightness uniformity and potential failure due to overpowering individual LEDs that happen to have a lower forward voltage.

Another method to reduce LED-consistency-related issues is to use binned LEDs. LED manufacturers can bin LEDs based on voltage, brightness, and color. This allows LED backlight manufacturers to select only those LEDs that meet their acceptable performance ranges; however, there is a cost premium for this service.

Table 1: Avnet LED-backlight options based on an actual 7-in. TFT solution.

Metric	Factory Specifications	Avnet Option 1	Avnet Option 2
Brightness (nits)	350	350	1500
Power (W)	3	1.4	6
Temperature (°C)	25	40	40
Backlight life (hours)	30,000	100,000	50,000
Binned LED	N	Y	Y

AB: To compensate for the known issues in LED backlighting, Avnet Embedded offers an LED-backlight enhancement program that effectively addresses brightness, backlight life, and temperature issues. Avnet also offers LED-backlight enhancements that take advantage of higher efficiency, tightly binned LEDs – yielding higher brightness, longer life, and more consistent specifications at real-world operating temperatures.

In the example in Table 1, Option 1, an Avnet LED replacement backlight cuts power in half, while more than tripling backlight life at a higher operating temperature. In Option 2, an Avnet LED-backlight solution can provide easy readability in sunlight with long life and wide operating-temperature ranges.

Avnet's LED Backlight Replacement Program gives customers many performance choices for LCD backlighting. Our LED-backlight solutions start with LED components from leaders in LED technology and partnerships like that with Display Logic and others. These partnerships ensure that the specific needs of our customers are met. Avnet, and our partners, create LED backlight solutions with the highest efficiencies and performance characteristics, as well as multiple options to meet our customers' desired results.

ID**: What is the future of LCDs and backlighting?**

AB: We should continue to expect performance improvements at the LED component level. These enhancements will continue to improve on the ratio of brightness to power/heat and color consistency. One emerging technology is organic light-emitting diodes (OLEDs). Simply put, OLEDs are a matrix of pixel-sized LEDs. Each red, green, and blue subpixel within the OLED matrix is self-light-emitting, thus eliminating the need for any backlight substructure. While lifespan issues have kept OLEDs from advancing into the mainstream, there is little doubt that OLEDs will quickly become the next big thing in the display market.

How can a customer learn more?

Avnet Embedded has a team of regional Display Business Development Managers and dedicated technical experts to assist customers during every phase of the design cycle. For more information on display products from Avnet Embedded, e-mail ask-lcd@avnet.com, visit: www.em.avnet.com/embedded, or contact your local Avnet representative. ■

__Andrew Blum__ is Director of Display Technical Marketing for Avnet Embedded with over 20 years of industry experience. He is widely considered one of the top market experts in this field, with a deep knowledge of technology, product, and market trends. Andrew and his team take a consultative approach that results in best choices in components and solutions that fully match all key metrics that are important to our customers.

__Keith Morton__ is the President of Display Logic, with over 25 years of experience in LCDs and related technologies. He has spent the past 12 years specializing in LCD enhancement technology with a focus on LED backlighting. Display Logic is a recognized leader in LCD enhancement solutions and LCD connectivity.

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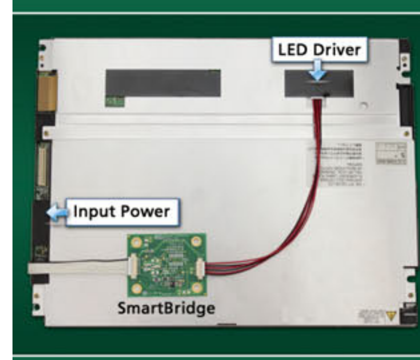

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Creating a More Efficient Light Guide for a 2-D-Type Local-Dimming LCD Backlight

The realization of an optically dimmable, segment-addressable BLU using a single monolithic light-guide plate (LGP) with a light-control function is challenging but has the potential to cut costs and boost performance. This article describes the development of an edge-lit BLU with a monolithic segmented functional LGP.

by K. Käläntär

THE advantages of 2-D dimming for liquid-crystal-display (LCD) backlights have been widely investigated and also discussed in the pages of this magazine (see, for example, "Adaptive Backlight Dimming for LCD Systems" in the November 2009 issue). The author has developed another variation of the concept by creating a monolithic segmented light-guide panel (LGP) that can control cross-talk between segments and is structured to be used as a local-dimming backlight. This architecture can be mass-produced, thus cutting costs and boosting the performance of region-dimming backlights for high-dynamic-range LCDs.

Power savings and high contrast are especially important goals for designers of LCD-based TVs. An LCD module comprises a power-hungry backlight unit (BLU) and a liquid-crystal panel that modulates the light to create 2-D spatial information. Conventionally, when uniform and high-luminance BLUs have been used for displays, they lead to wasted light energy, especially when the display image is of low-average brightness.

The so-called "dimming technique" is a promising concept for solving light-energy waste.[1–3] In its ideal form, the brightness of the backlight is controlled spatially and temporally to match the image's local luminance. The luminance of the BLU is changed in cooperation with the transmission of the LCD.[3] When the two are successfully managed together, the resulting operation leads to a reduction in the power consumption of the BLU.

With regard to black levels, the dimming technique improves contrast because the backlight can dim the darkened area in the same region as the dark pixels of the image. In addition, the dimming technique enhances moving-image quality because it presents the possibility of inserting the black segment(s) in each frame picture.

Monolithic Segmented BLU Structure

To achieve a power-efficient LCD with high-quality images, a local-dimming backlight is indispensable. The conventional design method has been to use an array of distinct edge-lit backlights, an array of segments of light chambers, or a single light guide and programmed control system to shape the light

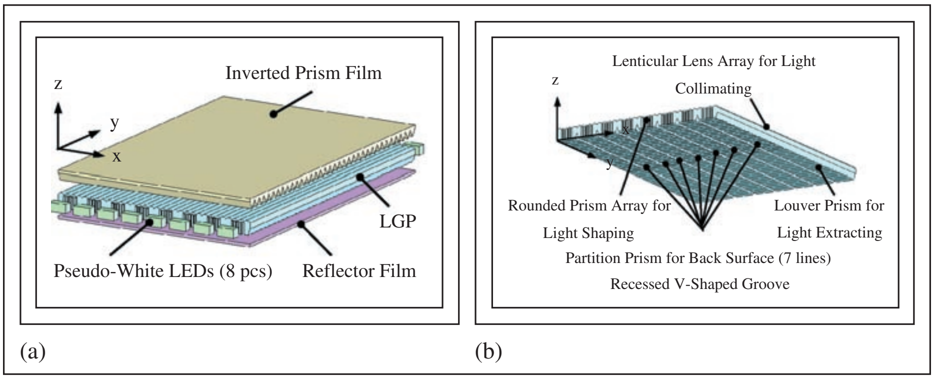

Fig. 1: (a) Left: the structure of a monolithic BLU. The BLU is a combination of a functional LGP, 16 pseudo-white LEDs, a LGP reflector film, and an inverted prism. (b) Right: An LGP with light-controlling features on the light injection surface, back surface, and "V-groove" optical partition.

K. Käläntär is with Global Optical Solutions, R&D Center, 2-50-9 Sanda-Cho, Hachi-Oji-Shi, Tokyo 193-0832, Japan; telephone: +81-90-4410-0426, e-mail: gosx2010@gmail.com.

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distribution on the LCD panel.[2,3] One of the more recent challenges is the creation of a thin backlight with a monolithic light guide for a local-dimming display.

As shown in Fig. 1(a), the backlight is a combination of a segmented functional LGP, an inverted single prism, a reflector, and 16 pseudo-white LEDs; eight LEDs at each short side. Seven recessed V-shaped grooves are used to make the segments in the light guide [Fig. 1(b)]. The grooves are along the light guide for light isolation between the segments.[4-7] An array of rounded prisms is applied to the light-incident surface of each segment for controlling the light distribution inside the light guide, *i.e.*, to eliminate the hot spots. An array of louver prisms is used on the back surface of the light guide to get proper light distribution and propagation. An array of lenticular lenses on the LGP collimates and shapes the emergent light from the LGP. A single inverted prism film is used for directing the emergent light toward the backlight surface normal to the back surface of the LCD.

Monolithic Light-Guide Plate

An array of rounded prisms is structured on the light-injection surface for forming a uniform light distribution inside and on the LGP close to the light incident surface. The function of the optical microstructures on the light-injection surface is basically to widen the injected light distribution inside the LGP.[8] The widening of light-distribution results in reducing the dim regions and increasing the luminance uniformity of the light guide near the light source.[4,5] Each microstructure is a rounded prism, *i.e.*, a combination of semi-"V"-prism and round curvature. The light sources are set near the light-injection surface of each segment that face the rounded prisms at a distance of 0.4 mm.

The LED distribution is semi-Lambertian. The light distribution inside the LGP is designed to be collimated at the center and slightly diffused at larger angles. The injected light flux after passing the rounded prisms, *i.e.*, inside the light guide is plotted in Fig. 2.

The features transmit a significant portion of the light and expand some portion up to 170° inside the LGP. This results in illuminating both sides of the light source that are the dark zones inside the LGP and increasing the uniformity on the LGP near the light-injection surface. The light-coupling efficiency is about 93.6%. For comparison, the light distribution on a flat light-injection surface is shown in Fig. 2. The light distribution is limited to about 42° because of the PMMA material and its refractive index (1.492 at the Sodium D-line). The light-coupling efficiency for a flat surface is about 90.6%. In contrast, the round-prism features show how the light is widened and coupling efficiency increased inside the LGP due to the increase in the light-coupling surface.

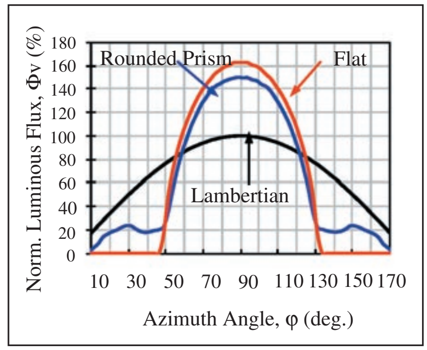

Fig. 2: The light distributions are shown inside and outside of the LGP. The LED distribution has a semi-Lambertian luminous distribution. The distribution is widened after passing through the light-injection features. For comparison, the light distribution after passing a flat light injection surface is plotted.

Recessed U-Groove as Partition

In a segmented backlight with a 2-D dimmable function, the interaction between the segments due to optical cross-talk has a large impact on the overall performance of segment dimming, *i.e.*, the cross-talk limits the effective spatial backlight modulation.

