DISPLAY WEEK 2017 REVIEW ISSUE

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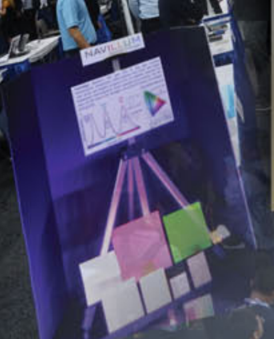
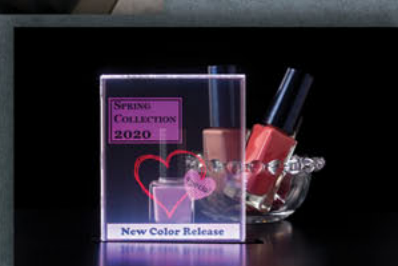
Stretching the Design Envelope at Display Week 2017

Plus:

Best in Show and I-Zone Winners

Laser Glass Cutting Comes of Age





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ON THE COVER: Images from Display Week 2017 in Los Angeles include (clockwise from upper left): The Innovation Zone (I-Zone) on the show floor; LG's 77-in. "Wallpaper" OLED (photo by Tom Fiske); BOE's 15.6-in. curved FHD LCD (photo by Karlheinz Blankenbach); Samsung's 9.1-in. stretchable AMOLED (image courtesy Samsung); cockpit display from Corning; JDI's color transparent display (image courtesy JDI); Tianma booth on show floor; and JDI's narrow-bezel LCD (image courtesy JDI).

Cover Design: Jodi Buckley

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- AR/VR at Display Week
- The Market for Stretchable Technology
- Best Student Paper

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editorial

Drawing Inspiration from Display Week

by Stephen P. Atwood

Welcome to the annual Display Week review issue, which covers highlights from our terrific gathering in Los Angeles last May. As I promised, it was one of the best in recent years, with an amazing array of innovative demonstrations and clever embodiments of the latest display developments.

A number of things caught my eye as noteworthy this year, including the truly stretchable OLED display demonstrated by Samsung, the LCD-based headlight concept from IGM at the University of Stuttgart in the I-Zone, and a mobile phone-based 3D display from LEIA that resembled the artist's rendering on our January 2017 cover a lot more closely than you might think. (That issue includes an interview with LEIA founder and CEO David Fattal.)

In my experience, many aspects of different Display Week events over the years start to blur together, but the key pivotal exhibitions and announcements stand out regardless of the time that has gone by. For example, I remember vividly the first OLED TV panels shown by LG and Samsung, the first demonstrations of Texas Instruments' DLP technology, Sony's clever idea for a plasma-addressed LCD, the panel-size wars in both plasma and LCD technology, the first papers on oxide TFTs, and the liquid-crystal-on-silicon microdisplay emergence, among others. Depending on what field you work in, I'm sure you can name dozens of other milestones and seminal moments like these.

Display Week Reviews

So, with minimal introduction, let's dive right into the review articles compiled by our team of contributing editors, who took the time to chronicle their subject areas for you. Materials were a big topic this year, with several headliners. Ken Werner took the assignment and covered all the highlights in his article, "Materials and Other Game Changers." We saw a lot of action in quantum dots, a result of companies moving toward RoHS-compliant solutions for LCD enhancement while pursuing several embodiments for direct emission enhancement as well. New players have come online and familiar ones are expanding their scope.

In the OLED space, there was substantial activity around thermally activated delayed fluorescence (TADF) – which we also covered earlier this year in *ID* – as well as some incredible demonstrations of OLED displays. And there were innovations in reflective materials, including foldable E Ink technology and a new entrant named CLEARink that was showing video-rate updates on a reflective platform. CLEARink won a Best in Show Award from SID this year.

Automotive displays and their applications were a very important subject this year, both on the floor and in the presentations. Author Karlheinz Blankenbach reported on many of the key developments in his article, "Automotive Displays Proliferate at Display Week," in which he showed how we are just starting to imagine all the ways displays can be deployed in cars, and what that means to developers in the coming years. My favorites at the show included the all-glass custom-format display concepts, and the systems that can replace mirrors and enhance perimeter awareness while you drive. But displays that can meet these needs must achieve even greater performance and "flexibility," and yes, I use that term to mean several things at the same time. Enjoy the article and you will see what I mean. *(continued on page 44)*

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industry news

By Jenny Donelan

HMD Global/Nokia and ZEISS Form Partnership, Release Flagship Phone

If all goes according to company plan, Nokia smartphones will soon regain some of their former luster. The Finnish company HMD Global, which operates Nokia's phone business, and ZEISS, a German maker of optical and measurement systems, recently announced a partnership that (according to a joint press release), "aims to set new imaging standards within the smartphone industry."[1] For decades, Nokia phones, including the 2013 Lumia 1020 with its PureView camera technology, were some of the most highly regarded mobile devices on the market.[2] (ZEISS was a partner during some of that period.) In 2013, Nokia's mobile phone division was sold to Microsoft, after which Nokia-branded phones weren't developed or marketed as rigorously as before. In 2016, however, HMD and FIH Mobile, a division of Foxconn, purchased Nokia's mobile phone business from Microsoft and announced plans to release a line of higher end Android-based smartphones.[3] In fact, the Nokia 8, the company's first "flagship" phone in years, was announced in August 2017.[4]

The new phone (Fig. 1) has a 5.3-in. LC display (2,560 × 1,440) and is powered by a Qualcomm Snapdragon 835 processor with 4GB of RAM, and 64GB of storage. The company is promoting the camera aspect – the ZEISS optics on the front and rear cameras both have 13-megapixel sensors. A dual-camera array at the rear also includes a monochrome camera. Nokia 8 will broadcast video (with the front and rear cameras) to Facebook or YouTube natively through the camera interface. There is also 360-degree audio for live streaming.

Fig. 1: Nokia's new smartphone, the Nokia 8, is designed to help put the company back on the map with regard to high-performing smartphones.

Whether the HMD Global acquisition and the renewed relationship between ZEISS and Nokia will make these phones competitive in the high-end range is yet to be seen. What is more certain, however, is that new players and new devices create a healthier and more interesting market.

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[1]www.hmdglobal.com/press/2017-07-06-press-hmd-zeiss
[2]www.stuff.tv/features/12-nokia-phones-changed-world-and-9-crazy-ones-entertained-us-along-way/nokia-6310-2002
[3]www.anandtech.com/show/10879/hmd-closes-nokia-brand-and-patents-deal-with-microsoft-nokia-smartphones-on-the-way
[4]www.hmdglobal.com/press/2017-08-16-nokia-8

Foxconn Announces Plans to Build LCD Fab in Wisconsin

CEO Terry Gou of Foxconn, the Taiwan-based contract electronics maker, announced over the summer in a press conference with US President Donald Trump and Wisconsin Governor Scott Walker in attendance that Foxconn plans to build a 20,000-square-foot LCD fab in Wisconsin. Foxconn is the maker of Apple's iPhone and is also a supplier to Amazon, Microsoft, Nokia, and Sony, among other major companies. It is the world's largest contract electronics manufacturer. If plans for the facility go through, it would be the first time for Foxconn to manufacture displays in the US.

