DISPLAY WEEK 2018 SHOW ISSUE

Information DISPLAY

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May/June 2018
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Seven New Products Recognized for 2018 Display Industry Awards

ARE MICROLEDS THE NEXT BIG THING?

ANALYZING THE POTENTIAL DISRUPTION FROM GEN-10 DISPLAY FABS

ADVANCES IN CALIBRATION SOURCES FOR DISPLAY METROLOGY

Plus

David Sarnoff, RCA, and LCDs
Products on Display at DW 2018
Q&A with Radiant Vision Systems' Doug Kreysar

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ON THE COVER: The winners of this year's Display Industry Awards are, clockwise from upper right: Sharp's 70-in. 8K LCD TV; LG Displays' UHD Crystal Sound OLED; Apple's iPhone X; Apple's iPad Pro Display; Synaptics' Clear ID Optical In-Display Fingerprint Sensor; Kolon's Colorless Polyimide; and Continental Automotive Systems' 3D Touch Surface Display.

Cover Design: Jodi Buckley

In the Next Issue of *Information Display*

Vehicle Displays

- The Dawn of Autonomous Driving
- Quality Assurance for Automotive LCDs
- The Architecture of Interconnected Vehicle Systems
- Q&A with Harman
- Display Week 2018 Highlights

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editorial

Return to Southern California

by Stephen P. Atwood

Welcome back to Los Angeles, California, for our 55th annual Display Week event, where we will celebrate the 50th anniversary of the liquid-crystal display! The display technology we all use virtually every day was first unveiled by George Heilmeier and associates at RCA back in 1968. For some of us, that means we have literally grown up with this technology. I'll have more to say about this later on.

This year we return to a place widely considered the cultural, financial, and commercial center of Southern California. There is a deep and rich history of display technology development here, and Southern CA continues to be a hotbed of innovation in many important display-related areas. If you are new to visiting LA, I hope you will find the time to get around the city and see some of the more famous landmarks, but I'm willing to bet it will be hard to make the time because of the incredibly busy calendar. That calendar includes the SID International Symposium, Seminar and Exhibition, as well as the market focus conferences, business conference, investors conference, seminars, short courses, and the many other great happenings that are organized each year for your benefit and enjoyment.

The excitement begins on Sunday with two short-course tracks covering emissive technologies (OLEDS, quantum dots, microLEDs) and virtual- and augmented-reality technologies. These are great surveys of the technology spaces that you shouldn't miss if you want to get up to speed. Monday brings the seminars, a more compact version of the short courses, with a wide range of relevant topics, and the business conference program co-organized by Display Supply Chain Consultants (DSCC) and the Society for Information Display. There will also be two market focus conferences this year, concentrating on critical market development issues facing automotive displays (Tuesday) and immersive technologies (Wednesday).

Tuesday brings the opening of the Display Week Symposium, which features 82 technical sessions consisting of more than 500 oral and poster presentations, including about 85 invited talks, many related to the three special hot topics this year: augmented reality/virtual reality (AR/VR), microLEDs, and wearables. Tuesday also brings the investors conference, the opening of the world-famous Display Week Exhibition, and a special 50th anniversary LCD celebratory session in the afternoon. According to Erica Montbach of Kent Displays, who is coordinating the event with Linghui Rao of Microsoft and Professor Shin-Tson Wu from the University of Central Florida, the presenters will talk about how the industry got to where it is today, and describe some of the key innovations made along the way. The list of speakers is a stellar line-up of key experts in the field. This is truly a can't-miss event! The symposium continues through Friday and the exhibition runs until Thursday afternoon. On Wednesday afternoon, last year's very successful "Women in Tech" forum will return, featuring some of today's top female technology leaders, who will share personal and professional insights about their experiences in the world of displays.

When exploring the exhibits, don't forget to make time for the I-Zone. The Innovation Zone is a three-day exhibit of pre-commercial prototypes from academics, startups, and even some large companies. Following SID's mantra of "showing you tomorrow's technology, today," the I-Zone has been a big hit since its debut in 2012, and 2018 similarly promises to have the most exciting prototypes on display. In fact,

(continued on page 55)

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What's Next (in Display Technology)?

by Yong-Seog Kim
President, Society for Information Display

"What's next [in displays]?" is a question I am frequently asked, especially by company leaders pondering their next move in the display industry. I typically answer as follows: If you look at the history of the information display industry, you will see that it took approximately 30 years for it to become a major industry. Therefore, if you find a display technology that has endured scrutiny and competition for more than 20 years, that technology has a good chance of becoming the next major display technology in the future. Many people are not very satisfied with that answer, which may be one of the reasons why people come to SID Display Week – to find their own answers.

People know that at Display Week they will find high-quality and cutting-edge information regarding the trends of information display technologies. SID has built a solid reputation as the authoritative source of information for the industry. This year's technical conference was built from more than 700 submissions, reviewed (and in some cases rejected) for quality by more than 150 SID program committee members who were vigilant in maintaining the high-caliber standards that have become the SID hallmark.

Display Week 2018 in Los Angeles will feature the world-renowned technical symposium, short courses, and seminars; the three-day exhibition; the Innovation Zone; and the Business, Investors, and Market Focus Conferences. The technical symposium has designed special sessions to attract emerging display technologies, including Augmented Reality, Virtual Reality, and Artificial Intelligence; Quantum Dots and microLEDs; and Wearable Displays, Sensors, and Devices.

This year, SID is inaugurating the David Sarnoff Industrial Achievement (DSIA) Prize to honor individuals for long-term and significant leadership and/or exceptional contributions to the advancement of the information display industry. The prize is named after the late David Sarnoff, a pioneer of American radio and television who served as Radio Corporation of America (RCA) president and chairman for many years. This prestigious and unique award provides the opportunity for us to recognize an outstanding person who might not qualify for one of SID's technical achievement awards but who nonetheless has had a profound, positive effect on the display industry.

At Display Week 2005 in Boston, Sang Wan Lee, who was in charge of the LCD division of Samsung Electronics at the time, gave his now-famous keynote speech, "LCD Revolution – The Third Wave." Dr. Lee made a provocative prediction that production volumes of 100 million LCD TVs per year could be achieved by 2010. Considering that at that time, CRTs had 70 percent TV market share and 40-in. LCDs cost $2,500 each, his speech was very controversial, but an effective way to share his goal with the display community at large. As we know now, the 100-million-per-year milestone was actually achieved earlier, in 2008. At that time, Lee answered the question: What's next? He will be the first winner of the DSIA prize and I hope SID will have more industry leaders to share their visions with our members in coming years.

During Display Week 2018, Dr. Helge Seetzen will take the reins as SID's incoming president. I hope you will join me in welcoming Dr. Seetzen. He has done outstanding work for SID for many years, and I have no doubt that our organization will prosper under his leadership. It has been my great privilege to serve the SID membership during these past two years.

Enjoy Display Week 2018 in L.A. ■

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industry news

by Jenny Donelan

Foxconn Buys Belkin

Taiwan-based electronics manufacturer Foxconn, best known as a maker of Apple's iPhones, recently announced that it would acquire Los Angeles-based consumer products maker Belkin International, Inc., for US $866 million in cash. Belkin got its start in a garage in the 1980s, selling computer cable assemblies to local dealers and manufacturers. It now sells products in more than 50 countries. In 2013, Belkin bought router and WiFi company Linksys, and more recently acquired Wemo, a maker of "smart home" devices.

According to Belkin's press release,[1] the acquisition by Foxconn Interconnect Technology (FIT) is designed to enrich the company's consumer product portfolio and to "accelerate our penetration into the smart home," said FIT CEO Sidney Lu. A recent article in *The Verge*[2] notes that the addition of Belkin, Linksys, and Wemo will indeed give Foxconn, known for manufacturing other companies' products, a foothold in the consumer space, where it will be less dependent on the successes and failures of its clients. The article also notes that the purchase is expected to require approval from the US Committee on Foreign Investment.

[1]www.belkin.com/us/pressreleases/8805137941564/
[2]www.theverge.com/2018/3/26/17166272/foxconn-buys-belkin-fit-linksys-wemo

Light-Field Camera Company Lytro Shuts Down

Lytro, a light-field imaging startup focused on virtual reality, announced in March 2018 that it will be ceasing operations. On its website, Lytro stated that it was not closing immediately, but winding down and not taking new orders.[3]

Lytro was founded in 2006 by Executive Chairman Ren Ng. In late 2015, Lytro announced a light-field product for VR, Lytro Immerge, followed by the 2016 launch of Lytro Cinema, a light-field capture system for cinematic content.

The company's principals provided no reason for the closure, but stated on its website: "At Lytro, we believe that Light Field will continue to shape the course of Virtual and Augmented Reality, and we're incredibly proud of the role we've been able to play in pushing the boundaries of what's possible."

[3]https://support.lytro.com/hc/en-us

HP Debuts a Tablet Contender

HP's new Android-powered Chromebook X2 offers both a detachable keyboard-free tablet and a notebook in one device. The LCD tablet is only 8.2 mm thick and weighs 1.62 pounds. With the included keyboard, the device is 15.3 mm thick and weighs 3.14 pounds. It includes a pen for note-taking and sketching on the 2,400 × 1,600 display. The Chromebook X2 comes with 4GB of RAM (8GB optional), 32GB of expandable storage, and a claimed 10.5-hour battery life. The Chromebook X2 starts at $599 – about $50 less than an iPad Pro. ■

HP's new Android-powered Chromebook X2 can be used as a tablet or a notebook.

CORRECTION

The article "OLED Displays and the Immersive Experience" in our March/April issue contained a mislabeled photograph and a statement that was attributed in error to eMagin CEO Andrew Sculley. The corrected photo caption and text appear below:

Fig. 9: *eMagin's 2K x 2K OLED microdisplay-based HMD allows for a more streamlined design than the standard HMDs based on direct-view displays. Source: eMagin*

According to eMagin CEO Andrew Sculley, immersive AR needs a display with full-color high luminance, high contrast, high pixel density for wide FoV, high speed, and capabilities like global shutter and low persistence. eMagin believes OLED is preferable to LCoS in this case because it supports the contrast levels needed for AR, has faster response times, and can reach pixel densities of over 2,000 ppi with luminance levels above 5,000 nits. (eMagin demonstrated a 5,000-nit display with over 2,600 ppi at Display Week in 2017.) According to eMagin, it is the only company that has shown direct-patterned OLED with pixel pitches above 2,000 ppi and is the only US company that manufactures OLED microdisplays. Its direct-patterned displays are bright because they don't have color filters, which block two thirds of the light by design, and because they use more efficient OLED stacks for each color. One example of AR is in aviation. eMagin is now in a major helicopter program and is in qualification for a multi-service fixed-wing aircraft program.

The editors of *Information Display* regret the errors. ■

This Year's Winners: A Fun and Compelling Group

Each year, SID's Display Industry Awards Committee selects products that have advanced the state of the art of display technology in the categories of Display of the Year, Display Component of the Year, and Display Application of the Year.

Compiled by Jenny Donelan

THIS year's seven Display Industry Award winners (two displays, three components, and two applications) have fun on their side. While we honor products and technologies because we believe they will make our lives easier, safer, more productive, and so on, there's also something to be said for products that just plain make you eager to use them. This is true of every one of this year's award recipients. Consider the two Display of the Year winners: Apple's iPad Pro display and Sharp's 70-in. 8K LCD TV. The new iPad uses Apple's ProMotion technology, with a 120-Hz refresh rate that brings a new standard of realism to the hand-held display experience while also extending precious battery life. And if home theater is your thing, is there anything more you really need to know about an incredible 70-in. 8K TV, except how much it costs and where do you get one?

The category of components might seem less exciting at first glance, but what about Continental's 3D Touch Surface, which uses haptics to help you control your in-vehicle display content so you can use it while hurtling down the highway and keeping your eyes on the road? A safety feature for sure, but haptics done right are also very pleasing to use. As for the second winner in this category, Kolon Industries' colorless polyimide, it's going to be a key factor in making all those futuristic folded and rolled displays into the stunning performers we've been promised. And Synaptics' in-display fingerprint sensor adds a "touch" of cool to your HMI along with convenient and robust security authentication capability.

Applications are *always* fun, and the iPhone X, Apple's first OLED phone, offers more screen and less non-screen than any of its predecessors. The home button is gone at last, and the whole experience lives on the beautiful 458-ppi OLED display. The second winner in the applications category, LG Display's Crystal Sound, integrates sound right into an OLED TV, so that your audio and visual are coming from the same place, just like they do in the real world.

There's just something about this year's group of award winners that makes us want to go out and buy them, touch them, and use them. It's exciting when design and technological advances align to create products that demonstrate this kind of innovation and continuous improvement.

With that, we applaud the winners of this year's Display Industry Awards. May the researchers, engineers, chemists, and designers at these companies never stop innovating. Please join us in saluting their efforts.

Jenny Donelan *is the editor in chief of* Information Display. *She can be reached at jdonelan@pcm411.com.*

Displays of the Year

This award is granted to display products with the most significant technological advances or outstanding features.

Apple's iPad Pro Display

The latest iPad Pro displays come in 10.5-in. and 12.9-in. sizes, each featuring the same 264-ppi pixel density, corresponding to 3.7 million and 5.6 million pixels, respectively. These iPad Pros also offer unparalleled visual performance enabled by Apple's innovative ProMotion technology. This is the first time that a mainstream consumer-product display has delivered adaptive screen-refresh rates ranging from 24 Hz to 120 Hz. The 120-Hz refresh rate provides an unprecedented visual experience, with fluid scrolling, excellent touch response (for both finger and Apple pencil input), and smooth motion content. The lower refresh rate can be enabled depending on real-time on-screen content requirements, reducing overall panel power without image-quality compromise. To achieve the ProMotion display technology, a new high-performance oxide TFT with high mobility and low leakage current was developed, as well as newly engineered liquid-crystal materials with low flexoelectricity, and advanced photoalignment materials and processes.

In addition, a highly customized display timing controller (TCON) was developed

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DISPLAYS OF THE YEAR

*The **Displays of the Year** are Apple's iPad Pro display (left) and (right) Sharp's 70-in. 8K LCD TV.*

from scratch for this generation of iPad Pro displays. The controller is designed to work seamlessly with the system on chip (SOC) – the Apple A10X fusion chip – which works with iOS, to deliver the stunning retina ProMotion display. By demonstrating the advantages of the unique property of oxide TFT, iPad Pro displays will help accelerate the display industry's transition to 120-Hz technology.

Sharp Corp.'s 70-in. 8K LCD TV

On August 31, 2017, Sharp announced the release of the AQUOS 8K series of 8K-compatible TVs and displays, a world first. 8K is a revolutionary technology for ultra-high-definition images, with 16 times the resolution of full high definition, which cannot be expressed with 4K images. 8K reproduces images at ultimate reality, with ultra-fine details smaller than the eye can see. Apart from being used to display TV broadcasts and other media content, 8K will dramatically impact many aspects of our lives: medical care, business, security, signage, *etc*.

Sharp's 70-in. 8K-resolution LCD TV has the following features:

- Resolution: 7,680 × 4,320 pixels
- Luminance: Full white 400 cd/m^2
- Peak white: 1,000 cd/m^2
- Contrast: 4,000:1 (dynamic contrast using local dimming is 1,000,000:1)
- Color gamut: BT. 2020 coverage ratio 86 percent (CIE 1976 u′v′ color space)
- Maximum power consumption: 470 (W) for Japanese 8K TV model
- 8K signal input with HDMI 4 cables and 8K static imagery via USB flash memory

Sharp has been leading the industry by releasing 8K-related products in Japan. In October 2015, the company released an 85-in. 8K professional monitor using an 8K LCD panel with an indium-gallium zinc-oxide (IGZO) backplane and followed up in June 2017 with the release of a 70-in. 8K professional monitor. Sharp is eager to bring worldwide consumers the thrill of this revolutionary technology, and to this end has released the world's first 8K TVs in Japan and China, and the world's first 8K displays in Taiwan and Europe. Sharp is also complementing its 8K TVs by accelerating development of 8K broadcast receivers, 8K cameras, and other 8K products to help establish a global 8K ecosystem.

Display Components of the Year

This award is granted for novel components that have significantly enhanced the performance of a display. A component is sold as a separate part destined to be incorporated into a display. A component may also include display-enhancing materials and/or parts fabricated with new processes.

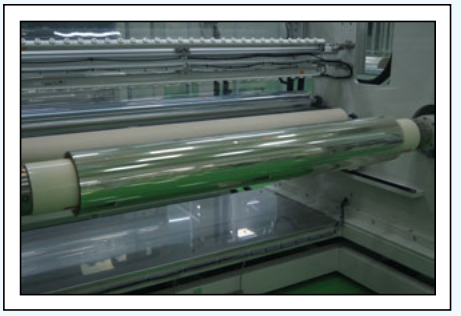
Continental Automotive GmbH's 3D Touch Surface

Continental's 3D Touch Surface display, the world's first touchscreen with a 3D surface on top of a display, engages multiple senses to create a holistic and intuitive interaction.

Growing demand among users for new features and integration of digital content has resulted in bigger and bigger in-vehicle touchscreens. However, large-size touch displays tend to increase driver distraction. The 3D Touch Surface Display strongly supports the intuitive locating of control elements on large touchscreens while at the same time providing a reliable confirmation of a successful operation.

Control elements on the display surface, including buttons, sliders, and flat regions,

DISPLAY COMPONENTS OF THE YEAR



*The **Display Components of the Year** are Continental Automotive GmbH's 3D Touch Surface (left), Kolon Industries' colorless polyimide (center), and Synaptics' optical in-display fingerprint sensor.*

can be easily identified just by feeling the edges of the topographic hills and valleys. The completion of an interactive task is confirmed with active haptic feedback, which provides the user with a safety-enhancing mechanical confirmation that the chosen screen element has been activated. The impulse is provided in the form of a short and highly precise mechanical momentum that is transferred to the display surface after having exceeded a certain force threshold; any mechanized movement of the display is completely invisible to the naked eye. With active haptic feedback coming from screen-element edges, users can also distinguish among virtual buttons or even flat areas without having to look at the screen. The actuators can be finely controlled based on force and acceleration, which makes different haptic characteristics possible.

The surface of the 15-in. demonstrator features topographical elements with hills and valleys of up to 10 mm. The touch surface itself is generated by forming a touch-sensitive film into the final 3D surface, which comprises buttons, sliders, and flat display areas. To optimize the contrast of the 3D Touch Surface Display, Continental has employed optical bonding and homogeneously tinted materials.

In terms of design individualization, the 3D elements allow brand-specific differentiation. The implemented technology enables the distribution of 3D soft keys or soft sliders in a flexible way on the display surface to match the design and user interaction philosophy of the car brand.

From a user experience point of view, this display solution not only allows for exciting design, but ensures that drivers can operate the various functions without having to take their eyes off the road. As human machine interfaces become ever more complex, the combination of active-haptic feedback and passive feedback from the 3D surface ensures an outstanding user experience and significantly improves operational safety.

Kolon Industries' Colorless Polyimide

Emerging concepts for the next generation of consumer devices demand more flexible displays to enable a variety of form factors. The promise of these displays is that they can be folded or even rolled and will offer the strength and transparency needed to replace the glass-based displays used in many of today's devices.

Kolon Industries has helped fulfill this promise with its Colorless Polyimide (CPI) – a powerful and optimized solution backed by more than 12 years of research and development. Built with a patented, high-heat-resistant, optically and mechanically superior material, Kolon's technology offers the potential to revolutionize flexible displays, organic light-emitting diodes (OLEDs), consumer devices, and other transparent flexible electronics.

Kolon's revolutionary material – available both in film form and as a varnish for coatable materials – has the technical performance to truly transform the industry. It offers optical transparency of 90 percent, over 6 GPa modulus, 2H surface hardness, superior folding properties, and roll-to-roll processing capabilities. It also has a smooth surface finish that is tunable with various functional treatments.

All of these features make Kolon CPI ideal for the next generation of portable, flexible devices, as well as industrial applications and emerging markets. Now boasting the world's first mass-production facility optimized for the manufacture of CPI, Kolon is primed to extend its innovation to a broad market that also includes organic photovoltaics (OPVs), flexible printed circuit boards (FPCBs), and specialized applications that may benefit from flexible display technology.

Synaptics' Optical In-Display Fingerprint Sensor

Synaptics, Inc., a leading developer of human interface solutions, recently announced mass production and retail availability of its new Clear ID FS9500 family of optical in-display fingerprint sensors. Smartphone maker Vivo is now using this technology in two shipping smartphones, the X20 Plus UD, and the X21 UD.

Designed to enable smartphones with bezel-free OLED infinity displays, Synaptics' Clear ID in-display fingerprint sensors are placed in a natural location directly in the touchscreen, eliminating the need for buttons and bezels. A fingerprint icon in the display guides the user and disappears upon authentication. In combination with Synaptics' SentryPoint technology, Clear ID is highly secure and faster than alternative biometrics such as 3D facial recognition. It is also very convenient, with one-touch/one-step biometric authentication directly in the touchscreen display area of smartphones.

Synaptics' Clear ID optical fingerprint sensor is laminated below the OLED display and works with both flexible and rigid OLEDs. The OLED display illuminates the finger. Clear ID captures the reflected fingerprint between the OLED pixels via its complementary metal-oxide semiconductor (CMOS) sensor, and advanced signal-processing technology provides for fast and accurate matching. Clear ID leverages standard optical production materials and processes. It supports up to 1.7-mm thickness and the addition of screen protectors. It also works in sunlight and bright conditions.

The Clear ID FS9500 optical solution excels with wet, dry, and cold fingers, and since it's protected by glass, is durable, scratchproof, and waterproof. In-display fingerprint technology allows users to conveniently and securely unlock the device at any angle, whether it's sitting on a table or in a car mount.

Synaptics' optical fingerprint sensors and SentryPoint technology provide a wide range of unique and highly secure authentication features, including adaptive fingerprint template matching and authentication; anti-spoof technology; and support for transport layer security protocol (TPS) with elliptic curve cryptography (ECC) authentication and AES (advanced encryption standard) encryption.

Display Applications of the Year

This award is granted for novel and outstanding applications of a display, where the display itself is not necessarily a new device.

Apple's iPhone X

Since the birth of the original iPhone, Apple's vision has been of a product that is entirely screen, without decorative elements, physical keyboards, or dedicated function buttons. However, until now there has always been one button on the face of an iPhone. With iPhone X, that button has been eliminated and the display has become the primary element for all interactions, allowing the display to flow to fill the face of the iPhone.

This design was achieved by the utilization of advanced technologies, including panel-edge folding for border symmetry, circuit-stacking technology for corner border minimization, and subpixel anti-aliasing for enhanced display spline appearance.

The beautiful 458-ppi 5.8-in. Super Retina display is the first OLED panel that rises to the standards of iPhone, with stunning colors, true blacks, a million-to-one contrast ratio, and wide color support with the best system-wide color management in a smartphone. The HDR display supports Dolby Vision and HDR10, which together make photo and video content look even more amazing. The addition of True Tone dynamically adjusts the white balance of the display to match the surrounding light for a more natural, paper-like viewing experience. The iPhone has revolutionized the last decade of phones; iPhone X will set the stage for the next decade, with the display in the starring role.

(continued on page 27)

DISPLAY APPLICATIONS OF THE YEAR

*The **Display Applications of the Year** are Apple's iPhone X (left) and LG Display's UHD Crystal Sound OLED (right).*

David Sarnoff, Display Industry Visionary

His many contributions to the display industry are closely linked to the pioneering of flat-panel displays and the invention and eventual success of the LCD.

by Larry Weber

FIFTY years ago, on May 28, 1968, the liquid-crystal display was born. On that day the Radio Corporation of America (RCA) held a press conference at Rockefeller Center in New York City, where inventor George Heilmeier taught the world about a new display technology that used a well-studied but little-known (outside a small research community) material called liquid crystals. A large number of newspapers and magazines published this exciting news, and the publicity aroused the interest of most of the scientists and engineers who contributed to the blossoming of the LCD technology in the following decade. This event is of such importance that Display Week 2018 will host a special session celebrating the 50th anniversary of the LCD on Tuesday, May 22, 2018, from 2 to 5:30 pm.

Another event of interest at this year's Display Week will be the presentation of the first SID David Sarnoff Industrial Achievement Prize. This new SID award recognizes individuals for long-term and significant leadership and/or exceptional contributions to the advancement of the information display industry. The award is named after the late David Sarnoff, a pioneer of American radio and television who served as RCA's president and chairman for many years.

Sarnoff's many contributions to the advancement of the display industry are closely linked to the pioneering of flat-panel displays and the invention and eventual success of the LCD.

***Larry Weber** was the president and CEO of Plasmaco, Inc., and is also a past president of the Society for Information Display. He can be reached at larryweber@ieee.org.*

Courtesy Hagley Museum & Library © Yousuf Karsh

David Sarnoff

A Start in Radio

Sarnoff was born in Russia and emigrated to New York City in 1900 at the age of nine. By 1906, at age 15, he had found a job at the Marconi Wireless Telegraph Company of America, where he soon became a junior telegraph operator and rose to a management position by age 19. In 1919, RCA was founded by the General Electric Company (GE) through acquisition of the American division of Marconi. Sarnoff became an RCA commercial manager as part of that acquisition. By 1922 he had been promoted to RCA vice president and general manager. He became a good friend of radio pioneer Edwin H. Armstrong, and in the '20s, with the help of Armstrong and his inventions, Sarnoff led RCA to become a major commercial success in the rapidly growing area of radio broadcasting. Sarnoff became RCA president in 1930.

Electronic TV Development

RCA's great success in radio in the 1920s stimulated Sarnoff to look for other electronics development opportunities, which he found in the then-primitive mechanical-based television.[1] He became intrigued by the potential for an all-electronic television, and launched electronic TV R&D at RCA by recruiting television pioneer Vladimir Zworykin from Westinghouse in 1929. This was the start of a 40-year relationship between these two men, in which Sarnoff and RCA financially supported the many inventions of Zworykin.

In 1930 Sarnoff asked Zworykin to assemble a rather large team of 45 people just to research TV. Zworykin and his team had invented the Kinescope tube in 1929, which became the familiar TV picture tube. In 1933 Zworykin invented the Iconoscope, which became the practical TV camera tube used in most commercial TV broadcasts in the late '30s and early '40s. Sarnoff led RCA to develop a practical TV system during the Great Depression of the 1930s, when few companies had interest in TV or a budget to invest. Using a TV broadcast, Sarnoff personally announced at the opening of the 1939 New York World's Fair the regularly scheduled TV broadcasting of NBC, the RCA subsidiary broadcasting network. By 1940 RCA had invested $9.25 million in TV, which was nine times as much as the nearest competitor, the pioneering television inventor Philo T. Farnsworth.

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Television broadcasting was halted during World War II, but in 1943 the very sensitive Image Orthicon camera tube was developed at RCA by Albert Rose, Paul K. Weimer, and Harold B. Law. The Image Orthicon became the preferred TV camera tube for the next 20 years. After TV broadcasting began again after the war, RCA sold 5,400 TV sets in 1946 and 7 million TV sets in 1950. By 1959, 86 percent of US households had TVs. In that same year, commercial sponsors underwrote $1 billion in broadcasts.

Color-TV Development

Sarnoff also drove RCA to pioneer the development, manufacturing, and broadcasting of color TV. In 1947, RCA's Alfred Schroeder invented the shadow-mask cathode ray tube (CRT). This technology developed rapidly, and in 1950 RCA demonstrated a full-color TV system that was monochrome-TV compatible. This system was competing with the mechanical color-wheel field-sequential system promoted by the rival broadcasting network, CBS, which in 1950 was adopted as the United States color television standard by the Federal Communications Commission (FCC). But in 1953 the FCC reversed itself and approved the "RCA" all-electronic color TV standard. This paved the way for NBC to begin regular color broadcasts in 1954. In that same year, RCA sold its first color TV set.

Color TV had a rocky start. By 1956 all of RCA's competitive color-TV-set manufacturers had dropped out due to poor sales. *TIME* magazine called color television "the most resounding industrial flop of 1956." RCA endured years of poor color-set sales due to lack of color-TV programs. Sarnoff forced NBC to take big losses and develop innovative color programming such as "Disney's Wonderful World of Color," which went on the air in 1960. The first year of RCA break-even for color TV sales was 1962. With the competitors having earlier dropped out, RCA became the sole supplier of shadow-mask color CRTs, selling to 20 OEM TV-set manufacturers in 1964. By 1965, the competitive networks ABC and CBS began regular color programming and the gross value of color sets sold finally exceeded that of monochrome sets.[1]

Flat-Panel Display Development

On September 27 of 1951, David Sarnoff made a speech directed to the technical staff at RCA Laboratories in Princeton, New Jersey (also dedicated this same day as the David Sarnoff Research Center [DSRC]). This was at an event celebrating the 45th anniversary of his first entry into the electronics industry as a junior telegraph operator back in 1906. During this speech he asked that in five years, during the celebration of his 50th anniversary, he be given three anniversary presents. One present he requested was a "light amplifier." He said:

> *"Now I should like to have you invent an electronic amplifier of light that will do for television what the amplifier of sound does for radio broadcasting. Such an amplifier of light would provide brighter pictures for television that could be projected in the home or the theatre on a screen of any desired size. An amplifier of sound gave radio a 'loudspeaker,' and an amplifier of light would give television a 'big-looker.'[2]"*

This speech inspired a response from the team at the DSRC that planted the seeds of the flat-panel display industry. The next five years saw the success of two significant development programs in response to Sarnoff's dream. The first was a light amplifier developed by Ben Kazan (who later became the editor of the *Proceedings of the SID*, now known as the *Journal of the SID*) and Frederick Nicoll. This was a 12 × 12-in., 0.25-in.-thick flat-panel display that used a thick-film powder AC electroluminescent light-emitting phosphor placed in series with a thick-film powder cadmium sulfide (CdS) photoconductor. The working device with a gray-scale image, first demonstrated in 1954, is shown in Fig. 1.