The control of the light-leakage rate between backlight segments is necessary for the careful handling of the display panel timing. The uniformity in luminance and directionality of the emergent light between the backlight segments are prerequisite for higher-quality displays. The nature of cross-talk between the segments was investigated and several grooves with different geometrical shapes were adopted. A U-groove with fixed width and a gradually increasing height along the y axis of the segment was found to work well to reduce the cross-talk. The gradation in U-groove height corrected the light profile along the length of the segment and resulted in light profiles that were similar to each other, both near and far from the light source along the y axis. The shape of the U-groove is shown in Fig. 3.

The height of a U-groove is designed to change from 0.1 to 0.5 mm at the center with a width of 0.020 mm as shown the variation along the length of the LGP in Fig. 4. The variation is decided by optimizing the light leakage between the neighboring segments, and in order to obtain a uniform light profile along the segment. The graded height and the fixed width of the U-groove control the amount of light leakage (the cross-talk) between the neighboring segments in order to obtain uniformity and high-quality imagery for a front-of-screen display.

Louver Prism for Light Extraction

In order to distribute and extract the light uniformly in the segment, an array of unilateral micro-prisms that have a louver-shaped cross section is used on the back surface of the LGP. The propagated light (inside the light guide) is reflected onto the prism and a signif-

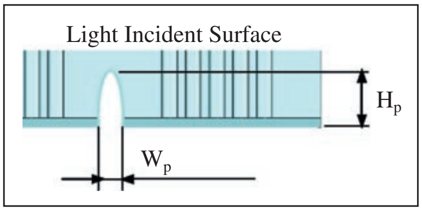

Fig. 3: The outline of the recessed "U-groove" is shown on the light-injection surface.

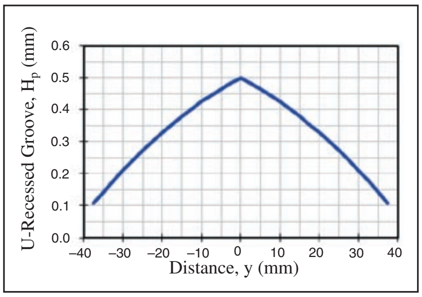

Fig. 4: The height of the "U-groove" increases along the y-axis in order to decrease the leakage of the light to the neighboring segments. The increase of the groove's height is the same as the left side groove. The peak of the graph shows the center of the LGP.

icant amount of the light is directed toward the segment's front surface. The reflected light is controlled by the total internal reflection (TIR) that results in light-energy preservation on reflection. The cross-section of the light guide with a louver prism on the back surface is shown in Fig. 5, where α_r and β_r, are the prism's angles and P_{r1}, P_{r2}, and P_{r3} ($= P_{r1} + P_{r2}$) are the projected prism's widths.

In order to have uniform luminance on each segment and to reduce the light at the end of the segment, *i.e.*, at the center of the LGP, an angle gradation (α_r varies gradually) for the prism array is designed to reflect the propagated light. The same gradation is applied to the prism arrays of the other segments to make a uniform luminance on the entire backlight. For making uniform light on the left segments, the louver prism that is shown in Fig. 5(b) is applied.

The surface of a unilateral prism that is confronted to the left light source is adjusted in order to extract the ray that propagates to the right. For extracting light that is injected from the right, the louver prism that is shown in Fig. 5(c) is used. The uniformity on the segment is optimized by changing the α_r angle of the louver prism that varies with distance as shown in Fig. 5(d). The angle β_r can be kept constant, so that the angle γ_r varies with distance. The left half of the graph shown in Fig. 5(d) shows the variation in the prism angle that controls the light propagating toward the right. The left louver prisms reflect the light that propagates only toward the right. The right part of the graph is the variation of the prism angle, containing the light that propagates toward the left.

Since the louver prism is unilateral (*e.g.*, the left segment), the left side surface of the prism does not function as that of the right surface of the prism. The reflection characteristic of the louver prism functions as optical isolation between the left and right segments. This is the reason for controlling the light from both sides.

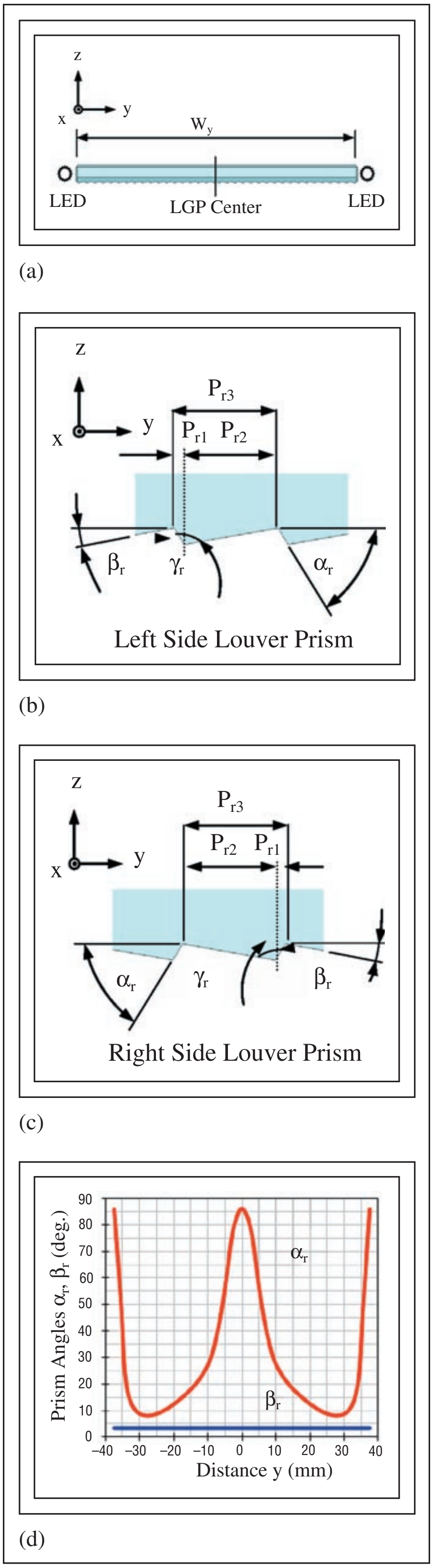

Fig. 5: (a) Top: the cross-section of the LGP is shown with light-extraction features on the back surface. In (b), the light-extraction features are shown for the left side of the LGP. In (c), the light-extraction features for the right side of the LGP appear. In (d), shown is the angle variation of the light-extraction feature for making uniform luminance distribution on the LGP.

Lenticular Prism for Light-Cone Shaping

An array of lenticular prisms that are part of a cylindrical lens is structured along the y axis on the LGP to deflect the propagated light toward the rear surface of the inverted prism film with a TIR function that is set on the light guide [Fig. 1(a)]. The array functions as low-power light-collimating elements. The cross-section of the array in the x–z plane is shown in Fig. 6.

The prism array has an equal sag of H_f (= 15 μm), a curvature of R_f (= 28.33 μm), and a pitch of P_f (= 50 μm). The prism array of the light-injection surface, the rear prism array, and the front lenticular prism array are designed in combination in order to obtain a uniform luminance on the inverted prism film.

Results for the Monolithic Segmented Light Guide

The dimensions of the monolithic LGP are 41.7×75.0 mm^2 and the effective area is about 39.88×64.8 mm^2. The widths of the second to seventh segments are equal and are designed to be 5 mm. However, the first and eighth segments have widths of 5.85 mm because these segments have only single neighboring segments, and their luminance should be compensated. Therefore, the widths of the first and last segments were designated as 5.85 mm and the effective widths of these segments were set to 5 mm, the same as the other segments. The material of the LGP is PMMA with a refractive index of 1.492 at a Sodium D-line. The backlight is a combination of a monolithic segmented functional

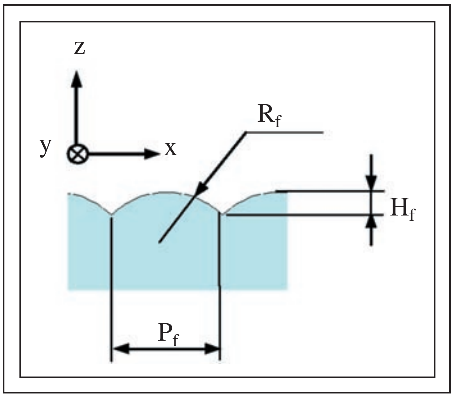

Fig. 6: The light-cone-shaping feature is shown on the LGP. This is an array of low-power light-collimating lenses.

light guide, a reflector with a reflectivity of 98% (ESR, Sumitomo 3M Co.), an inverted prism film with a TIR function (M065HS, Mitsubishi Rayon), and 16 pseudo-white LEDs (NSSW206, Nichia Chemical Co.). Each LED has a flux of 6.6 lm at 20 mA.

The luminance uniformity and optical isolation on the backlight were evaluated. All segments were switched on and the profile of light along the width of the backlight was measured. The ripple of the light is about 5%, resulting in a uniformity of more than 95%.

For evaluation of the cross-talk and the light distribution, a single segment was switched on, as shown in Fig. 7(a). The light profiles along the width of the segment at three points were plotted in Fig. 7(b).

Almost the same profiles were obtained at three positions. This means that the light distribution of the segment is uniform along the segment. The cross-talk was evaluated between the confronted segments – that is, an ON segment and an OFF segment as shown in the profile of averaged luminance along the D–D′ line (x axis) in Fig. 7(c). The profile shows that the gradation of the unilateral louver prism could make uniform light on a single segment by controlling the light direction. The average cross-talk was found to be 6:1 in confronted segments of the ON and OFF conditions.

Ramifications of the New Technology

The author's aim was to optically integrate functional LGP segments to fabricate a monolithic light guide that could be mass-produced, thus cutting costs and boosting the performance of local-dimming backlights for high-dynamic-range LCDs. For this purpose, a monolithic segmented functional light guide (a single plate 85.81 mm on the diagonal) was developed, using characterized recessed U-grooves as partitions, an array of unilateral louver prisms for light extraction, lenticular prisms for extracted light-cone shaping, and rounded prisms for light shaping inside the LGP. This test piece was relatively modest in size due to the cost of creating it, but the concept could be realized much more cost effectively in much larger sizes using roll-to-roll technology. The cross-talk between the segments suppressed to 20% and 4% (center-to-center) in the first and second neighboring segments. This amount of cross-talk was an optimized ratio from a vantage point of the evaluation of the uniformity of luminance on the display.

The luminance enhancement was 1.5–2 times that of a conventional BLU, depending on the front-of-screen optical components. In general, sharp cut-off of the illuminated segment enhances the power consumption and the display image. Wide light distribution can result in widening the viewing angle. However, it does not enhance the image. The recessed optical isolators should produce an optimized cross-talk (for the sake of good front-of-screen quality) to enhance the image, while limiting the viewing angle of the display. Possible uses for this monolithic segmented functional LGP are a scanning backlight or a field-sequential-color display with higher frame rates; a scanning-type field alternative 3-D backlight; and a segmented BLU for local dimming, or for local dimming a 3-D display.