The LCD panels that would be produced in Wisconsin would be for TV maker Sharp, which was purchased last year by Foxconn's parent company, Hon Hai.[1] Foxconn Technology Group would receive up to $2.85 billion in cash payments from the state in exchange for building an up-to-$10-billion flat -screen plant and hiring up to 13,000 workers.[2]

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Making large panels in the US to be used for US products would presumably reduce shipping costs, as well as any applicable tariffs. In addition, such a large facility would provide jobs for thousands of workers and be an overall boon to the Wisconsin economy.

At press time, however, Gov. Walker's administration was seeking to tighten job creation requirements as part of the deal.[2] And Ohio Governor John Kasich, whose state is currently “pitching” Foxconn for a manufacturing deal of its own, spoke negatively of the tax incentive deal made between Foxconn and the state of Wisconsin. New analysis, he said, shows that the deal may provide fewer jobs and less revenue than previously predicted. The state might not break even on a deal with Foxconn until 2042.[3]

Foxconn actually announced a US manufacturing initiative back in 2016, according to IHS Markit analyst David Hsieh. In a recent article in his technology blog, “Foxconn Sharp intends to build LCD fabs in US: but is it practical?” Hsieh wrote that the company was also considering a Gen 6 fab in Michigan.

In fact, there are pros and cons for both Foxconn and the US, Hsieh wrote in his blog: “All told, it makes sense for the Foxconn Sharp group to build fabs in the US, given the growing demand for panels by both the global and US markets, and also for the company to expand its business. Having a US-based LCD fab could also gain Foxconn a measure of political goodwill, since the investments that are needed will stimulate local employment and economics. On the other hand, such a move is rife with challenges — among them the substantial use of natural and human resources alike, as well as the painstaking process of building a supply chain from the ground up.”[4]

In the past, plans to build Foxconn plants in the US have fallen through; a 2013 proposal to build a large facility in Harrisburg, PA, did not work out. Still, it would be exciting to have large panels made once again in the country where TVs were invented, said Gou.[5]

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[1]www.theverge.com/2017/7/26/16034394/apple-iphone-manufacturing-foxconn-wisconsin-plant-donald-trump

[2]www.jsonline.com/story/money/business/2017/08/22/wisconsin-budget-committee-hears-testimony-billion-foxconn-bill/589265001/

[3]http://thehill.com/blogs/blog-briefing-room/news/347769-kasich-rips-foxconn-deal-in-wisconsin

[4]http://blog.ihs.com/foxconn-sharp-intends-to-build-lcd-fabs-in-us

[5]https://www.biztimes.com/2017/ideas/educationworkforce-development/wisconsin-lands-10-billion-foxconn-project/

Gamma Scientific Intros Compact Spectroradiometer/Flicker Meter

Gamma Scientific’s new GS-1160B spectroradiometer is a compact industrial spectroradiometer/flicker meter designed for fast, accurate, and repeatable display measurements (Fig. 2).

***Fig. 2:** Gamma Scientific’s new benchtop spectroradiometer/flicker meter combines light weight and a small footprint with a wide array of measurement capabilities.*

It features an extensive suite of analysis capabilities for display designers, manufacturers, and engineers in a lightweight package. The instrument is about the size of a mobile phone (204 mm × 90 mm × 45 mm), weighs 620 grams, and is suitable for color and intensity measurement of all display types including LCD, LED, OLED, and quantum dot.

The GS-1160 delivers key display measurement capabilities for color chromaticity, gamma, white balance adjustment, contrast, flicker (VESA and JEITA), and uniformity. Its luminance measurement range is from 0.05 to 5,000 cd/m^2, with CIE 1931 and CIE 1976 color chromaticity output, and fast integration time down to 100 µsec.

LG’s Next Smartphone to Feature Plastic OLED Display

The next flagship smartphone from LG Electronics will feature the company’s plastic OLED FullVision display, which follows the trend toward curved edges and minimized bezels in smartphones (Fig. 3).

***Fig. 3:** At press time, LG was revealing only this teaser photo of the new smartphone. Although it shows just the bottom portion of the phone, the thin bezel and rounded edges are clearly visible.*

The 6-in. FullVision display will be LG’s largest in four years, and will include 4.15 million pixels in the QHD+ (1,440 × 2,880) panel. According to LG, the display will deliver 148 percent of the sRGB1 color space for digital images and 109 percent of the DCI-P32 color space for digital cinema. The phone’s plastic substrate will be protected by Corning’s shatter-resistant Gorilla Glass 5. LG also reports that its advanced encapsulation and pixel-scanning technology all but eliminates the burn-in issue that has affected OLED technology in the past. Encapsulation reduces oxidation of the pixels and the pixel-scanning technology allows for less energy to be applied to each pixel, also saving battery power.

The phone was scheduled for an official release at the end of summer 2017.

Apple Readies 3 Phones for Fall Announcement

A variety of sources, including Forbes[1] and CNET[2], have reported that Apple will reveal new smartphones in September, as usual, in a set of three, as usual. There will be two LCD models (upgrades to the 7 series) and one OLED (the iPhone 8), marking Apple’s first

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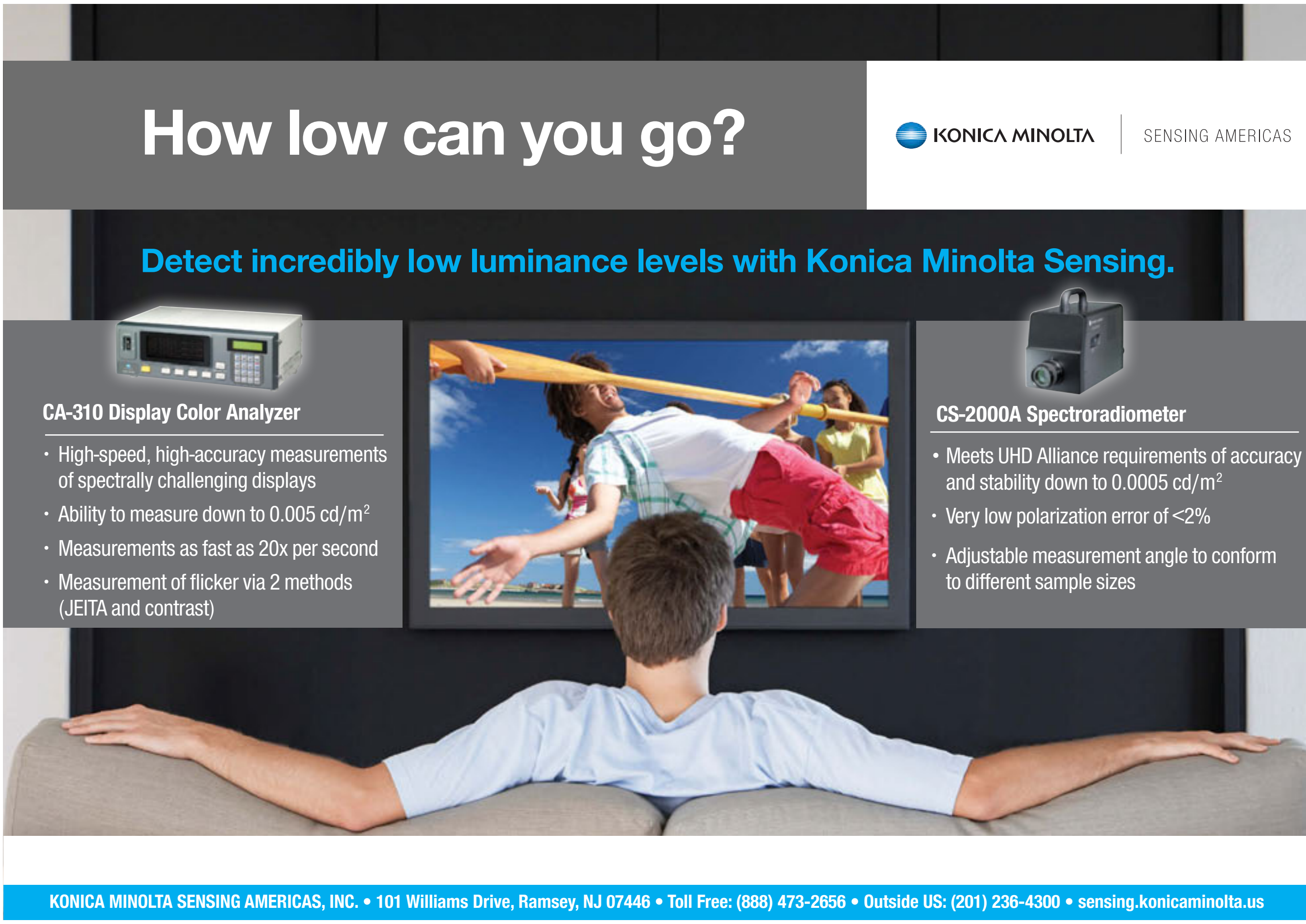
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Materials and Other Game Changers