Fig. 1: *This 12-in. × 12-in., 0.25-in.-thick flat-panel light amplifier was demonstrated by Ben Kazan and Frederick Nicoll in 1954. Source: IEEE and Proc. IRE*

Light from a rear optical slide-projector would cause the photoconductor to locally apply a spatially modulated AC voltage across the electroluminescent thick film, thereby emitting light for the flat-panel image. This early device could achieve light amplification factors of 60. David Sarnoff is seen standing next to this device in a 1955 photo shown in Fig. 2.

The second and much more significant flat-panel development also used an AC thick-film electroluminescent phosphor as the light emitter. But in this case, the image was a live-TV gray-scale image generated electronically by active-matrix electronics. This was developed by Jan Rajchman, who had earlier worked with Zworykin at RCA to develop electron multipliers. Rajchman had also developed the magnetic-core memory at RCA in 1950, which became the dominant form of random-access memory used in digital computers in the 1960s and early '70s. Rajchman wrote in 1952 in an internal RCA note:

> *"For a long time there has been the desire to produce a 'Mural Television Display' which would be a large flat box-like device with a large rectangular face and relatively small thickness. This then could be used on the wall of the viewing room."*[3]

Rajchman recognized that for each pixel "there should be a means 1) to store the level of display information, 2) to energize the EL cell according to the stored level, and 3) to establish the stored level by the coincidence of row and column excitations without affecting the stored level of any other element." The AC electroluminescent (EL) pixels required driving with high-voltage bi-directionally conducting AC voltages, and so the transistors of the early '50s would not work. However, through experience with core memories at RCA, a magnetic-core-based switching element called the transfluxor had been invented that could do the job. For Rajchman's flat-panel display, this was organized like a core memory plane with a magnetic-core active-matrix switching element at each pixel. Rajchman made a 1,200-pixel prototype electroluminescent 14-in. × 18-in. at 1.5-in. thick display that was driven by an active matrix of 1,200 transfluxors in 1955. This prototype could achieve a moving video gray-scale image at 15 frames per second and is shown in Fig. 3.

While not as impressive as Kazan and Nicoll's panel (Fig. 1), Rajchman's prototype was of much greater technical significance since it demonstrated the fundamental building blocks found in today's flat-panel displays. In his 1955 filed patent for this device is the vision of the "hang-on-the-wall" TV that we all enjoy today (Fig. 4).

SID has very appropriately named its award for outstanding scientific or technical achievement in flat-panel displays the Jan Rajchman Prize.

On September 30, 1956, the day celebrating the 50th anniversary of his entry into the electronics business, David Sarnoff wrote in a *New York Times* article:

> *"The developments in our laboratories on a true amplifier of light—the second 'present' I requested—have been most encouraging. Electroluminescent materials, which emit light on the application of an electric current, show promise – when combined with other new materials – making possible mural television. The present TV picture tube will be replaced by a thin, flat screen that can be hung on the wall, and the controls will be cut down to cigar-box size."*[4]

Fig. 2: *In this 1955 photo, David Sarnoff stands next to the flat-panel light amplifier developed at RCA. Courtesy Hagley Museum & Library*

LCD and Active-Matrix Developments

The flat-panel-friendly research environment Sarnoff stimulated at David Sarnoff Research Labs ultimately gave the display industry other critically important fundamental developments: the thin-film transistor, the LCD, and active-matrix addressing.

Thin-Film Transistors

By 1960, RCA's Paul Weimer had gained considerable experience with thin-film semiconductor deposition through his earlier development work on the RCA TV camera tubes such as the Image Orthicon and the Vidicon. In this year he wanted to work in the exploding new field of solid-state electronics.

He started work using single-crystal bulk silicon but soon realized that integrated circuits might be easier to make with an all thin-film planar structure. This led him to invent the first thin-film transistors, which he published in 1962.[5] His first devices used cadmium sulfide as the semiconductor but Frank Shallcross in Weimer's group found that cadmium selenide worked better. This DSRC group was able to make both n-type and p-type TFTs and used these to make the first CMOS logic gates – before this was done with bulk single-crystal silicon. The legendary inventor Peter Brody became aware of Weimer's TFT achievements and soon began the very successful program at Westinghouse to also develop TFTs. Brody's Westinghouse group was the first to make active-matrix displays using TFTs, in 1972, and that group became the major champions of the TFT technology for the display industry.

Liquid-Crystal Displays

In the spring of 1962, Richard Williams, a researcher at the DSRC, was working on ways to modulate light. He placed a ~0.1-mm-thick layer of the liquid crystal para-azoxyanisole (PAA) between two glass plates coated with electrically conductive transparent tin oxide and applied a DC voltage to the electrodes. The microscope stage needed to be heated to 110-140 C in order to melt the PAA solid crystals to the liquid-nematic phase. His April 10, 1962, lab notebook entry states:

> *"[o]n applying a DC voltage as shown there is a crinkling effect at ~1000 V/cm and vigorous turbulence at ~10 000 V/cm."*[3]

Williams immediately recognized the possibility of this effect as a "liquid crystal light valve," as written in his notebook. The low field effect he observed is now known as Williams Domains[6] and the high field effect is known as dynamic scattering.[7] He filed a patent in November of 1962, which included the now-very-familiar ideas shown in Fig. 5. In this patent Williams mentions the application of his invention to the "mural television art" of the 1955 filed Jan Rajchman patent of Fig. 4.

In 1964, George Heilmeier at the DSRC was looking for ways to use organic materials as an electro-optic modulator for lasers when he learned of the prior work of Williams.

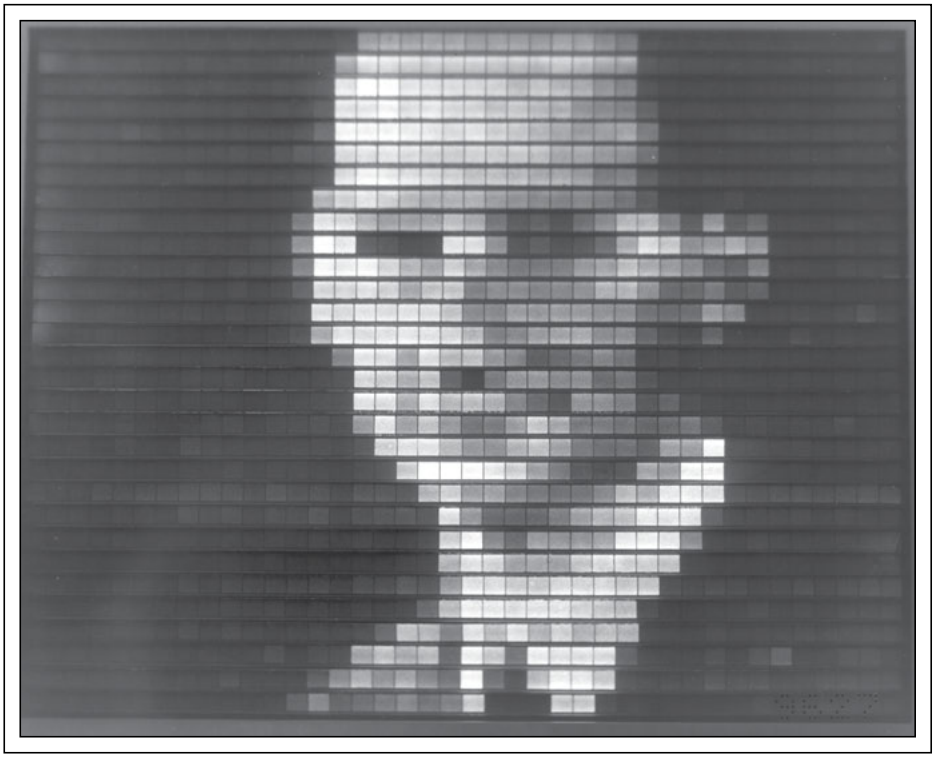

Fig. 3: *A 14-in. × 18-in. at 1.5-in.-thick electroluminescent flat-panel live TV display with 1,200 pixels, developed in 1955, shows the face of its inventor, Jan Rajchman. Courtesy Hagley Museum & Library*

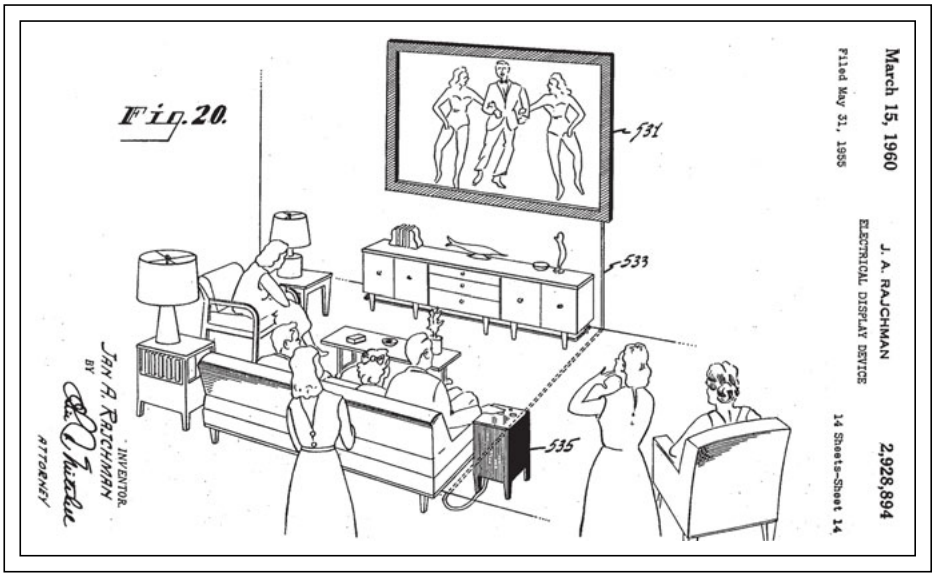

Fig. 4: *This conceptual drawing of a "hang-on-the-wall" TV appears in Jan Rajchman's patent filed in 1955.*

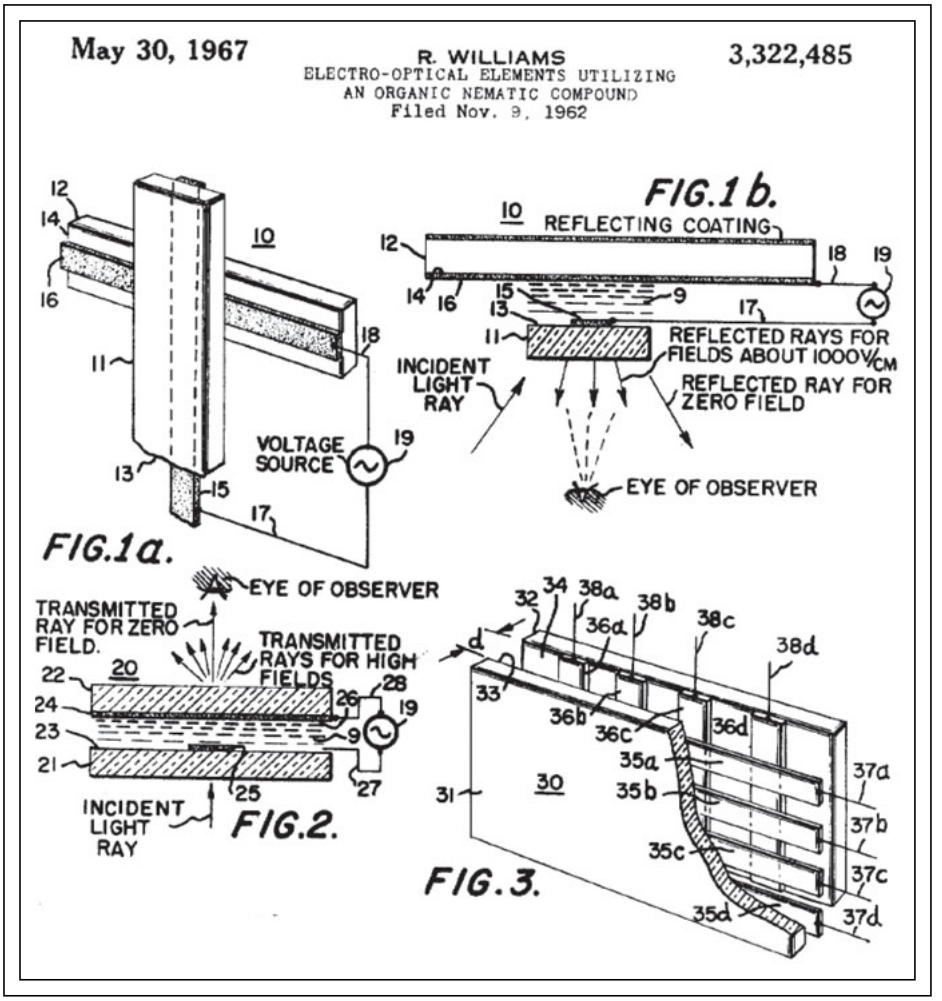

Fig. 5: *These liquid-crystal display device patent figures were filed by RCA's Richard Williams in 1962.*

Heilmeier and his team used various dyes mixed with a liquid-crystal material sandwiched between the tin oxide-coated plates to make a successful guest-host light-modulator device. Heilmeier wrote in his lab notebook:

> *"Since large area flat panels can be fabricated & driven by low voltages, this device should find application in displays where such properties are desirable." He further wrote: "With suitable dyes, one could cover the visible portion of the spectrum by passing light through a series of such panels."*

Heilmeier took up the challenge to find ways to use liquid crystals in practical flat-panel display devices. In 1965, while he was exploring improved liquid-crystal materials, one combination resulted in an electro-optic effect that gave a very high reflective-contrast ratio. This was obtained with the same dynamic-scattering mechanism observed three years earlier by Williams. The high quality of the image sparked great internal interest at the DSRC, and a major, internally funded, secret liquid-crystal research program was established.

One of the biggest challenges was the very high temperatures (typically 100 C) needed to achieve nematic-phase liquid crystals. In 1965, DSRC organic chemist Joe Castellano discovered that the temperature could be significantly lowered with eutectic mixtures of liquid crystals.[8] By 1966 ternary mixtures had achieved a nematic phase down to 25 C, which was a critical turning point toward practical LCDs.

In 1969, while at the DSRC, theorist Wolfgang Helfrich conceived of a new type of LCD that we now know as the twisted-nematic LCD. He could not get anyone at RCA interested in it because it required two polarizers, making it costlier and more complicated than the dynamic-scattering LCD. After leaving RCA he joined experimentalist Martin Schadt at Hoffman-La Roche in Basel, Switzerland, in the fall of 1970. Helfrich explained his twisted-nematic idea to Schadt, and within a few weeks they had a working prototype. They quickly applied for a patent and published what is today the most successful LCD mode, making dynamic scattering obsolete.[8]

Active-Matrix LCDs

In 1966, a group at the DSRC led by Bernie Lechner (who later became SID president) started work on solving the problems of LCD addressing. The researchers soon realized that the LCD was indeed fast enough to achieve TV speeds but would need some sort of suitable switching device to drive each pixel at these speeds. Various methods were considered, including the following elements to drive each pixel: two diodes and a capacitor, silicon-on-sapphire metal-oxide semiconductor field-effect transistor (MOSFET), monolithic-silicon MOSFET, and a Weimer TFT. From this work came the famous circuit seen in Fig. 6, which is now used in all active-matrix LCDs.[9]

Final Years

By the time of the unveiling of the LCD at the 1968 RCA press conference, David Sarnoff's health was failing, but his great interest in LCD developments was not. While he was too sick to attend the public press conference, he did attend the private dress rehearsal held the day before, where he saw the presentations of George Heilmeier on dynamic scattering and Bernie Lechner on active-matrix addressing.[1] He also heard James Hillier, VP of RCA Laboratories, explain how LCDs could be used as electronic clocks and wristwatches, automobile dashboard displays, scoreboards, stock tickers, and ultimately, pocket-size television receivers that could be viewed in bright sunlight. Unfortunately, David Sarnoff did not live to see the most significant results of his flat-panel dreams that were to unfold in the

years to come. But during his lifetime he envisioned and promoted development of the everyday displays that we now all use, such as portable telephones with flat-panel displays that communicate wirelessly and large, flat color TVs that hang on the wall and receive signals from communication satellites.

Sarnoff was not an inventor of display technology, but for more than 40 years he drove RCA to become the dominant world company in the electronic TV and color-TV industries. Under his leadership, RCA planted the seeds that grew into the flat-panel display industry. (RCA, however, failed to become a dominant commercial success in flat panels.) One can only imagine what success RCA would have had in flat panels had Sarnoff been able to continue his leadership.

David Sarnoff remained RCA chairman until 1970 and died at age 80 in 1971. In Sarnoff's eulogy, New York Governor Nelson Rockefeller said Sarnoff had a "capacity to look at the same things others were looking at but to see far more."

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[1]For more details, see *Television: The Life Story of a Technology*, Alexander B. Magoun, Greenwood, 2007.

[2]For the full speech, see http://www.davidsarnoff.org/kil-chapter08.html.

[3]For a detailed historical account of the development of the flat-panel display and LCDs at RCA see: "Crystalizing Innovation: The Emergence of the LCD at RCA, 1951–1976," Princeton University Ph.D. dissertation, Benjamin H. Gross, 2011, available at http://dataspace.princeton.edu/jspui/handle/88435/dsp011g05fb62p
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[5]P. K. Weimer, "The TFT – A New Thin-Film Transistor," *Proc. IRE* **50**(6), 1462–1469, 1962.

[6]R. Williams, "Domains in Liquid Crystals," *J. Chem. Phys*. **39**(2), 384–388, 1963.

[7]Bernie Lechner gives an interesting account of how he and his boss Jan Rajchman first saw the Williams LCD experiment in:
B. J. Lechner, "History Crystallized: A First-Person Account of the Development of Matrix-Address LCDs for Television at RCA in the 1960s," *Information Display*, January 2008.

[8]J. A. Castellano, *Liquid Gold: The Story of Liquid Crystal Displays and the Creation of an Industry*, World Scientific Publishing, Singapore, 2005.

[9]B. J. Lechner, "Liquid Crystal Displays," presented at a conference on Pertinent Concepts in Computer Graphics held at the University of Illinois from March 31 to April 2, 1969, and published in *Pertinent Concepts in Computer Graphics*, edited by M. Faiman and J. Nievergelt, University of Illinois Press, 1969. Also: B. J. Lechner *et al.* "Liquid Crystal Matrix Displays," *Proc. IEEE* **59**, 1566, 1971. ■

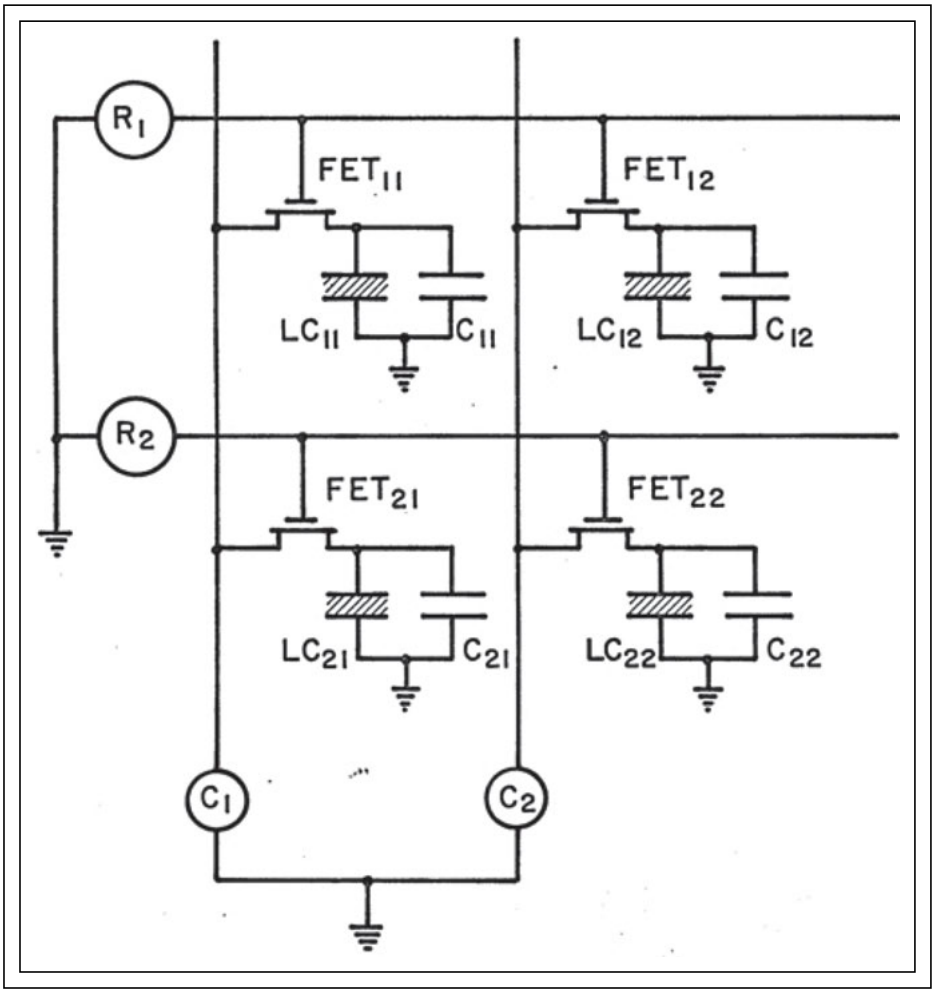

Fig. 6: *This classic active-matrix circuit for driving LC pixels with field-effect transistors was first published in 1969.*[9]

Gen-10 Fabs Will Create Upheaval in the Display Market

Several display companies have recently announced Gen-10 fab construction projects. If Gen-10 capacity is built out as anticipated, the industry could face risks of systemic oversupply as a result.

by Ian Hendy

OVER the past 12 months, several different Gen-10 fab construction projects have been announced or rumored. These are primarily intended to support the market for TV panels that are 65 inches diagonal or larger. Among companies thought to be considering Gen 10 are BOE (2 fabs), HKC, LGD (for OLED), ChinaStar, and Sharp/Foxconn. Market research company IHS reports that there is a potential for up to 735K/month of motherglass start capacity at the substrate size of 2,940 × 3,370 mm.[a,1] The issues we will discuss in this article are the impacts of these proposed factories, focusing mainly on LCD fabs, and including predictions of who will win and who will lose as a result.

Figure 1 shows the impact of Gen-10 capacity on total input capacity for large-area displays. While the final build-out in terms of total capacity for Gen 10 is yet to be seen, it could represent an increase of up to 60 percent of the current large-panel installed capacity, based on plans that have been discussed by various players.

In the follow-up to Gen 8, Gen-10 facilities supporting substrates around the above size are the new key platform for production of LCDs and OLEDs, especially as Gen 9 didn't really happen. Gen-10 facilities are specifically well set up to produce 8-up, 65-in. and 6-up 75-in. displays (Fig. 2).

It is difficult to know how to interpret the strategic impact of all this new capacity. First, we need to understand the general background of substrate economics. In general, the profit margin at a cell level created by a set of differ-

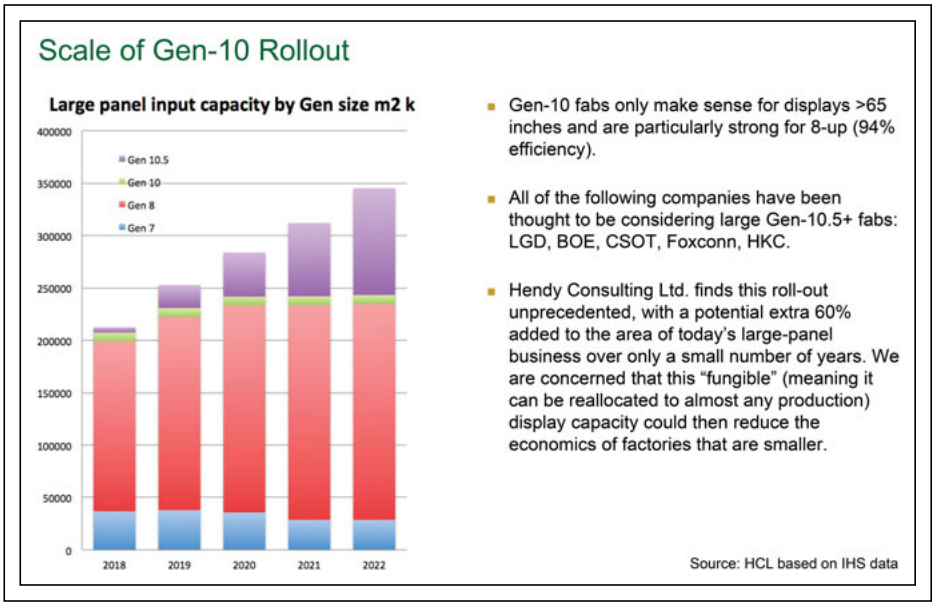

Fig. 1: *Gen-10 fab rollouts are predicted to increase substantially over the next five years. Additional source: IHS 2017*

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[a]For the purposes of this article, we refer to Gen 10 and Gen 10.5 interchangeably. However, some people may consider Gen 10 to be 2,880 × 3,130 as used at Sharp's Sakai fab and Gen 10.5 to be 2,940 × 3,370 mm.

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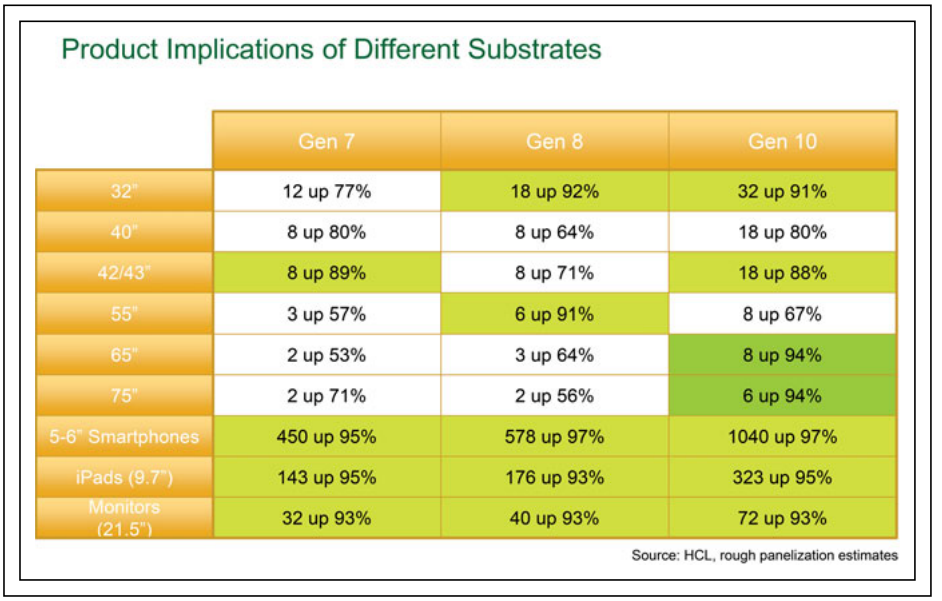

Fig. 2: *Above are shown mass-production specifications for different key platforms, including the number of panels per substrate and the approximate glass use. These differences in glass utilization make a big difference in the profitability of the production lines. Gen 10s support 65- and 75-in. displays particularly well.*

ent fabs varies directly with area. The capital expenditure (capex), on the other hand, increases with only the square root of the substrate size. This tends to lead to the finding that larger is better, economically. However, defect density, handling costs, and other problems have always meant that there is a diminishing return to substrate size beyond a certain value. Gen 10 is on the table largely due to fundamental belief in strong markets for 65-in. and larger displays. If you believe in these markets, then Gen-10 fabs make sense; otherwise, they may not.

We present here our own intellectual framework of 10 factors that we consider important in thinking through the question of the impact of Gen 10 on today's industry (Fig. 3).

Issue 1: Fungibility of Capacity

Fungibility in the context of this article refers to the ability of large LCD factories to serve nearly all markets (at some level of technical abstraction that we will discuss further on). The author's colleague, business partner, and friend, analyst David Barnes, first publicly discussed the concept of fungibility at Display Week in 2011. For now, the industry seems to have decided that Gen 6 (and half-Gen 6 for OLED processing) is the key platform for small-panel manufacturing. However, Sharp has also shown that its Gen-8 (2,200 × 2,500-mm) fab in Kameyama, Japan, can make a large number of oxide-TFT AQUOS smartphone displays.

The general point underscored by this article is that unlike the semiconductor industry as a whole, where a 7-nm dynamic random-access memory (DRAM) fab serves a specific market, and a radio-frequency (RF)-capable fab serves a distinctly different market, display-industry Gen-8 fabs are able to serve *all* of the display markets served by Gens 2-7. While there is some lithography gear that allows for tighter overlay and is only available in smaller generations from Nikon, overall, larger fabs serve more markets and thus have the capability to negatively impact the economics of more markets (Fig. 4).