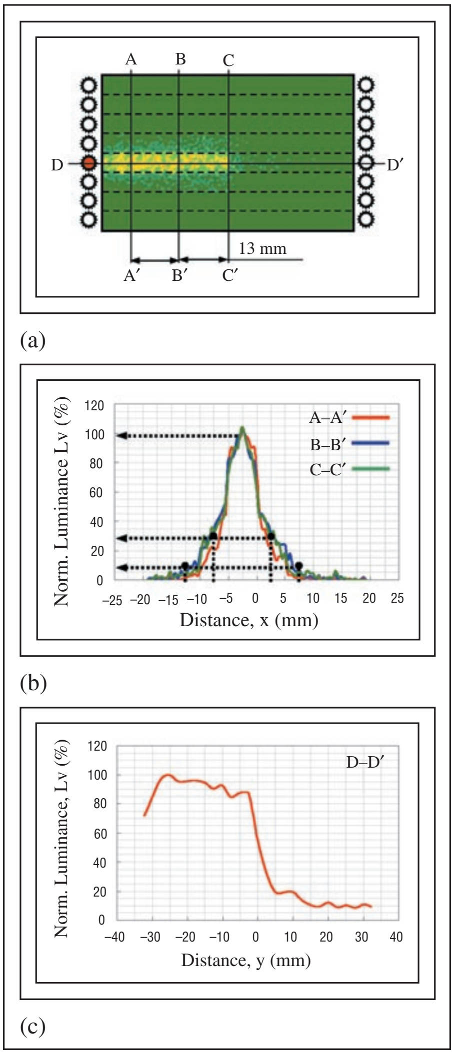

Fig. 7: (a) A single segment is switched "ON" and the leakage light of the confronted segment is evaluated. (b) The profiles of the luminance along the x-axis at three points are plotted (A-A′, B-B′, C-C′) and the same ratios for the leakage light are obtained. (c) The leakage light from the lit segment to the confronted segment is about 6:1.

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Light Guides Evolve from Display Backlighting to General Illumination

Once used primarily for backlighting small–to–medium-sized LCDs in portable and handheld devices, LED-based edge-illuminated light-guide technology has transitioned from cell-phone backlights to PC monitors and large TV backlights and is now even being used to illuminate entire rooms.

by Brett Shriver

WHAT IS THE BEST backlighting technology? That depends on what your application is and who you talk to. One thing is certain: LCD backlighting has come a long way since the days of passive-matrix monochrome character displays. Historically, many different light sources have been used for LCD backlighting, including incandescent lamps, electroluminescent (EL) lamps, vacuum fluorescent (VF) lamps, cold-cathode fluorescent lamps (CCFLs), and, more recently, light-emitting diodes (LEDs).

CCFLs are still used in legacy applications such as medical equipment (*e.g.*, defibrillators and patient monitors) and point-of-sale (POS) equipment (*e.g.*, ATMs and slot machines). In medical applications, for example, components tend to be specified for use over a long period of time. Extensive and expensive testing and verification are required to replace them, so a switch to new components is not undertaken lightly. But, as is well-known, CCFLs are being displaced by LED-based backlight units (BLUs) in virtually every LCD, from smart phones to laptop and tablet PCs to large-screen TVs. According to a survey conducted by LED Inside, the LED research division of TrendForce, the LCD-TV market is expected to increase to 70% in 2012 and, according to WitsView, the panel research division of TrendForce, LED technology's penetration rate is expected to increase to 65–70% of TVs sold.[1]

LEDs solve many design challenges, providing increased luminance with less heat and greater uniformity, longer lifetime of the BLU (including better white-point consistency over the operating lifetime), improved color gamut (when discrete RGB LEDs are used), wide-range dimming to suit changing ambient light conditions, wider operating temperature range, lower voltage (no inverter), no mercury, and a thinner BLU that is more efficient and easier to integrate into slimmer designs than is CCFL-based technology. Also, since luminous efficacy and color consistency among LEDs in batches can vary, LED manufacturers can bin the components for flux, color, and forward voltage. Fine binning for brightness and color can also be used to obtain the proper consistency for color-critical applications. While there are still some applications for EL and CCFL, LED backlighting is being used by the vast majority of LCD applications, while LED technology continues to improve and the cost premium over CCFL moves ever closer to zero.

Brett Shriver is Vice-President of Sales at Global Lighting Technologies (GLT), Inc., 55 Andrews Circle, Brecksville, OH 44141; telephone 440/922-4584, e-mail: bshriver@glthome.com.

BLU Efficiency Backgrounder

Where space is at a premium and the thickness of the BLU must be kept to a minimum – and where isn't it? – a light guide using white or tri-color (RGB) LEDs is the implementation of choice for most designers. Years ago, backlight units utilizing edge-illuminated LED lighting with high-efficiency molded light guides containing pixel-based micro-optical light-extraction technology were just emerging as the technology of choice for a variety of backlighting applications. These included displays and keypads in cell phones (including flip and clam-shell versions), as well as the LCDs in digital cameras, MP3 players, and PDAs with cellular phones and Internet capability.

The introduction of these light guides using molded-in LEDs goes back to the 1990s, when they were also referred to as "light pipes" and were starting to look like viable alternatives to LED arrays (and CCFL and EL backlights). A light guide is a device designed to transport light from a light source to a point at some distance with minimal loss. They are typically made of thermoplastics such as acrylic or polymethyl methacrylate, also known as PMMA. Light is transmitted through a light guide by means of total internal reflection (TIR). The author's company, Global Lighting Technologies (GLT), pioneered molded light-guide technology in

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1998 using pixel-based light-extraction technology combined with high-brightness white LEDs encapsulated within the polymer structure of the light guide (Fig. 1). These light-guide assemblies utilized hundreds of thousands of micro-optical elements – miniature reflective and refractive surfaces – per square inch to extract light precisely and uniformly across the LCD panel to deliver more collimated light, which increased the efficiency of the optical system, requiring up to 30% less power or up to 30% fewer LEDs than other light-extraction technologies such as printed, stamped, etched, or V-groove. By 2007, these molded light-guide assemblies had moved beyond their established turf in the portable/handheld arena and were delivering luminances from 3,500 to 12,000 cd/m^2 (depending upon the number and type of LEDs), with excellent uniformity for mid-sized LCDs (3.5–7.0 in. on the diagonal) while lowering overall manufacturing costs.

Enter Edge Lighting

As opposed to direct lighting, which places LEDs directly behind the LCD in a cavity, edge-lighting positions the LEDs on the edge of the light guide using side-firing LEDs that focus the light into a high-performance optical light guide, which extracts, directs, and distributes the light as required by the application, employing one of several different light-extraction technologies available. The light-extraction technology can be printed dots, chemical or laser-etched dots, V-grooves, or pixel-based, depending on the requirements of the application (Fig. 2). Up to this point, the molded-in LEDs had worked well in use with the focused LEDs with the built-in reflector cup, *etc.*, but when the LED industry began developing LEDs specifically designed to couple with light guides (surface mountable, side emitting, thinner, and with wide-output-profiles) there was no longer a need for the insert molding, which was actually rendered impractical. GLT continued to refine LED-based edge-lighting technology for use in a wide range of LCDs, from < 1 in. to > 50 in. on the diagonal, using high-brightness white LEDs (HBLEDs) as the light source.

With regard to white *vs*. RGB LEDs, only white LEDs are currently used in GLT's LCD backlights. Though color mixing can be addressed during initial design by using larger transition areas and lens arrays in front of the devices, the RGB-LED-based BLUs create issues with the successful control of color mixing not only initially during production, but also because of drift in color over the life of the product due to the LEDs degrading at different rates.

A wide range of display applications would utilize the benefits of edge lighting – LCD and keypad backlights for mobile phones, GPS devices, portable DVD players, scanners, automotive interior displays, programmable touch-screen thermostats, home-security system controllers, industrial instrumentation and control displays, laptop and desktop computers, LCD TVs, and more.

Laptop computers widely adopted edge-illuminated backlighting with white phosphor LEDs and have been a driving force behind the development of ever thinner BLUs. In these applications, a blue LED is imbued with an amber phosphor to convert the visible wavelength to white. The white LEDs still deliver a percentage of the color spectrum (per CIE 1931 chromaticity diagram XYZ color space) comparable to CCFLs (approximately 75% compared to 70–80% for CCFLs) while consuming less power. Traditionally, these backlights have been 2–3 mm thick; however, with advances in LED and light-guide technology, backlights as thin as 0.4–0.6 mm are being created, enabling reductions in the devices' overall weight and thickness.

TV Backlighting

Techniques to utilize LEDs for LCD-TV backlighting were being explored as early as

Fig. 1: *An early example of a light-guide BLU shows molded-in LEDs (inset).*

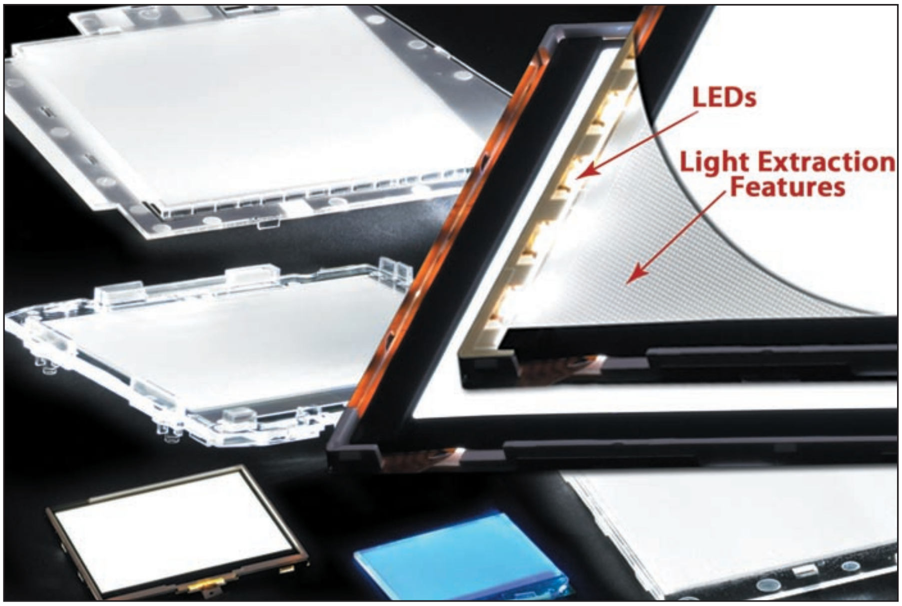

Fig. 2: *LEDs positioned on the edge of the light guide employ pixel-based light-extraction features. As shown in the background, mechanical holding features can be designed into the backlight.*

2005. One solution included RGB-LED backlight modules or "tiles," each incorporating a color-mixing waveguide with light-emitting optical elements arranged in a pattern behind the LCD. This provided wider LED spacing that minimized thermal issues and offered higher efficiency with fewer LEDs.