Quantum dots, OLEDs, phosphors, e-paper, glass, and films represented significant materials developments on display in Los Angeles.

by Ken Werner

Unless you are one of the engineers who builds display panels from primary materials and components, you probably think "quantum dots *vs*. OLEDs" when you see the phrase "display materials." That's fair enough, and we saw lots of dots and OLEDs at the Society for Information Display's Display Week event at the Los Angeles Convention Center, May 21–25 of this year. But the situation is becoming increasingly complicated, and some of the truths we thought we knew are changing. In addition, there is a lot more to the field of display materials than quantum dots and OLEDs, including phosphors, e-paper, and glass and films.

Quantum Dots

With the recent acquisition of QD Vision by Samsung, Nanosys has been the only company making QDs in commercial quantities and licensing its technology for customers to manufacture in volume. All other players have struggled to reach commercial success while polishing their technologies and looking for revenue streams. Nanosys continues its march from strength to strength, but some of the other companies have announced developments that are keeping them in the game.

At Display Week, Nanosys was vigorously promoting its Hyperion quantum-dot material set, which contains a little cadmium, but so little that it falls below the restriction of hazardous substances (RoHS) limit without requiring an exception. Hitachi is mass producing the film, which is currently being used by Hisense and AUO. Hisense previously used Nanosys cadmium-based dots in 3M quantum-dot enhancement film (QDEF) before switching to the Hyperion/Hitachi product. AUO is making panels for Vizio. Nanosys was not focusing on its other quantum-dot technology, which it licenses to Samsung for the QLED QDs that go into Samsung's Q family of super-premium LCD TVs.

Nanosys CEO Jason Hartlove described his company's plans regarding opto-emissive technology – this is the term Nanosys uses to describe quantum dots used to replace the conventional matrix color filter (MCF) in LCDs. "Customers say they are on track for TV intros with opto-emissive technology in 2018," he said. Sets using the technology were shown privately at CES 2017 and will probably be shown publicly at CES 2018, if not before.

Hartlove continued, "Customers say the internal polarizer fabrication and assembly process is proceeding on schedule. The opto-emissive approach should cut power consumption by 50 percent [compared to MCFs] unless some compensation films are needed; then, it will be a bit less. The opto-emissive system puts the QD 'sources' on the surface, so the appearance and viewing angle are very much like those of an OLED but much brighter." Hartlove noted that one TV maker might sneak in with an opto-emissive set at the very end of 2017.

In other developments, Hartlove confirmed that Nanosys is working with microLED developers, and is thinking about how they can become part of the supply chain for direct-emissive devices.

3M to Retire QDEF

3M had a lot to show and talk about in its Display Week booth (see the discussion of several new films toward the end of this article), but the company's industry-changing QDEF was noticeably absent both from the booth and from 3M's pre-show press releases. Given the importance of QDEF to 3M and to the LCD panel industry, this was curious to say the least.

Following the show, I dug into my contact list and wound up speaking with Marketing Specialist Mary Auvin in 3M's Display Materials & Systems Division. She said 3M is indeed retiring from the QDEF business, though it will be produced and supported with customers through 2018. By phone, she suggested that the panel industry's growing reluctance to use cadmium-based quantum dots was a factor in the decision. But 3M could presumably use cadmium-free QDs in a replacement film. Could it be that 3M thinks that QDEF will soon become a low-priced commodity, with the high-value part of the business going to opto-emissive quantum dots?

I discussed these issues with Jeff Yurek, director of marketing and investor relations for Nanosys. He wouldn't comment on what

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his customer 3M is doing, but he did comment on Nanosys's view of the situation.

"We definitely see both QDEF and photo-emissive quantum dots coexisting in the market for a long time to come. QDEF offers important benefits to LCDs in terms of color volume and HDR performance. The massive installed base of LCD manufacturing capacity is not going anywhere any time soon, so there will be a place for QDEF.

"In fact, I think it's likely that we'll see all three generations, including electroluminescent quantum dots, in the market at some point in the not-too-distant future. The three QD implementations offer benefits that display makers will find attractive for different applications and market segments.

"Nanosys continues to sign QDEF coating partners to expand the supply of QDEF to the market in addition to the announced partners that you already know of. This is probably the best signal that I can give you for the continued and increasing demand we see for QDEF."

Nanoco Receives First Commercial Order

At Display Week, Nanoco focused on a new, somewhat puzzling collaboration with OLED-maker Kyulux. (See the OLED section of this article.) And a month after the show, the company announced the receipt of its first commercial order from Wah Hong Industrial Corp., a manufacturer of optical films and sheets for the display industry. The order is for resins containing Nanoco's cadmium-free quantum dots (CFQDs).

The CFQD resin products will be produced in Nanoco's plant in Runcorn, UK, and delivered to Wah Hong for conversion into films, which will be supplied to an OEM for use in TV and monitor products. This first order is for initial production, which is expected to ramp up over the next few months. Nanoco and Wah Hong expect products to appear in the display market during 2017.

Wah Hong seems to be taking the initiative seriously. Said Wah Hong President C. P. Yeh, "We are pleased to announce our first orders for Nanoco's CFQD resin following an extensive trial sampling program performed over recent months. As a business, we recently invested in a new, wider coating line that will enable films large enough to fit 100-in. TVs to be produced and we remain on track to commence production of CFQD films for our customers during the second half of 2017."

After a several years-old agreement with Dow Chemical that produced a plant in Korea to make QDs that were apparently never ordered in significant quantities, and a recent licensing and manufacturing agreement with Merck that seems to have led nowhere after being enthusiastically promoted in 2016, this order from Wah Hong feels like an important one for Nanosys.