Issue 2: Panelization

We often help people understand display making with the example of gingerbread making. You can roll out the dough to different sizes, and then the issue is how many whole gingerbread men you can get out of the one piece without cutting off a vital leg or arm. The larger the cookie cutter for the gingerbread man, the fewer of them you can make. This correlates to specific product sizes in the display industry. Clearly, as the panel size gets larger, the amount of what the glass industry calls "cut loss" – expensive processed glass that is not sold as finished displays – increases. When we get down to processing fewer than, say, 10 displays on a motherglass, then the exact handling, scribing, and metrics such as the shape and area of the panel are key to working out how much "gingerbread" is thrown away.

Gen-10 fabs are particularly efficient at producing 65-in. and 75-in. displays. To build

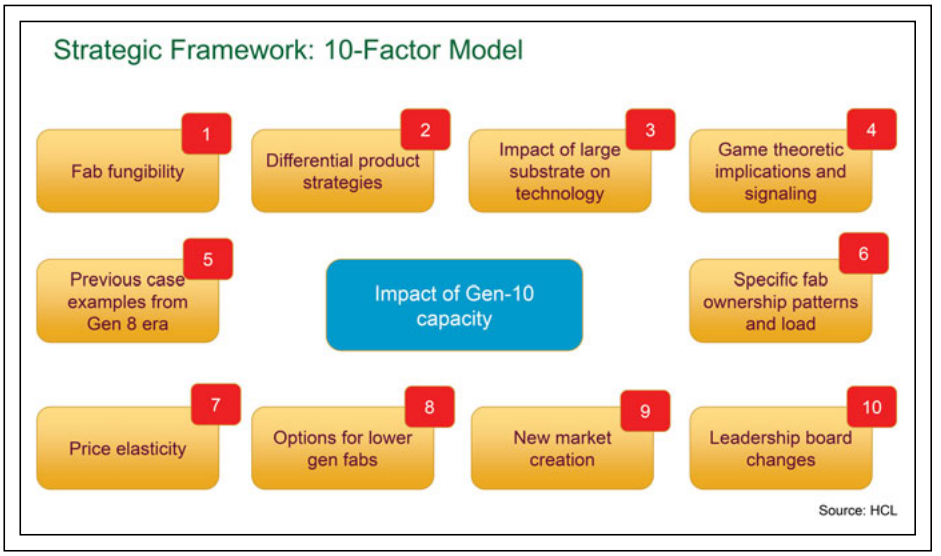

Fig. 3: *It is useful to consider the impact of Gen 10 in terms of 10 different factors.*

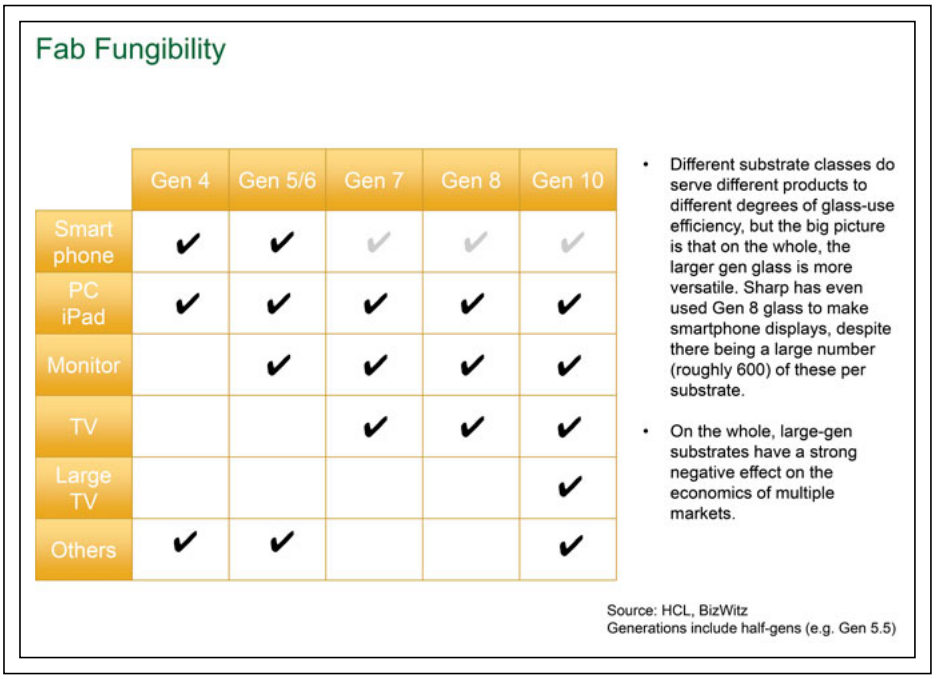

Fig. 4: *Larger fabs reduce value in the display market since they can serve all markets.*

such a fab, you need to believe that you can sell a lot of those larger displays. The easiest way to help improve the net-present value (NPV) of a fab's business plan is to increase the portion of the mix that sells super-premium (large) displays for higher prices than their fair share of glass size would indicate. The challenge the industry faces is that it may plan for a large portion of the fab output to sell at 65 and 75 inches, but the reality is that often much of the mix gets used for smaller product sizes and hence reduced prices and margins.

Issue 3: Implications of Large Glass

For Gen 10, it is largely accepted that glass facilities that supply the borosilicate glass will need to be co-located with the LCD or OLED production. This means that companies like Corning and Asahi will be deeply involved and influential in any major investment decisions. We would not be surprised to see the oligopolistic glass players demand strong terms from the related display firms before they commit to building furnaces.

Other issues raised by large glass sizes are more speculative, but it will be interesting to see whether they do or do not get included into concrete plans. The first of these is that Gen-10 fabs are by nature aimed at premium TVs and other large-panel applications (signage perhaps, video walls and large education displays). There is a very distinct cost to cover technology bets (though as a portion of the total investment perhaps not so huge), but we wonder to what degree companies will plan options for oxide TFT backplanes, quantum-dot color filters (QDCFR CFs) – perhaps in later phases of Gen-10 expansion – or other market opportunities. Gen-10 fabs will generate economic returns by selling large portions of the capacity at the optimal panel sizes – how will display companies plan this into the equipment arrangements? We wonder the degree to which display firms will look into large-area coating methods now as a replacement for sputtering and perhaps as a way to transfer value that previously might have been seen in the optical film stack.

Issue 4: Game Theory for Fab Announcements

Of interest here is signaling behavior – the game theory around market announcements of capacity expansions *vs*. the likely true expansion. Display players make announcements – often very ambitious announcements – about their future investment plans in part to defer others from making similar investments. A historical review of actual capacity added after such signaling announcements reveals that around half of the total is actually built out. Increasing and decreasing prices as part of the so-called crystal cycle used to heavily impact this. The best economics are to ramp up the fab so that the first years of full capacity occur during a period of high or rising market pricing.

Issue 5: Gen-8 Case Study

It is useful to study the history of the Gen-8 capacity build-up that began in 2007 to illustrate the implications for markets and smaller substrate fabs. This issue may prove to be one of the most useful strategic elements to consider; that is, how has the display industry responded to previous build-ups of major capacity? Figure 5 illustrates the capacity build-up just for Gen 8 since that time. Two things are interesting in this picture. First is that the Gen-8 expansion continues – Gen 8 has been a very successful platform for the display industry. Second is that if you review the impact on other factories from the price changes accompanying the surge of Gen-8 capacity, then you see it takes between 2 and 10 years for players to begin to withdraw obsolescent capacity. This is an important insight, as it suggests that fabs that will ramp in 2018 might impact the way the display industry makes products toward the *end of the following decade*.

Issue 6: Fab Owners and Portfolios

The next matter we address is: If all this Gen-10 capacity is a bad thing because it will cause price declines across all markets (see Issue 7), then where will the greatest pressure be felt? Overall, we believe that large-panel fabs cause downward pressure on all smaller generations of factories.

However, there is a caveat – and that is that Gens 5.5 and 6 in particular are well suited to the production of small smartphone panels and the like. Some of the glass handling and other practical issues are simply more easily solved at this relatively more modest glass size (1.5 × 1.85 m). The reality is that much of the smaller capacity (Gen 4-5) has already been allocated to niche production opportunities or is being used as R&D lines. As a result, the pressure from Gen 10 will be primarily on the Gen-7 capacity that remains in the market and the options for the owners of such capacity (Samsung, AUO, and Innolux). Of these, Samsung may have a broader range of options for its remaining Gen-7 production capacity. One

option may be selling the equipment and using the cleanroom for future flexible OLED capacity expansion if and when that is warranted.

Issue 7: Price Response to Capacity

The effect on pricing of major chunks of new capacity arriving into the market is one of the most important implications to consider. What is clear is that for the targeted panel sizes (*e.g.*, 65 and 75 inches) there will be head-on competition from the owners of Gen-10 fabs (and all others producing similar panels). Typically, prices for these target panels start high but then skitter very rapidly toward arbitraged commodity levels. The less evident impact is that declining prices for these panels also transmit downward pressure on smaller displays. Gen-10 fabs will cause downward pressure on large TV-panel prices and this will transmit downward pressure elsewhere. Since all major players play in all markets, this affects all markets.

Issue 8: Rededication Options for Smaller Fabs

So then if you are the owner of a smaller Gen fab – what next? From our experience of strategy projects inside display companies, there is a hierarchy of options that are available to management for the use of the capacity. The way to think about these is that the options that cost nothing (in terms of additional conversion capex) or risk nothing (for example, the conversion to a new process for new market opportunities) are more valuable than those that require a one-way conversion or a definitive action like closure.

At the top of the list is rededication of capacity to compete in other established markets, leveraging commercial strength to take market share from others. Second might be the opportunity to use the current fab, as is, to compete in markets to be created by some action of the marketing and sales department. Third would be the option to spend some money changing the focus of the fab – say from a-Si to oxide to compete in different markets with better pricing. Options to sell equipment or factories to others would be at the bottom of the heap. It should be noted that for major players such as Samsung or LGD, the risks of a shift from a-Si to OLED are less than they might be for another player and hence an option considered more quickly for them than by others (Fig. 6).

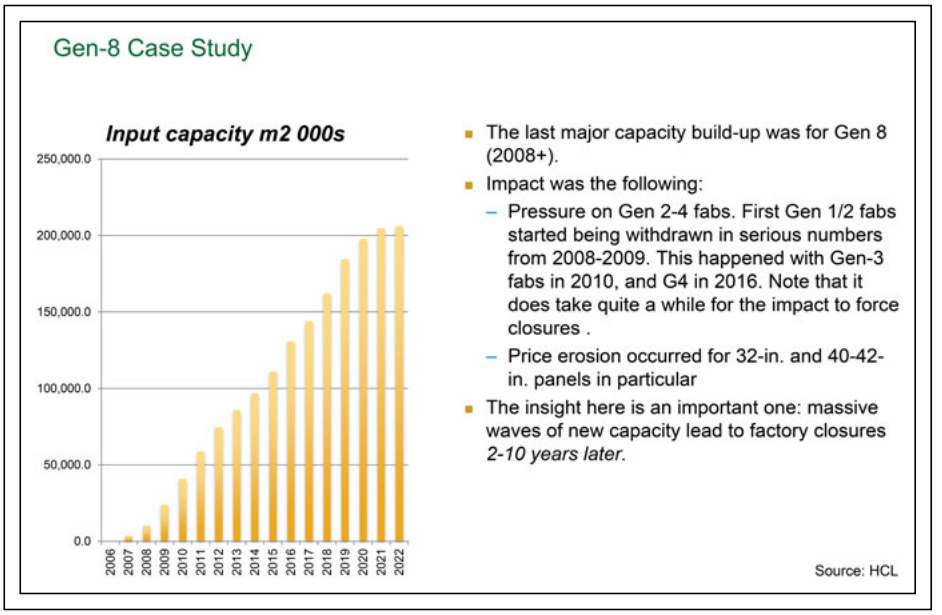

Fig. 5: *The Gen-8 pile-up that started around 2008 is still happening, showing that the trickle-down that causes fab closures can take years.*

Issue 9: Market-Creation Impact

New market-creation activities are often linked by top display firms to large-gen expansion projects. The business strategy of Sharp, the first owner of Gen-10 capacity, is helpful in thinking about this. After Sharp built its plant in Sakai, Japan, not only did it focus the positioning of its new AQUOS range of TVs toward the large end of the range, it also sought to build up B2B efforts in targeting the education market – with such programs as the massive Turkish classroom transition that put

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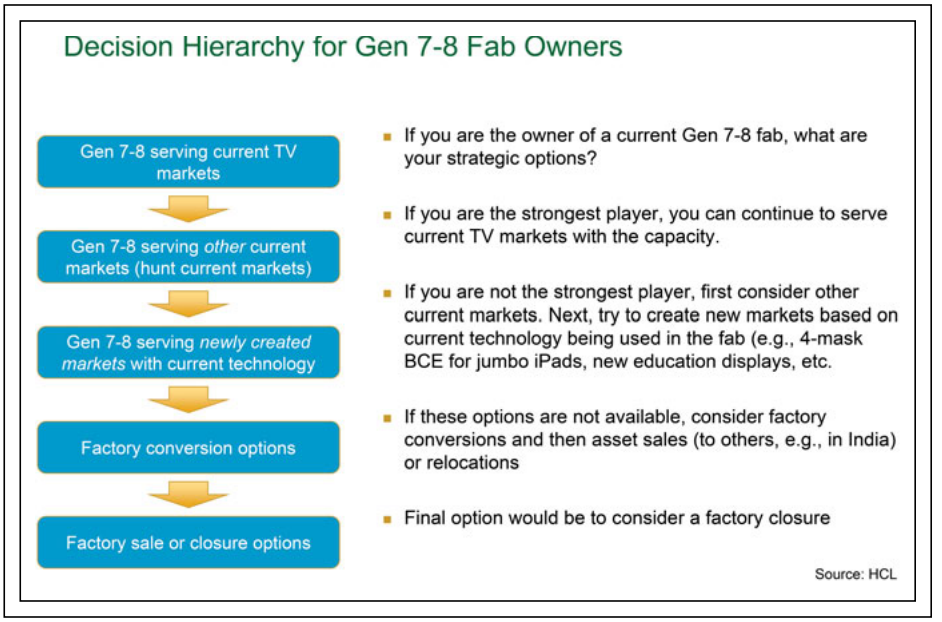

Fig. 6: *Options for rededication for Gen 7/8 fab owners include new uses of capacity, conversions, or sale. Closure of the facility is the least likely option.*

Are MicroLEDs Really the Next Display Revolution?

Interest in microLED displays has grown exponentially since the acquisition of microLED maker LuxVue by Apple in 2014. The technology offers the potential for multiple disruptive features, but it is also inherently complex and presents many challenges.

by Eric Virey

TRADITIONALLY packaged, or more recently, chip-scale-package (CSP) light-emitting diodes (LEDs) have been used for more than a decade and are now the omnipresent illumination source in LCD-panel backlights. Various types of packaged LEDs are also used in the large video billboards that are a common sight in stadiums, malls, and video facades (such as in Times Square in Manhattan). In those giant displays, discrete-packaged LEDs containing red, green, and blue chips form the individual pixels, with pitches typically ranging from 1 to 40 mm depending on display size and resolution (Fig. 1).

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This article has been written in collaboration with Dr. Nicolas Baron, CEO of Knowmade and co-author of "MicroLED Displays: Intellectual Property Landscape" (Yole Développement and Knowmade, January 2018).

LEDs, however, have never been used as the direct emissive element (pixel) in small-pitch consumer displays. The reasons for this limitation are multiple and include cost and manufacturability. Nevertheless, the idea of using microLEDs at sub-millimetric pixel pitches to realize a display is almost as old as the invention and commercialization of LEDs themselves.

The concept picked up steam in 2001 after researchers at Kansas State University showed a 10 × 10-pixel-resolution display with 12-µm diameter µLEDs at a 50-µm pitch.[1] Various research groups have since been active in the field, including Saitama University,[2] Hong Kong University of Science and Technology, ITRI, Sun Yat-Sen University, Columbia University, Tyndall National Institute, University of Illinois, Strathclyde University, CEA-LETI, and many more.

In 2014, excitement in the tech and display communities was palpable after Apple acquired microLED display startup LuxVue. Since then, many large consumer electronics and semiconductor companies have committed to the technology. In 2016, Oculus, the AR/VR arm of social networking behemoth Facebook, first acquired InfiniLED and later licensed patents from mLED, another UK-based microLED startup. In 2017, Sharp acquired eLux, a startup company spun off by its US R&D organization, Sharp Laboratories of America, to develop microLED displays leveraging on the fluidic self-assembly transfer technology the research outfit had been working on since the early 2000s. (The con-

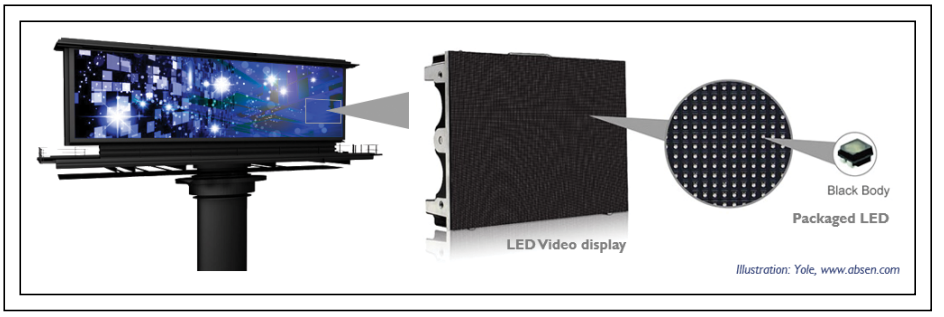

Fig. 1: *Traditional LED video walls are based on packaged LEDs. The LED packages used in those applications are black in order to minimize reflection of ambient light and improve contrast.*

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cepts of fluidic self-assembly had been pioneered earlier by Alien Technologies, but Sharp proceeded to develop its own version of the technology independently.)

Later that year, Google invested around $13 million in nanowire LED startup company glō AB (winner, with Jasper Display Company, of an I-Zone honoree award at Display Week 2017), and early this year, Intel led a $35 million funding venture into glō's competitor Aledia. Finally, Samsung, which had long been rumored to be interested in acquiring Taiwan-based microLED company Playnitride, signed a supply-and-development agreement with leading Chinese LED-chip manufacturer San'an.

Seeing such companies committing to microLEDs shows that whether the technology is being viewed as a sure path toward disruptive displays or more as a defensive project, it is now being taken seriously and is no longer just a lab curiosity.

The Patent Trail

The seriousness is confirmed by looking at patent activity in the sector. A thorough analysis conducted in collaboration with Knowmade, a partner of the author's company, Yole Développement, shows that more than 120 companies or research organizations have already filed about 1,500 patents in more than 500 families.[3] These include startups, display makers, OEMs, semiconductor companies, LED makers, and research institutions. The study also confirms the commitment of companies like Intel and the Chinese company Goertek, which are not typically associated with display technologies. On the flip side, some that are known to be active in the field, *e.g.* Huawei, have yet to have any published patents in the field.

In any case, as seen in the graph in Fig. 2, patent activity has increased rapidly over the past few years. The patent corpus is relatively young, with an average age of 3.2 years across all families. Sony and Sharp, along with various research institutions, were the first to describe microLED display concepts as early as 2000. Innovative startup companies joined the race in the early 2010s, and display and LED makers are relative latecomers: Most only initiated or ramped up their efforts after Apple showed faith in the technology with the LuxVue acquisition.

Tackling a Complex Technology

Complicating matters is that there is no commonly accepted definition for microLEDs. A die with a total surface of less than 2,500 μm^2 is generally considered a microLED. This corresponds to a 50 × 50-µm square or a ~55-µm diameter circular die. By this token, it could be argued that microLEDs are already on the market today, unveiled by Sony in 2016 in the form of a small-pitch, large-LED video wall in which packaged LEDs have been replaced by microLEDs about 30 µm in size. But how far off the horizon are small-pitch consumer microLED displays such as those found in our cell phones, smartwatches, TVs, and laptops or in augmented-/mixed-reality head-mounted devices?

To get there, multiple challenges need to be tackled. The art of making microLED displays consists of processing a bulk LED substrate into an array of microLEDs, which are then transferred to a backplane substrate for integration into a heterogeneously integrated system incorporating LEDs, pixel-driving transistors, optics, *etc*. Epiwafers can accommodate hundreds of millions of µLED chips compared to thousands with traditional LEDs.

There are two major routes to realizing a display from microLEDs. The microchips can be picked up and transferred individually or in groups onto a thin-film transistor (TFT) substrate similar to the ones already used in OLED displays. Alternatively, a full monolithic array of hundreds of thousands of µLEDs can then be hybridized on a CMOS-driving circuit (Fig. 3).

For the former, assembling a 4K display means picking up, positioning, and individually connecting 25 million LED chips (assuming no pixel redundancies) to the transistor backplane. Traditional pick-and-place equipment typically delivers processing speeds of around 25,000 units per hour (UPH). Assuming this equipment could manipulate such small devices, it would take more than one month to assemble a single display! To be cost-compatible with most consumer applications, microLED chip transfer must reach rates of about 50 million to 100 million per hour.

A wide variety of technologies are being investigated to tackle the transfer and assembly challenges. Electromagnetic and electrostatic micro-electro mechanical systems (MEMS) are championed by Apple/LuxVue and others. X-Celeprint got a head start with polymer stamps. Other companies use "sticky tapes," flexographic and semi-continuous printing processes, or "self-assembly" technologies such as eLux's fluidic transfer. However, efficient and high-yield transfer of dice below 10 µm remains problematic in most cases.

Another challenge is the LED chip itself. Below 10 µm, microLED operations tend to

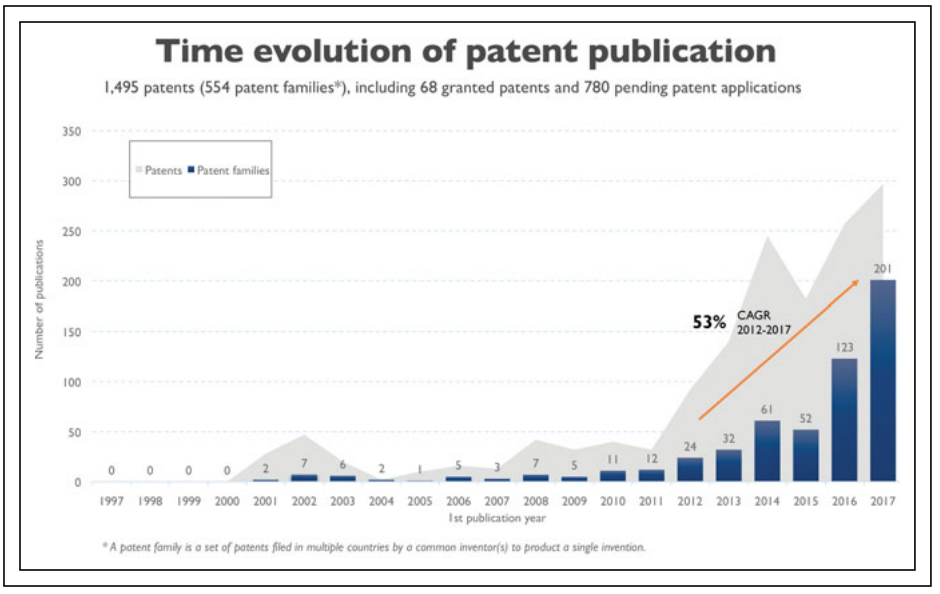

Fig. 2: *The number of microLED patent publications has soared, especially from 2012 to 2017. Source: Yole Développement/Knowmade*

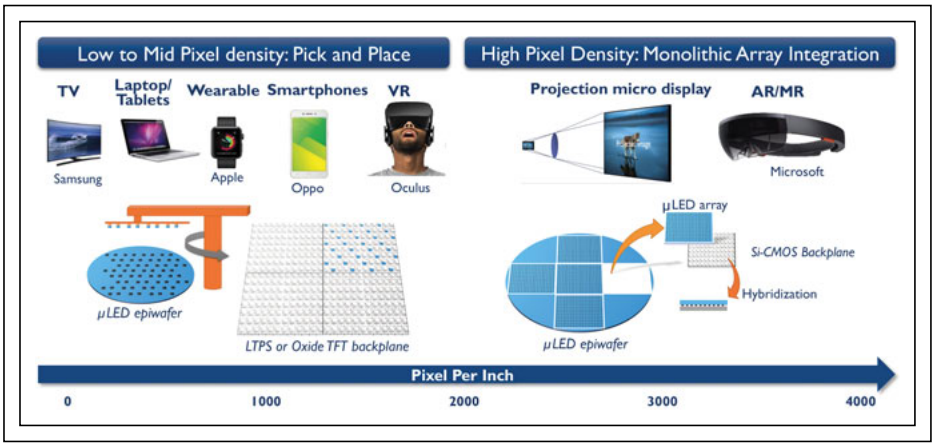

Fig. 3: *MicroLED display assembly technologies include pick and place and monolithic array integration. Illustration: Yole Développement*

be dominated by nefarious "sidewall" effects related to surface and subsurface defects such as open bonds, contaminants, or structural damages in which non-radiative carrier recombination dominates. Sidewall effects result from the manufacturing process (plasma etching) and can spread over distances similar to the carrier diffusion length, typically 1 to 10 µm – not a big deal in LEDs that are hundreds of microns large but a killer for microLEDs, where they could affect the entire volume of the chip.

As a result, the reported peak efficiency of microLEDs is often below 10 percent or even 1 percent at the smallest dimensions (<5 µm). This doesn't compare well with the best traditional "macro" LEDs that now deliver peak external quantum efficiencies above 70 percent.

At low efficiency levels, microLED displays can't deliver on the key promise of reduced energy consumption. Solving this issue is a key priority. Strategies include new chip designs and improved manufacturing technologies in order to reduce sidewall defects and confine electrical carriers away from the edges of the chip. Other disruptive avenues include nanowire LEDs, which naturally grow 3D structures without sidewall damage.

Other challenging technology nodes include color conversion and light-extraction beam shaping. Interestingly, nobody in the industry seems to agree on what is the most pressing bottleneck. Some see transfer and interconnects as the most daunting challenges; others argue that transfer is just an engineering problem and will soon be solved.

Ultimately, the major issue might be defect management: In modern displays, defective pixels are not acceptable. No matter how good one is at improving epitaxy, chip manufacturing, and assembly yields, defective pixels will always occur. Manufacturers must therefore develop effective defect-management strategies combining pixel redundancies and/or individual pixel repair along with chip and pixel testing and binning. As anticipated, the microLED IP landscape shows a high level of research activity in chip transfer and assembly, but very few solutions have emerged regarding defect management (Fig. 4).

Solving the Supply Chain Puzzle

Enabling microLED displays requires bringing together three major areas of expertise: LEDs, TFT or CMOS backplanes, and chip transfer. The supply chain is complex and lengthy compared to that of traditional displays. Each process is critical, and managing every aspect effectively will be challenging. No one company today appears positioned to execute across those multiple technologies and vertically integrate all the components.

Traditional display makers have little experience with LED manufacturing and vice versa. To serve the microLED market, LED makers need to revamp or build greenfield fabs with proper clean rooms and higher resolution lithography. This could be handled by CMOS fabs, which already have depreciated class 10 or 100 clean room, high-resolution steppers, *etc*. However, LED epitaxy is new to them, so collaboration with LED makers could help jumpstart the supply chain and perhaps even finally establish silicon wafers as a credible microLED platform.

The IP landscape reflects those challenges through the variety of players involved. Only a few companies have a broad microLED IP portfolio, but enough have patents on key technology bricks that complex licensing and legal battles are likely to arise if and when microLED displays enter volume manufacturing (Fig. 5).

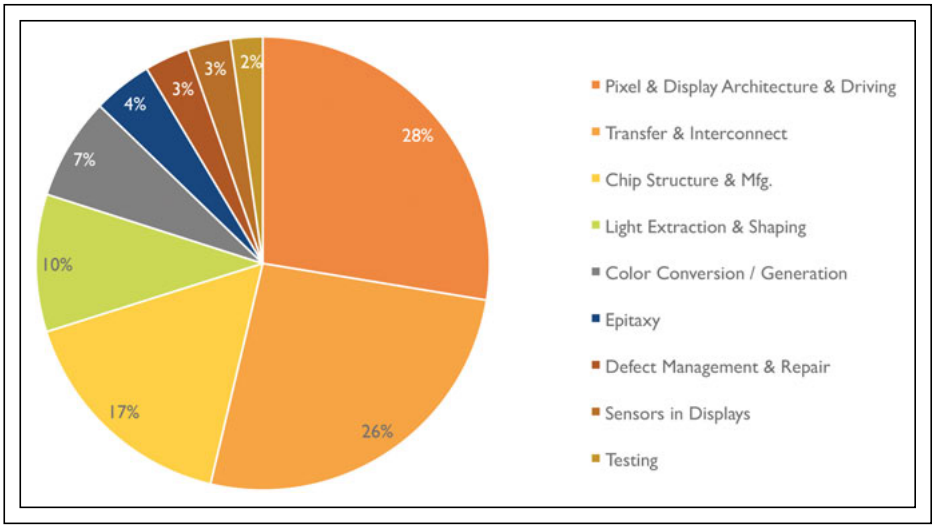

Fig. 4: *MicroLED display patents per key technology nodes include pixel and display architecture with 28 percent of the whole, and testing with 2 percent. Source: Yole Développement/ Knowmade*

Rolling Out "Real" MicroLED Products

Samsung's giant 146-in. microLED TV, named "The Wall," was a major attraction at the 2018 Consumer Electronics Show in Las Vegas (Fig. 6). ("The Wall" is also mentioned in the March/April issue's Industry News section.) However, despite its 0.84-mm pixel pitch, it doesn't strictly qualify as "microLED" since it uses traditional SMD-packaged LEDs with chip sizes larger than 0.1 mm. Such displays have been available for some time: Korea-based LED maker Lumens was also showing a 139-in. display with a smaller 0.8-mm pitch at CES, although in a booth of more modest proportions compared to Samsung's. Some companies such as Leyard-Planar already offer products with even smaller pitches.[1]

Mainstream technology media were quick to tout Samsung's Wall as the first-ever microLED TV, having obviously forgotten that Sony created a similar buzz back in 2012 when it showed the first microLED TV, a full high-definition 55-in. TV prototype called Crystaled.