In 2006, GLT teamed with Luminus Devices, Inc., Woburn, MA, to produce modular LED-based edge-lighting assemblies for large-screen LCD TVs. Luminus's PhlatLight LED technology, combined with GLT's light guides with pixel-based light extraction and high-brightness LEDs, enabled large-sized LCD panels to be edge-lit, as opposed to directly backlit. For more about the PhlatLight technology, see "Rapid Progress in High-Brightness LEDs for Projection" in the September 2007 issue of *ID*.

The rapid evolution of LEDs in the last few years has brought edge lighting to a new level of performance and efficiency. In 2008, HBLED light sources for LCD backlighting were offering efficiencies of ~ 43 lm/W [2] compared to ~ 40 lm/W for CCFLs. Today, HBLED components are routinely delivering efficiencies > 80–100 lm/W and above (in cool white @ 5500K).

Light guides using white HBLEDs are now being used to backlight larger-sized LCDs with a thinner form factor. The light guides themselves are much thinner – as thin as 3.0 mm at up to a 60-in.-diagonal area for large LCDs.

Light-Extraction Technologies

Edge lighting utilizes several light-extraction technologies, depending on the application.

Printed, chemical, and laser dots are diffuse light-extraction technologies in which light is scattered in all directions (360°). They offer the advantage of not requiring additional films to prevent headlight effects, *etc.*, due to the diffuse nature of the light extracted (Lambertian spread of light), and iterations can be completed very quickly. (A headlight effect is a bright area near the LEDs at the edge of the light guide where the illumination looks like the headlight of a car.) However, brightness is from low to medium for most applications. Output angles cannot be precisely controlled, and any non-transparent dots can block a portion of light that is scattered downward from reflecting back through the panel and exiting the top surface. Figure 3 compares the acceptance angle of light between pixel-based and other methods – printed, chemical, or laser-etched.

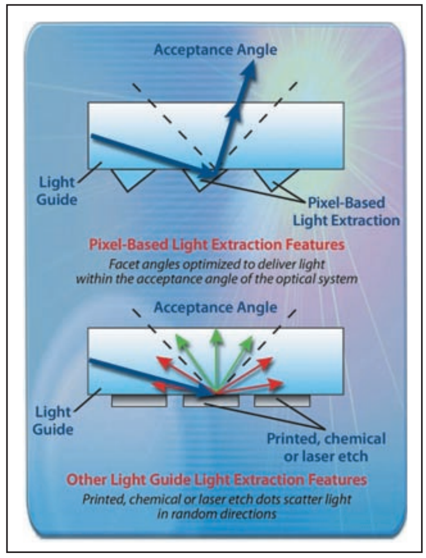

Fig. 3: Pixel-based light extraction (top) is compared to other light-extraction technologies.

V-grooves or pixel-based technologies can achieve higher efficiencies in some designs and can control the target direction of the light being extracted, but they require more optical design and development time. And V-grooves, though they offer higher brightness with very good efficiency, are limited in that 2-D uniformity correction (side-to-side correction) is not possible.

A specular, pixel-based light-extraction technology provides high brightness and reflects and transmits light from the optical features in a specular manner. Here, 2-D uniformity corrections are possible, optical features are transparent, and the angles at which light is emitted from the light guide can be controlled. The benefits of this approach include better optical control – especially of color and uniformity – fewer LEDs, better repeatability at all levels, reduced power consumption, and the thinnest possible light-guide package. Table 1 compares some of these light-extraction technologies.

The Push to Thinner and Touch

Every manufacturer wants a more-efficient BLU, and a big part of the efficiency equation is *thinner*. Light guides are being manufactured as thin as 0.3 mm or less for applications such as keyboards, touch sensors, and small smart-phone-type backlights. GLT, for example, is addressing the push to thinner BLUs (and the challenges this creates) by sourcing thinner and thinner LEDs as they are being released by the LED manufacturers, as well as pushing manufacturing processes in order to manufacture light guides 0.25 mm thick or less. These thickness reductions, however, can lead to challenges with uniformity and brightness, which can be addressed through the use of custom-designed optical-extraction features

Edge-lit LED light guides employing pixel-based light extraction technology have become so thin; in fact, that they are now being used to backlight touch screens and illuminate touch-enabled display graphics (on/off and function buttons, menus, keypads, directional symbols, *etc.*) used in applications such as appliances, printers, home-entertainment devices, and multi-device desktop speakerphone systems for office environments with LCD and multiple graphic touch inputs.

In cases where the light guide is employed between a capacitive touch sensor and a top graphic overlay to illuminate the overlay, reducing thickness is a critical parameter in improving the sensitivity of the combined touch-sensitive control. Edge-lit light guides with thicknesses of 0.2–0.6 mm can be used in this application, allowing acceptable touch sensitivity.

The use of low-profile side-firing white LEDs placed along the edge of an ultra-thin light guide in concert with a pixel-based light-extraction technology that spreads the light uniformly across the area to be illuminated has proven to be particularly effective in applications utilizing capacitive touch technology, which transmits approximately 90% of the light from the backlight and has become

Table 1: A comparison of edge-lighting methodologies shows the principal light-extraction technologies used in light-guide BLUs

Technology	Efficiency	2-D Pattern Possible
Printed dots	low	yes
Etched dots	good	yes
V-grooves	very good	no
Pixel-based	very good	Yes

the touch technology of choice for appliances and a variety of other touch-enabled applications where a slim, touch-friendly backlight is desirable. Now, in many applications, one LED can be used to illuminate multiple graphic icons, eliminating the need to use individual LEDs for each graphic interface or multiple LEDs for larger areas such as company logos (Fig. 4).

Keeping It Uniform

The use of binned HBLEDs combined with advanced light-extraction technologies and optics go a long way toward providing a truly uniform backlight. An issue that remains, however, is headlight effects. Headlighting can also be seen when using a lens-based light-extraction technology because it will create a direct reflection of the LED in the user's eye. This can be addressed through the use of a diffuser and BEF films on the light-guide panel (LGP) as well as the addition of optical features on the top surface of the LGP, which will break up the user's view of the lens-based features.

One Side? Two Sides? More?

Edge-lit LCDs have utilized side-firing LEDs on one, two, or more sides of the BLU. However, as white HBLEDs become ever brighter and more efficient, the number of LEDs required has decreased. This makes it practical – and more effective – to move all the LEDs onto a single edge of the LGP and keep the LED spacing as close together as possible. This allows the LGP manufacturer to still maintain the smallest possible distance between the LEDs and the visible edge of the output area, and also lowers the bill of materials for the manufacturer. It does, however, make the design of the LGP more difficult, as the light must travel farther down the light guide. This is compensated for by advanced optical light-extraction technology as well as careful material selection, enabling maintenance of a high level of uniformity and efficiency, even with the increased lengths. And in some applications, both in backlighting and general illumination, it is still most efficient to space the LEDs along two sides of the light guide, such as in the 2 × 2-ft. troffer downlight shown in Fig. 6.

General Illumination

Edge lighting has also made it possible to take existing light-guide technology and expand it into a variety of general illumination applications.

LEDs are becoming more and more commonplace in general lighting, and their benefits over incandescent bulbs and regular hot-cathode fluorescent tubes are well known (longer life, less energy usage, greater control and directionality of light, more design flexibility, wider color gamut, and smaller form factor). The proven benefits of edge-lit light guides as BLUs for LCD backlighting are being leveraged to make the LED light source an integral part of light fixtures in general illumination applications rather than a replaceable part to be designed around reducing the time-to-market and increasing the appeal of LED-based light fixtures in general.

Common examples of edge-lit LED-based light guides at work in the general illumination arena include room lighting (ceiling downlights, wall sconces); under-cabinet, splash, and desk task lighting; illumination of industrial and commercial enclosures (refrigerators, for example.); and architectural lighting, as well as in outdoor applications such as pathway illumination and pedestrian traffic signs.

These applications were a natural design evolution for edge-lit light guides, as they were developed to take light from a point source (*i.e.*, LEDs) and provide uniform distribution of it over large areas (Fig. 5). The "large area" has expanded from a cell-phone backlight to an LCD TV to illumination of an entire room or office. (You could, in fact, think of the floor of your office as the back of a big LCD panel.)

The downlight shown in Fig. 5 was designed to provide a brighter, more efficient replacement for 2 × 2-ft. fluorescent lay-in troffers used in recessed ceiling lights, such as those shown in Fig. 6. Switching from fluorescent tubes to LEDs was made easier from a design perspective and more cost effective from a manufacturing perspective because of the design and form-factor flexibility and excellent repeatability of edge-lit light guides with embedded optics.

Illumination Distribution :

	3000K	4000K	5000K	6000K
A	1100Lux	1340Lux	1500Lux	1550Lux
B	275Lux	335Lux	375Lux	385Lux
C	120Lux	145Lux	165Lux	172Lux

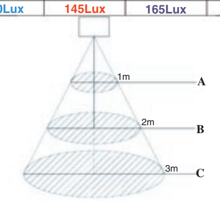

Fig. 5: The cone shows the illumination distribution from a light source – in this case, a 2 x 2-ft. LED flat-panel downlight employing edge-lighting technology, with 100 LEDs spaced along two sides of the light guide for optimal light dispersion – at a distance of 1, 2, and 3 m (roughly 3, 6, and 9 ft.) over four different color temperatures ranging from warm white (3000K) to cool white (6000K).

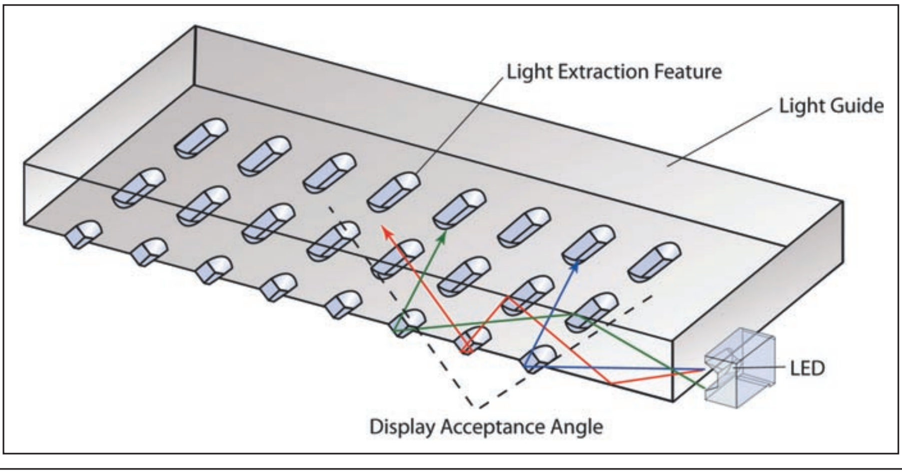

Fig. 4: In many touch-enabled display graphics applications, one LED can be used to illuminate multiple graphic icons.