QMC Focuses on Continuous Production Line

In the closing hours of Display Week, we had an exclusive interview with QMC Senior Director of Business Development Toshi Ando. Ando said partner Uniglobe Kisco is buying sample quantities of QMC's cadmium-free OLED materials. QMC is shipping small quantities and is transitioning to the large reactor, Ando said.

QDs with low or no cadmium are clearly what panel makers and their customers are looking for, but everybody knows that and all suppliers have them. So cadmium-free is no longer a differentiator. Several analysts, including this one, have suggested that QMC's continuous production reactor, which permits in-line rather than batch manufacturing, could be QMC's greatest asset. Ando said that facilities for in-line manufacturing are relatively inexpensive and permit materials to be fabricated at low cost. Since the process can be tuned in real time, it is easier to optimize the production process and obtain consistent characteristics. Specifically, Ando said, the output spectra (designated by the measured full width of the peak at half of its maximum value (full width at half maximum, or FWHM) are consistent.

During Display Week, QMC announced that the United States Patent Office had granted a patent (#9,577,149) "for the continuous synthesis of high quantum yield InP/ZnS nanocrystals."

Prior to Display Week, QMC had announced a Chinese investment to support manufacturing and applications facilities in Chengde and Beijing. The land with pre-existing buildings has been purchased and equipment has been ordered, said Ando.

__Fig. 1:__ Avantama showed a green emitter at its booth in Los Angeles. All photos by Ken Werner.

Equipment installation should take six months, and process optimization two to three months. Ando said the company expected to be shipping samples to prospective customers from the end of Q2 '17, and to start shipping in volume Q2 '18.

Ando also said that QMC has been working on dot-on-chip. The most recent data show no degradation for four hours at 150 C.

Other Materials Makers

- Avantama AG (Zurich) was promoting its perovskite-type QDs (Fig. 1) at Display Week. The technology is well developed and a pilot line is under development, a company rep said. Materials sampling will follow.
- We first became interested in StoreDot a couple of years ago at CES, when the company showed organic molecules that have properties similar to those of quantum dots. This year, the Israeli company had a booth at Display Week, where it was showing but not pushing its quantum emitters for displays. A spate of recent news stories focused on the other main application of StoreDot's technology, fast-charging batteries. The company's FlashBattery system uses a super-capacitor architecture and its own chemistry, StoreDot says, to recharge either mobile-device or automotive batteries in 5 minutes, while providing more energy density than Li-Ion batteries and supporting a large number of charge-discharge cycles, despite the rapid charging.
- Crystalplex, to the best of my knowledge the only quantum-dot company in Pittsburgh, exhibited at Display Week for the first time in 2017, showing its sapphire-passivated QDs. A year ago, the company received a key US patent (#9,425,253) for the fabrication of sapphire-passivated quantum dots that are environmentally stable without additional protection against moisture and oxygen – *i.e.,* environmental stability without additional barrier layer protection. Another key technology is the method for producing its alloy gradient core, which changes the effective size of the quantum well by gradient of a transition in the chemical composition rather than physical size. Thus, the exterior diameter of the QDs is approximately 8 nm, independent of the color each is designed to produce. It is possible that the consistent dot size could make fabrication of opto-emissive films somewhat easier.

OLEDs

LG Display showed an automotive transparent OLED with a transmissivity of 60 percent. The company's signage OLED display is still at 45 percent. The increase to 60 percent for the automotive OLED is significant because the US National Highway Traffic Safety Administration requires 70 percent transmissivity for an optical element that is placed between a driver and his view of the road, and one of LGD's use cases is a direct-view HUD sitting on the dash between the driver and the windshield. We were not permitted to photograph this display's predecessor at CES, but that restriction was relaxed for Display Week (Fig. 2). An LGD rep said the transparent signage display is ready for customers.

Nanoco and Kyulux

During Display Week, British QD developer Nanoco and German thermally activated delayed fluorescence (TADF) OLED developer Kyulux announced a collaboration and joint development agreement. Both are development-stage companies, although Nanoco may be graduating from that position. (See accompanying entry in the earlier quantum-dot section of this article.)

TADF is a technology through which the high efficiency of phosphorescent OLEDs (for which the essential IP is controlled by Universal Display Corp.) can be realized with certain fluorescent OLEDs. UDC has very good red, green, and yellow phosphorescent emitters, so in this arena, it would seem that the biggest potential advantage of TADF would be a blue emitter that combines the necessary lifetime, efficiency, color coordinates, and emission width. That full combination has not yet been demonstrated, although Kyulux competitor Cynora says it's close. (See below.)

One possible synergy in combining the talents of a company that makes OLEDs (light sources) with a company that makes down-converting devices (quantum dots) that change the color of incoming light to a light of lower wavelength is that if you can't make an emitter for a crucial color, you might want to use a down-converter to make the color you need. In the Innovation Zone (I-Zone) on the show floor, Kyulux showed its "hyper-fluorescence" materials, the company's name for its fourth-gen TADF. A company said a yellow emitter will be available for customer sampling by the end of the year. But QDs can only down-convert; that is, convert to colors with a longer wavelength than the wavelength of the incoming photon. So you could produce orange and red from Kyulux yellow, but not blue and green. And a deep, efficient, long-lived blue is where the need lies.

Cynora

At his presentation at the SID/DSCC Business Conference, Cynora CMO Andreas Haldi

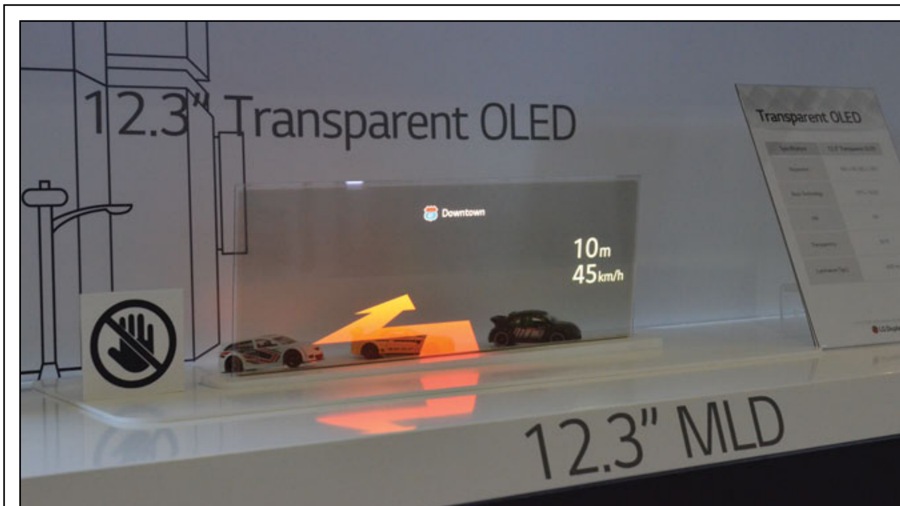

Fig. 2: *LG Display's transparent OLED display for automotive applications features a transmissivity of 60 percent.*

promised his company would produce a high-efficiency blue TADF OLED in 2017, and commented, "We are very happy that OLEDs are not still perfect." (For more from Haldi, see *ID*'s Q&A with him in the November/December 2016 issue.)