At the time of writing, Samsung had yet to release information on pricing for the Wall. The author estimates that each individual LED chip in this display is at least 125 × 250 µm in size. Assuming $600 for the cost of a fully processed 6-in. LED epiwafer, that is about $26,000 for LED chips alone, before singulation, SMD packaging, transfer, assembly, *etc*. It therefore seems unlikely that such a display could be offered below $250–300K per unit. The Wall is an amazing product for the indoor digital signage market, but it is doubtful that it will trigger riots at your local electronics store on the next Black Friday.

For more than 20 years, the LED industry has delivered impressive cost reductions. There is more ahead, but the low-hanging fruit has already been harvested. To be cost-compatible with the consumer TV market, the LED die must shrink to about 5–10 µm. At this size, the transfer and efficiency challenges are compounded. Smartphones are an even harder nut to crack, with an estimated die-size target of 3 µm or below.

These are aggressive but not unrealistic targets. However, with the current state of technology and factoring in the supply chain challenges, it will probably be at least another three to four years before one could reasonably envision purchasing a microLED TV or smartphone.

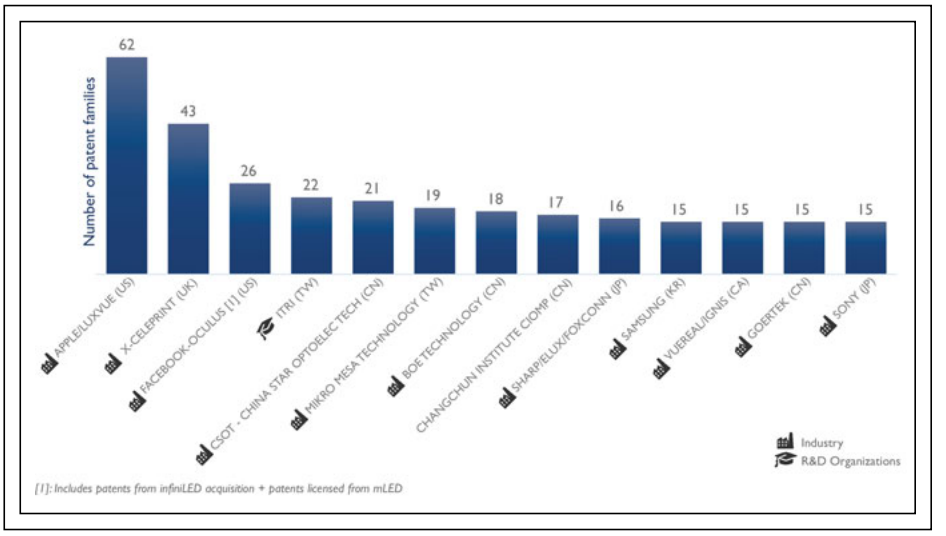

Fig. 5: *Top patent assignees are ranked by number of families. Source: Yole Développement/ Knowmade*

Which products come first to market will result from a complex interplay among technology maturity, the evolution of competing technologies such as OLEDs, company strategies, and specific supply-chain requirements for each application.

Yole Développement is optimistic regarding microdisplays to be used in augmented-reality or head-up displays. Many companies and research organizations have already shown convincing prototypes and it is conceivable that a well-funded startup could bring together the different technology bricks and manage the supply chain without having to deploy significant capital expenditure (capex). Once yields are up, major elements such as the LED epiwafer and the CMOS backplane can be outsourced. Those are also applications in which microLEDs are highly differentiating. As a matter of fact, they currently seem to be the only technology capable of delivering the combination of small form factor, low power consumption, and high luminance (hundreds of thousands of nits!) required for those applications.

For high-volume consumer applications such as smartphones or TVs, the cost targets are more aggressive. The high volumes translate into high capex and multiple challenges to set up the supply chain, something that only a large company could enable.

Wearables such as smartwatches fall in between microdisplays and those very high-volume consumer applications. Cost targets enable the use of larger dice and allow pixel redundancy, easing the challenges in defect management. With smaller displays and lower volumes, a motivated company could set up the supply chain through a combination of strategic partnerships and internal investments. As long as the TFT backplane can be outsourced, manufacturing 20 million displays per year for a smartwatch wouldn't require more than 20 of the latest generation MOCVD multi-wafer reactors and a few dozen transfer tools. This is a lot of money for a startup, but a drop in the bucket for companies like Apple or Samsung. Wearables would be an efficient way to establish a "beta" supply chain and serve as a beachhead before moving on to mid-size displays with high added value such as automotive applications, and finally addressing more challenging applications such as TVs or smartphones.

Fig. 6: *Samsung's 146-in. microLED TV was unveiled at the 2018 Consumer Electronics Show.*[4]

A Paradigm Shift in TVs

Fifty-five-in. diagonal-size TVs have been commoditized, thanks to the multiplication of Gen-8.5 fabs, which enable efficient production of six panels from a single 5.5 m^2 glass substrate. Consumers are now demanding larger 65-in, 75-in., and 85-in. panels, and, although the size of the average living room will eventually limit this trend, many consumers would gladly purchase "wall-sized" TVs up to 110 inches or more if those were affordable. This possibility poses tremendous challenges for TV makers, since the manufacturing of large panels on existing Gen-7, -8, or -8.5 fabs is relatively inefficient (Fig. 7).

As a result, prices have remained high. Some panel makers are addressing the challenge by building Generation-10.5 fabs that can efficiently produce 65-in. and 75-in. panels. As of Q1-2018, at least seven of those fabs have been announced and should enter production by 2022, with the first one from BOE coming online as we write. These fabs will help bring costs down, although they come with a pretty stiff price tag, typically around $7 billion, which means significant depreciation costs. (For more about the impact of Gen-10+ fabs, see the article "Gen-10 Fabs Will Create Upheaval in the Display Market" in this issue.) An alternative is to convert mostly depreciated Gen-6, -7.5, or -8.5 fabs to multi-modal glass (MMG) configurations where different sizes of panels are manufactured on the same substrate. However, this also brings added complexity and presupposes that there is a market to absorb the smaller panels.

MicroLEDs offer potentially disruptive answers to this problem as well as ways to create arbitrarily large displays without significant capex.

With traditional displays (LCD, OLED), the cost of both the TFT backplane and the frontplane scales with their area. With microLED, however, the frontplane cost doesn't scale with the area but with the number of pixels: for a 4K display, the 25-million microLED chips are the same size and cost the same whether they are spread out onto a 55-in. or a 110-in. backplane. Therefore, only the TFT backplane cost scales with the surface.

One could part with the TFT entirely and use discrete silicon chips to drive groups of pixels (Fig. 8). In a 4K 85-in. TV, the pixel pitch is 163 µm. Using 5-µm microLEDs leaves plenty of space for a silicon microchip driver and associated circuitry. These could be assembled by the same technologies used for the microLED. If one assumes that the silicon can drive reasonably large groups of pixels (32 or more), the solution could be to eliminate the traditional TFT backplane entirely. In this case, the cost of a modular TV would essentially be independent of its surface area and would be based instead on the cost of the

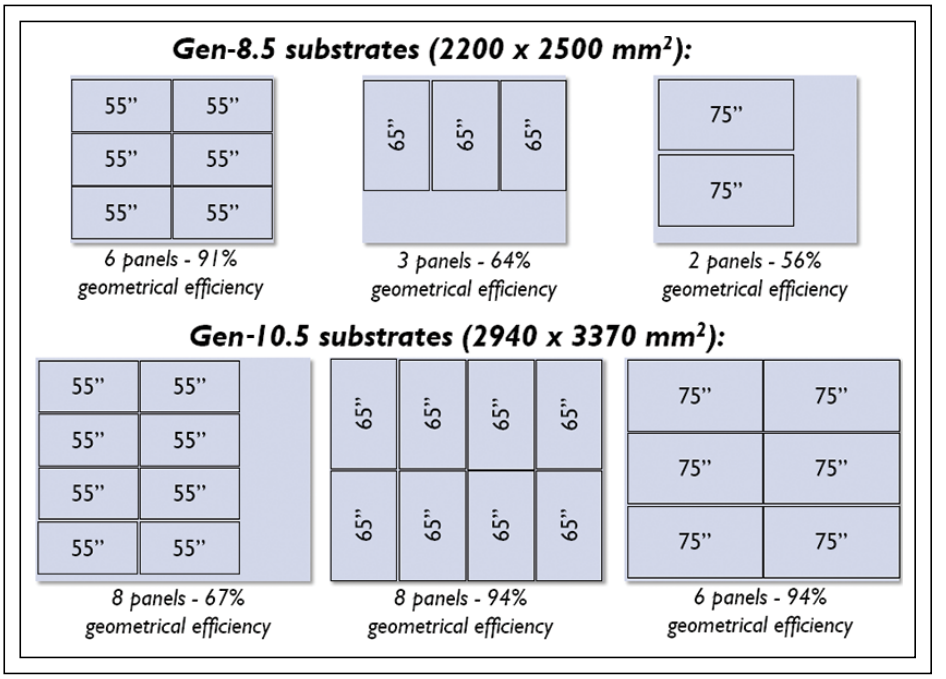

Fig. 7: *Panel cuts on Gen-8.5 and Gen-10.5 substrates show different possible configurations. Source: Yole Développement*

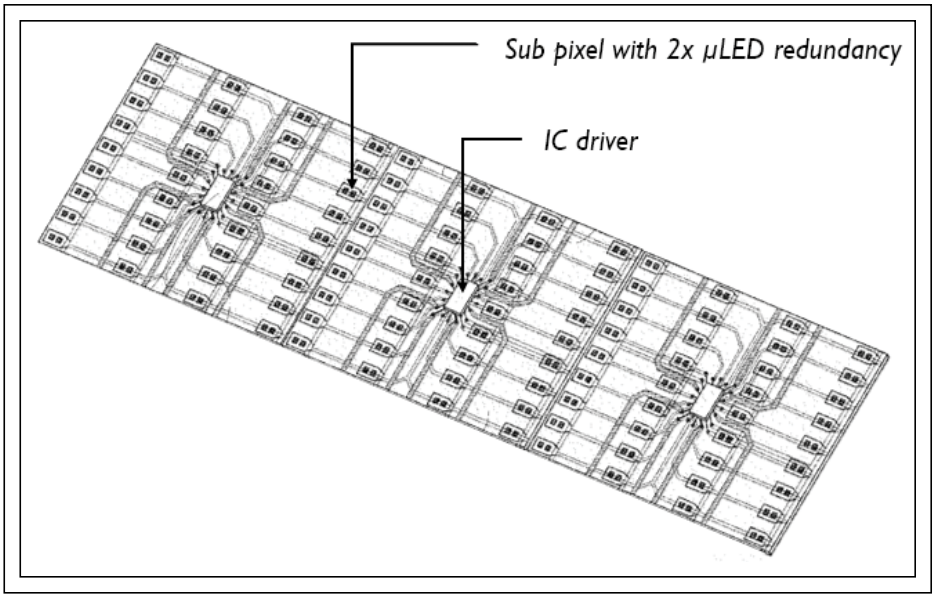

Fig. 8: *This µLED display's discrete ICs positioned on the front face can drive groups of 36 subpixels. This display module features a 2× subpixel redundancy.*[5]

circuit boards and mechanical assembly. A 110-in. TV would cost essentially the same as a 65-in. unit!

Besides opening the market for very large TVs, this could transform the competitive landscape: This modular construction doesn't require multibillion-dollar TFT and front-plane fabs. Assembly can be contracted to outsourced semiconductor assembly and test ("OSAT") companies. This environment could foster new competition in the TV market, where previously, very few companies could absorb the multibillion-dollar fab sticker shock required for suitable expansion.

This rosy scenario of course has its caveat: While the cost of those modular microLED TVs wouldn't scale with surface size, it would scale with the number of pixels. So expect an 8K TV that requires four times more LED chip and silicon drivers to cost significantly more than a 4K TV. And as the size increases, higher resolution becomes more desirable to maintain the pixel density within the "retinal display" range where individual pixels remain indistinguishable when viewed from a normal distance.

Applications Grow as LEDs Shrink

So how long will we have to wait until we see the first consumer applications? The science is here, but microLED is an inherently complex technology with cost drivers different from those of incumbent materials OLED and LCD. Based on the current status of the developments and the maturity level of the supply chain, late 2019–2020 appears to be the earliest that a product could hit the market. AR microdisplays or wearables are the first candidates. Relatively high-added-value displays such as automotive applications could come next, but large-volume consumer products such as TVs or smartphones will require significantly more time.

There is reasonable expectation that microLEDs will succeed in various segments, but it is still too early in the technology development cycle to assert whether they will take the industry by storm or crash and burn like many other "promising" technologies in the past.

In the meantime, the LED and display industries are already shrinking traditional LED packages or using "chip-on-board" concepts for "miniLEDs." Those are typically >100 µm in size and don't present the handling, assembly, and efficiency challenges of microLEDs. MiniLEDs are expected to enter the market by late 2018 in full-array local-dimming (FALD) multizone LCD backlights that could significantly improve black levels, as well as in low-pitch LED videowalls for indoor digital signage.

Finally, the large amount of ongoing research and development on the microLED topic will likely bear fruit and cross-pollinate into other applications, leading to better and more efficient LEDs, high-speed light-fidelity (Li-Fi) communication, lithography applications, and micro-device transfer technologies that could benefit many other industries.

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continued from page 11

LG Display's UHD Crystal Sound OLED

Crystal Sound OLED (CSO) is one of the latest in a line of OLED advancements made by LG Display. The company launched a ground-breaking 55-in. FHD OLED TV in 2013 and completed a full line-up of 55-/65-/75-in UHD OLED TVs in 2015. Since then, UHD and 8K pixels have been incorporated for high image quality. And the company has continued to develop and apply various image-quality improvement algorithms such as high dynamic range (HDR) to lead the market.

LG Display introduced its extremely thin "Wallpaper" OLED TV panels in 2016 and 2017, a design differentiation that leveraged the structural merits of OLED. Around this time, the company also developed an OLED panel integrated speaker, Crystal Sound OLED, as a convergence product, launching it in 2017.

Crystal Sound OLED technology operates on the key principle of vibrating the panel with the exciter attached to the back of the panel and separating one panel into the stereo sound. This technology is possible because OLED panels do not require a backlight unit. In regular TV, a speaker is placed on the back of the panel to project the sound around the outside of the set, so the sound characteristics are uneven and the sound is easily affected by the environment. On the other hand, TVs with Crystal Sound technology (the vibrations generated by the exciter transmit their sound directly to the audience through the OLED panel) reproduce crisp, clear, and balanced sound from low to high frequency.

In normal TVs, the imagery and sound emerge from different places, but the Crystal Sound technology enables sounds to emit from exactly the same place as the video. In other words, the position of the person's face and the position of the sound are exactly matched, so that the sound is natural and maximizes the realistic feeling, thereby increasing the immersion of the viewer.

LG Display expects this technology to expand into a variety of areas, such as smartphones, monitors, automobiles, and OLED lighting. ■

Calibration Requirements for Demanding Measurement Challenges

Today's state-of-the-art displays, with their wider dynamic ranges and larger areas, demand state-of-the-art measurements. Those measurements must start with accurate calibration sources. The author offers two new designs for light sources geared toward wide-angle and low-luminance calibrations.

by Edward F. Kelley

As displays continue to evolve in terms of size and wider dynamic range – "brighter" brights and deeper blacks – they are straining the limits of our measurement capabilities, particularly in the dark regions. Companies may possess the tools to perform the required optical measurements, but these tools must be calibrated using suitable standard sources to produce accurate results.

In the case of large displays, for example, many companies use various cameras and imagers to capture the entire surface of the display at one time for analysis. But with large displays and a camera placed at a close viewing distance, there is the problem of providing a calibration that supports the wide-angle lens and image field to be measured – often referred to as a flat-field correction. That is, we want the response of the camera to be uniform for all angles it observes. To make such a calibration, a uniform source of light over that wide angle, as described here, is necessary.

A second challenge involves the very dark blacks – even zero-luminance blacks – that the newest displays are now able to produce. We need to be sure our measurement instrumentation is sensitive enough at those very low light levels. Can what we are using really measure as low as we need it to measure, and be linear at those levels? Once again, an adjustable low-luminance source of light is the key. To perform such calibrations and checks of linearity, we need a well-characterized source of light down to the limits of human sensitivity. A dual-sphere source is described herein to provide such a source of light.

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Uniform Source for Wide-Angle Lenses

The first design addresses the issue of measuring large displays. Often cameras or tristimulus imagers are employed to characterize the uniformity of such displays. To calibrate such wide-angle devices, a uniform source over 180° can be very useful.

Some integrating spheres exist that can accommodate such wide-angle calibrations, but they tend to be larger. Figure 1 shows the author's solution in a cut-away view of the uniform source with a transmissive-diffusing, slightly flattened, flanged dome at the exit port. The interior diameter of this sphere is 229 mm (9 in.) yet the exit port is almost 152 mm (6 in.). Normally, the maximum exit port size is one third of the sphere diameter or less to assure a 1 percent uniformity; this one is two-thirds the diameter.

The dome is made of white plastic acrylic that serves as a transmitting diffuser. It is sandblasted on both sides to make its surfaces diffusing as well. Nonuniformity is avoided by ensuring that any ray from the source cannot strike the dome directly. Thus, a baffle of sufficient diameter is installed ahead of the source that prevents lamp rays from hitting the dome. This baffle is mounted on a transparent polymethylmethacrylate (PMMA) sheet. An iris can be used to regulate the luminance of the dome. A 12-V Soraa 5,000-K light-emitting-diode (LED) lamp is used to provide a broad spectrum, and a 12-V fan draws air from in front of the lamp to keep it cool, below 30 °C. A 40 °C thermal switch (not shown) is placed against the base of the lamp to turn it off should the fan fail. The entire apparatus was prototyped on a 3D printer and could be reproduced this way.

Also shown in Fig. 1 at the bottom left is an alternative way to mount the baffle on a semi-transparent holder that fits within the hole for the lamp. The sphere interior and baffle are painted with several coats of white interior latex paint. A better coating material would be barium sulfate, of course, because of its higher reflectance and more uniform spectral reflectance.

Note that the flange that holds the dome in place has a smaller diameter than the inner diameter (ID) of the dome. The face of this flange that faces the dome is white, and that provides a small amount of illumination on the interior of the dome next to the flange.

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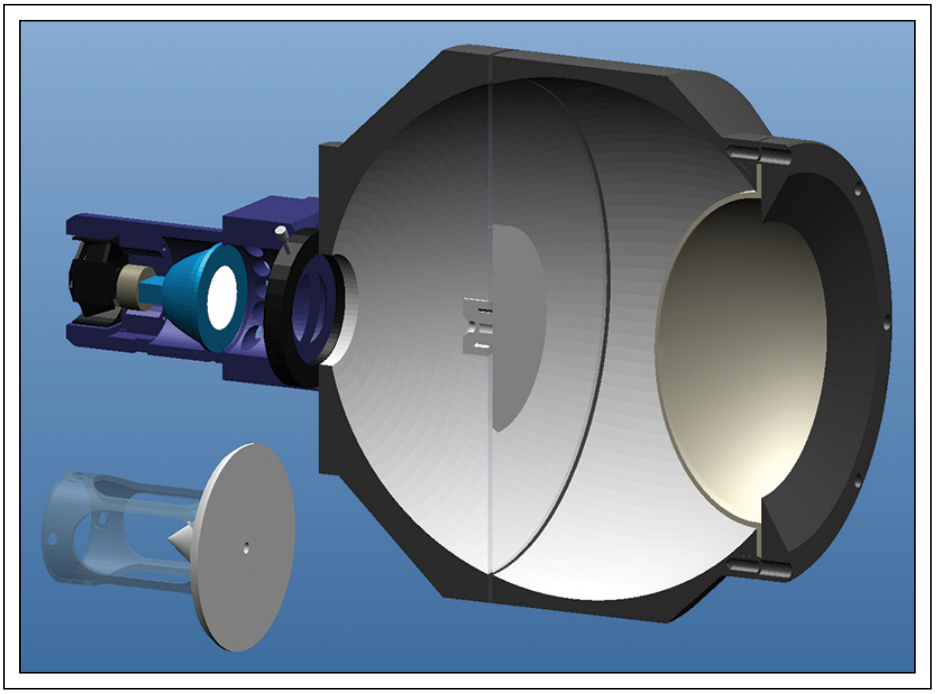

Fig. 1: A cut-away view of the uniform source shows a sphere with an interior of 229 mm (9 in.) and an exit port that is almost 152 mm (6 in.). An alternative baffle is shown at bottom left.

This is done to improve the uniformity at very large angles from the normal of the dome. However, if we increase the exit-port diameter 10 mm or more with the same-sized dome, the region near the flat-flange of the dome will then be better illuminated by the sphere interior and can permit a flange of the same inner diameter (ID) as the ID of the dome.

Figure 2 shows the normalized luminance uniformity of the dome as a function of angle around the center of the exit port from the normal of the dome. This data was obtained with a spectroradiometer placed some distance away from the dome, and the entire source structure was rotated about the center of the exit port to obtain the data. There is a maximum deviation from the central value along the normal of approximately 2 percent at the right side and top. We thus have a source that could be used to obtain a flat-field correction for even a fish-eye lens.

This uniform dome is only useful for lenses placed just inside the dome. It is not useful for cameras with lenses placed some distance from the exit port. This is because the interior surface of the dome is only quasi-Lambertian. When a lens is just inside the dome, the rays entering the lens at wide angles are nearly perpendicular to the surface elements of the interior of the dome. But when the lens is a distance away from the exit port, the rays near the edges of the dome that are directed toward the lens are at a large angle to the interior dome surface, and the imperfect Lambertian surface renders such light darker than at the center of the dome. To allow this device to be used with cameras at a distance from the exit port, one would replace the dome with a flat, white, acrylic-plastic disk that is also sand-blasted on both sides. It is not possible to use this source without a diffuser at the exit port because the baffle is considerably smaller than the diameter of the exit port.

Research is under way to improve the design and attempt to make the device smaller using a 150-mm (6-in.) sphere with a 100-mm (4-in.) exit port. Attempts will also be made to eliminate the white region on the interior of the flange by modifying the internal shape of the sphere in the vicinity of the exit port.

Dual-Sphere Source for Low-Luminance and Linearity Testing

The second design addresses the problem of measuring displays with very deep blacks. There is an entire section in the *International Display Measurements Standard* (IDMS) that covers making low-light measurements and testing.[1] Of course, to do those measurements you need a uniform source of light in the same

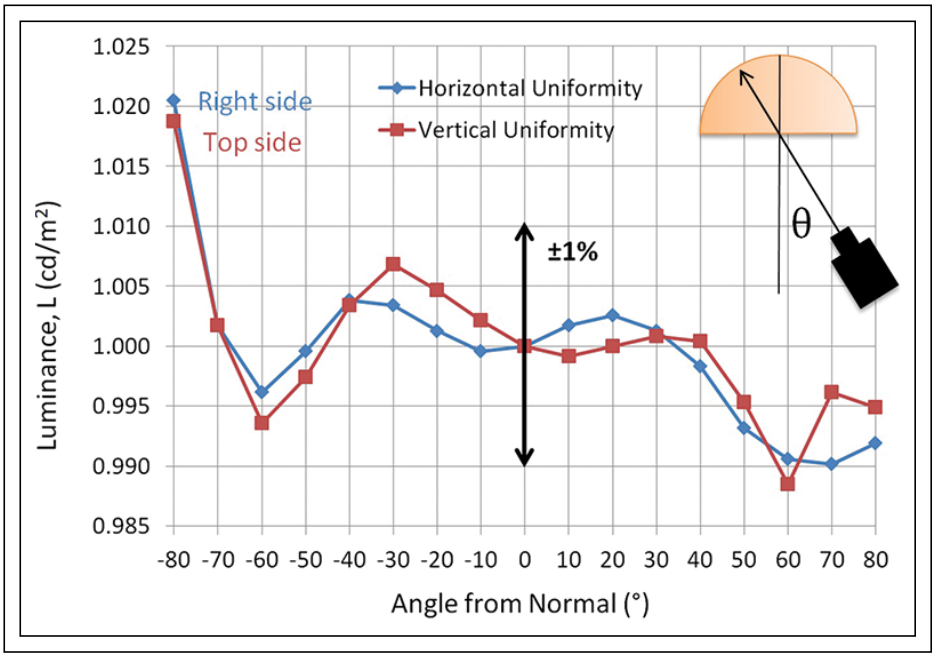

Fig. 2: Dome luminance uniformity vs. *angle from the center normal line of the dome appears in terms of horizontal (blue) and vertical (red) uniformity.*

order of magnitude of the luminance you intend to measure. This is hard to achieve with typical sources: Just turning down the power to the light source lamp isn't adequate because the spectrum of the lamp may vary too much with power level, and mechanical reductions using apertures can produce insufficient light distribution into the sphere to permit a reliable calibration of the sphere. One of the recommended methods to create low-light sources is to use two integrating spheres (see IDMS, p. 420). This kind of arrangement is employed here, with some improvements.

The main improvement shown in Fig. 3 is a stray-light-elimination tube (SLET) that is placed between the first sphere (#1), the source sphere, and the second sphere (#2). Sphere #1 can be calibrated either by rotating it away from the SLET or removing it entirely from the apparatus. The calibration of sphere #1 is made using a spectroradiometer or luminance meter to obtain the relationship between the photopic photodiode current J and the luminance L_1 of the sphere #1. The lamp on sphere #1 is a fan-cooled LED. The luminance can be changed by changing the LED current, by an iris, or both. After calibration of sphere #1, it is replaced against the SLET. The advantage of the SLET is that it prevents any back reflections from sphere #2 into sphere #1. Preventing any stray light from entering sphere #1 from reflections is important to maintaining the $L_1(J)$ calibration relationship when sphere #1 is positioned up to the SLET. Sphere #1 has an extension between the two sphere halves that greatly decreases the nonuniformity of the baffle in sphere #1 to approximately 0.1 percent. This reduces any aiming sensitivity in L_1 measurements.[2]

Light from the exit port of sphere #1 travels through the SLET and into sphere #2. Thus, there should be a linear relationship between L_2 and L_1 based upon a geometrical factor g. To calibrate that factor, we make $L_1(J)$ as large as possible and measure the luminance L_2. Thus, $g = L_1(J_{max})/L_2$, and for this prototype apparatus we find that g = 1,060 with an uncertainty of 10 percent (coverage factor of two) for L_1 above 1 cd/m^2 (for lower light levels, the uncertainty in g increases because of various factors discussed below). It is possible to monitor the photodiode current with a good picoammeter and then predict L_2 based upon the photocurrent J. However, to reliably reach and control the light in the realm of the limits of human vision of $L_{rods} = 3 \times 10^{-6}$ cd/m^2, we would need to make sphere #1 have a luminance of L_1 = 0.003 cd/m^2.[3] It is possible to reach L_{rods} with this prototype apparatus by looking at the exit port of sphere #2 using dark-adapted eyes and averted vision, but because of the increase in the uncertainty of our measurements at these levels, the L_2 accuracy may be compromised.