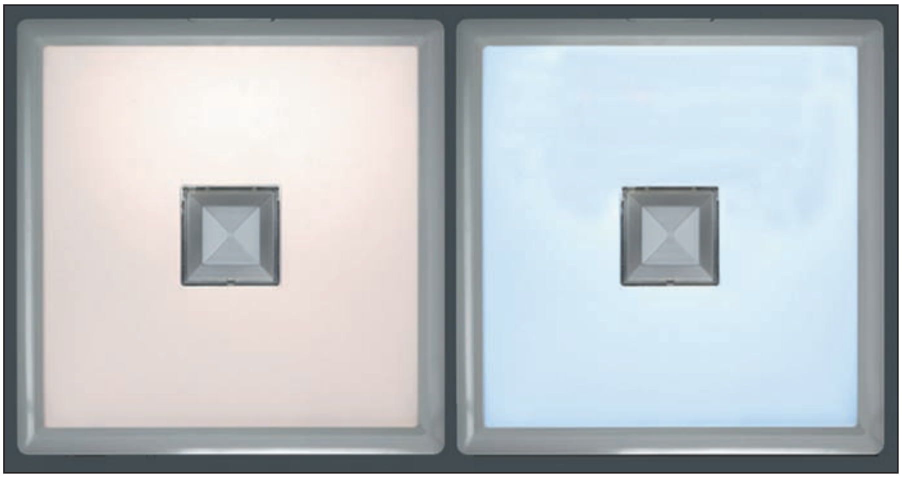

Fig. 6: The excellent uniformity of color and luminance provided by the edge-lighting approach is seen in the OL2 Series 2 x 2-ft. downlight, which can be provided in four color temperatures ranging from warm white (left) to cool white (right).

Many companies are also starting to realize that in order to take advantage of the true benefits of an LED package, they have to design the luminaire to work with the LED rather than trying to take a luminaire that was designed to use a florescent bulb or an incandescent lamp and trying to retrofit it to LEDs.

Measuring Efficiency

The edge-lighting approach achieves maximum efficiency in light dispersion. But how do you measure efficiency? Application efficiency – *i.e.*, the actual amount of light delivered to the targeted area in relation to the total light output of the fixture – is the true measure of performance. It includes

- Luminous efficacy (lm/W)
- The optimal efficiency of the total fixture
- Ray-angle control

Luminous efficacy, sometimes referred to as brightness, is measured in lumens per watt (lm/W) and indicates how well a light source produces visible light. Lumens per watt are calculated based on the total output of light from the final product as measured within an integrating sphere versus the power that is input into the product. Currently, the target for most BLU suppliers is 70 lm/w because this is the requirement to achieve Energy Star performance on a luminaire. Luminous efficacy is one component of the luminaire's total application efficiency. In order to achieve high application efficiency, a lighting fixture must direct as much of the light to the target area as possible instead of scattering it in all directions, focusing on the target area to avoid wasted light emissions. That is where ray-angle control comes in. Specular optics embedded in the light guide can direct the light in the specific direction desired. As shown in Fig. 5, pixel-based light-extraction technology can be optimized to deliver light within the acceptance angle of the optical system. In order to reach maximum application efficiency, the luminaire manufacturer must work with each supplier in the system to achieve the highest possible efficiency. This includes those responsible for the power supply, LEDs, drivers, LGPs, and films.

Luminaires Leading the Way

The luminaire is where LED-based solid-state lighting is going to really succeed because that is where LEDs can be most elegantly used, as opposed to being retrofitted into an old light-bulb form factor. Over the last year, products have emerged that represent a redesign of the entire luminaire rather than just the light source. For example, GLT, in cooperation with luminaire manufacturers, has developed recessed ceiling lights that involve a top-down design of the entire luminaire around the end light source – the LED. One of the fixtures that has seen growth in the last year are the industrial 2 × 2-ft. troffer-type replacements. When designed as an entire fixture to take advantage of the LEDs, efficiency increases significantly. Some of these luminaires have efficacies greater than 60 lm/W with a power consumption of 45 W, CRI of ≥ 75%, and lifetimes of 30,000 hours.

As in everything, there is what people say they would like to have and what they are willing to pay for. When the author's company shows customers the price differential between a luminaire with 50-lm/W luminance and a CRI of 80 at a unit cost of approximately $125, and a luminaire with 60 lm/W and a CRI of 85 for approximately $175 per unit, many choose the lower cost module without hesitation. For high-volume products, the most important specification is often price, although that involves several factors. For example, pricing for GLT's UL-certified OL2 Series troffer 2 × 2-ft. downlight assemblies begins at about $122 each in volumes of 100 pieces, compared to $45-80 per unit for similar conventional fluorescent troffers. Given the much greater lifetime of LEDs and the effective elimination of costs for re-lamping, customers have found the LED troffers to be very competitive.

In general, edge lighting using LED-based light guides lends itself well to cost-efficient manufacturing in high volumes. This is made possible due to the use of fewer LEDs, advanced light-extraction technologies that extract light precisely where needed to provide bright, uniform light in a thinner form factor without hot spots or dark areas, the excellent repeatability of light guides, and the approach of designing around the LEDs rather than trying to retrofit them to designs meant for bulbs or tubes, as well as production in multiple dedicated facilities in Asia. All these factors have combined to make the production of not only the most efficient light guides for LCD backlighting a practical reality, but entire assemblies for general illumination, and at competitive prices. Moving forward, the author hopes to see lighting companies working with LED, driver, and light-guide manufacturers to form more partnerships rather than continuing to operate as completely separate suppliers. Such cooperation will enable a truly efficient system for presenting LED-based general illumination products to the market.

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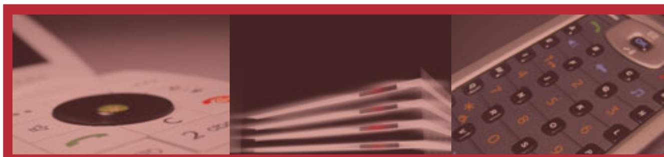

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Part II: What Companies Need to Know about the Leahy–Smith America Invents Act (AIA) Patent Reform Legislation

The America Invents Act, the most significant change to the U.S. patent system since 1952, was signed into law on September 16, 2011. This series of articles focuses on selected provisions of the AIA which are likely to be the most relevant to companies in the display industry. Part II looks at new examination provisions, fees, fee structures, and review processes.

by Clark A. Jablon

PART I of this series of articles on the America Invents Act described many of the key litigation-related provisions. Part II discusses key provisions of the AIA that relate to U.S. Patent & Trademark Office (USPTO) and patent examination provisions, including a new prioritized examination process, fee surcharges, and a "micro entity" designation for patent applications that allows for significantly reduced government fees. New USPTO validity review proceedings, including a new post-grant review process (opposition proceeding), are also outlined.

Clark Jablon is a Partner and Registered Patent Attorney at Panitch Schwarze Belisario & Nadel LLP (PSB&N) in Philadelphia, PA. His practice involves the preparation and prosecution of patent applications, enforcement, and litigation of patents, and opinion work on patent validity, infringement, and patentability. He is a degreed electrical engineer and has worked as a patent practitioner for more than 28 years. He can be reached at cjablon@panitchlaw.com. The opinions expressed herein are those of the author and not necessarily those of PSB&N.

New Prioritized Examination Process (Available Now)

The U.S. Patent & Trademark Office (USPTO) has a backlog of over 1,200,000 pending patent applications, including more than 700,000 that have not even received a first Office Action. In response to complaints from the public regarding the excessive amount of time it takes to start the examination process, about 4 years ago the USPTO instituted the "Accelerated Examination" (AE) program, which is designed to complete the examination process within 1 year of the application filing date. (For more about the Accelerated Examination program, see the article, "Intellectual Property: How to Get a Patent Quickly," in the September 2010 issue of *ID* magazine.)

In AE, the applicants effectively conduct a preexamination of their own applications, basically doing the examiner's job, including prior-art searching and identifying patentable subject matter in the claims. The examiner still performs a normal examination of the application, but the applicant's preexamination typically resolves many issues that would arise in the examination process and significantly improves the likelihood of a successful outcome for the applicant. In fact, AE applications have allowance rates that are significantly higher than the USPTO average, and the number of Office Actions per application is significantly lower than the USPTO average. However, the Accelerated Application program has been very unpopular among patent practitioners and is rarely used. It has

> ***". . . the Accelerated Application program has been very unpopular among patent practitioners and is rarely used."***

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high upfront costs due to the expense in preparing the special documents that must be submitted with the application. There is also a real concern that statements made in the AE submission may be used against the patent owner in any subsequent litigation. The patent community has asked for an alternative program. "Prioritized Examination" (PE) is being touted as that alternative, although AE is still available.

PE is a "pay-to-play" program. You just give the USPTO a large amount of extra money, in addition to the normal filing fee, and the USPTO presses a few buttons and puts your application at the front of the queue. No prior-art searching or analysis is required for a PE application. Accordingly, the filing costs are typically lower than an AE application, even after paying the extra fee, which is $4800 for a large entity and $2400 for a small entity (small entities are usually individual inventors, universities, or companies with fewer than 500 employees). Under PE, the USPTO promises a goal similar to that of AE, which is to complete the examination process within about 1 year from the application filing date.

Which is the better option for receiving a quick examination – AE or PE? If filing costs are the main concern, PE is the better choice because it has cheaper upfront costs than AE. If effectiveness in achieving desired patent protection is the main concern, then AE is likely to be the better option because of its proven track record of higher allowance rates and fewer Office Actions.

Fee Surcharges (effective now)

A 15% surcharge has been added to most USPTO fees. For companies that maintain large U.S. patent portfolios and do not wish to increase their patent maintenance fee budget, the surcharge will likely result in more decisions to abandon issued patents before their normal expiration date by not making maintenance fee payments on selected patent properties, particularly for patents that have not shown any actual or potential commercial value by the due date of their 12th-year maintenance fee, which is the last and most expensive fee that is due (currently $4730 for a large entity).

Government fees related to prosecution costs (filing fees, extension fees, and issue fees) represent only a small portion of total prosecution costs, and thus the fee surcharge should not result in a significant reduction in patent applications. There are many ways for companies to reduce prosecution costs so as to offset the government fee increases, such as minimizing the need to pay excess claim fees (due for each independent claim over three and each number of total claims over 20), submitting Office Action responses by their initial due date (usually 3 months from the mailing date of the Office Action) to avoid having to pay government extension fees and conducting patent searches before filing so that a more focused set of claims can be prepared that will likely require less prosecution. The latter action may also lead to a decision not to file at all if the search results show that broad patent protection for the invention is not available.