As evidence of the "booming market" in OLEDs, he cited the following:

1. Samsung Display plans to supply 72 million flexible OLED panels to Apple this year;
2. Google has offered at least $880 million to LG Display for OLED investment; and
3. LG Display is directing 70 percent of its capital expenditure to OLED production.

He also cited projections from UBI Research that revenues from OLED panels will approximately triple from 2017 to 2021 and that revenues from OLED materials will more than triple. He noted that while high-efficiency red-and-green OLED emitters are commercially available, "an efficient blue emitter is still missing." Therefore, Cynora's top priority is to "bring a first efficient commercial blue material to the market."

Haldi announced what Cynora called "record results for high-efficiency blue OLED emitters," including a 15 percent external quantum efficiency at 1,000 nits with an emission peak at less than 470 nm and a lifetime of greater than 90 hours at 700 nits to 97 percent of initial luminance (LT97) on a device level. Haldi also said the color purity is 62 nm, which presumably refers to the FWHM of the emission curve. He said that these numbers are "close to customer specifications," and that the company will now focus on moving the emission peak toward 460 nm. (The blue LED commonly used in quantum-dot LCD sets emits at approximately 450 nm.) The company expects to commercialize this high-efficiency blue TADF emitter by the end of 2017, with green in 2018, and red in 2019.

E-Paper Advances

Electrophoretic display company E Ink showed a developmental foldable E Ink display with a 7.5-mm bend radius, pixel density of 227 ppi, and diagonal of 10.3 inches. (At 7.5 mm, the "fold" is a gentle one – Fig. 3.)

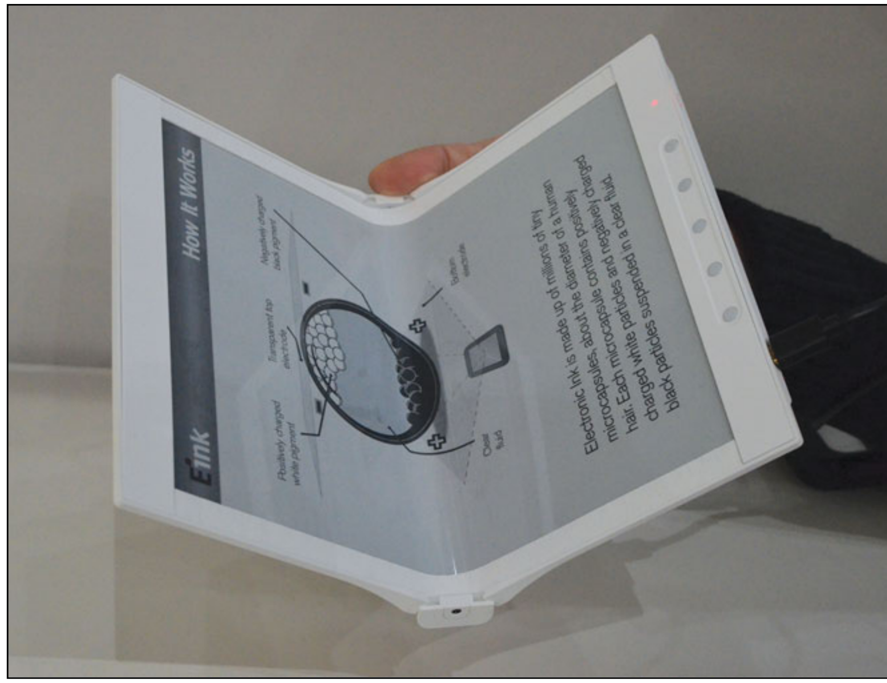

Fig. 3: *E Ink's prototype foldable display has a 7.5-mm bending radius.*

E Ink is talking to customers about this innovation now and expects to start manufacturing foldable displays in 2018.

At last year's exhibit, we thought it was remarkable that the color panel E Ink was showing could produce 30K colors with a 10-second-update, cycle-driving waveform. This year the capability was increased to 50K colors with a 10-second waveform, or 30K colors in 4 seconds. And this year, the company's full-color EPD panels measure 20 inches on the diagonal *vs*. 32 inches last year, incorporate improved chemistry, and, according to an industry source, demonstrate a "vastly improved lifetime." Production will come in late 2018, E Ink said. And it promised a 32-in. full-color panel will be shown later this year.

An E Ink rep said there is room for further update cycle-driving waveform improvement, as each new chemical formulation changes the interaction with waveform and colors. High voltage produces much better colors, he said, but current electronics won't produce the necessary waveforms at the required voltages.

The two-year-old Dutch company Color CNTRL, which was built with the people and IP of the now-defunct IREX, showed its transparent and reflective e-paper technology (Fig. 4).

The CMY technology delivers a 22:1 contrast ratio, representatives said. The technology is ready for manufacturing, and Color CNTRL is looking for a manufacturing partner. The company is also looking for smart windows and smaller applications. The films are UV and IR stable, and have an operating temperature range of –20 to +50 C. The display is very transparent and is designed to produce intense colors, using highly stable automotive pigments. The company is looking for a pilot line, and in the next six months, will develop thin-film transistor versions of its displays, said Director of Displays Hans Hermann.

In the I-Zone, the South China Academy of Advanced Optoelectronics of South China Normal University showed a three-layer color subtractive display using an electro-fluidic approach similar to that developed by Liquavista. Researchers have constructed a Gen 2.5 manufacturing facility and are focusing on relatively large pixels for outdoor displays. There seemed to me no concern about possible IP conflicts with Amazon, which purchased the Liquavista technology.

We first saw CLEARink in its suite during last year's Display Week, and were impressed

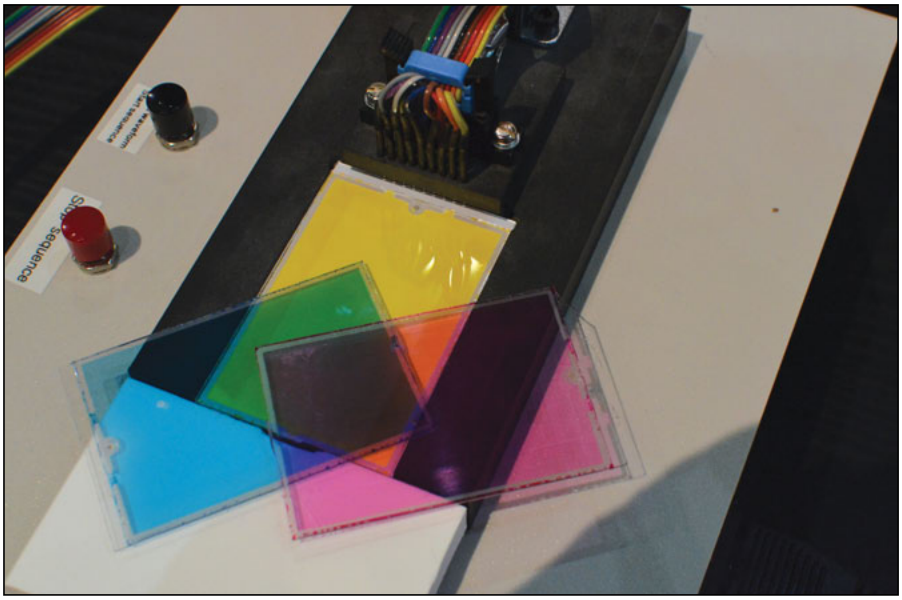

Fig. 4: *Color CNTRL showed its transparent and reflective e-paper technology at Display Week.*

by its technology for creating a high-speed EPD. CLEARink features a clever implementation of electrophoresis that uses an optical plate and lenslets combined with the traditional moving black-ink particles. In the white state, incoming light experiences total internal reflection (TIR) and returns to the viewer. Lurking behind the optical plate is an "ink" containing black particles that are moved toward or away from the plate. When the particles touch the plate (actually, when they get close enough to interfere with the evanescent light wave), the TIR is defeated and light at that point is absorbed. This approach requires the particles to move only a very small distance (~0.5 microns) and therefore can enable update rates compatible with video images. This year, the company earned a Best in Show Award from SID, with an exhibit that included several impressive hand-built prototypes (Fig. 5).