A new dual-sphere apparatus is being designed in order to make the low-light realm in the vicinity of L_{rods} more reliable than the prototype apparatus in Fig. 3. The present apparatus shows changes in the apparent geometrical factor g on the order of tens of percent in $L_2(J)$ with the iris almost closed and LED current reduced, providing sufficiently low levels of light in sphere #1. Since the spectrum from the LED changes with drive current, it is not a good idea to change that current (after initial calibration). Using apertures and an iris in a new apparatus design will be required. Any change in g with the iris diameter in the present apparatus probably has to do with changes introduced in the light distribution by the photodiode not confining its monitoring to the light on the baffle and using light from the interior wall; the new apparatus will correct this. To increase the geometrical factor g so that L_{rods} can readily be reached and controlled well in sphere #2, the apertures on each side of the SLET must be reduced, but in order to calibrate that

(continued on page 54)

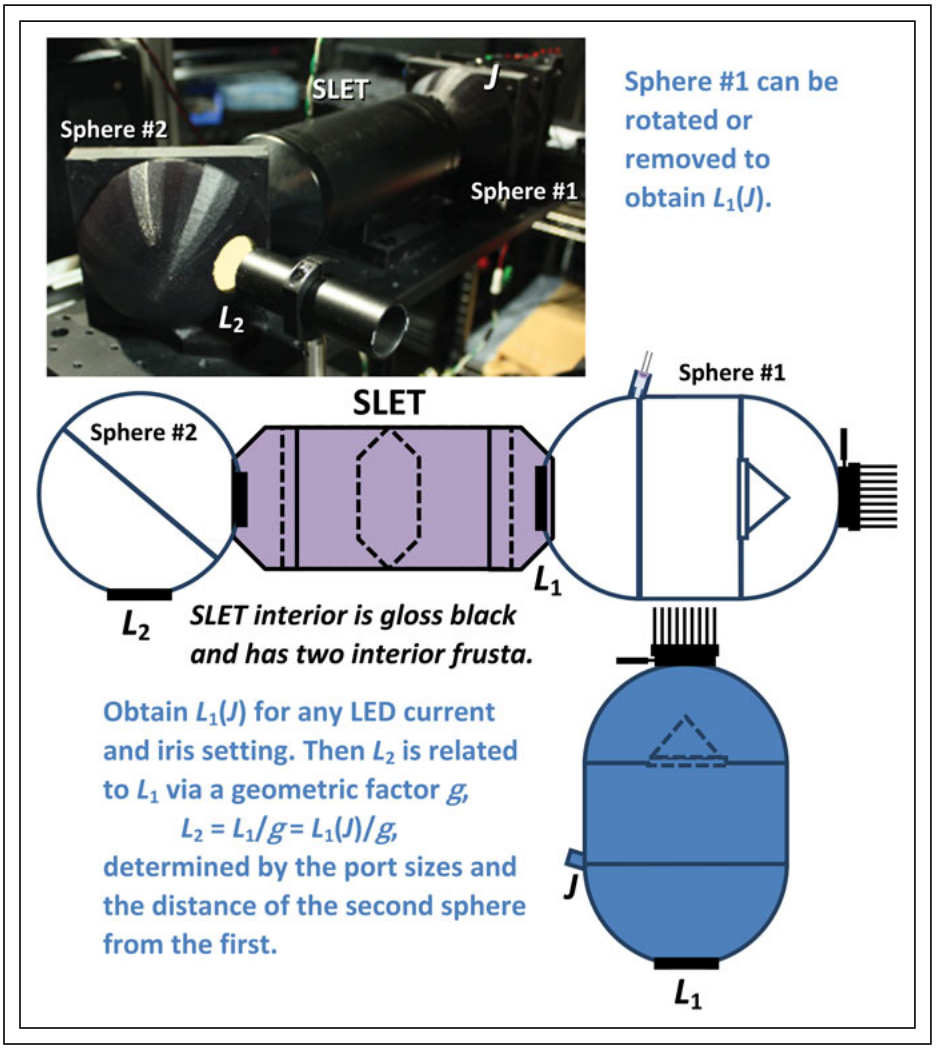

Fig. 3: *This dual-sphere source prototype is designed for more accurate measurement in very low light levels.*

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ID Interviews Doug Kreysar, Chief Solutions Officer at Radiant Vision Systems

Doug Kreysar heads engineering, operations, and quality teams for Radiant Vision Systems, a company based in Redmond, Washington, that creates imaging systems for light and color measurement. Kreysar received a B.S. in physics from Vanderbilt University and an M.S. in applied physics from the University of Michigan. He is the author of multiple technical papers and has been awarded eight US patents.

Conducted by Jenny Donelan

Information Display:
Radiant Vision Systems has had a few name changes over the past 15 years. Could you walk us through the history behind those?

Doug Kreysar:
Radiant Imaging started out in 1992 as an optical-design company. We designed illumination systems – projectors, surgical lights, and similar items. At some point, the founders of the company decided it would be helpful to have imaging systems to measure their prototype designs, so they designed their own systems. Eventually, customers wanted to buy those camera systems as well as the designs. So our products grew out of in-house tools that we made. By 2002, we had pretty much converted from an optical-engineering company to one that created products.

Doug Kreysar

By the late 2000s, we realized that if we were going to satisfy big production orders from companies that, for example, wanted to install large numbers of our systems on their production lines, we had to take some executive steps, such as creating a China office. That's where displays are manufactured. If you're going to do production testing, you have to have a big support team in China. So we added a China presence, and now have offices in Shanghai and Shenzhen, as well as in Seoul and in Washington, where our headquarters are.

In 2011, with the help of private equity, we merged with Zemax, a raytracing company. That merger enabled us to make those global investments and propelled us to the next level in terms of being able to support a wide range of customers.

ID: That's when you became Radiant Zemax.

DK: Yes, we changed our name from Radiant Imaging to Radiant Zemax. Over the course of 2011 to 2015, we really focused on two major initiatives. One was making sure we could satisfy the production needs of customers all over the world, and the other was a new machine-vision sector, which we called Advanced Vision. We had been making high-end cameras with high-end software that enabled the detection of all sorts of defects in displays. And our customers asked: If you can detect these mura defects in my displays, what about scratches, dings, and defects in other parts of my device [like the back of a mobile phone] that are not lit up? This functionality required a machine-vision type of application that could detect the kinds of defects that human visual inspectors typically find.

Then, in 2015, Konica Minolta acquired Radiant Zemax as part of its Sensing group. Shortly before that we had divested Zemax, which now runs its raytracing business on its own, and became Radiant Vision Systems. We have about 200 employees.

ID: At what point did you join the company?

DK: I actually started in 2000 as an optical engineer, so at the very

This article is based on phone and email interviews conducted by Jenny Donelan, editor in chief of Information Display.

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end of our first phase. When we became a product company, I joined operations because I had a background in automotive, which is a highly disciplined area in terms of quality and production.

ID: Your newest product is an augmented-reality/virtual-reality (AR/VR) lens for testing. How did you come to develop that?

DK: I would love to claim that we had the wonderful foresight to develop this ahead of the market demand, but to tell the truth, our customers were pretty much hitting us over the head, saying you need to come up with something to give me the testing I want.

ID: When did this AR/VR demand begin?

DK: AR/VR started to get hot as far back as five years ago. About three years ago, there was specific demand from customers who said: I really want you to provide an off-the-shelf lens that can act as though it's a human looking inside the goggles.

ID: What were some of the challenges of creating that kind of off-the-shelf AR/VR product?

DK: Metrology is difficult to begin with, but when you add a new lens to your known equipment, it can be very difficult to understand how to calibrate it. There are so many different "gotchas" for a lens that has to basically act as an eye inside an AR/VR system. You need a long barrel, with the "pupil" at the end, and you've also got to have a very wide field of view. Optically, that's a challenge, as is getting a manufacturer to make all the high-quality optical components required. The right apertures and so on are critical.

Once you have the lens, you have to learn how to calibrate it for metrology. To get correct absolute measurements, we had to calibrate response non-uniformity, or "flat-field" calibrate, as well as having to remove lens distortion and calibrate for absolute luminance and color accuracy. The equipment we had for calibrating standard lenses was not appropriate for this new type of lens. So we had to develop all new equipment for this lens. But that's the kind of thing we love doing.

ID: How has customer reaction been thus far?

DK: It's been wonderful. We've probably gotten as good a reaction to the AR/VR lens as to any product we've ever come out with. It's a hit. But there's more work to be done. For example, what are the standards for testing near-to-eye displays? What are the distance units we're going to use? What are the coordinates? These questions really need to be answered by the industry as a whole, as we all gather more experience on AR/VR device metrology.

ID: In terms of revenue stream, everybody in the display industry is always looking for the next big thing to replace TVs. To some extent, that's the automotive market. But people are also looking to AR/VR. From your perspective, do you have a sense of whether AR/VR will be a shot in the arm for the display industry? Are people having successes with these products that might eventually make them ubiquitous?

DK: My answer revolves around the book and soon-to-become motion picture *Ready Player One*.[1] Everybody at SID needs to make sure they have read, or when it comes out, watched, *Ready Player One*. It has a pretty dismal view of the future, and I don't subscribe to that. But I do subscribe to the author's interpretation of the potential popularity of VR. I think if you look at gaming applications alone, the market is huge. And when you talk about AR, be it medical or military or automotive applications, I think that market is huge as well. These AR applications are going to save people's lives. So they will be put in place. I don't think it's an option. 3D, by contrast, is a bit of an option. In short, I'm very bullish on the AR/VR market.

ID: What kinds of AR applications do you think are the musts? The life-saving ones?

DK: First, there are military applications. If you are training people in an airlift space or in space exploration, all of your training can be done in a virtual world, which is such a savings in terms of expense and safety. In the medical space, AR opens up all sorts of new surgeries and techniques to enhance a surgeon's capabilities. And finally, in automotive, you're talking about enhancing our driving capability or of course coupling that with self-driving cars.

ID: What makes a successful metrology company? What are some of the best practices as well as some of the biggest challenges involved in your space?

DK: The problem with a metrology company is that so much of metrology is engineering. How do I get an accurate answer and how do I calibrate it? It's extremely complicated. But your focus can't *just* be on engineering. It has to be on the customer. The customer doesn't care what product is being used to measure what they want. We care about the product, of course. It's our product. But the customers care more about the result. Is it a pass/fail? What's the uniformity of this display? What's the color of this display?

So the most important thing is listening to your customer. And creating the product that your customer wants. If your customers are having difficulty measuring something and you can diagnose

> **"Everybody at SID needs to make sure they have read, or when it comes out, watched, *Ready Player One*."**

[1] *Ready Player One* is a 2011 science fiction novel by Ernest Cline that features a worldwide virtual-reality game. The movie based on the novel came out in late March of 2018.

(continued on page 53)

Products on Display at Display Week 2018

Those products on display at North America's largest electronic-display exhibition that were offered for preview are described here.

by The Editorial Staff

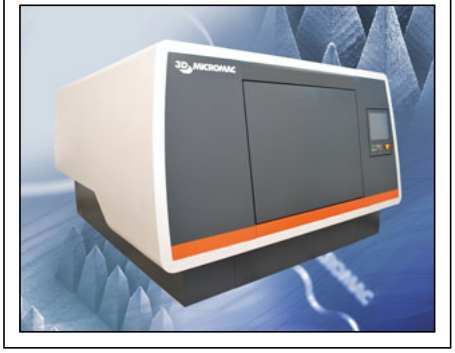
THE SID 2018 International Symposium, Seminar, and Exhibition (Display Week 2018) will be held at the Los Angeles Convention Center in Los Angeles, California, the week of May 20. For three days, May 22–24, leading manufacturers will present the latest displays, display components, and display systems. To present a preview of the show, we invited the exhibitors to highlight their offerings. The following is based on their responses.

3D-MICROMAC AG

Chemnitz, Germany 49-3714004326
www.3d-micromac.com
Booth 631

Laser Lift-Off System

Laser processing is a key enabling technology for display device fabrication. Especially for the manufacturing of ultrathin and flexible display components, laser lift-off processes are essential. 3D-Micromac will be showcasing its new microLIFT product family for laser lift-off for large areas as well as selective debonding of LED, OLED/AMOLED, and microLED devices. The microLIFT systems deliver the highest flexibility in tool design with multiple laser sources and process head configurations. The systems have been optimized for processing with high throughput in mass production and offer some of the best duty cycles in the market.

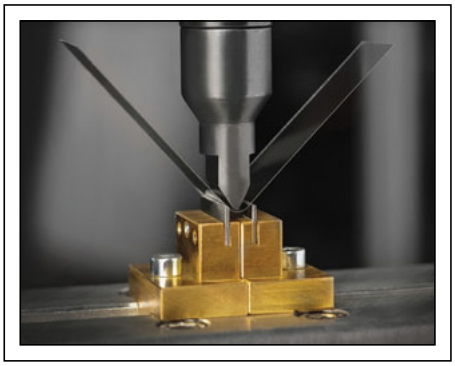


ABRISA TECHNOLOGIES

Santa Paula, CA 805-312-5873
www.abrisatechnologies.com
Booth 1135

Ultra-Thin Damage-Resistant Glass for Touch Displays and Sensors

Abrisa Technologies now offers ultra-thin yet strong SCHOTT AS 87 aluminosilicate glass solutions of 0.1- to 0.25-mm thickness, complete with fabrication, optical coatings and in-house high ion-exchange strengthening process. AS 87 is made to withstand the high levels of mechanical impact, bending, and scratching expected with mobile, touch, and portable devices. AS 87 thin-glass solutions are ideal for touch sensors where increased sensitivity is desired. It is a lightweight protective glass for wearables, portable or mobile devices, and a low-profile damage-resistant solution for slim displays. Abrisa Technologies also offers products with wide-angle anti-reflective and specialty coatings.

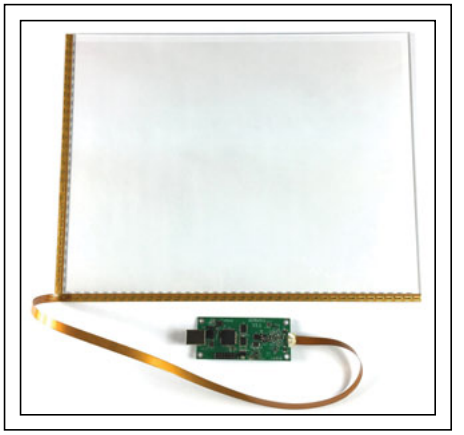


A D METRO

Ottawa, Canada 800-463-2353
www.admetro.com
Booth 1235

Multiplexed Projected Capacitive (MPC) Technology

A D Metro presents the first production prototype of its next-generation projected capacitive (MPC) technology. Some of the key benefits are that one controller works with any size of sensor; there is no more controller programming to handle specific sensor channels and orientation and no need for a large ribbon cable – only three wires are required. Additionally, the system is much more tolerant of radio interference. Cost and production methods are identical to those of conventional PCAP.



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AGC ASAHI GLASS

Tokyo, Japan 81-50-9014-3589
www.agc.com/english/index.html
Booth 717

Windowless Room Technology

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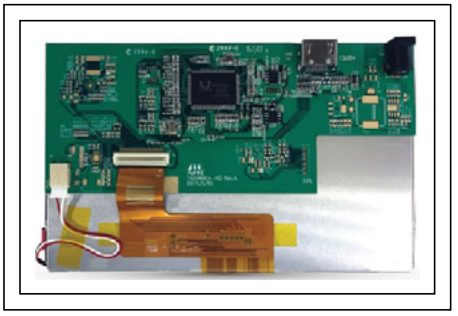
New Taipei City, Taiwan 886-2-2696-7269
www.ampire.com.tw
Booth 335

Industrial Open-Frame LCD and HDMI AD Board

Ampire provides an open-frame LCD for easy integration with an AD or ARM board and the option of resistive touch screen and capacitive touch screen, which provides an excellent and easy integration for applications like kiosk, POS, or control panel. Ampire also offers a new display control board with HDMI interface, resolution support up to 1,920 × 1,080, single-power supply operation, and single/dual channel LVDS output. With Ampire's wide range of displays, its HDMI control board provides an easier and friendlier option for customers' designs.



ANI CO., LTD.

Suwon, South Korea +82-10-2763-9856
www.anieng.com
Booth 650

Colorimeter

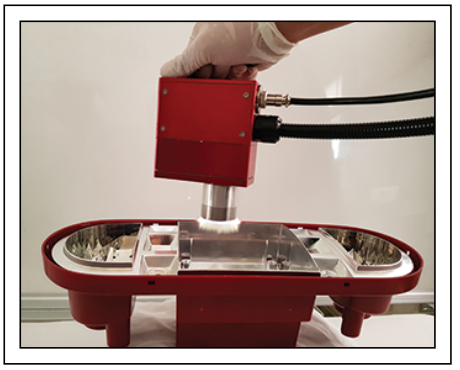
The CM-H600 colorimeter delivers key capabilities to measure flat-panel displays. ANI Co. has been continuously improving product performance since launching its first colorimeter developed with its own technology in 2013. Features include: tristimulus values sensor photodiode adopted; color chromaticity, luminance, and flicker contrast/JEITA measurement mode; high-speed measurement suitable for in-line tester (30 counts @≥10 cd/m^2); no controller, light weight of 300 g (10 oz) and easy-to-use button with built-in display-enabled portable use; ability to measure low luminance levels @ 0.02 cd/m^2 with accuracy of ±0.003 (chromaticity).

APP CO., LTD

Dongtan, Korea 82-10-5295-0579
www.applasma.com
Booth 1149

Atmospheric Plasma

APP Co., a professional research business focusing on atmospheric plasma, offers general solutions (cleaning, activation), nanoprocessing solutions (etching), and functional solutions (reduction, sterilization). APP leads in the areas of atmospheric plasma technology and applications.

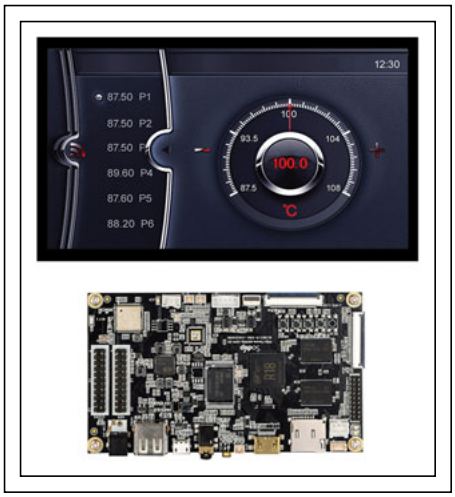


AVD (SHENZHEN AV-DISPLAY CO., LTD.)

Shenzhen, China 86-755-88860696
www.av-display.com
Booth 204

Video Driver Board Packages

AVD's total solution includes video driver board, serial port/HMI, ARM M3/M4/A9 and other product platforms, supporting RTOS/Android/Linux and other operating systems, which are widely used in industrial control displays, home appliances, and smart homes. Intelligent applications such as human-computer interaction products integrate TFT/CTP/control boards and other resources to provide various cooperation modes such as complete machine manufacturing/JDM/ODM/OEM/SKD.

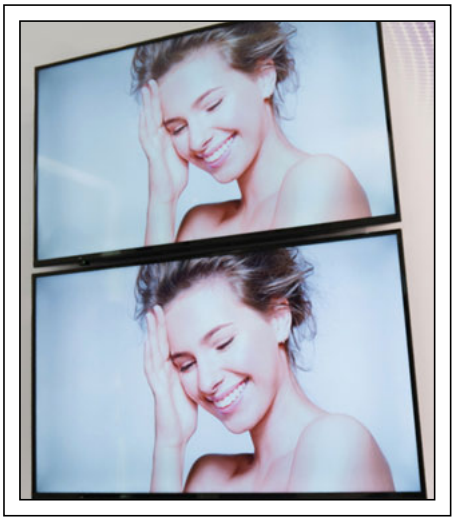


BENQ MATERIALS CORP.

Taoyuan, Taiwan 886-3748800
http://benqmaterials.com
Booth 1057

OLED-Like Materials

BenQ Materials Corp. (BMC), a BenQ Group company with some of the world's top-functioning film technology, is going to demonstrate an "OLED-like" product during Display Week. Through its own coating and ultra-precision machining technology, BMC's OLED-like product is able to deliver a true black and vivid viewing performance for high resolution (especially 8K) LCDs. Benefits of this product are more noticeable on larger displays. BMC will also demonstrate solutions of high durability and flexiblility.



BENTELER MECHANICAL ENGINEERING

Fort Wayne, IN 260-434-3505
www.benteler-glass.com
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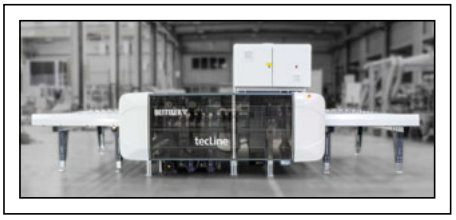
Glass Processing Equipment

BENTELER glass processing equipment enables solutions for architectural, automotive, and technical glass. With more than 3,000 successfully delivered machines; BENTELER is one of the largest leading suppliers for the glass industry.

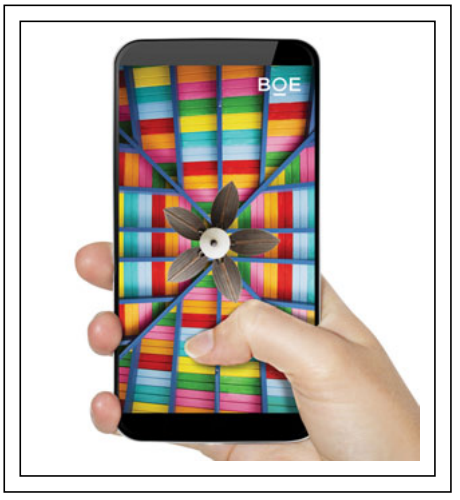


BOE

Beijing, China 86-18610920719
www.boe.com/en/index/pei.html
Booth 705

6.18-in. AMOLED Panel with Fingerprint Identification

BOE's 6.18 FUD is an AMOLED panel with fingerprint identification under the display, which is designed according to the principle of pinhole imaging. The total thickness is thinner in the case of Mapis integrated in BP. The resolution is as high as 800 dpi, which makes it possible to identify pores as well as lines as fine as 31.75 µm, and meets the requirement of three-level fingerprint identification. FPS thickness is less than 570 µm and response time is less than 300 ms.

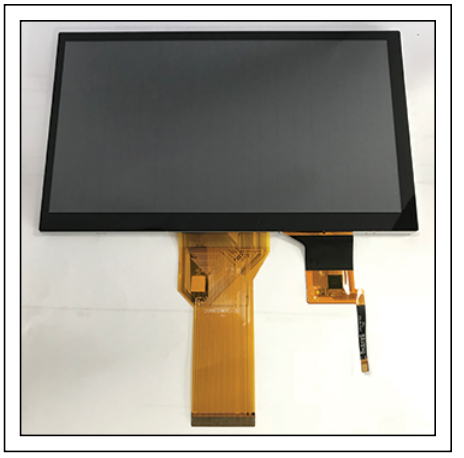


CDTECH ELECTRONICS CO., LTD.

Shenzhen, China 86-137-1368-9582
www.CDTECH-LCD.com
Booth 214

7-in. Panel with PCAP

Shenzhen CDTech's S070SWV94HG-DC16 is a 7-in. TFT panel with PCAP and a resolution of 800 × 480. The LCD interface is 24-bit RGB and luminance (with PCAP) is 450 nits. Operating temperatures are –20 ~ +70 C. Potential applications include POS machines, handheld devices, portable devices, medical devices, GPS, industrial devices, and more.



CHROMA ATE, INC.

Irvine, CA 949-421-0355
www.chromaus.com
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8K Display Testing Solutions

The Chroma 8K Video Pattern Generator model 2238 is an industry-leading and extremely competitive display testing unit that meets the highest standards for customer display testing needs at the lab or on the production floor. From USB Type-C, HDMI 2.0a, and DisplayPort 1.4 to traditional analog signals, Chroma 2238 can incorporate up to four modules and output both timing and pattern signals from all four modules simultaneously. Its modular design allows easy upgrades to the latest industry signal standards without replacing the whole unit. Ethernet remote control allows easy integrations to custom-built automatic testing system.

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Fremont, CA 925-487-7259
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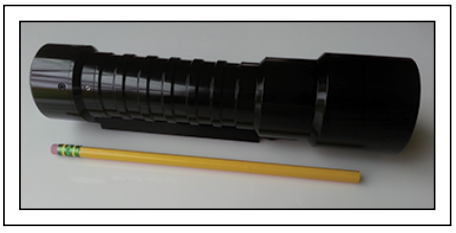
Booth 1345

Portable Photometer

The CR-120 is a portable, high-end photometer with the performance of a laboratory-grade instrument. Specifically designed to measure black levels on OLED displays and room darkness in a few seconds, it can measure 0.001 cd/m^2 in 1 second with only +/– 2 percent error and measure down to 0.0001 cd/m^2 in 8 seconds.

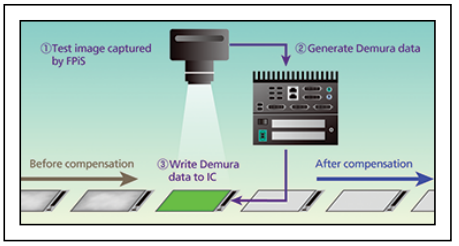


CYBERNET SYSTEMS CO., LTD.

Tokyo, Japan
www.cybernet.co.jp
Booth 236

Mura Correction for OLED Displays

Cybernet Systems offers a Mura correction system for use in OLED display production lines. The system performs high-precision, high-speed Mura correction in consideration of the impact of "gray-scale dependent for Mura (sub-pixel unevenness, IR drop)," which are characteristic problems for OLEDs. Automation is achieved for all processes, from measurement to Mura correction and Mura compensation data writing via customization based on applicable panels and production lines.

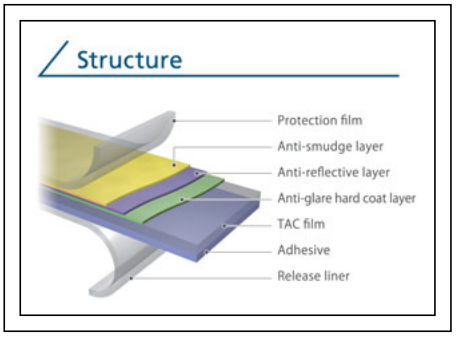


DEXERIALS CORP.

San Jose, CA 408-564-5744
www.dexerials.jp/en/
Booth 1339

Anti-Reflection Film

Dexerials' sputtering process controls thin-film thicknesses at the nano level to form films with an anti-reflection layer consisting of multiple layers with different refractive indices. This structure uses interference of light to reduce reflection. In addition to excellent optical properties, the film has an "easy to clean" function. Applications include, but are not limited to: center information displays, instrument clusters, and mirror displays.

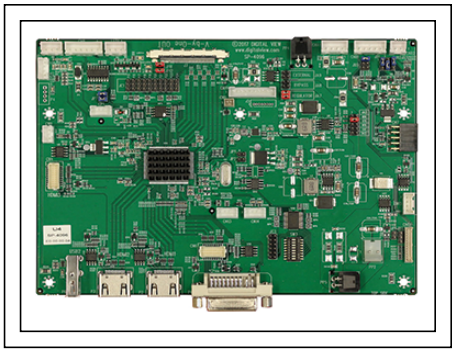


DIGITAL VIEW, INC.

Morgan Hill, CA 408-500-3509
www.digitalview.com
Booth 514

LCD Video Controller

The SP-4096 4K version from Digital View is the latest generation LCD controller for video signals up to 4,096 × 2,160 and LCD panel resolutions up to 4,096 × 2,160 with V-by-One connectivity. The SP-4096 meets the needs of many applications but is likely to appeal most to the digital signage market, given the built-in H.264 fail-over media player, and the legacy industrial market for its composite video input. The SP-4096 is supported by a wide selection of panel-connection cables and other accessories, together with system development documentation including 3D drawings.

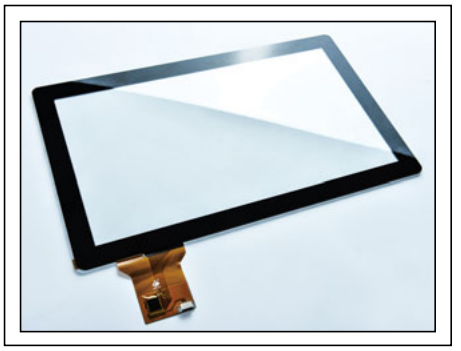


DIGNITY TOUCH SOLUTIONS

Foshan, China 86-757-2290-8381
www.dignity.com.cn
Booth 210

PCAP Touch Products

Dignity's newest line of PCAP touch products consists of a range of small- to medium-sized touch panels and touch display modules (from 3.5 in. to 10 in.) specifically designed for use in appliance, instrumentation and medical applications. The panels are suited for use in extremely adverse conditions, with exceptional EMI, water and fingerprint resistance, and support for cover lens thicknesses of up to 7 mm. A range of customization options are available for cover lens and touch performance. This product line is designed for exceptional reliability and ease of integration and is highly suited for companies upgrading product controls from analog to digital.



DIMENCO

Veldhoven, The Netherlands 31-040-401-1980
www.dimenco.eu
Booth 1519

Simulated Reality Display

The ultimate simulated reality (SR) is a great experience that you can't distinguish from reality.

Dimenco proudly presents an SR Level 1 experience at Display Week. The company strongly believes that the way we interact today with our displays will radically change. In the past we had to learn to interact with our display by using a mouse. Nowadays we use touch and gestures. We now have the technology to build an SR display with which you interact with objects as you would in real life.

DLC DISPLAY CO., LTD.

Shenzhen, China 86(0)18929371045
www.dlcdisplay.com
Booth 221

AMOLED Display

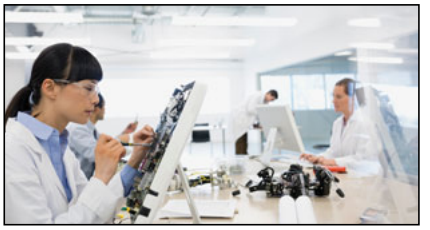
DLC Display Co. has created a 1.3-in. round AMOLED display with 360 (RGB) × 360 resolution.

DOW CHEMICAL COMPANY

Midland, MI
https://consumer.dow.com/en-us/industry/ind-pcb-systems-assembly.html
Booth 1439

Silicone Technologies for PCB and Systems Assembly

The DOWSIL product brand name represents the combined power of Dow and Dow Corning and emphasizes longstanding global expertise in silicone technologies across dozens of industries, including printed circuit board (PCB) and systems assembly.



EDGE ELECTRONICS

Bohemia, NY 631-860-1127
www.edgeelectronics.com
Booth 415

LCD Harsh-Environment Quick Kit

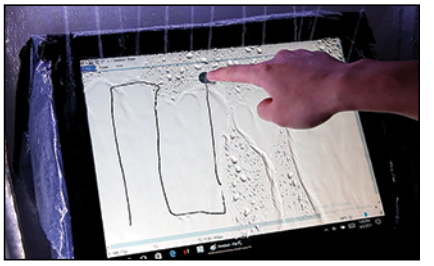
The EDQKN116FH2DHE301 is one of Edge Electronics' most popular kits. Its base is an 11.6-in. industrial FHD LCD panel. This is an ultra-wide embedded DisplayPort (eDP) panel featuring superfine TFT, high contrast, wide color gamut and temperature range, LED backlight with built-in LED driver, and an eDP interface. The unassembled kit includes the LCD panel, harsh-environment controller board, OSD board, OSD cable, eDP cable, and power cable. Other custom LCD kit solutions include SBCs, LCD controllers, LED drivers, touch screen integrations, and custom cables.