New "Micro Entity" Designation for Patent Applications (Awaiting Implementation)

Current patent application designations include "large entity" and "small entity." Small entities, as mentioned above, are generally individuals, non-profit organizations including universities, and businesses with no more than 500 employees. All other applicants are large entities. Small entities are entitled to a 50% reduction in most of the government fees compared to large entities. The America Invents Act will provide a new designation, called a "micro-entity," which will be entitled to a 75% reduction in most of the government fees compared to large entities. Certain "low income" independent inventors and all universities will be eligible for the micro-entity status. The USPTO is preparing the regulations for this new designation and will make the fee reduction available upon completion and implementation of the regulations. The vast majority of patent applicants will not be eligible for this new designation, so it will not likely result in any further cost savings to most companies who file patent applications.

New Post-Grant Review Process (Effective March 16, 2013)

This process, also referred to as an "opposition proceeding," allows anyone to challenge the validity of an issued patent before the USPTO on any ground within a 9-month window following issuance of the patent. Such proceedings have been in existence in Europe for many years, and thus many international technology companies may already be familiar with the concept behind an opposition proceeding. The entity requesting the challenge is referred to as the "Petitioner." To obtain a post-grant review, the petitioner must file a request that demonstrates to the satisfaction of the USPTO that there is a "reasonable likelihood" that the petitioner will prevail (in proving invalidity) on at least one of the issued claims. The request must be accompanied by whatever evidence the petitioner believes demonstrates invalidity, which will typically be new prior art, but may also include arguments that the patented claims are indefinite or are not properly supported by the written description. If the request is granted, then the USPTO will effectively reexamine the issued patent and make any rejections that it believes should be made based on the information presented in the request. The patent owner will then have a chance to respond to the rejection(s) in the same manner that occurs during normal prosecution of a patent application. The original petitioner may also file certain types of limited responses to the patent owner's response.

If the patent validity is reconfirmed as a result of the opposition proceeding, the petitioner will be estopped (prevented) from reasserting most validity arguments in any subsequent litigation over the patent. Thus, the petitioner may be limited to asserting only a non-infringement defense in a subsequent litigation.

Most companies will likely find that the new post-grant review process is not helpful

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in invalidating patents of concern because the vast majority of patents are issued before competitors begin to engage in potentially infringing activity. Thus, for most patents of concern, the 9-month window will pass before a competitor becomes aware of the patent. Furthermore, the easiest and cheapest way that most accused infringers escape liability for patent infringement is by proving to a court that they are not infringing the patent. Proving invalidity of the patent is a much harder path to take, and, as stated above, the need to do so typically arises well after the opposition period ends.

Notwithstanding the above comments, certain companies have a limited number of competitors and may be in a position to take advantage of the post-grant review process. Such companies should consider establishing a formal review process wherein all issued patents from such competitors and/or all patents directed to a specific technology of interest are identified shortly after issuance using a "watch service." In this way, the patents can be reviewed to determine if a validity challenge should be brought before the expiration of the 9-month window. Most patent law firms can assist companies in establishing such a watch service, which is typically provided by third parties that specialize in this area. Procedures should then be put in effect at the company regarding who will conduct the review and who will be notified of patent(s) that the company may wish to challenge. A patent lawyer will then need to identify and review the proposed evidence of invalidity to determine whether it will likely meet the USPTO standards for a post-grant review, and, if so, prepare and file the post-grant review request.

New Inter Partes Review (Effective September 16, 2012)

Patents may still be challenged at the USPTO after the expiration of the post-grant review proceeding; *i.e.*, 9 months after issuance of the patent. Proceedings have always existed for such challenges, including ex parte reexamination and inter partes reexamination. These reexamination proceedings are limited to validity challenges based on novelty and obviousness grounds based on prior art "patents and printed publications," in comparison to the more extensive validity challenges that will be permitted during the opposition period described above that can be based on any grounds of invalidity.

The AIA maintains "ex parte reexamination" but replaces "inter partes reexamination" with "inter partes review." Both of these proceedings require that a challenger (referred to as the "Requester") file a request for reexaminations stating why certain claims of a patent are invalid due to lack of novelty or because of obviousness. The USPTO must then determine whether there is a reasonable likelihood that the requester would prevail with respect to at least one of the claims challenged by the requester. If so, then the patent undergoes a reexamination; the USPTO will effectively reexamine the issued patent and make any rejections that it believes should be made based on the information presented in the request. The patent owner will then have a chance to respond to the rejection(s) in the same manner as during the normal prosecution of a patent application. The original requester may also file certain types of limited responses to the patent owner's response.

The same estoppel rules discussed above with respect to "post-grant review" also apply to the requester of an inter partes review in any subsequent court proceeding that involves the patent.

Supplemental Examination (Effective September 16, 2012)

The AIA adds a brand-new process that allows patent owners (not third parties) to request that the USPTO "consider, reconsider, or correct information believed to be relevant to the patent." In most instances, the Supplemental Examination (SE) will be used by patent owners to submit prior art that was not originally considered by the patent examiner during the original examination, and which the patent owner now wishes to be considered. SE is not limited to new consideration of prior-art patents or publications, and other evidence of lack of novelty or obviousness may be presented. The patent owner must file a request for SE that shows why the information presented in the request (*e.g.*, new prior art) raises a "substantial new question of patentability" (SNQP). If the USPTO determines that a SNQP exists, then it will initiate a reexamination of the patent.

If the patent is reissued in view of the new information, then the information (*e.g.*, prior art) presented by the patent owner in the SE request generally cannot be used in a subsequent court proceeding to challenge the validity of the patent.

This process is primarily designed to allow a patent owner to "cleanse" a patent of potential validity challenges brought by a defendant in a subsequent patent lawsuit based on the above-mentioned new information. It is par-

> *. . . certain companies have a limited number of competitors and may be in a position to take advantage of the post-grant review process.*

> *Companies will now have a new avenue to shield a patent that they wish to enforce from a validity challenge over prior art . . .*

ticularly aimed at validity challenges based on an assertion of "inequitable conduct" for not bringing the information to the attention of the USPTO during the original examination of the patent. Stated another way, the process is primarily designed to reduce the number of "inequitable conduct" challenges brought by defendants in patent lawsuits.

Companies will now have a new avenue to shield a patent that they may wish to enforce from a validity challenge over prior art that they become aware of that might be used against them in a litigation. However, companies will need to weigh the above-discussed benefits of this process against its costs and risks before filing a SE. The costs will include the currently proposed USPTO fees of about $22,000, as well as attorney fees, which are likely to be a multiple of that number. One potential risk is that the USPTO might ultimately determine that the patent is invalid over the new prior art. Another potential risk is that if the USPTO determines that there was "material fraud" involved in the original examination or the SE, the USPTO will forward the matter to the U.S. Attorney General for review.

Pre-Issuance Submissions of Prior Art for Pending Applications (Effective September 16, 2012)

The USPTO currently has procedures that allow third parties to submit prior art to the examiner for consideration during the examination process. However, the rules governing the procedures and the timing of the submissions are such that almost no third parties make such submissions. The AIA implements new procedures that are supposed to encourage more submissions. The new procedures have the following requirements:

i. The prior art must be an issued patent, published application, or any other printed publication.
ii. The submission must be made before the earlier of the date of a notice of allowance of the patent application, or the later of (i) 6 months after the date of publication of the application or (ii) the date of the first rejection.
iii. The submission requires a "concise statement of relevance" of the document.

The real party of interest making the submission does not need to be identified. Thus, the submission can be made anonymously through an entity unaffiliated with the third party that wishes for the prior art to be considered, often referred to as a "straw man."

Companies that wish to challenge a pending application over prior art that has not been brought before the examiner may wish to use this new procedure instead of resorting to more complicated prior art-based validity challenges, such as post-grant review or inter partes review. However, as discussed above, most companies only learn about patents of interest well after they are issued, so this procedure will not be of help in the majority of situations. However, if companies ramp up their policing of pending applications through a "watch service," they may learn of such patent applications early enough to consider using this procedure.

> *The main policy goal behind post-grant review, inter partes review, supplemental examination, and pre-issuance submissions is to reduce litigation costs . . .*

Policy Goals of New AIA Examination Proceedings

The main policy goal behind post-grant review, inter partes review, supplemental examination, and pre-issuance submissions is to reduce litigation costs by providing a forum at the USPTO to challenge patent applications and patents that would otherwise be litigated in a more expensive court proceeding. Whether the new examination proceedings will achieve that goal remains to be seen.

Part III of this patent series will focus on the changeover in the U.S. patent system from a "first to invent" to a "first to file" system, as briefly discussed in the first article in the series, which appeared in the February 2012 issue of *ID*.

The U.S. Patent & Trademark Office (USPTO) has an information web page regarding the AIA at: http://www.uspto.gov/aia_implementation/index.jsp that provides links to specific details of the AIA. ■

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editorial

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Society know this and live it by example every day. In fact, as you can read further in our feature article unveiling the SID 2012 Honors & Awards recipients, all of this year's major winners have a distinguished record of giving back to students and colleagues through the years. Among them is Larry Tannas, Slottow-Owaki Prize winner, who has taught for over 30 years at UCLA and even endowed a chair of Display Systems Engineering within the engineering department. Similarly, Dr. Jun Souk, winner of the Karl Ferdinand Braun Prize, is now a professor at Hanyang University after a distinguished career at Samsung. We should all follow their leads and help build the next generation of technology leaders from the students of today.

Another tangible way the Society helps in this cause is through local SID chapters that sponsor student chapters on university campuses and include those students in their regular meetings and conference events. Students who are studying display technology are strongly encouraged to publish their work in the *SID Journal* and to present at the annual Symposium in conjunction with Display Week. SID even provides travel assistance to students whose papers are accepted for publication and presentation. SID also recognizes each year the best student paper submitted to the *SID Journal*, and this year the winner is "Limonene as a chiral dopant for liquid crystals: Characterization and potential applications" by Rafael S. Zola, Young-Cheol Yang, and Deng-Ke Yang of Kent State University. You can read about their work and the significant findings presented in the paper in this issue under the SID News heading.

We have a packed issue this month, as we simultaneously celebrate our SID 2012 Honors and Awards recipients, preview the upcoming 2012 Symposium, and tackle the latest innovations in backlighting technology. Of course, the Honors and Awards are the most fun, recognizing the many accomplishments of those who have invested so much of their careers to furthering the field of displays. While the honors are being bestowed on them, the real honor is to those of us who have the privilege of working with them, learning from them, and using their innovations to build better products and enrich people's lives. When you read the biographies and citations thoughtfully compiled by our own Jenny Donelan, I'm sure you will come away with something from their lives and work you can relate to. Take the time to reach out to them and say "Congratulations and Thank You" for everything they have achieved.

Our backlighting coverage was compiled this month by our Guest Editor Adi Abileah and starts out with a retrospective of how LED technology has changed so many things about the business and technology of LCDs. Authors Jimmy Kim and Paul Semenza from DisplaySearch take us through the recent history of LED backlight innovations and focus on how they have affected the supply chain, business model, and other aspects of the business of LCDs.