CLEARink's Steven Gou said the company is working with a large display maker on a pilot line to produce units for sampling.

Red Phosphors

General Electric showed its RadiantRed TriGain red phosphor, which is intended to be used within an LED package. The phosphor consists of potassium silicon fluoride (PSF) doped with Mn^{4+}, which produces a sharp emission centered at 631 nm.

In contrast, "typical red nitride phosphors produce a broad red spectrum, resulting in a slight orange tint or significant spillage into the infrared," according to GE's literature. Thus, according to GE, RadiantRed produces "the truest red available in LCDs without compromise." In 2014, GE licensed Nichia and Sharp to make LEDs using the phosphor for display backlighting applications, and now has more than 10 announced licensees, including Toyoda Gosei, Citizen, and Samsung.

Glass and Films

As usual, Corning had an extensive booth with knowledgeable people eager to tell the glass-maker's story. One part of that story is that Lotus NXT high-dimensional-stability glass is being used as the carrier glass for making the flexible OLED Infinity displays Samsung uses in Galaxy S8 and S8+ smartphones. A major focus was Lotus Iris glass, a thin glass intended to replace polymer for use as a light-guide plate (LGP). Compared with polymer, Iris glass offers less thickness, less color shift, better light transmission, more stability, and greater heat tolerance, according to Corning.

With many premium TV sets using edge lighting for 1D local dimming, Corning was stressing the superior local dimming index of Iris glass. The index refers to minimizing the lateral dispersion of the light from each LED in the edge light. A high index results in less light bleeding into adjacent local zones that should be dark or black, thus producing higher dynamic range, or less cross-talk for more exacting calibration of the regions. Corning is working to justify the greater base cost of Iris glass (over polymers) by lowering overall system cost. LEDs, for example, can be closer to the LGP for better coupling (hence less light loss and greater efficiency), according to Bob Quinn, commercial director for advanced glass innovations. Corning said that using Iris glass for the LGP can improve luminance by 5 to 10 percent, as well as delivering a local dimming index greater than 80 percent.

Another major focus was the use of Gorilla Glass as the cover glass for automotive interiors. Even complex three-dimensional shapes can now be cold-formed, which will produce parts that are cheaper and lighter, said Christie McCarthy, Corning's director of commercial operations for auto interiors.

Over at Asahi Glass Company's booth, the main draw for visitors was a cartoon-like digital concierge, but more interesting to dyed-in-the-wool display geeks was AGC's new flexible cover glass intended for foldable smartphones, rollable PCs, and "seamless design PCs," in which the display and keyboard are on a continuously curved substrate. The glass has a radius of curvature of 2.7 mm at 70-µm thickness, and has been tested to more than 100,000 bending cycles. Surface hardness is greater than 9H.

Bendable and Free-Form LCDs

Among the many things Merck representatives were happy to discuss at their Display Week booth was the continuing development of bendable and free-form LCDs. Two weeks before the show, Merck had announced a collaboration with FlexEnable from the UK, "to accelerate the development of free-form displays, following a recent breakthrough by FlexEnable with conformable, large-area, full-color and video-rate organic [LCDs] on plastic. With a bend radius that can go below 30 millimeters, organic LCDs can satisfy market needs for new use cases; for example, in automotive applications. In the near future, organic LCDs can be curved around even more complex surfaces and shapes by combining FlexEnable's high-performance organic thin-film transistors with the innovative polymer-wall LC technology from Merck KGaA, Darmstadt, Germany," which was described in a paper at last year's Display Week.

Merck doesn't want the industry to forget that it is also very serious about OLEDs. Last year, the company opened a new production facility in Darmstadt that allows production capacity to be increased by a factor of five. The capacity of a Korean application lab is to be doubled this year.

Merck/EMD's Bob Miller said the company's plans to produce guest-host liquid-crystal architectural glass are on schedule. The manufacturing plant should be completed by the end of 2017, and production should start early in 2018. Whether the initial production will focus on privacy mode or solar control will depend on the initial customer. All Miller would say about that customer is that it will be in Europe.

Fig. 5: CLEARink's display features 80+ percent white reflectance, 212-dpi XGA, and text and video on the same page.

Additional Observations

- Among much else, AUO was showing a 3.5-in. flexible LCD, which the company called the "world's smallest bending radius flexible transmissive TFT-LCD." The colorless polyimide substrate was carrier coated and removed with laser lift-off technology. The "chip-on-glass" was direct-bonded onto the plastic film, which presumably makes it "chip-on-plastic." The folding radius is 20 mm; contrast ratio, 1,000:1; pixel dimensions, 320 × 480; luminance, 300 nits; thickness without backlight, less than 110 µm; and total thickness, 1.5 mm. AUO is targeting applications such as bendable, conformable, and instrument-cluster displays.
- In the I-Zone, Ngomad was showing an aftermarket anti-reflection film that uses a slow-sputtered titanium dioxide (TiO_2). The company said the film reduces reflectivity from 4.5 percent to 0.7 percent and is available now.
- Among the many optical films 3M showed in its booth at Display Week was an optimized phone film stack. The conventional stack comprises a silver reflector below the light-guide plate and a diffusor and two prism films above the LGP and below the LCD sandwich. The thickness of this stack (excluding the LGP and the LCD) is 252 µm. 3M's optimized stack consists of a 3M ESR-80v2 reflector under the LGP and a diffusor, 3M ASOC3-106 (24), and 3M APF film between the LGP and the LCD. The thickness of this stack is 254 µm, but the center brightness of the testbed phone was 390 nits, compared to 230 nits for the conventional stack. There's an even thinner stack consisting of 3M ASR-80, diffusor, 3M ASOC4-LS-82 LH (24), and 3M APF-QWP, which totals 231 µm, with an axial center brightness of 420 nits at the cost of a modest reduction of the brightness cone to 52/57 FWHM.
- 3M also presented its new dual-brightness enhancement film (DBEF-PVOH), which acts as both an absorbing and reflecting polarizer, and introduced what it called a new concept in light control film (LCF). The conventional film-based way to control light from automotive dashboard instruments is to apply a film that contains, literally or effectively, louvers that allow the light to reach drivers' eyes, but block light that would otherwise reflect off the windshield. 3M's new approach is to replace the louvers with an "engineered refractive structure." Claimed benefits are improved zone

(continued on page 46)

Automotive Displays Proliferate at Display Week

The vehicles of our near future will use unprecedented numbers of displays, in form factors, materials, and sizes we are only beginning to discover.

by Karlheinz Blankenbach

Automotive displays are on the rise – not only in terms of mass production but in size, resolution, and overall capabilities. Automotive displays represent a steadily growing market, which is projected to reach 5 percent share of the worldwide display market over the next several years. It's no wonder that this market evolution is having an impact on SID's Display Week (Fig. 1)! This article provides a brief overview of automotive-related content presented at the symposium and a look at selected automotive displays shown at the exhibition during the 2017 event held in Los Angeles.