EGALAX_EMPIA TECHNOLOGY, INC.

Taipei, Taiwan 886-2-87515191
www.eeti.com
Booth 1145

PCAP Touch Controller for Harsh Environment

eGalax's touchscreen solution offers superb dual-touch performance in the harshest environments. Tested for ruggedization and approved by world-wide top-tier marine navigation system companies and high-standard industrial display manufacturers, this controller family features robust performance and supports water rejection, gloved hands, palm rejection, EETI active stylus pen, and vandal-proof thick cover glass.



E INK CORP.

Billerica, MA 617-499-6030
www.eink.com
Booth 521

Reflective Electronic Displays

E Ink, a leading innovator of electronic paper display technology, partnered with Ueberall International and the San Diego International Airport to introduce DAZZLE, the world's largest public artwork installation of reflective electronic displays. Located at the San Diego International Airport's Rental Car Center, DAZZLE enhances visitors' experience through over 2,000 individual flexible E Ink Prism tiles that display dynamic animations across the 1,600-foot-long exterior façade of the building. This visual experience is viewed daily by hundreds of thousands of airport visitors, motorists, and public transit users.

ELDIM

Hérouville Saint-Clair, France 33-2-31-947-600
www.eldim.eu
Booth 1121

Optical Measurement Systems

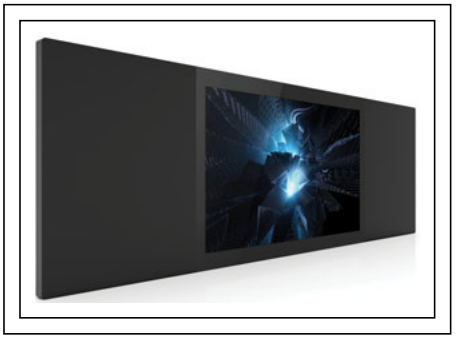
ELDIM's VCProbe system allows an extremely fast viewing-angle measuring solution for flat, curved, and flexible displays. VCProbe's optics and sensors concentrate many innovations. The system requires only one measurement and all the angles are measured at the same time. Display characteristics are measured in less than 2 s with a viewing-angle aperture up to +/– 80°. Mounted on a robotic arm, it can take several measurements on different areas, making it an extremely fast mapping tool to use on production lines and for quality control.

FAYTECH TECH. CO., LTD.

Ottobrunn, Germany 49-1623313235
www.faytech.com
Booth 655

86-in. Interactive Blackboard

An interactive blackboard is an ideal addition to a classroom. Faytech's 86-in. optically bonded multitouch capacitive touchscreen allows easy demonstration and interaction with any media. Blackboard additions to the sides of the screen and a special cover glass allow writing with chalk on the surface to enhance the educational process. Main features include: display resolution of 3,840 × 2,160; viewing angle of 178°/178°; full dimensions of 4,200 mm × 1,350 mm × 70 mm; display area of 1,895 mm × 1,066 mm; aspect ratio of 16:9; and luminance of 320 cd/m^2.

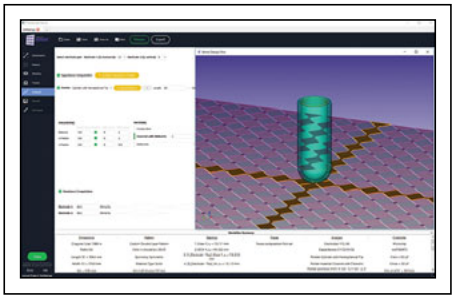


FIELDSCALE

Thessaloniki, Greece 302310947484
https://fieldscale.com/
Booth 1529

Simulation Software for Touch Sensor Design

Fieldscale SENSE is the first simulation software dedicated to touch sensor design. It can be used by any engineer, beginner or expert, to make informed design decisions, starting from day one. SENSE's fully automated simulation features include automated 3D touch sensor modeling, compatibility check between any touch sensor and any controller, simulation of metal-mesh patterns, and simulation accuracy within 3 percent against measured values of actual touch-sensor manufacturers. With SENSE, IC and touch sensor manufacturers can experience unprecedented simulation speed and massive cost savings by scaling their customer support and improving their product development cycles.

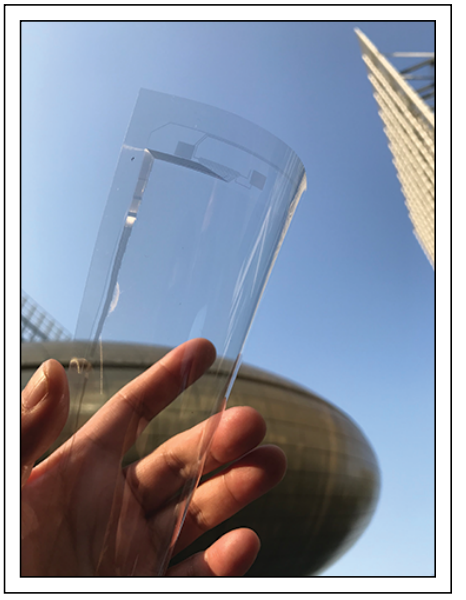


FLECTRODE TECHNOLOGY LTD.

Hong Kong 852-51269091
www.flectrode.com/
Booth 1051

Transparent Conducting Films

Flectrode Technology's standard transparent conducting film comes in substrate sizes of < 500 × 500 mm and thicknesses of 100 to 200 µm. Mesh linewidth is 2-5 µm and mesh linewidth tolerance is ± 0.5 µm. Transmittance is ~90% and sheet resistance is ~0.8 ohm/sq. Also available are touch-panel films in substrate sizes of 73 × 138 mm and film thicknesses of 100–200 µm.

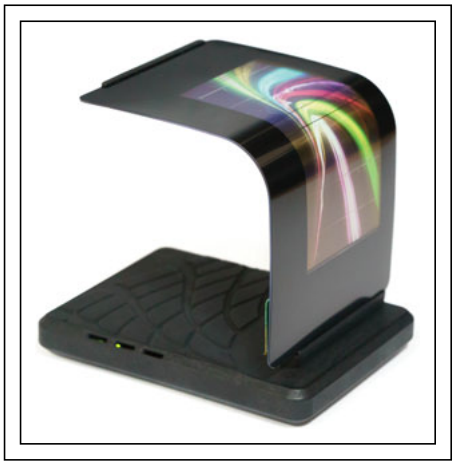


FLEXENABLE

Cambridge, UK 44-1223706000
www.flexenable.com
Booth 1338

Organic LCD

FlexEnable's glass-free organic LCD (OLCD) delivers high-luminance, long-lifetime, flexible displays that are low cost and scalable to large areas, while also being conformable and shapeable. The use of plastic substrates and organic materials makes OLCD at least four times thinner and ten times lighter than glass-based LCD. With the technology currently being transferred into mass production in China, OLCD will transform how and where displays are used in products. It enables new product paradigms and use cases for a range of applications across consumer electronics, smart home appliances, automotive, digital signage, and beyond.

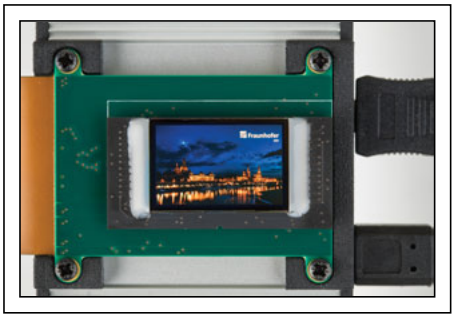


FRAUNHOFER INSTITUTE FOR ORGANIC ELECTRONICS, ELECTRON BEAM AND PLASMA TECHNOLOGIES (FEP)

Dresden, Germany 49-351-8823-238
www.fep.fraunhofer.de
Booth 613

OLED Microdisplay for VR Headsets

Within the EU-funded project LOMID, a new microdisplay with WUXGA resolution (1,920 × 1,200 pixels) has been developed. The new OLED microdisplays have a 1-in. diagonal and a pixel density of 2,300 ppi. They benefit from the very high frame rate possible with new 120-Hz chips. This helps to minimize "motion sickness" effects that can arise with VR systems. The project has designed the microdisplays in conjunction with novel optics using the ThinEyes technology patented by Limbak. The new optics enable very high-resolution VR by using four WUXGA displays in a particularly compact design.



FRAUNHOFER INSTITUTE FOR SILICATE RESEARCH (ISC)

Würzburg, Germany 49-931-4100-515
www.isc.fraunhofer.de/
Booth 629

Outcoupling Layer Based on Micro-Optical Elements

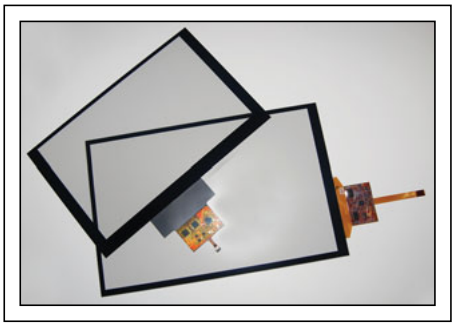
Below is an outcoupling layer based on an arrangement of 10,000 microprisms forming the logo of the Fraunhofer Institute for Silicate Research. It was fabricated by femtosecond laser-based additive manufacturing (two-photon polymerization). The individual prisms redirect by total internal reflection. The geometry of a single prism is as follows: height = 30 µm; size = 60 µm. The lateral pitch of the individual prisms is 75 µm. Arrangements like this can be fabricated with arbitrarily shaped micro-optical elements in different sizes and on a variety of substrates. Mass production can be enabled by replication technologies.

FUJITSU COMPONENTS AMERICA

San Jose, CA 800-380-0059
http://us.fujitsu.com/components/
Booth 1305

PCAP Touch Panels

The PCAP-S series projected-capacitive touch panels feature a film-film sensor with cover glass in sizes from 7 in. to 21 in. Basic features are 85 percent transmissivity with 1 percent haze, 2-finger gesture operation (10-finger detection), and an operating life of 10 million touches. A chip-on-film (COF) controller IC with USB interface is standard, with a 1-mm-pitch FFC connection. The panels are suitable for a wide variety of applications including industrial, instrumentation, and medical products. The cover glass is often required to be customized to meet product design requirements, so Fujitsu offers cover-glass customization, as well as full custom-sizing design services.



FUTABA CORP. OF AMERICA

Plymouth, MI 734-459-1177
www.futaba.com
Booth 1036

Capacitive Touch Panels

Futaba's capacitive-touch panel products were developed using thin-film formation technologies perfected in its electronic component manufacturing processes. With their outstanding sensitivity and resistance to harsh environmental conditions, they are finding an increasing number of applications in consumer products and automotive in-vehicle equipment that requires a high level of reliability.

GAMMA SCIENTIFIC

San Diego, CA 858-279-8034
www.gamma-sci.com
Booth 405

Near-to-Eye Measurement

The GS-1290 NED is one of the world's first precision instruments for characterizing the qualified viewing space of near-to-eye displays, delivering high-spatial-resolution color and contrast measurements for virtual and augmented reality and head-up displays (HUDs) as viewed by the human eye. The NED employs an integrated autocollimator camera viewing system and high accuracy spot spectroradiometer, providing information such as luminance, color, contrast, uniformity, spectral transmittance, response time, MTF, and parallax error. The system is ideally suited for manufacturers of near-to-eye displays in entertainment, medical, avionics, and industrial applications, conforming to standards being developed by the IDCM committee of the SID & IEC.

GOOCH & HOUSEGO

Orlando, FL 407-422-3171
www.ghinsyruments.com
Booth 1314

Spectroradiometer

The new Aries Spectroradiometer is a total top-to-bottom, next-generation design, utilizing state-of-

the-art, high-speed signal processing and a new, powerful software suite for anything from research to high-speed production applications. Processor-level calculations offer the highest production-capable throughput to acquire measurement results in the fastest times possible. The Aries comes standard with an internal automated ND filter wheel, providing increased dynamic range for flexible low to high light-level measurements. Aries is offered in wavelength ranges covering 200 nm to 1100 nm and has built-in wavelength check and reference lamp sources.

GROGLASS

Riga, Latvia 371-6750-2910
www.groglass.com
Booth 652

Anti-Reflective Coatings

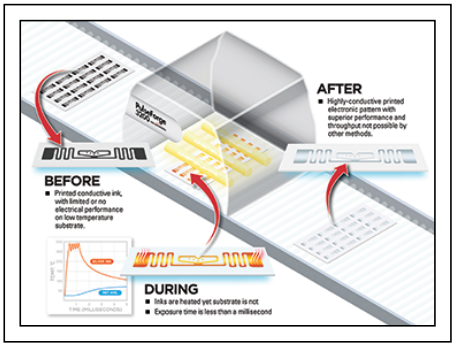
Groglass is a high-quality coating manufacturer offering its customers from over 50 countries a wide variety of specialized value-added coatings on glass, polycarbonate, and acrylic for indoor and outdoor applications across multiple industries like high-end electronic displays, cold-storage displays, commercial showcases, architecture, and lighting. In addition to its anti-reflective high-reflective UV blocking and low-e + anti-reflective coating, this year Groglass is adding several new products to its portfolio, including a combination of near-infrared blocking coating + anti-reflective coating as well as three new base materials for customers to choose from: acrylic, polycarbonate, and etched glass.

HITACHI HIGH-TECHNOLOGIES

Schaumburg, IL 847-273-4330
www.hitachi-hightech.com/global/
Booth 341

Photonic Curing System

The Hitachi High-Tech Group has formed strategic partnerships with various companies who have developed leading-edge thin-film technologies and who have unique products covering multiple applications. During Display Week Hitachi is showing a few of these unique technologies and products related to the display industry, including the NovaCentrix PulseForge Photonic Curing System. The PulseForge tools continue to revolutionize the printed electronics industry through photonic curing, enabling product innovators and manufacturers the option of flexible substrates not possible with conventional ovens and lasers.



HODOGAYA CHEMICAL (U.S.A.), INC.

White Plains, NY 914-422-0888
www.hodogaya.co.jp/english/
Booth 610

Materials for OLED Development

Hodogaya Chemical Group has developed hole-transport materials (HTMs), electro-transport materials (ETMs), electro-blocking layers (EBLs), and emitting materials for OLED applications. In particular, one of its group companies, SFC, supplies blue dopant and host materials, and red host materials, to meet customers' needs. The company is also developing new materials for thermally activated delayed fluorescence (TADF) and soluble OLED applications. Its unique materials will help extend life, decrease voltage, and increase efficiency for OLED devices.

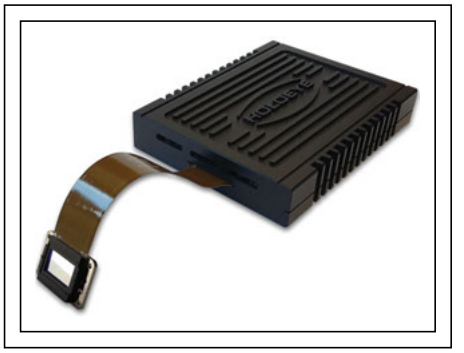
For the latest on Display Week 2018:
www.displayweek.org

HOLOEYE PHOTONICS AG

Berlin, Germany 49-3040369380
holoeye.com
Booth 606

Phase-Only Spatial Light Modulators

The GAEA-2 phase modulator models are based on reflective LCOS microdisplays with a maximum resolution of 4,160 × 2,464 pixels and small (3.74-µm) pixel pitch. The display size is 0.7 inches (15.32 × 9.22 mm). Other specs include a 90 percent fill factor; 8-bit addressing; 133.5 lp/mm maximum spatial resolution; and the following input frame rates: 60Hz (3,840 × 2,160), 60Hz (4,000 × 2,160), and 58Hz (4,160 × 2,464). Currently the GAEA-2 series includes a version for the visible (420–650 nm), for the NIR (650 to 1,100 nm), and for 1400 to 1700 nm (e.g., C-Band 1,550 nm).

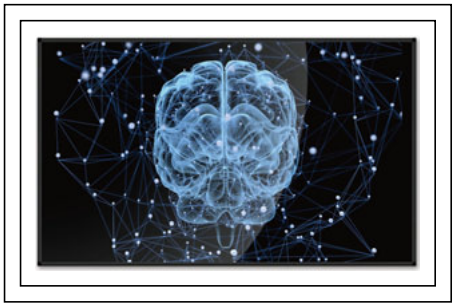


HUAXIN ELECTRONICS CO., LTD.

Guangzhou, China 86-18922422707
www.huaxintouch.com
Booth 215

Multipoint MD Series

Based on a brand-new 1-GHz A8 processor, Huaxin's MD series achieves excellent performance with multipoint 3-mm nib simultaneous writing. A smoother experience in touch and writing makes it a more effective tool. Fingers, smart stylus, pencils, and even toothpicks can all be used as writing tools. And due to object-size recognition, different color writing can be achieved even with a passive stylus.

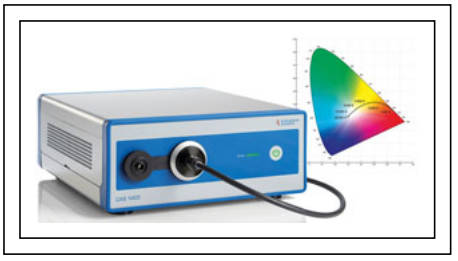


INSTRUMENT SYSTEMS GmbH

Munich, Germany 49-89-4549430
www.instrumentsystems.com
Booth 1329

Light Measurement Equipment

At Display Week 2018, Instrument Systems will be presenting its latest light-measurement solutions certified by the company's test laboratories which recently were accredited to ISO 11664 for the measurement of colorimetric quantities. The key product for related applications is the innovative stray-light corrected array spectrometer CAS 140D that ensures a uniquely high level of accuracy. The traceable measurement uncertainties are only ±0.0015 on the standard chromaticity coordinates of white LEDs and are reliably estimated using state-of-the-art validated Monte Carlo calculations. In interaction with other modules the CAS 140D is ideal, e.g. for highly accurate measurements of CCT or CRI.



I-PEX CONNECTORS

Austin, TX 512-339-4739
www.i-pex.com/Products/detail/144
Booth 510

Micro-Coaxial Cable Connector

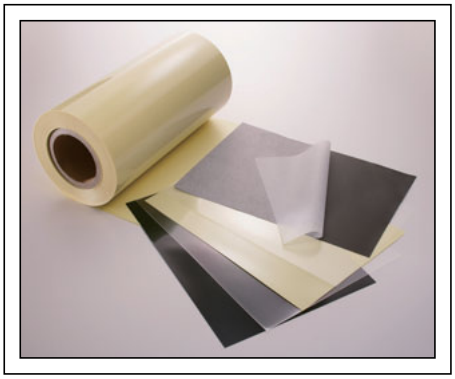
The CABLINE-VS II Micro-Coaxial Cable Connector is a new graphics connector from I-PEX for Thunderbolt 3 and higher-data-rate (+20 Gbps) differential signal-transmission cable assemblies. The new I-PEX CABLINE-VS II accepts micro-coaxial wire into the 0.5-mm pitch connector, which includes 360-degree shielding for EMI containment. Thin LED-backlighted display assemblies use the low-profile, high-speed graphics connector with a mated height of 1.3 mm maximum. The graphics connector also delivers backlight and TCON power to the display.

IWATANI CORP. OF AMERICA

Houston, TX 713-838-5018
http://electronic-materials.iwatani.co.jp/eng/index.html
Booth 429

Acrylic Foam and Silicone OCA Technology

Iwatani Corp. provides functional film and industrial tape products that are specialized for electronic devices. The ISR-ACF series acrylic foam has high-impact-absorbing performance and is widely used for display breakage prevention. The ISR-SOC series silicone OCA has high durability, heat resistance, and flexibility suitable for specialized displays such as reflective, flexible, and OLED. Furthermore, its low refractive index improves the visual quality of the display. With those innovative technologies, Iwatani's products provide the possibility of different design concepts so customers can develop freely.



JDI DISPLAY AMERICA

www.j-display.com
Booth 917

Automotive Cockpit Display

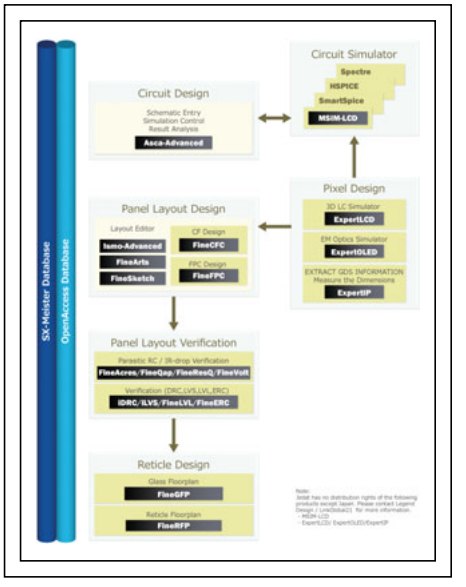
JDI believes displays will be the key human-machine interface in future autonomous driving vehicles. An automotive cockpit, showcasing three 12.3-in. displays tiled into one multicurved, panoramic display; a large-size 16.7-in. curved and shaped "Pixel Eyes" center information display with capacitive touch functionality; and, a 9.5-in. mirror-shaped rear-view display will demonstrate JDI's concept of the next-generation interior automotive space. Displays for other markets and applications, including mobile, virtual reality (VR), industrial, and electronic shelf label (ESL) will be exhibited as well.

JEDAT, INC.

Tokyo, Japan 81-3-6262-8401
www.jedat.co.jp/eng/
Booth 543

Flat-Panel Display Design Environment

Jedat provides an advanced design environment that facilitates the design of circuits, layout, and reticles of flat-panel displays, including both panels and peripheral circuits. It has extensive dedicated design and verification functions specializing in the design of flat-panel displays that are all used to increase design productivity. The flexibility that is inherent in Jedat tools allows tailoring to the specific needs of customers, further shortening the design verification cycle and improving the quality.

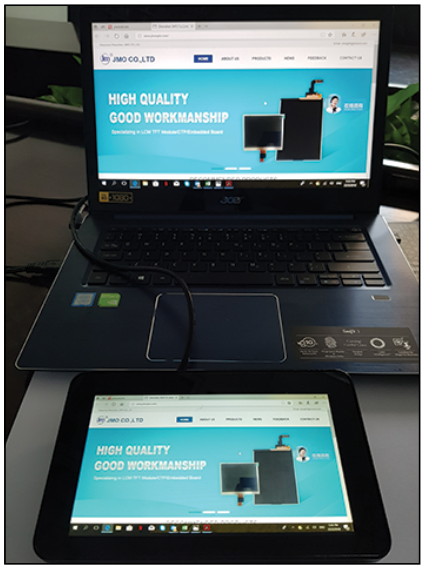


JMO DISPLAY

Singapore 65-90084831
www.jmoopto.com/
Booth 1543

USB Industrial Monitors

JMO offers capacitive-touch USB monitors for industrial applications in 7-in. and 10-in. sizes with resolutions of 1,024 × 600 and 1,280 × 800, respectively.



KIMOTO TECH, INC.

Cedartown, GA 310-522-5911
www.kimototech.com
Booth 508

LC3 Coating Line

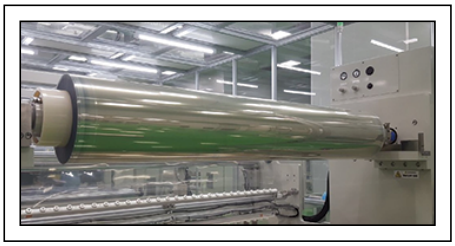
Kimoto Tech is a leader in the application of functional coatings and adhesives via roll-to-roll process on a wide range of flexible, web-based materials. The LC3 coater operates in a Class 1000 cleanroom and offers slot die, gravure, and Mayer rod technologies to dispense solvent and water-based coatings cured via UV and thermal drying. The advantages of a roll-to-roll coating process include greater productivity vs non-continuous processes and the ability to apply multiple layers of coating to optimize product performance. This machine has the capability to make high-performance coated films and laminates for functional and protective applications for displays.

KOLON INDUSTRIES

Apex, NC 919-303-5874
www.kolonindustries.com/Eng/main.asp
Booth 235

Colorless Polyimide

The flexible display revolution is now here, with a 1,500-mm-roll colorless polyimide (CPI) film technology from Kolon Industries. This is one of the best alternatives to glass and traditional optical displays available. The film can be folded or rolled, and boasts high transparency, superior mechanical properties, and heat resistance, along with a super-smooth surface. Now available in ultra-wide 1,500-mm rolls, CPI can easily be applied beyond flexible mobile devices to large applications.



KONICA MINOLTA SENSING AMERICAS

Ramsey, NJ 201-818-3574
https://sensing.konicaminolta.us/
Booth 1329

Display Color Analysis

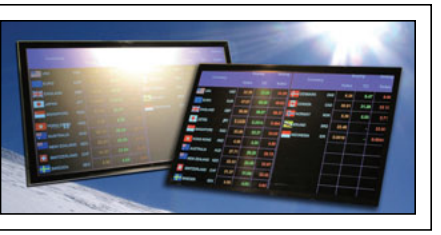
Konica Minolta Sensing presents a breakthrough in display color analysis and flicker and luminance measurement with its latest series of display color analyzers, the CA-410, the first in its next generation of light measurement. A primary feature of the CA-410 is flicker measurement. The CA-410 is capable of measuring both JEITA and contrast flicker. A new addition to the CA-410 is that it has an expanded frequency measurement range and adjustable frequency response. It allows accurate characterization of the flicker characteristics of modern/cutting-edge display technology.

KYOCERA INTERNATIONAL, INC.

Plymouth, MI 734-781-4879
www.kyocera-display.com
Booth 421

Optical-Bonded TFT LCDs

Kyocera will demonstrate its in-house optical bonding capability at Display Week 2018. Optical bonding integrates the display and a touch panel or cover layer into one unit. This technology eliminates the air gap, dramatically reduces internal reflections, and improves contrast, color saturation, luminance, and sunlight readability. Bonding the display and cover layer into one module also increases ruggedness and impact resistance, eliminating dust and condensation that could be trapped inside with conventional perimeter tape processes. For applications such as military, transportation, marine, medical, and outdoor use, optical bonding is a great way to improve display performance and offer additional protection.

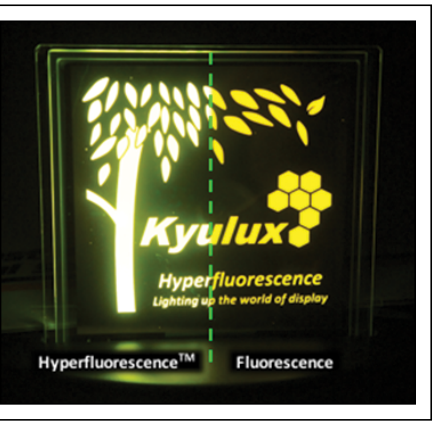


KYULUX, INC.

Fukuoka, Japan 81(92)834-9518
www.kyulux.com
Booth 238

TADF Hyperfluorescence

Thermally activated delayed fluorescence (TADF) and hyperfluorescence are the third and fourth gen-



erations of OLED emission technologies, respectively. TADF enables 100-percent quantum-efficient emission without using iridium. TADF, however, has a disadvantage in color purity because of its wide color spectrum. Hyperfluorescence combines TADF and fluorescence to provide the ultimate solution for OLED emission. In hyperfluorescence, TADF acts as a highly efficient exciton generator and energy transfer to fluorescence molecules. The result emits light of more than four times higher efficiency than conventional fluorescence. Unlike phosphorescence, it enables full RGB color, 100 percent IQE, and pure narrow-spectrum color.

LITEMAX TECHNOLOGY, INC.

Fremont, CA 510-509-7506
www.litemax.com
Booth 513

32-in. TFT LCD with LED Backlight

Litemax USA will be featuring the IPPS-3205-SDM1, a 32-in. industrial-grade sunlight readable and high-color-saturation LCD, with high luminance (800 nits) and high color saturation. The LCD produces sharp images, crisp text, and lifelike colors. The IPPS-3205-SDM1 will include the Intel SDM "Smart Display Module" pluggable and modular architecture to deliver new specifications that expand integrated form factors into additional market areas such as outdoor applications, kiosks, factory automation, military, transportation, and gaming.

LUMINIT

Torrance, CA 310-320-1066
www.luminit.com
Booth 1311

Transparent Holographic Component Development Kit

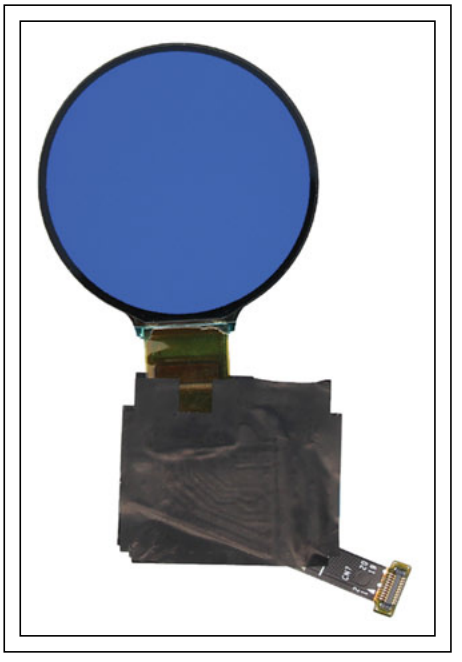
With Luminit's Transparent Holographic Component Development Kit, users can experiment with a variety of optical designs using Luminit transparent holographic optics. The combined THC Grating and THC Lens pair (also sold separately) essentially mimic the function of a conventional lens. These components can be combined in other configurations, or have other optics located in-between. This kit allows for basic experimentation with holographic optical elements that can lead to customized customer-specific designs.