If you need any proof that there is still lots of room for innovation in the design of optical light guides, look no further than our Frontline Technology contribution from K. Käläntär from Global Optical Solutions, who describes his development of a monolithic light-guide panel that provides addressable segments of light that can be used for local dimming of an LCD panel. Not only can this light guide be produced at lower cost than conventional local-dimming light guides, but the light-extraction efficiency has been improved by 1.5–2.0 times that of a conventional BLU. Incidentally, while Adi was working on recruiting the articles for this issue of *ID*, he was also being selected as the winner of the Otto Schade Prize for all his years of work enhancing the performance of displays, including lots of backlight innovation. We offer him our congratulations and thanks.

Another company that has been innovating in the backlight arena is Global Lighting Technologies. Author Brett Shriver from GLT has contributed a survey of the various advances, titled "Light Guides Evolve from Display Backlighting to General Illumination." I found it intriguing to look at all the ways the basic light-extraction optics can be modified, adapted, and repurposed to suit the many and varied applications described in this article.

We also continue this month with part two of our three-part series on the Leahy–Smith America Invents Act (AIA) Patent Reform Legislation, written by attorney Clark A. Jablon. In this installment, Jablon looks at the new examination provisions, fees, fee structures, and review processes, and offers some very valuable insights into how you can get the most for your money using the new patent process.

Of course, on top of all this we're busy getting ready for Display Week this year in Boston, my home city. Based on the preview we've assembled thus far, it looks like another "can't miss" year for the show and I hope all of you are planning on coming. Trying to summarize the highlights of the upcoming SID Symposium in a few short pages is a daunting task – every topic and every paper is important in its own right, having been selected from a pool of more than twice as many submitted in the past year. When I look at the range and depth of topics, I'm always amazed that there are so many diverse aspects to display technology and that each of them is so potentially rich with new ideas and innovations.

This year is probably the most exciting I have seen in the last few years, with a full array of papers on multiple aspects of 3-D, flexible displays, green technologies, solid-state lighting, and touch. Oxide TFTs were used in many new processes this year, as you will hear in the manufacturing technology sessions, and even projection technology is exciting again with new innovations in pico-projectors being discussed. After reading Jenny's overview with descriptions from all the sub-committee chairs, I'm sure you will also agree it's going to be a banner year for the Symposium. And so, our April issue is complete and we look forward to May/June when we'll be unveiling the Display Industry Awards and so much more. I hope you are all planning on coming to Boston and I look forward to seeing you here. Travel safe. ■

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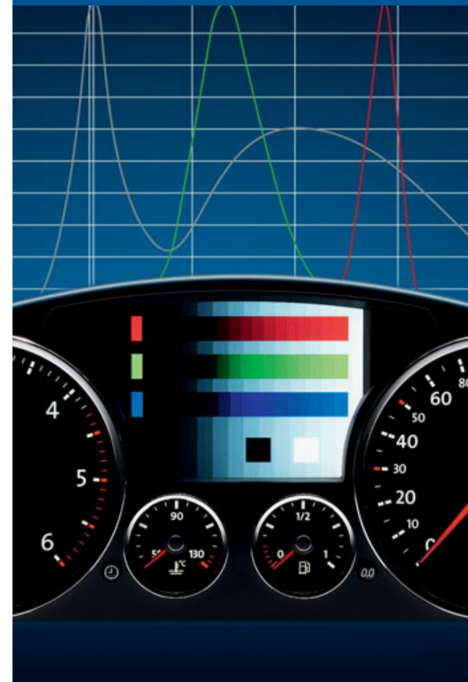

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2011 JSID Outstanding Student Paper Award

Each year, the *Journal of Society for Information Display* (JSID) recognizes a published student paper on the basis of originality, significance of results, organization, and clarity. The 2011 award went to Rafael S. Zola, Young-Cheol Yang, and Deng-Ke Yang, from the Liquid Crystal Institute and the Chemical Physics Interdisciplinary Program at Kent State University, for the paper "Limonene as a chiral dopant for liquid crystals: Characterization and potential applications."

by Rafael S. Zola

Rafael S. Zola

Young-Cheol Yang

Professor Deng-Ke Yang

It has been known for many years that adding a material to liquid crystals can change their physical properties in desirable ways, particularly in terms of display applications. Many liquid-crystal-display technologies take advantage of chirality to work. Chirality, the property that describes the helical (twisted) alignment of molecules, is one of the most intriguing subjects in nature. Over the years, it has attracted attention from chemists, physicists, biologists, and engineers.

In liquid crystals, chirality shows up in very elegant ways. From a research point of view, chirality is the difference between the ordinary nematic phase and the exciting Bragg-reflecting cholesteric phase, or the ferro-electric smectic C* and the regular non-ferroelectric smectic C. From an applications point of view, chiral phases can be used in many ways, including several quite successful modes: twisted nematic (TN), super-twisted nematic (STN), polymer-stabilized cholesteric textures (PSCT), and bistable reflective cholesteric displays.

Since chirality is so crucial for liquid-crystal displays (LCDs), every little step taken toward a better understanding and development on this matter is important. For many years, the scientific community has taken great efforts toward synthesizing new chiral materials, which is not a trivial task because a good chiral dopant must satisfy certain requirements, such as helical twisting power and solubility. However, while naturally occurring chiral materials exist, very few non-synthesized elements have been used as chiral dopants.

For my first thesis work, my advisor, Professor Deng-Ke Yang, suggested studying the chiral dopant effect on liquid crystals, aiming for physical parameter changes. After the initial experiments, our team realized that this addition, even if small, has a great impact on the host. Since the chiral additive is a "necessary evil," we decided to seek a material that would both induce twist and improve the host's properties. We started considering synthesized materials only, but after some research, we realized that scientists have leaned toward synthesized compounds over the years, almost forgetting the natural chiral materials, even though the first liquid crystals themselves were essentially biological systems.

I then noticed that while many textbooks use Limonene, a natural molecule easily extracted and purified from citrus fruits, as an example of chirality, none ever mentions any application in the liquid-crystal field. As the essence of science is experimenting with the new and avoiding bias, I decided to use Limonene as a chiral additive. As additional motivators for us, Limonene is a "green" material and is easily found at very low cost. Most importantly, Limonene is a low-molecular-weight compound, much lower and smaller than liquid-crystal molecules or commonly used chiral dopants.

We therefore used D-Limonene as a chiral dopant for TN displays and bistable cholesteric displays. The results: a lowering of the switching voltage and incredibly faster response times, achievements presented at the SID 2010 Symposium. This first set of results led us to an invitation for publishing more complete and detailed data in a *JSID* special edition on Nano-Technology in FPDs. This work was performed with much help from Dr. Young-Cheol Yang. Our findings were very interesting and confirmed what we observed before: We had a material that changed the physical parameters of a well-known nematic liquid crystal at different ratios, despite the small amount added. The most fascinating discovery was the large decrease in rotational viscosity, one of the most desirable achievements for fast displays. The elastic constants were also lowered, decreasing the switching voltage without compromising the improvement on response time induced by the great change of viscosity. These results suggest potential applications of liquid-crystal phases that were heretofore unreasonable to consider, such as for active-matrix bistable reflective cholesteric displays working at video rates.

With our paper published in the *JSID*, we hope to reach researchers with regard to the many possibilities encountered by "mixing" liquid-crystal compounds with other materials, an interdisciplinary field involving biology, physics, chemistry, and engineering. For us, it is surprising how many synthesized materials have been used in the industry as the liquid-crystal field moves forward, while naturally occurring molecules have not. D-Limonene, for example, can cost up to 250 times less in terms of price and helical twisting power (HTP) as compared to conventional chiral dopants such as (R)S811. This makes it a better choice for teaching purposes, for example, than more expensive synthesized chiral additives. And as a matter of practicality, the performance benefits we measured can be useful in engineering better displays.

*Winning-paper authors **Rafael S. Zola** and **Young-Cheol Yang** are both with the Liquid Crystal Institute and the Chemical Physics Interdisciplinary Program at Kent State University. They were assisted by Kent State University **Professor Deng-Ke Yang**. Rafael Zola can be reached at rzola1@kent.edu.* ■

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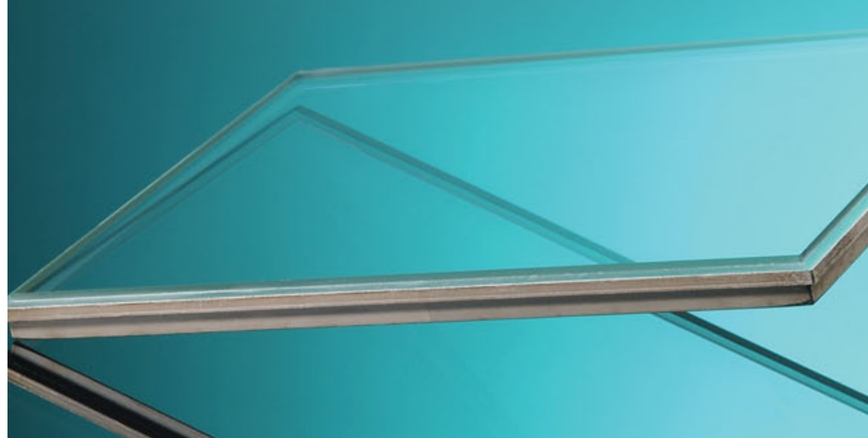

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Volunteers represent the backbone of SID. Volunteers with a "volunteering spirit" are the ones who create astounding progress. Volunteers without that spirit are not healthy for any organization. I am fortunate to have had volunteers with a great deal of volunteering spirit during my presidency. It is solely due to them that substantial progress has been made.

Some salient features of this progress are as follows:

1. SID has created new partnerships with SEMI (Semiconductor Equipment & Materials International) China and the Society for Motion Picture and Television Engineers (SMPTE) to further the growth of display science, display technology, and the display business.
2. SID has created five student branches. We all know that students are the future pillars of SID and that we need to invest in them. A regular SID Chapter formation is also in progress in Turkey through Professor Herbert Smet's efforts.
3. In 2011, SID achieved a financial surplus in its global operation.
4. Webinars have commenced with archival capability.
5. A new Web site has been designed and made operational with financial savings. All the chapter Web sites are linked, with content, to the main SID Web site for the first time in 10 years.
6. A new business direction has been given to our publications by our Publications Committee Chair, Helge Seetzen, with a high potential for improving their visibility and impact.
7. We have added features such as the Market Focus Conferences, the Best of Show Award, and the I-Zone (dedicated area for exhibiting cutting-edge technologies) to Display Week.
8. We have created a focus for non-traditional subjects such as solid-state lighting in our main Symposium.
9. We have created a new three-tier sustaining membership
10. SID, with its long history of promoting display technology, including 3-D, has begun exploring Emmy nominations in the "technology" category.

The list goes on, but due to limited space, I am stopping here. Once again, the key to this substantial progress is working volunteers. Dedicated service comes from those who have an inherent volunteering spirit. Thanking these volunteers for the span of my entire life would still not be adequate.