Technical Presentations

The Display Week symposium traditionally starts with keynote addresses from three industry luminaries. This year, one of the speakers was Sanjay Dhawan, president of the connected services division of Harman, who spoke on "Humanizing the Autonomous Car Experience." Dhawan predicted that autonomous driving will transform the car from a place where the driver primarily performs the task of driving into a place for both leisure and work. Displays and advanced

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***Fig. 1:** Asahi Glass Company's booth at Display Week 2017 exemplified a trend toward automotive-related exhibits at the show in recent years. All photos courtesy Karlheinz Blankenbach.*

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human-machine interfaces (HMIs), in combination with connectivity, will play a major role in that transformation. Within the symposium, six sessions (two of them joint sessions) were dedicated to automotive topics. Here is a brief summary of the ideas and themes presented in those sessions.

- Quantum dots are being used to enhance the gamut of automotive LCDs and are key to enabling an outstanding HMI experience. A display with a large color gamut will appear less "bleached out" by ambient light reflections than will a low-gamut display. However, quantum-dot technology has to improve in terms of lifetime and temperature range in order to meet automotive display requirements.
- Automotive-grade OLEDs with larger lifetimes and higher temperature endurance are paving the way toward series production.
- Curved, flexible, and freeform automotive displays are requiring dedicated technical solutions and new measurement methods. These displays enable new interior design visions and greater control over ergonomics.
- Reflection reduction methods and measurements including low sparkle are essential for bright ambient light use such as in convertibles or any open-top vehicle.
- Head-up displays (HUDs) provide ergonomic benefits. A 3D HUD was presented by Philippe Coni from THALES, France, in the distinguished paper, "Development of a 3D HUD Using a Tunable Bandpass Filter for Wavelength Multiplexing." Related talks discussed improvements in picture-generating units like liquid-crystal-on-silicon (LCOS), as well as multi-depth approaches.
- The HMI within an automobile is becoming more important, with increasing numbers of displays and fewer knobs and pushbuttons providing the means by which drivers and passengers select functions related to climate, entertainment, lighting, etc. User interaction topics include multimodalities such as haptic feedback.
- Automotive interior lighting will see hundreds of RGB LEDs in premium cars in the near future. A new approach to overcoming the challenges involved in incorporating them was described in a paper by Robert Isele of BMW, in which RGB LEDs were equipped with intelligent drivers in the same housing, providing temperature and aging compensation as well as data connectivity. (For more on this topic, see "Automotive Interior Lighting Evolves with LEDs" in the

Fig. 2: The wide color gamut and 1.5-mm bezel featured in this 12.3-in. freeform dashboard LCD from AUO represent two major trends in LCD automotive panels.

Fig. 3: These 12.3-in. LCDs from Tianma are shown with local dimming (top) for power savings and without local dimming (bottom).

May/June 2017 issue of *Information Display*.) The distinguished student paper from Christiane Reinert-Weiss and co-authors at the University of Stuttgart, "Development of Active-Matrix LCD for Use in High-Resolution Adaptive Headlights," described the development and benefits of a 30,000-pixel AMLCD that modulates the frontlight to avoid bothering oncoming traffic. The prototype for this development was exhibited in the I-Zone and received the Best Prototype Award for 2017.

Three other presentations on automotive topics by the author of this article and Dr. Thomas Fink of Porsche included the address, "Automotive Display Measurements – Challenges and Solutions," during the International Committee for Display Metrology (ICDM) workshop on Sunday; another talk on "Automotive Displays" for a Monday Seminar; and the automotive sessions keynote. Last but not least, Display Supply Chain Consultants (DSCC) organized a well-attended market focus conference on automotive displays – "Safety, Utility, Ubiquity" – that took place on Tuesday, May 23.

On the Show Floor

As in the technical program, the impact of automotive topics is increasing on the exhibition floor, from innovations in LCDs, OLEDs, HUDs, materials, and measurements to new approaches on the horizon like microLEDs. The latter promises luminance in the 10,000 candelas-per-square-meter (cd/m^2) range with high efficiency, making microLEDs quite suitable for automotive applications. Unlike with consumer displays, the race for automotive display size is not over. However, 12.3-in. panels with 1,920 × 720 pixels are becoming a standard for larger-sized automotive displays. Raising image quality through larger color gamuts (as is happening for consumer displays), low reflectance (through films and optical bonding), integrated touch, curved and flexible displays, longer lifetimes for OLEDs, and reduced low-temperature response times for LCDs were among the many features showcased by different companies at Display Week. The rest of this article provides selected highlights from the exhibition.

Fig. 4: This 12.3-in. OLED display with 600 cd/m² was shown by AUO.

Fig. 5: AUO's dual-LCD panoramic dashboard consists of two 12.3-in. panels that are seamlessly connected.

The vast majority of today's automotive high-resolution displays are thin-film transistor (TFT) LCDs. One trend involving this technology is seamless integration, which favors freeform displays like that shown in Fig. 2 from AUO.

This example highlights two other sought-after features in automotive displays: narrow borders and large color gamuts for high-quality HMI visualization.

Sought-after reductions in power consumption for automotive displays are necessary for fuel and electrical energy savings, but the high luminance required from automotive displays draws a lot of power. Another severe and costly task for integration is sophisticated heat management, so power reduction helps quite a bit. This can be achieved for LED-backlit LCDs, for example, by using local dimming methods (similar to those in high-end TV sets) as shown in Fig. 3.

Compared to typical movie content, the average automotive HMI content promotes lower gray levels and brightly highlighted characters, requiring more sophisticated dimming methods that are more difficult to measure. This issue can be overcome by using OLEDs like those in Fig. 4 in the display from AUO. Only the lit pixels draw electrical power (similar to the way "always-on" displays work in OLED-based smartphones). As an example, the content of Fig. 4 can be visualized on an OLED at about 15 percent the energy usage of a comparable LCD.

Most of the showcased automotive LCDs featured a white luminance in the range of 1,000 cd/m^2, while the values for OLEDs reached 500 to 600 cd/m^2, which enables an automotive-compatible lifetime.

Another big trend is a large-area, glass-covered dashboard. Corning showcased an all-glass prototype for the entire dashboard,

Fig. 6: This 3D instrument cluster from LG combines a transparent head-up display (top) — which is a 12.3-in. OLED (60 percent transparency and 600 cd/m^2) with a multilayer display (MLD) at bottom, which uses both a transparent OLED and LCD with 1,060 cd/m^2.

including the center console. A seamless dashboard shown by AUO was built with two 12.3-in. LCDs, resulting in an impressive 27-in. panoramic display (Fig. 5). Such an approach, using optical bonding, is already in mass production at Mercedes.