LUMMAX ELECTRONICS CO., LTD.

Shenzhen, China 8675523099151
www.lummax-ele.com
Booth 1509

1.39-in. Circular AMOLED

The AHEM0139-01 from Lummax is a circular shaped 1.39-in. AMOLED, a super-thin color display that is only 0.20 mm thick. The dimensions are 38.6 × 40.5 × 0.67 mm. The resolution is 400 (W) × RGB × 400 (H). Features include: faster response time, unlimited viewing angle, self-luminousness, high luminance, high contrast ratio, wide operating temperature, lower power consumption, and sunlight readability. It can also be equipped with a capacitive touch screen and is very suitable for smart-wear products, especially the smartwatch.



MCSCIENCE, INC.

Suwon, South Korea 82-1099951679
www.mcscience.com
Booth 312

Colorimeter for Optical Tests and Measurements

The Qbism HEXA50 is a new product in a series of colorimeters for various optical test and measurement applications. It has special features such as object-adaptive hardware design compatibility with DeJign test jig and other environmental systems, dual-mode functions of color and spectrum measurement, wireless data communication, and powerful interface features for Windows PCs, Android tablets, and ParaMetric test instruments. Optical focusing, alignment, and viewfinder monitoring are basic features of the standard colorimeter's display measurement. Small and cubic, the colorimeter has good space efficiency in the integration of its display test system.

NANOCOMP OY, LTD.

www.nanocomp.fi
Booth 412

High Performance Frontal Lightguide for e-Paper and Digital Signage Displays

Nanocomp has developed a film-based lightguide for 13.3-in. e-paper displays. The ultra-thin (0.5-mm) lightguide has excellent luminance uniformity and color properties. It's designed for digital signage applications such as timetable displays, but also works for handheld devices. Full optical bonding minimizes outside reflections. While the lightguide is an off-the-shelf component, made by roll-to-roll UV-imprinting, it can also be cut to a desired outline. This allows a perfect fit with products in a variety of dimensions, and offers freedom in selecting the amount and locations of LEDs (min. 8 pcs). Available in PMMA and PC.

NANOSYS

Milpitas, CA
http://www.nanosysinc.com/
Booth 737

Quantum-Dot Materials

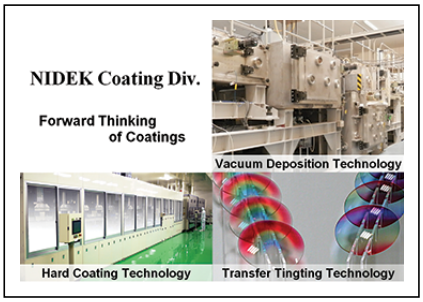
The future of quantum dots on display: Find out how this super-small light emitter is perfecting displays from LCDs to microLEDs. Featured demonstrations include inkjet-printed, photo-emissive, and electroemissive materials.

NIDEK

Gamagori, Japan 81-533-58-3755
www.nidek-intl.com/
Booth 1335

Customizable Anti-Reflective Films

NIDEK's Acier coating technology controls visible and invisible light to offer anti-reflection and transmittance/reflectance of specific wavelengths. The coating also provides functions like surface protection, conductivity, and anti-smudge. Nidek offers its coating technology to a variety of fields such as automotive, information and communication, electrical appliances, and spectacle lenses. Its thin-film coating technologies such as hard coating, vacuum deposition coating, and transfer tinting enhance the performance of day-to-day advancements in various optical components. The combination of nano-level thin films from NIDEK allows transmission and reflection of specific light wavelengths according to customers' various needs.



NSG - PILKINGTON

Toledo, OH 419-250-5537
www.pilkington.com/na
Booth 441

Glass as Wire

NSG TEC is the original ITO replacement. Due to its excellent conductivity and light transmission, it can be used in many industries and applications. Recently, NSG has produced the coating on 0.7-mm glass, a world-leading innovation in float-glass manufacture. This product will be exhibited along with device applications such as a wire-free LED display and OLED lighting, powered by NSG TEC.

ONYX HEALTHCARE USA

Orange, CA 714-792-0774
www.onyxhealthcareusa.com
Booth 1429

8-in. Medical Tablet

Onyx Healthcare USA, an ASUS Assoc. Co., will showcase its new fanless 8-in. medical tablet, the MPAD-800, with built-in type-A USB port and cellular communication. This medical-grade, safety-rated tablet has shift-ready battery life, is water/drop-proof, and bleach compatible. Applications include telehealth and home health, clinical workflow and patient admission, and medical-device remote control.

OPTOFIDELITY OY

Tampere, Finland
www.optofidelity.com
Booth 1334

Automated Smart Device Testing

Optofidelity Test Factory is the cutting edge of new-era test solutions for smart devices. Designed for automated, high-volume testing needs, with a highly modular approach, it offers unbeatable benefits, including: flexible test-cell configuration to match different customer needs; cost-effective manufacturing design; fast and scalable deliveries from the OptoFidelity factory; integration with fully automated testing processes; DUT handling without product-specific parts; automatic, fast configuration; and more.

PACIFIC GOAL OPTRONICS, LTD.

Hong Kong 852-92061706
www.pacificgoal.com.hk
Booth 541

4.3-in. Panel

Pacific Goal Optronics is showing a 4.3-in. (480 × 272) panel. The company specializes in R&D and manufacturing of mono-liquid-crystal modules.

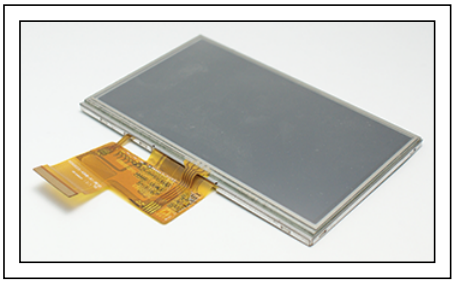


PHOTO RESEARCH, A JADAK BRAND

Syracuse, NY 818-725-9750
www.photoresearch.com
Booth 504

2D Imaging Colorimeter

The Tru-Image 2D Imaging Colorimeter provides a high-resolution, high-speed, research-grade solution for demanding applications. The Tru-Image shortens testing time, thus lowering cost. Tru-Image software automatically finds shapes, provides 3-point character averaging (MIL-L-7788H), pseudo color mapping, automatic pass/fail testing, customized reports, and 3D luminance analysis.

PIXEL SCIENTIFIC, INC.

Scotts Valley, CA 408-659-4630
www.pixelscientific.com
Booth 304

Custom-Sized Smart Display Modules

Pixel Scientific announces a series of rugged, custom-sized smart display modules (SDMs) that enable system integrators and solution providers to bring customized display solutions to market fast, with great differentiation as a complete solution. These SDMs offer modular architectures suitable for indoor or outdoor transportation and digital signage applications. Displays are thin with efficient performance and sleek, all-in-one design. The resized LCD 4K display shown here has a 1,000 nit backlight that produces high-color-saturation sunlight viewable for use in digital signage and public transportation applications.

POLOMO NEW MATERIALS TECHNOLOGY DEVELOPMENT CO., LTD.

Dongguan, China 86-769-89209611
www.powerbond.com.cn/en/
Booth 220

Adhesives and Applicative Material Solutions

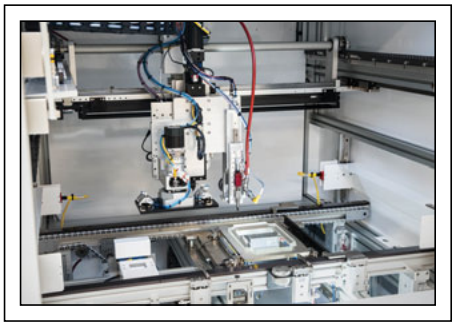
POLOMO focuses on photoelectronics/display device adhesives and providing applicative material solutions, also extending to semiconductors, microelectronics components, automobiles, e-home applications, and construction fields. The core adhesive products are used for LCDs, touch panels, AMOLEDs, QDEF, 3D displays, printing, flexible displays, e-paper, and other new display technology applications. POLOMO is also a leading maker of UV light-curing adhesives.

PRECISION VALVE AND AUTOMATION (PVA)

Cohoes, NY 1-518-320-6327
www.pva.net
Booth 1537

Automated Optical Bonding Equipment

PVA's Delta Bond Series optical bonding automated equipment is focused on flexibility and efficient use of space.

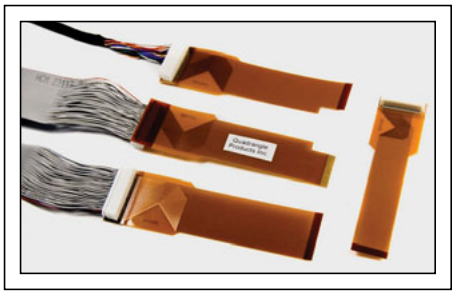


QUADRANGLE PRODUCTS, INC.

Englishtown, NJ 732-792-1234
www.quadrangleproducts.com
Booth 1241

FFC/FPC Transition to Discrete Wire Cables

Quadrangle Products offers various FFC/FPC transitions to discrete wire cables. The company has many solutions already designed to adapt from one interface to another. Applications include LVDS, eDp, touchscreen transitions, etc. Quadrangle also custom designs PCB and FPC adapter solutions if a customer's requirement is unique. The company is a Certified ISO 9001:2015 custom-cable manufacturer with more than 30 years of experience in the design and manufacture of custom-cable assemblies. It also offers prototyping and production volumes.



Submit Your News Releases

Please send all press releases and new product announcements to:

Jenny Donelan, *Information Display Magazine*
411 Lafayette Street, Suite 201, New York, NY 10003
fax: 212.460.5460 e-mail: jdonelan@pcm411.com

Q-VIO, LLC

San Diego, CA 858-735-2026
www.q-vio.com
Booth 234

7-in. 2,500-nit WUXGA LCD

Q-Vio is showcasing a new high-color version of its 2,500-nit 7-in. 1,920 × 1,200 ultra-bright display. Also available with bonded PCAP touch.

RADIANT VISION SYSTEMS, LLC

Redmond, WA 425-284-0587
www.RadiantVisionSystems.com
Booth 729

AR/VR Lens

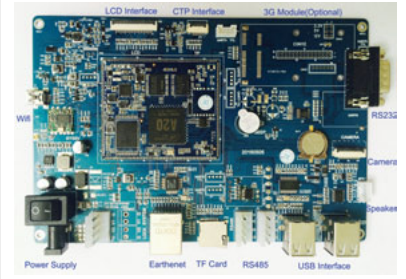
The AR/VR lens is a specially designed optical accessory that mounts directly to Radiant's Pro-Metric Imaging Colorimeters and Photometers. The lens enables imaging systems to measure near-eye displays from augmented-reality (AR), virtual-reality (VR), and mixed-reality (MR) headsets. The lens replicates the approximate size, position, and field of view (FOV) of the human pupil within headsets to evaluate display quality as the user experiences it. The lens aperture is located on the front rather than within the lens, positioning the entrance pupil at the same location in the headset as the human eye to capture a FOV to 120° horizontal without occlusion.

ROCKTECH DISPLAYS LIMITED

Shenzhen, China 86-13823714461
www.rocktech.com.hk
Booth 1504

Android System

Rocktech's Android system solution supports a wide range of display sizes, as well as LVDS/RGB interfaces, RS232/485, USB 2.0, HDMI/VGA/AV output, and wifi/3G/4G/ethernet/Bluetooth. Current standard-matching TFT and CTP sizes available in 3.5, 4.3, 5.0, 7.0, 10.1 inches, and more.



SAMSUNG DISPLAY COMPANY

San Ramon, CA
www.samsungdisplay.com/eng/index/index.jsp
Booth 745

AMOLED Display for the Samsung Galaxy S9

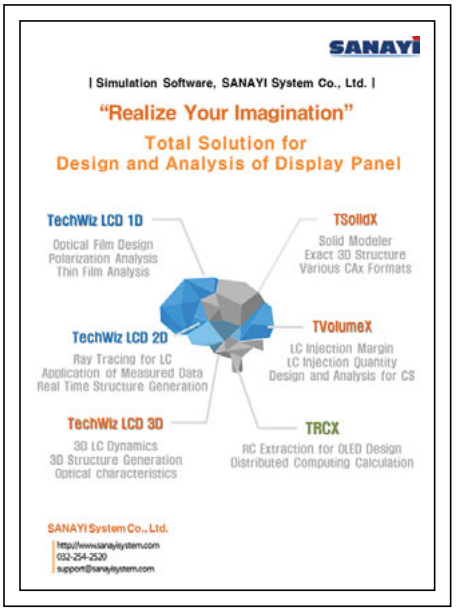
The eye-opening AMOLED display for the Samsung Galaxy S9, from Samsung Display, features an 18.5:9 QHD+ design. This "Mobile HDR Premium" display enables video and photographs to be viewed with a high degree of realism, thanks to its wide gamut of DCI P3, infinite contrast range, and an enviable level of brightness (normal 400 nits, HBM 700 nits, peak 1,130 nits). Color accuracy is rated 0.7 JNCD, making any extremely minor color variation undetectable to the eye. The Samsung Display AMOLED panel for the Galaxy S9 offers clearer images from any angle compared to mobile LCDs (example: 2.5X brighter at a 30-degree angle). This technology can be customized for other applications.

SANAYI SYSTEM CO., LTD.

Incheon, South Korea 82-32-254-2520
www.sanayisystem.com/eng/index.asp
Booth 1541

Simulation Software for Display Panels

SANAYI System Co. developed a series of simulation software programs for display panels. TRCX calculates the capacitance and resistance characteristics of LCDs, touch panels, and OLEDs. Distributed and parallel computing are supported to enable fast and accurate RC extraction for large OLED displays. TSolidX is software specialized for creating CAx files with various mesh formats such as polygon, triangle, and tetrahedron mesh. TVolumeX calculates injection quantities of LCs, as well as optimized design and density of column space in large LCDs. And TechWiz LCD can obtain the electro-optical characteristics and performance of display panels.

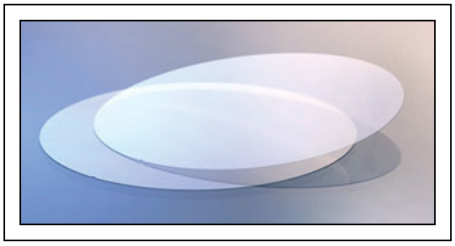


SCHOTT NORTH AMERICA, INC.

Mainz, Germany 49-6131664241
www.us.schott.com/advanced_optics/english/index.html?wss_setorigin=1&wss_iso=en-US
Booth 1045

High-Index Glass Wafers for AR

SCHOTT offers a high-refractive-index wafer for augmented reality (AR) applications. The excellent wafer quality enables the best-in-class device performance of your smart glasses. The SCHOTT wafer leads to a large field of view and has outstanding glass characteristics (*e.g.* homogeneity), which results in superior image quality. In addition, the SCHOTT wafer may come with a single- or double-side anti-reflective coating with tailored transmission and surface roughness.



SEEFRONT GmbH

Hamburg, Germany 49-40-41622648-0
www.seefront.com
Booth 611

32-in. UHD 3D Monitor

The new 32-in. SF3D-320MP autostereoscopic monitor from SeeFront delivers a cutting-edge 3D experience with the utmost freedom of movement for a single user. SeeFront 3D technology combined with an Ultra HD display panel with 3,840 × 2,160 pixels offer color fidelity, high brightness, and true 3D depth at high resolution. SeeFront 3D monitors use an integrated tracking system to give the user freedom of movement in all directions. The monitors display the 3D image content's original spatial depth, whether the content is from a 3D live video stream, 3D movie, game, 3D microscope, or 3D endoscope for industrial and medical applications.

SENSEL, INC.

Mountain View, CA 650-397-5085
www.sensel.com
Booth 216

Pressure Sensor Overlays

The Sensel Morph provides 20,000 pressure sensors, sensing a 5g–5kg range of 32,000 levels per touch. Swap overlays to change among music, writing, gaming, and other applications. USB or Bluetooth connectivity allows the Morph to work anywhere.

SENSING OPTRONICS CO., LTD.

Hangzhou, China 86-15306566699
www.sensingm.com
Booth 545

VR/AR Optical Measurement System

The VDM-1800 VR/AR Optical Measurement System is a measurement system that is specially designed for measurement of the optical performance, geometric parameters, and image quality of VR/AR devices. This system consists of an imaging lens that simulates human eye geometry, a high-resolution CCD camera, a high-sensitivity spectro-radiometer, and H-V spherical coordinate systems. The entrance pupil is matched with the VR eye box and constant field of view (FOV) independent of the image distance. This system can be used to test luminance; chromaticity; uniformity; monocular, binocular, and total FOV; pixel angular resolution; virtual image distance; and more.

SEVASA

www.sevasa.com
Booth 439

Anti-Glare Cover Glass

HapticGlas HPT-TEC is Sevasa's anti-glare cover glass for touch applications. Through constant innovation, microfloat and microwhite bases are

coming soon, in sizes up to 376 inches (126 × 345 in./3,210 × 9,000 mm), the market's largest sizes. Products offer exceptional tactile feedback, very low sparkling, wide gloss range, tight gloss control, and HD resolution. Resistant to scratches and stains, the glass shows fewer fingerprints and is bendable, temperable, and perfect for public use and outdoors, even in adverse conditions.

SHENZHEN TEAMWORKS TECHNOLOGY LTD.

Shenzhen, China 86-755-83752179
www.teamworks-display.com
Booth 1508

Small- and Medium-Size LCD Modules

Shenzhen Teamworks makes liquid-crystal displays in different sizes and resolutions that offer the following capabilities: wide temperature range, high luminance, full viewing angle, transflective mode, and special thicknesses. The company provides total display solutions, with touch and convertor boards/ driving boards.

SIOPTICA GmbH

Jena, Germany 49-3641-6345905
www.sioptica.com
Booth 710

Privacy Shield for LCDs

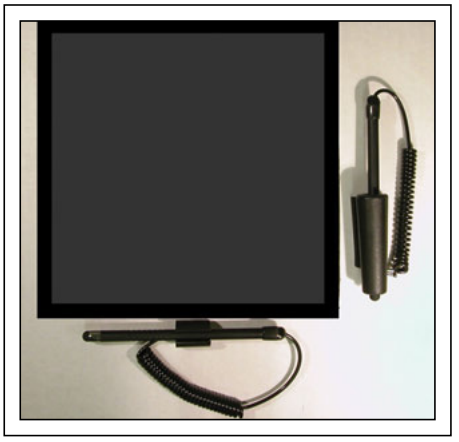
siOPTICA is a leading provider of innovative switchable privacy solutions for LCD panels. With its optical expertise and new, innovative materials, siOPTICA technology offers a high level of security for all LCDs. The sioSHIED solution is mainly used in the payment and automotive industries, as well as for laptops and other mobile devices.

SLENCIL

Orange, MA 978-544-2171
www.slencil.com
Booth 307

Tethered Stylus for Capacitive TouchScreens

Slencil's SC-411 is a popular commercial-duty tethered stylus with snap-in stylus holder and adhesive mount, for capacitive touch screens. A 4-in. tether comfortably extends to 40 inches (100 cm). Made-in-USA products can be imprinted with company logo or brand.

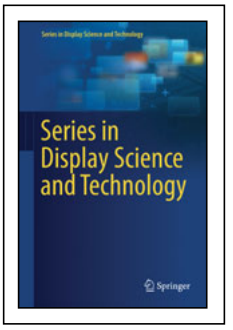


SPRINGER

London, UK 44 (0) 20-3192-2301
www.springer.com
Booth 609

Series in Display Science and Technology

The Springer Series in Display Science and Technology provides a forum for research monographs and professional titles in the area of displays, covering topics ranging from vision and color science, through display materials and processing, established and emerging display technologies, 3D displays, flexible displays, mobile displays, AR/VR, HCI, touchscreens, display metrology, standards, and characterizations. Springer welcomes new book projects – visit the booth to discuss your ideas.

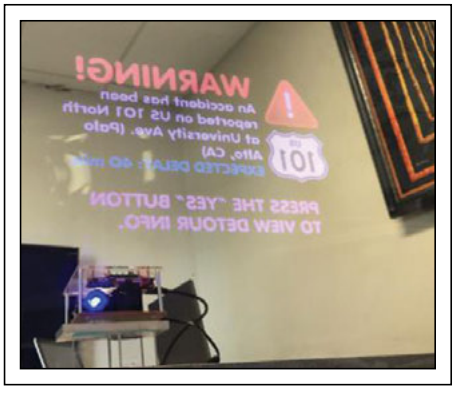


SUN INNOVATIONS, INC.

Fremont, CA 510-651-1329
www.sun-innovations.com
Booth 1513

Color LED DLP With Water-Clear Film

Sun Innovations' newest color LED DLP offers compact body design, high optical efficiency, low power consumption, long LED life, bright emissive display, and standard HD video interface. The water-clear emissive screen adheres to any windshield or glass surface. Also featured: scalable image size with unlimited viewing angles; bright teal, white, and red information display; compatibility with HD-video or image, miniHDMI and microUSB interfaces.



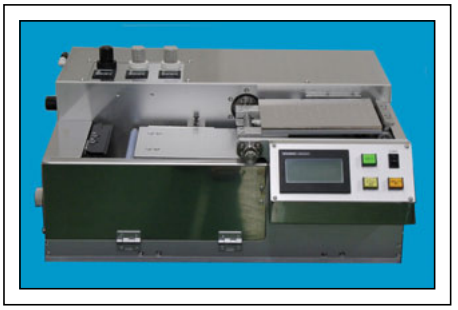
SUN-TEC

Scottsdale, AZ 480-922-5344
www.sun-tec.net
Booth 644

Sheet-to-Sheet Laminator

The TMS-S3 is the smallest and most compact of the Sun-Tec sheet-to-sheet laminators. This bench-top model is ideal for low-volume production or R&D work that involves a flex-to-flex or flex-to-rigid substrate lamination for sizes from 1–8 inches diagonal. The placement accuracy of the TMS-S3 is +/– 0.2 mm using manual loading and X/Y edge-

alignment guides. Adjustments can be made for lamination speed, pressure, and substrate thickness. Customizable features are also available.



TAICA CORP.

Santa Clara, CA 408-500-2971
www.taica.co.jp/gel-english
Booth 228

Optical Bonding Material

AG Coating OPT Alpha-GEL is an ultra-thin LCD protection film incorporating OPT Alpha-GEL, a high-performance optical bonding material developed by Taica. In combination with an advanced AG (anti-glare) layer, AG Coating OPT Alpha-GEL protects the display from external impacts. Protection against damage is enabled by the OPT Alpha-GEL layer, which provides the perfect balance of soft and thin. The AG Coating is effective in reducing glare, which greatly improves the visual performance of the display. Overall, because AG Coating OPT Alpha-GEL is extremely transparent, there are no concessions in terms of luminance or visibility when using this product.

TECHNOTEAM BILDVERARBEITUNG GmbH

Ilmenau, Germany 49.367746240
www.technoteam.de
Booth 617

Imaging Luminance and Color-Measuring Devices

Imaging luminance and color-measuring devices (ILMDs/ICMDs), in combination with adapted measuring lenses, provide effective one-shot solutions for evaluating modern near-to-eye displays (NEDs). NED suppliers ask for TechnoTeam's LMK brand devices adapted to their specific instrument structures. The wide range of field of view (FOV) and NED resolutions must be considered. On the basis of the company's experience in creating products, it offers a set of formulas to determine the basic parameters of lenses for different NED concepts.

THEIA, LTD.

Taipei, Taiwan 886-958967357
www.theia.tw
Booth 1544

3D Phone Case

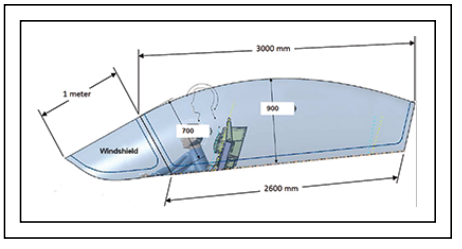
Theia offers a solution to the biggest problem that holds back 3D applications – lack of content. Theia's first product is a phone case (with a free downloadable app) that allows you to see 3D with the naked eye. The powerful app installs on your smartphone and is capable of directly shooting 3D photos, converting 2D content to 3D, and recording 3D videos.

THIN-FILM DEVICES (TFD)

Anaheim, CA 714-630-7127
www.tfdinc.com
Booth 505

Canopy-Shaped Plastic Film

TFD has successfully applied a thin film for touchscreens, hot mirrors, heaters, and dipole sensors.



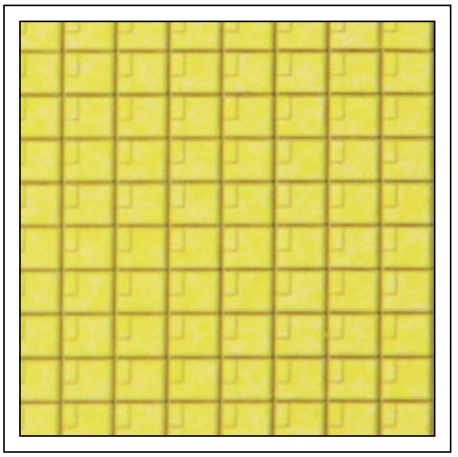
TIANJIN ZHONGHUAN ELECTRONIC LIGHTING TECHNOLOGY CO.

Tianjin, China 86-022-87975939
www.zhonghuanlighting.com/
Booth 310

On-Chip-Packaged Fluorescent QD-LEDs

Tianjin offers full-spectrum quantum-dot light-emitting diodes (QD-LEDs) for lighting applications. These can provide a comfortable light environment with fidelity index (Rf) >90 and gamut index(Rg) >99 throughout the correlated color temperature (CCT) 3,000 K–6,500 K ranges. QD-LED technol-

ogy for backlighting smartphones, laptops, and tablets can provide a wide color gamut.

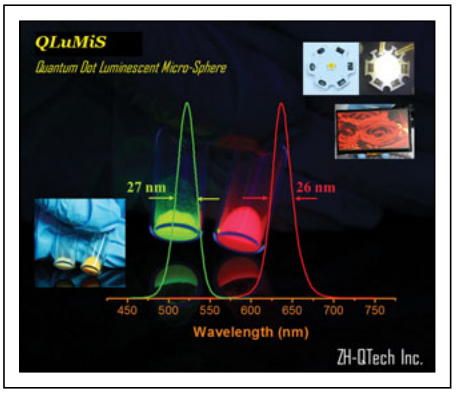


TIANJIN ZHONGHUAN QUANTUM TECH CO., LTD.

Tianjin, China 86-15620936493
www.zh-qtech.com
Booth 308

Quantum-Dot Composite

QLuMiS is a new kind of highly Robust QD composite featuring high efficiency, narrow full-width half-maximum (FWHM), and excellent long-term operational stability. QLuMiS is fully compatible with current LED-packaging processes and can be used as phosphors for direct on-chip applications. With adjustable surface functional groups, QLuMiS can be applied to different kinds of QD displays, including on-chip QD LED/microLED, flexible QD tube, and ultra-thin QDEF for small-size screens.



TIANMA

Santa Clara, CA 408-816-7010
www.tianma.com
Booth 1005

10.1-in. WXGA Ultra-High-Bright Display

Tianma will be featuring the new 10.1-in. WXGA Ultra-High-Bright Display, which, with a luminance of 1000cd/m^2, is ideal for industrial and outdoor applications such as construction and marine equipment. The ultra-high luminance provides vivid colors and excellent visibility even in direct sunlight. The module has a wide operating temperature range of –40 to +85°C and is resistant to vibrations up to 7.0 G. The display incorporates Tianma's proprietary wide viewing angle technology, Super Fine TFT (SFT), which provides ultra-wide viewing angles of 176 degrees horizontally and vertically while reducing color shift that may occur with changes in the viewing angle.

TOPCON TECHNOHOUSE CORP.

Tokyo, Japan 81-3-3558-2666
www.topcon-techno.co.jp/en/
Booth 1445

5000H Macro Lens Option

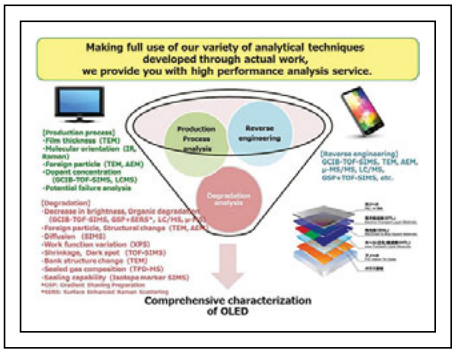
To satisfy demand for color gamut expansion, OLED/µLED will become mainstream. But luminance and chromaticity uniformity and mura are inevitable phenomena. One of the world's first absolute 2D spectroradiometers, the SR-5000 is the ideal tool for defect-finding and analysis for OLED/µLED. The SR-5000H is a hybrid model with built-in 2D spectral filter and XYZ filter. This versatile model enables the fulfillment of lower luminance levels up to 0.005 cd/m^2 and the minimization of site space in one unit. Moreover, the SR-5000H Macro Lens Option Type is especially designed for sub-pixel mura analysis to the 6µ-pixel level and even 2µm, equipped with c-mount-type microscope.