One important goal that remains is membership growth. Our society is 6000 members strong. I wanted to make it 10,000 members strong. We have created a new policy of 'membership sign-up' at SID-sponsored and co-sponsored conferences, but we will need other growth avenues in order to reach our goal. I am still dreaming of the day when we will be consistently over 10,000 members strong.

My time is up; I'm almost at my station. My term as President will be ending on June 2, 2012. The incoming President is Brian Berkeley. In my 10 years of experience in the SID Executive Committee, I have not known a member of the Executive Committee who works as hard as Brian. I am confident that his continued hard work will result in substantial progress for SID. I welcome Brian and wish him well. Goodbye. ■

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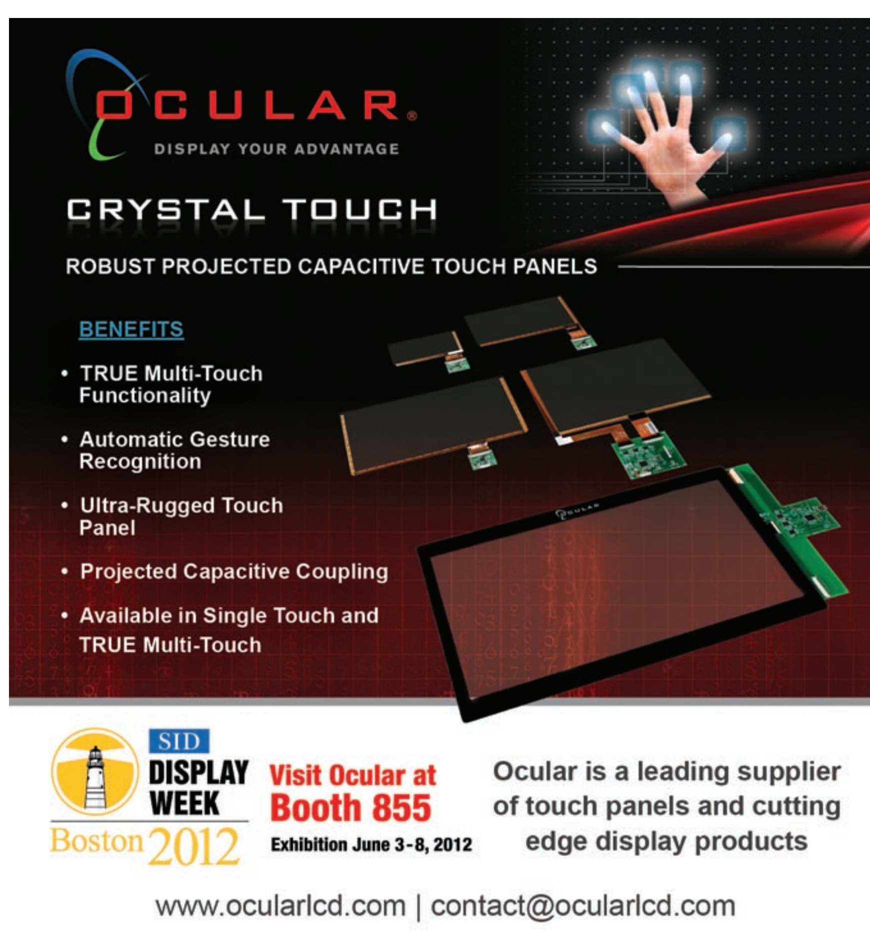

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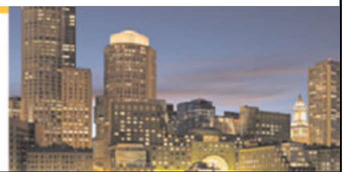

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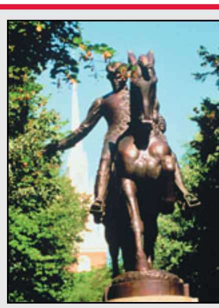

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The white LEDs are actually a blue LED with yellow phosphors coated on the upper layer. The blue peak is one component of the spectra. Part of the blue light is absorbed by the yellow phosphor and emits wide-band spectra with green and red peaks. This generates a well-controlled white spectrum. Controlling the phosphor concentration and mix affects the white balance. Individual red, green, and blue (RGB) LEDs have wider color gamut (*e.g.*, 110% NTSC) combined with the LCD color filters. However, their relative stability and long-term aging have to be controlled. White LEDs have a smaller color gamut (*e.g.*, 72% NTSC), but much more stability in terms of white balance over time. They are preferred for BLUs due to this stability, but also because of lower cost and fewer driving electronics.

A key topic related to LEDs is heat management. LEDs have very fast responses and operate in a wide range of temperatures. However, in hot temperatures they shift the dominant emission wavelength and have reduced luminance. This is followed by reduced life span (< 100,000 hours). The junction temperature should be below the vendor specs (*e.g.*, 110°C), and preferably much lower (*e.g.*, 80°C). It requires very careful design to extract the heat from the inner layers of the LED structure. Recent designs are handling this challenge efficiently.

A major link in the development of BLUs has been the development of diffusers, which make the light emitted from either a cavity BLU or light-guide structure become uniform and controlled over angles. Uniformity is needed to hide individual light sources, or surface-extracting elements. The idea of angular control is to direct the light to the useful viewing range and gain luminance. For instance, LCDs are viewed within wide angles left and right from normal, while span of the the vertical angles' span is relatively narrow. This control can be achieved with brightness enhancement films (for example, 3M's BEF™) or holographic diffuser (angular controlling films). The BEF was the first concept to gain wide acceptance in many LCD devices. In this case, the small prismatic structures are set horizontally to concentrate light in the vertical direction. This topic is close to my heart (my patent introducing this technology was sold to 3M). However, now there are more improvements and developments, some of which are covered in the GLT article, as well as in the second article, " Creating a More Efficient Light Guide for a 2-D-Type Local-Dimming LCD Backlight" by Dr. Kälil Käläntär.

As mentioned previously, the two major BLU types include cavity and edge-illuminated light guides. For a while, the cavity BLU was preferred because it is more efficient. However, a cavity BLU is significantly thicker. There has therefore been a trend to switch to edge-lit light guides. This coincides with improvements in edge-light coupling. In earlier designs, only a small portion of the light of the source was captured in the light guide (e.g.. 30%). With better optical designs that include reflectors surrounding the light sources, and the matching of light-source emission patterns to the light-guide acceptance angles (numerical aperture), it is now possible to more than double the efficiency over earlier designs. This makes the edge-lit light-guide option even better than the cavity BLU. The topic of light coupling is covered in Käläntär's article and also explained in the Shriver piece.

As we have seen, the BLU plays a major role in LCD structure and performance, and it is a complex subsystem. One additional development to improve the overall performance is local dimming. The concept is to dim the backlight in areas of the image that are dark, while keeping full luminance in areas with full brightness. This process has advantages: (a) improved contrast ratio of the image and (b) reduced power. In parallel, there are several challenges involved: (c) complex backlight design with sectional illuminants, (b) sectional driving electronics matching with the backlight design, and (c) image processing that generates the backlight sectional driving matching to the LCD image (frame by frame). The solution proposed by Käläntär handles the optical sectional design in a very efficient and elegant manner.

Future work on BLUs will focus on (a) further improvements of light coupling at the edge of light guides, (b) integrated optical design of the light guide with optical elements, (c) polarization enhancement through optical elements with better light recycling that matches the polarization orientation to the display rear polarizer, (d) local-dimming integral elements that allow easier control of local dimming, (e) optical elements for control of angular distribution and enhanced luminance, (f) LED optimization within their structure and as part of the BLU system, (g) transparent BLUs for new designs, and (h) color-saturation improvements.

I hope that this introduction provides a helpful, general overview of backlight units and that you will enjoy reading these two articles. ■

Adi Abileah *is Chief Scientist with the Technology Group at Planar Systems, located at 1195 NW Compton Way, Beaverton, OR, 97006-1992. He can be reached at Adi.Abileah@Planar.com.*

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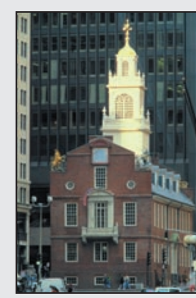

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For a preview of the papers go to sid.org/jsid.html.

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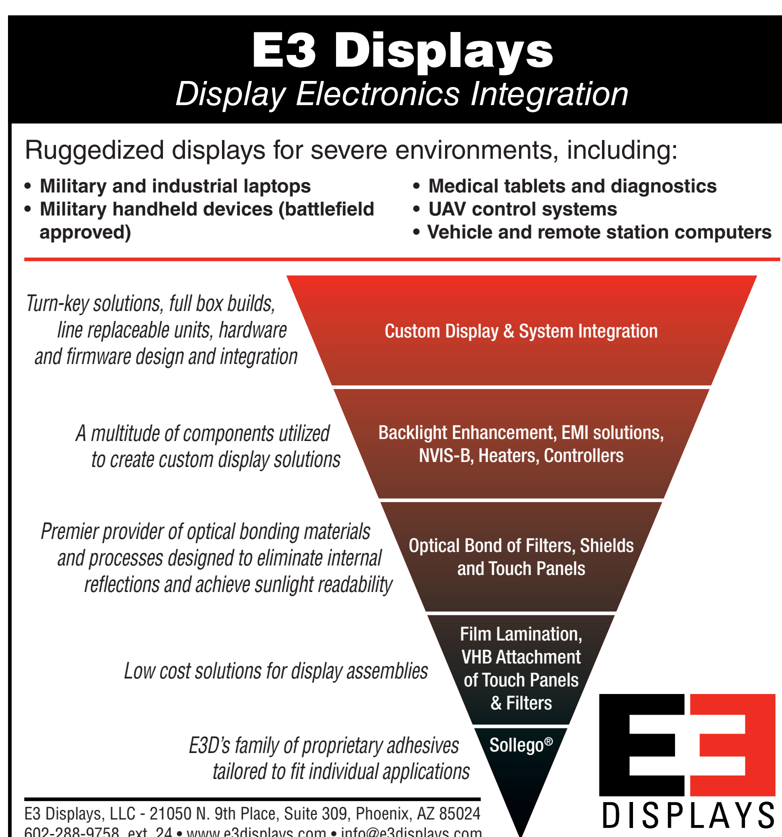

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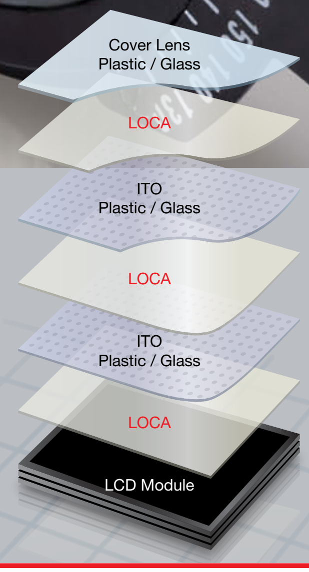

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