TORAY RESEARCH CENTER, INC.

Tokyo, Japan 81-3-3245-5665
www.toray-research.co.jp/en/
Booth 1505

Analytical Services for Displays and Peripheral Components

Toray Research Center (TRC) is one of the affiliated companies of Toray Industries, Inc., and provides an extensive range of high-quality material analysis services. TRC's superior ability to meet problem-solving requirements of clients is based on 40 years of experience in analysis and materials characterization. TRC serves the world's top R&D and manufacturing companies in a variety of indus-



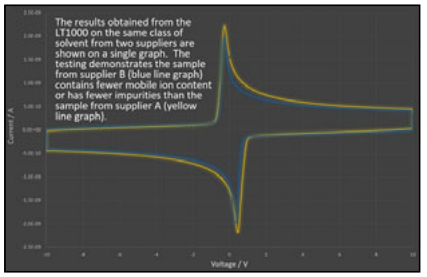
trial fields, including OLEDs, LCDs, TFTs, *etc*. Making full use of a variety of analytical techniques developed through actual work, Toray provides customers with high-performance analysis service.

TOYOTECH

Fremont, CA 510-438-9548
https://toyotechus.com/
Booth 1540

Liquid Impurity Measurement System

The TOYOTech LT1000 provides a new and innovative method to characterize and measure ion impurity levels in liquid substances. The patent-pending system works with both organic and inorganic materials. It is highly sensitive, providing measurements in the ppt (parts per trillion) range. A complete test cycle can be performed in seconds compared to conventional ion chromatography methods, which can take up to 30 minutes. The results obtained by the LT1000 have broad applications in the display industry, including liquid-material screenings to facilitate process optimization.



UBI RESEARCH

Seoul, Korea 82-2-577-4391
www.ubiresearch.com
Booth1238

OLED Display Market Research

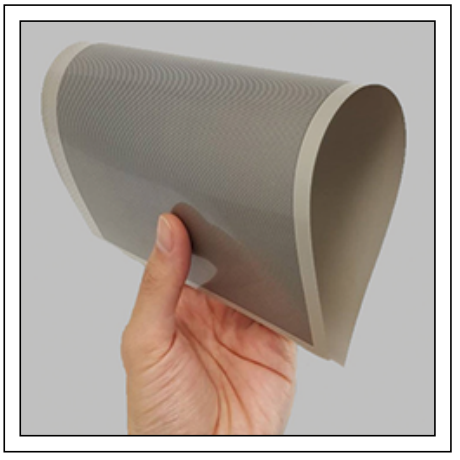
UBI Research's OLED Display Market Track with quarterly updates includes a wide range of recent and detailed OLED industry and market information. It covers the panel, equipment, materials, and components markets. The contents include the major players' activities, performance, products, supplies, and investments. The market forecast from UBI Research has received credits for its reliability over the past 15 years. Many companies use UBI Research's data for their business plans and strategy.

UNEO, INC.

New Taipei City, Taiwan 02-22252018
www.uneotech.com/uneo/us/
Booth 1517

Pressure Sensor

Uneo's microdeformable piezoresistive sensor is a technology developed for force-sensing applications requiring a slim and light form factor. Incorporating various patent-pending microstructure and surface engineering innovations, the device achieves unprecedented versatility and reliability to satisfy performance and cost expectations. It is ultraflexible – 0.1-mm thin – and withstands as low as 3-mm bend radius life testing. A Uneo sensor can accurately resolve the force of a gentle finger touch at 3g as well as heavy-duty weight measurements. Its X-Y spatial touch accuracy is better than 1 mm. It also supports non-conductive stylus input with contact diameter down to 0.5 mm.

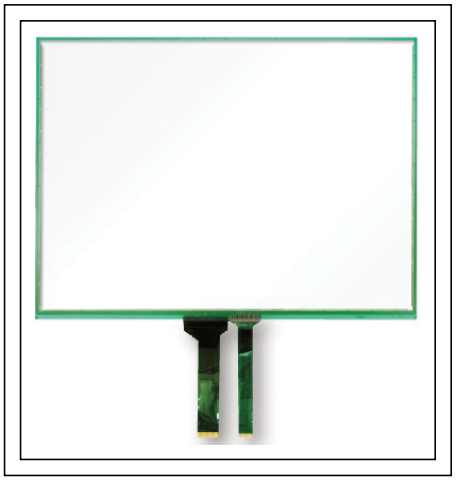


USCO AMERICA, INC.

Fremont, CA 510-931-9046
www.uscoamerica.com
Booth 232

Multitouch Resistive Touchscreen

USCO America has released a new type of touchscreen, multitouch resistive (MTR). It produces smooth multitouch like a smartphone and works easily, like a traditional resistive touchscreen. USCO will be demoing a full line-up, from 5.7 inches to 21.5 inches.



VISIONOX

Beijing, China 86-18710121394
www.visionox.com
Booth 945

5.99-in. Flexible AMOLED Full-Screen Display

This patent-protected high-quality flexible AMOLED display features a screen aspect ratio of 18:9, a total display thickness of 0.2 mm, a resolution of 1,080 × 2,160, a folding curvature down to 3 mm, and L/R/U/D border widths of 1.0/1.0/1.0/3.7mm. Customized products like this AMOLED display can be produced upon request.

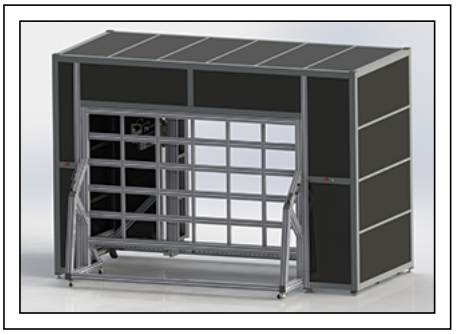
WESTAR DISPLAY TECHNOLOGIES, INC.

St. Charles, MO 636-300-5115
www.westardisplaytechnologies.com
Booth 1244

Large Display Measurement System

Westar Display Technologies, a supplier of display measurement systems, has introduced the FPM-540-FO test system for large-format displays up to 110 inches diagonal. The FPM-540-FO can be set up to run many standard ICDM, TCO, ISO, SAE, and other display optical measurement tests as well as programmable customized tests. The system includes a three-axis instrument deck for mounting

up to three instruments, and a two-axis gimbaled optical probe to perform measurements while the display remains fixed and in an upright position. This design allows for viewing-angle measurements without moving or rotating the large and heavy display modules.



WESTBORO PHOTONICS
Ottawa, Canada 613-729-0614
www.wphotonics.com
Booth 1304

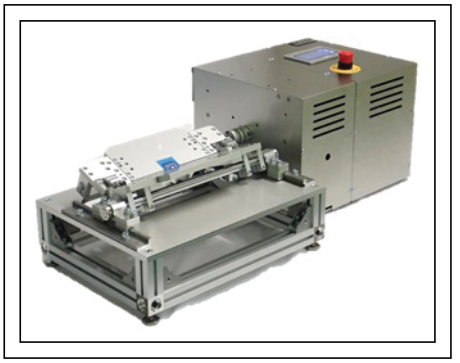
High-Resolution Imaging Colorimeters

The WP6E and WP6ES series imaging colorimeters from Westboro Photonics are optimal solutions for display measurements. With electronically controlled lenses, the systems are ideal for automation. Westboro Photonics' Photometrica software provides users with the most productive environment for measurement and analysis. The ES model includes an integrated high-performance spot spectroradiometer for automatic color correction of any display measurement. With sensitivity below 0.0001 cd/m², ultra-low light signals can be reliably analyzed. The WP6E and WP6ES are the smallest and lightest on the market.

YUASA SYSTEM CO., LTD.
Okayama, Japan 81-86-287-9030
www.yuasa-system.jp/en
Booth 1234

Tension-Free Clamshell Test Machine

Yuasa's clamshell-type test machine can be used to test tiny samples with a tiny banding radius. It can measure bending stress. General clamshell type test machines apply compression force, so Yuasa developed this ideal tester that does not place the tensile stress on the sample. Test results from a general clamshell tester and Yuasa's clamshell tester are completely different. ■



business of displays: Q&A

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the problem and provide feedback and figure out how to fix it – that's really quite exciting. Don't just get caught up in your product; get caught up in your customer.

ID: Every customer must be sort of a one-off.

DK: Absolutely – that's why my title is chief solutions officer. Every customer has their own personal needs for solutions. They have their own assembly lines, and their own testing that they want to do on their products. Every product is unique, and so is the testing. Customers want that critical information needed to improve their product, their yield, and whatever else they want to improve. It's critical that we have the software, hardware, and engineering expertise to provide that customer exactly what the customer wants.

ID: Do you have a sense of how large the overall market for metrology is right now?

DK: That's a good question, but I'm going to deflect it by asking: What is metrology? Metrology in the historical sense translates to absolute units of whatever it is you're measuring – the luminance of a display, the color, and so on. But is metrology also capturing blemishes and mura in a display? And what about scratches that are visible when you turn off the display? We think that demand — in terms of what is inspected by humans today and what we as suppliers can have inspected through advanced vision technology — is absolutely huge. The time is coming when you're going to have factories making mobile phones without a human in that factory. Radiant Vision Systems wants to be part of the test and measurement equipment in that factory. That's where I see metrology over the long term, and that's where we want to take Radiant: developing advanced inspection products that support a fully automated factory. ■

SID Elects New Officers

The Society for Information Display recently elected new members of the executive board for a two-year term. The new officers, who will start their terms during Display Week 2018, are Helge Seetzen, president; Takatoshi Tsujimura, president elect; Achin Bhowmik, treasurer; and John Kymissis, secretary. Yong-Seog Kim will move from his term as president to serve as past president.

Regional vice presidents are: Paul Lacey, Europe Region; Jun Souk, Rest of Asia Region; Katsumi Kondo, Japan Region; Sri Peruvemba, Bay Area Region; Adi Abileah, Pacific and South Americas Region; Mike Weaver, East Americas Region; and Xiaolin Yan, Cross-Strait Region.

To Display Week and Beyond: IMID, Vehicle Displays, and IDW

Display Week is just one of several international conferences hosted by the Society for Information Display. For example, you can find out what's happening in the display industry all over the world by visiting IMID, Vehicle Displays, and IDW, all happening later this year.

IMID, the **18th annual International Meeting on Information Display**, takes place August 28–31 in Busan, Korea. It is cohosted by the Korean Information Display Society (KIDS), the Korea Display Industry Association (KDIA), and the Society for Information Display (SID). The IMID committee reports: "The IMID has become a premier conference for academic, industry, and business leaders to meet, publish results, and share knowledge." The conference includes keynote presentations, oral and poster presentations, tutorials, workshops, and a special exhibition.

For those with a little time to sightsee in addition to taking in the conference, Busan, located at the southern tip of the Korean peninsula, is the second largest city in Korea and home to the country's longest river, longest beach, and largest port. Its coastline features excellent beaches and scenic cliffs. Hot springs throughout the city are a major draw for visitors. Visit www.imid.or.kr/2018 to find out more.

This fall, the **25th Annual Symposium on Vehicle Displays** takes place September 25–26 in Livonia, Michigan, with two days of technical presentations geared toward automotive original equipment manufacturers (OEMs) and display suppliers and manufacturers. The program features a special emphasis on the connected and autonomous vehicles of the near and somewhat more distant future. Visit www.vehicledisplay.org.

Later this year, the **25th annual International Display Workshops (IDW)** will be held December 12–14 in Nagoya, Japan. This event is sponsored by the Institute of Image Information and Television Engineers and SID.

IDW '18 will integrate 13 workshops in specialized fields important to information display technology. The event will also include I-DEMO, a space for live demonstrations by presenters. According to event organizers, the IDW workshops are designed to be of interest not only to researchers and engineers, but to those who manage companies and institutions in the display community. See www.idw.or.jp for more information. ■

Busan's Gwangan Bridge is a famous landmark in a city known for its proximity to water.

frontline technology

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factor, we will need more light in sphere #1. It is anticipated that a photopic-photomultiplier-tube detector will be needed to monitor L_2 in the region of L_{rods}. These changes will be made in the future and published in the open literature.

Why is it important to have a source that can reliably reach the limits of human low-light vision? If we want to measure just how black the new displays can get, we need an adjustable calibration light source that can provide those levels and not only check the measurement accuracy of any detector but also its linearity in that low-light region. Only then can we be sure of reliable black measurements.

Both of the above integrating-sphere-based instruments are offered to the display industry and placed in the public domain – no patents or licensing to impede their implementation. I hope these designs will be useful – consider them part of my swan song (I'm almost 70 years old).

References

[1]International Committee for Display Metrology of the Society for Information Display, *Information Display Measurements Standard* (IDMS) version 1.03, appendix A3.

[2]E. F. Kelley, A. Dowd, A. Fong, R. Bronson, B. Goodman, "Ultra-Uniform Oblong Integrating Light Source," paper P-64, Society for Information Display International Symposium Digest of Technical Papers, pp. 1375–1376, 2016.

[3]R. E. Miller and T. J. Tredici, *Night Vision Manual for the Flight Surgeon*, Ophthalmology branch, Armstrong Laboratory, Human Systems Center (AFMC), Brooks Air Force Base, TX 78235-5000, AL-SR-1992-0002 August 1992. They state, p. 9, "The dimmest light in which rods can fuction is about 10^{-6} millilambert …. This illumination is equivalent to ambient conditions of an overcast night with no moonlight. The dimmest light in which the cones can function is about 10^{-3} mL." To convert to luminance levels, 1 lambert = 1 L = 3183.1 cd/m^2. Thus 10^{-6} mL or 10^{-9} L = 3.2 × 10^{-6} cd/m^2. ■

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we've covered several great innovations in this magazine that have first appeared in the I-Zone. I'm sure this year will reveal more wonderful discoveries.

Display Week is a big event, and no one person can see it all. Hopefully you brought along some colleagues to help you divide and conquer everything of interest, but in case you can't, we have you covered. *Information Display* has invited a prestigious team of freelance technology enthusiasts to report on all the happenings, and they will be hard at work covering everything they can. We will have daily blog updates on the *ID* Web site (www.informationdisplay.org) and a full issue of post-show coverage later in the year. If you see anyone from our team walking around with a press badge with "*Information Display*" on it, please introduce yourself, ask questions, and share your interests so we can make sure we cover the things that interest you most.

The issue of *ID* you are reading now can be useful for your planning, because it features our "Products on Display" coverage, which is assembled each year by our staff to help you get the most out of the exhibition. Also, while good planning is essential, don't forgo the opportunity to just wander around the exhibits or pop in on a presentation you hadn't considered. Each year I find many surprises and new ideas that I can only discover if I explore as much as possible. It's a wonderful mix of the expected and unexpected that awaits you. I've never left Display Week without at least a handful of amazing new nuggets that have since proven invaluable in my day-to-day work.

The SID Community

Maybe you are a seasoned SID member returning after many previous years, or maybe you are brand new to the display industry scene and this is your first event. If so, you are not alone. Many people discover SID through Display Week when they automatically become new members by registering for the event. Later on, they realize that the Society for Information Display is about much more than just one great show per year. In fact, SID offers a calendar abounding with exciting international display-industry events, some focused on a particular technology or field of research and others almost as broad as the symposium itself.

For example, throughout the rest of this year you can experience other world-class display gatherings such as IMID: The International Meeting on Information Display in Busan, Korea, August 28–31, and the International Display Workshops (IDW) held in Nagoya, Japan, December 12–14.

These are outstanding events and give you an excuse to see great parts of the world as well. However, some of the most important society activities are those that take place regularly on a local and regional level at each of SID's 30-plus chapters worldwide. It is hard to find any industrialized part of the world that does not have some chapter activities going on. And if all that is not enough, SID's publications, online resources, and network make the organization a truly indispensable tool to a successful display-industry career. Even if you attend only one additional SID event or take even partial advantage of your local-chapter activities and the online resources, you get the value of your membership back many times over. So, if you are new to SID, I hope you find it a truly enriching experience, and do not forget about your membership after Display Week 2018 is over.

Awards and History

Our cover story this month features the winners of the SID Display Industry Awards, recognized in three categories: displays, components, and applications. As author Jenny Donelan explains, this year's winners are all products or components of products that are fun to use and truly enrich the user's experience. I can confirm as a member of the selection committee that the field of nominees was excellent this year and these choices are truly the best of the best.

Since I'm a big fan of history, I'm going to draw your attention next to a remarkable story brought to us by longtime supporter and accomplished author Larry Weber. His article, "David Sarnoff, Display Industry Visionary," chronicles the history of RCA under the leadership of David Sarnoff. For most of the last 99 years, RCA was home to the seminal developments of radio, television (B&W and later color), color CRTs and video cameras, light amplifiers, projection systems, electroluminescent flat panels, and the ubiquitous liquid-crystal display (LCD). It's remarkable to realize the scale of investment in innovation, the sheer brilliance of the assembled technologists, and the great business risks taken during this time to achieve so very much that we mostly take for granted today. It's also inspiring to read about the work of some great inventors, many of whom were early supporters of SID. Some are even commemorated in the names of our SID Honors & Awards.

If we look backward, we can observe the massive scale of manufacturing that has grown up around LCDs. Over the last decade, LCD fab lines have grown bigger and bigger, with the sizes expressed in increments of "generations" based on the size of the motherglass substrate that starts down the line. In the early 2000s, companies were building lines designated as Gen 5, which used a substrate size of 1,100 × 1,250 mm. By 2006, Gen 8 was on the table with a substrate size of 2,160 × 2,460 mm. At that point the industry seemed to slow down and digest its growth for a few years. But now, the capacity engine is at work again, with numerous projects announced to build Gen-10 fabs with substrate sizes of 2,940 × 3,370. That's about 7 times the square area of a Gen-5 line and allows for an astounding number of displays to be made from each substrate. Author Ian Hendy points out that the number of new Gen-10 fab construction projects announced, combined with the much larger format, could represent a substantial increase in the overall world-wide capacity for large-panel manufacturing. Is this a good thing or does it portend risks of overcapacity? Ian does the analysis for us in his article,"Gen-10 Fabs Will Create Upheaval in the Display Market."

MicroLEDs

While LCD technology continues to dominate in countless applications, new challengers such as OLED try to make in-roads in certain places, and they have certainly had some success, especially in small-format displays. The latest challenger is being developed with an eye first toward the larger size display market, and that technology is called microLED. It is almost exactly what is sounds like – traditional light-emitting diodes, but in very small formats suitable to form the pixel matrix of a direct-view consumer display such as a television panel or tablet display.

You have no doubt seen large signage displays made from LEDs and we've covered this space numerous times, including in the January/February 2016 issue, but now comes the chance to make large-format single-display panels from LED chips on the order of 30 µm in size or smaller. The semiconductor

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part of the challenge is relatively easy to achieve, but the big issue is how to assemble something on the order of 6+ million of these onto an addressable matrix substrate or how to stitch an array of wafer-scale substrates into a panel. In a Display Marketplace feature this month, author Eric Virey, senior market and technology analyst at Yole Développement, tackles the question of whether microLEDs are really the next display revolution. The opportunity for this approach is big, and so are some of the hurdles ahead. But I came away convinced that there is a lot of promise and with a much better understanding of the landscape, thanks to Eric's very thorough survey of the state of the art.

Regardless of which display technology you consider, today's displays are yielding record performance in terms of resolution, dynamic range, color saturation, overall size, *etc*. If your organization does any optical metrology to verify performance metrics, you know how difficult it is to set up and calibrate everything for satisfactory results. One of the growing challenges in this area is finding calibration sources matched to the luminance levels and wide measurement angles required for testing. In our Frontline Technology feature, "Calibration Requirements for Demanding Measurement Challenges," author Ed Kelley tackles the problem through a new set of prototype calibration reference sources he has developed and tested. These sources provide for both a very wide angle of uniform illumination for flat-field calibration on wide-angle lenses, and illumination values controlled down to virtually the limits of human vision to address those cases where very low-luminance black levels need to be correctly measured. If you plan on measuring the full dynamic range of an HDR display or want to take full-screen, high-resolution uniformity measurements, then you need the kind of calibration capability Ed is proposing. His results from these prototypes are very encouraging, and to put some frosting on the cake, Ed announces at the end of his article that he is gifting these designs to the industry free of charge! Thanks, Ed – we appreciate this very much.

One well-known industry company that focuses most of its efforts on light measurement is Radiant Vision Systems. The company has also been innovating lately, and recently launched a new product designed to aid in the testing of augmented-reality/virtual-reality (AR/VR) eyewear. This product is a lens that allows you to couple a photometer directly to the exit port of a set of goggles and measure what the observer would see through their eyes directly. This type of measurement is critical to verify the important optical parameters of a VR headset. In this month's Business of Displays, Jenny Donelan spoke with engineering leader Doug Kreysar about the recent work Radiant has been doing and his views on the future of AR/VR in particular. Doug points out how valuable it is not only to listen to your customers, but to anticipate their needs by knowing their business. He states with good experience: "Don't just get caught up in your product; get caught up in your customer."

Before I wrap up, I want to note that SID President Yong-Seog Kim wraps up his two-year term this month and hands the reins over to incoming SID President Helge Seetzen. Yong-Seog Kim is a kind and generous leader who has made significant contributions to our society. I have enjoyed immensely my opportunities to interact with him these past few years. Please take the time to read his President's Corner column, "What's Next (in Display Technology)?", before you finish this issue. The society will be in great hands with Helge, who has always been a great supporter and contributor to *Information Display* magazine. Our regular SID News page includes the results of this year's elections for the leadership positions of SID. Please join me in congratulating all of them and wishing them well. And, of course, I wish you all well and much success both here in LA and at home, wherever you have come from. ■

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e-mail: jdonelan@pcm411.com

Information DISPLAY

Official Monthly Publication of the Society for Information Display

SID
SOCIETY FOR INFORMATION DISPLAY

2018 EDITORIAL CALENDAR

■ March/April

Display Week Preview, Emissive Technology
Special Features: SID Honors and Awards; Symposium Preview; Display Week at a Glance; Commercialization of Quantum-Dot Light-Emitting Diodes; MicroLED Displays; New Processes for High-Resolution MicroLED Displays; OLED Manufacturing
Markets: OEMs, deposition equipment manufacturers, panel fabricators, materials industry research and developers, display and electronic industry analysts, OLED process and materials manufacturers
February 28: Ad closing

■ May/June

Display Week Special, Wearables
Special Features: Display Industry Awards; Products on Display; Stretchable AMOLEDs; Stretchable TFTs; Cutting-Edge Applications for Wearables; Sensors; Smart Fabrics
Markets: OEMs, deposition equipment manufacturers, panel fabricators, materials industry research and developers, display and electronic industry analysts, wearable designers
April 18: Ad closing
Bonus Distribution: Display Week 2018 in Los Angeles

■ July/August

Display Week Review Special Part 1, AR/VR
Special Features: Display Week Highlights from the Show Floor; Materials Advances at Display Week; Best in Show and I-Zone Winners; AR/VR Advances; Light-Field Breakthroughs
Markets: Research institutions, OEMs, entertainment industry research and development, consumer product developers, display industry research and developers, display industry analysts
June 18: Ad closing

■ September/October

Display Week Review Special Part 2
Special Features: Display Week Technology Reviews: High-Definition Displays, Automotive Displays, Metrology, Imaging, and Digital Signage
Markets: Large-area digital signage developers; OEMs; consumer product developers; display industry research and developers; display industry analysts; metrology manufacturers; automotive and automotive display manufacturers; entertainment industry manufacturers
August 22: Ad closing

■ November/December

Stretchable/Flexible Technology
Special Features: Advances in Stretchable AMOLEDs; Stretchable Oxide TFTs and LEDs; Challenges in Manufacturing Stretchable Substrates and Electronics; From Flexible to Foldable
Markets: OEMs, consumer product developers, research institutes, entertainment and gaming developers, panel fabricators
October 18: Ad closing

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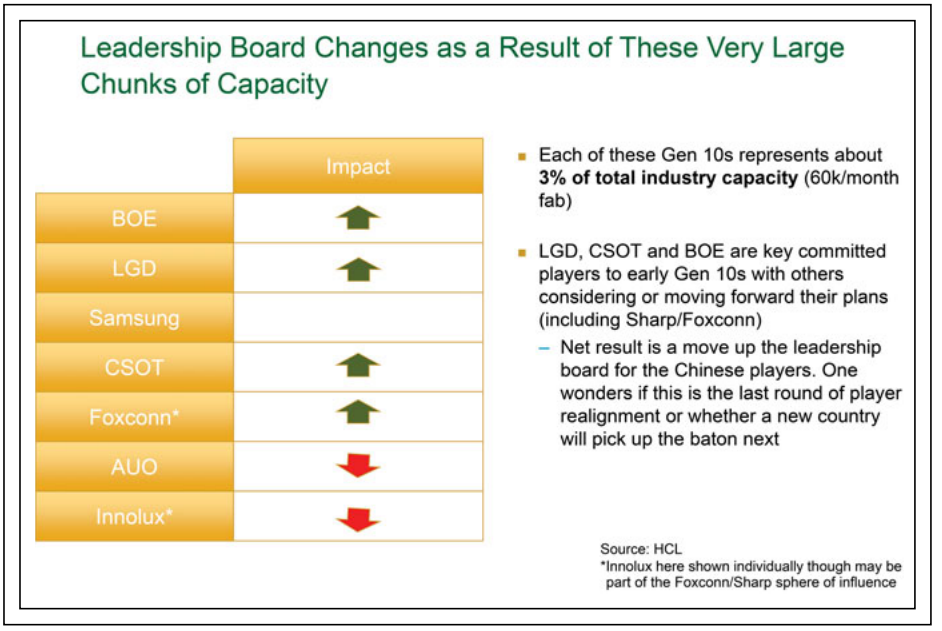

Fig. 7: *Gen-10 fabs will move some companies up the leadership board, and others down.*

many flat-panel displays into schools across the country. As an adjunct to Gen-10 moves by the top players, we may see more business development by those firms into the areas of large-area signage, video walls, and the like.

Issue 10: Leadership Moves

Finally, it is useful to think about the impact that such large factories will have on the overall leadership of the industry. A number of players have been named as building Gen-10 fabs over the coming years and these include: LG Display, Foxconn, CSOT, BOE, and HKC.

For each of these, a factory of 60K/month 2,940 × 3,370-mm panels would represent a massive increase in capacity share and a move up the leadership board. Figure 7 shows our current thinking on how this might play out, but the final plans and peak capacities of the Gen-10 fabs are not yet known. The role of the Chinese government in coordinating who gets to invest is also not known.

Winners and Losers

Who ends up as winners and who ends up as losers will depend in part on the degree of the final rollout of Gen 10. If the rollout is muted and Gen-10 capacity is effectively sold at premium prices into new and existing value chains, then the industry as a whole could benefit.

If, as we fear could happen, lots of Gen-10 capacity is built, then the risk is systemic oversupply in which the only major winners are consumers and the equipment companies that make tools for the industry. Prices and profits would decline, and materials makers would only be happy if they could make up for lost margins with greater volumes. Gen-10 fabs represent sizable fungible capacity and could threaten the economics of many markets. Their impact may be felt for 2 to 10 years after rollout, which means we may see market dislocations for another decade after the fabs appear.

Reference

[1]http://news.ihsmarkit.com/press-release/technology/gen-10-and-larger-flat-panel-display-capacity-grow-59-percent-cagr-2022-ihs ■

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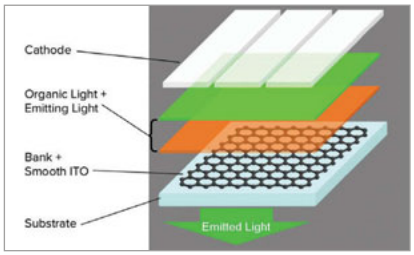

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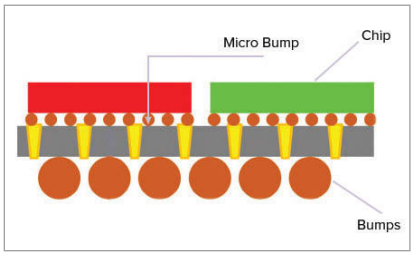
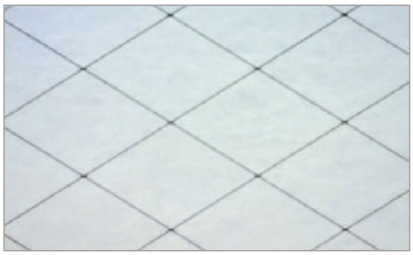
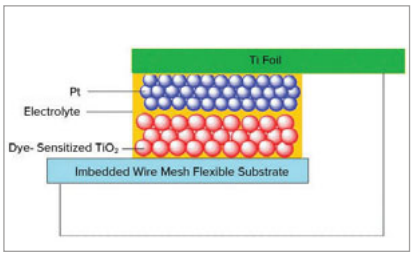


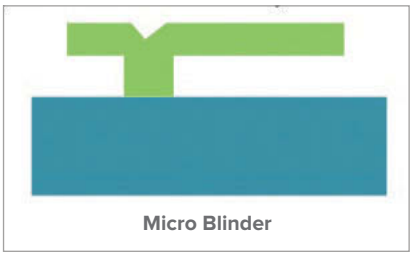
Glass Interposer



Imbedded Mesh
(≤ 5 OPS, T% ≥ 90% @ 420-680nm)



Flexible Dye Cell



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