A major requirement for non-autonomous driving is the fast and secure capture of driver-relevant information on the instrument cluster. Autostereoscopic 3D displays (beside HUDs) help a lot in this regard, but lack quality in terms of sharpness and eye-box sensitivity. Note that issues with autostereoscopic displays like convergence and depth-perception confusion are more likely to occur with prolonged (greater than 15 minutes) viewing. Most users will glance at these displays for only a second or two. A multilayer display (MLD) as showcased by LG in Fig. 6 (bottom) provides quick information gathering, even for "overloaded" instrument cluster HMIs.

An MLD consists of a rear display with high luminance (such as an LCD) and a (highly) transparent display (such as an OLED). The content, however, has to be optimized for this arrangement with software such as that currently being developed by Delphi. A transparent OLED (60 percent, Fig. 6 top) can be used as well for a direct-view HUD; both luminance and transparency must be high. A transparency of 70 percent is required in many countries for displays placed within the driver's viewing area.

Another trend in automotive displays is replacing rear-view exterior mirrors with cameras and displays, as shown in Fig. 7 with a cockpit display from JDI.

The 10-in. LCDs have 308 ppi, which is about 50 percent higher than today's high-end automotive instrument cluster displays. Above this impressive dashboard is a HUD, which is the size of today's standard with a field of view (FOV) of about 8° by 4°. For augmented reality applications, the FOV for HUDs has to be significantly larger – 30° × 15°, which requires more than 20 times the optical – and by consequence, electrical – power. There were some holographic HUDs (such as from Luminit) exhibited, but capturing their images on pictures was difficult on the show floor. (For more about automotive HUDs at Display Week, see "The Expanding Vision of Head-Up Displays" by Steve Sechrist.)

As there are generally no large, flat surfaces in car interiors, is it logical that curved displays are becoming more popular. Compared to mobile foldable displays, the radius for automotive large-sized displays can be in the range of hundreds of mm. Touch functionality (large size and curved) is a must for design-driven center stacks. This was demonstrated by BOE's 15.6-in. LCD (Fig. 8) with 1,000-

Fig. 7: This cockpit display from JDI was built with 10-in. LCDs with a resolution of 2,880 × 1,080 (308 ppi) and a standard field of view (FOV) HUD.

mm radius and 1,000 cd/m². A brighter display showcased by JDI (Fig. 9) was an S-shaped 12.3-in. panel with a radius of 800 mm.

Besides automotive displays, there were a lot of automotive-relevant subassemblies, materials, and improvements at the show. The following areas were of particular interest:

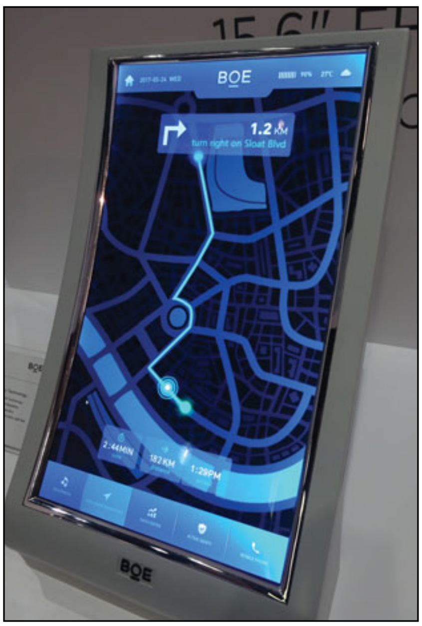

***Fig. 8:** A 15.6-in. curved (R = 1,000 mm) FHD LCD shown by BOE featured 1,000 cd/m² and in-cell touch.*

***Fig. 9:** This S-shaped 12.3-in. LCD from JDI was capable of 1,150 cd/m² and had a radius of 800 mm for each curvature.*

- Bright ambient light imposes significant challenges on automotive instrument cluster displays, especially as it relates to readability of critical data such as speed or RPMs. At Display Week, Dai Nippon Printing (DNP) was promoting a display front film with just 0.1 percent reflectance (and a high transmission of 96 percent), which is about one tenth of standard reflection reduction methods. This improves readability significantly, by about one order of magnitude (assuming the contrast ratio as CR ≈ $L_{Display}$ / $L_{Reflected}$ + 1).
- Many car functions are operated while driving, so especially for center stack displays, touch operation is best for both ergonomics and safety. Haptic feedback can be especially effective. Touch operation and larger panels, however, require scratch resistance. And one undesirable effect of anti-glare reflection reduction is "sparkling" for high-resolution displays. All these challenges can be met by the "haptic glass" from Sevasa shown at Display Week.
- Unlike consumer (aftermarket) displays, OEM displays have to withstand severe impacts – such as a person's head hitting the display. Glass shattering is unacceptable. Corning showed a simulated head-impact-test video (Fig. 10) demonstrating how its convex and concave Gorilla Glass can successfully withstand major impacts.

The above-mentioned presentations and exhibits represent only a modest selection of the huge variety of automotive technology featured at the Display Week 2017 symposium and exhibition. There will be much more to come in 2018, with additional auto-related content both in the technical programs and on the show floor. Looking forward, automotive displays will also be a focus of attention when (semi-)autonomous driving comes of age. Vehicle displays will then serve drivers from the standpoints of entertainment and occupation as well as driving information. ■

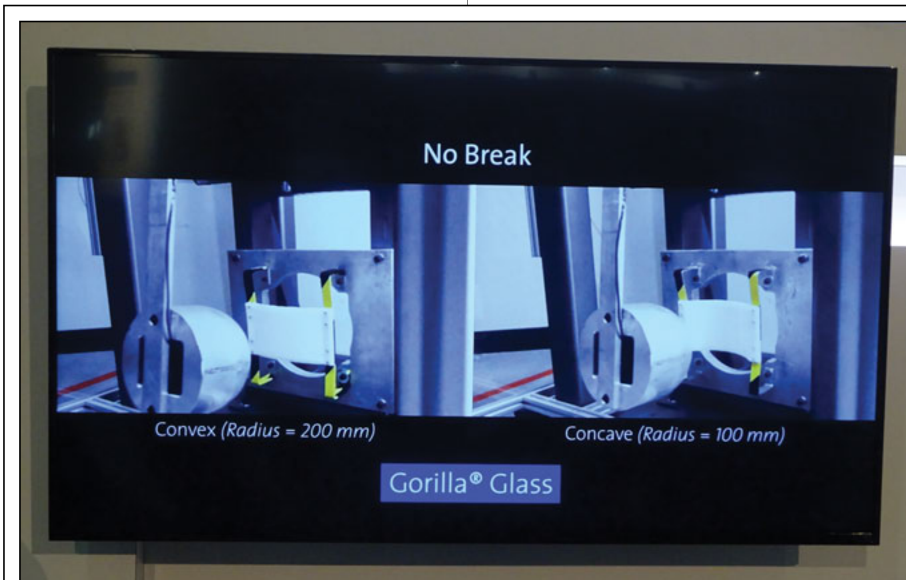

***Fig. 10:** This screenshot is from a video of a simulated head-impact test from Corning based on its curved Gorilla Glass displays.*

SID

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Please contact Jenny Donelan, Editor in Chief, at jdonelan@pcm411.com with questions or proposals.

Turn to page 47 for a list of 2017 editorial themes, with approximate dates for submitting article proposals.

The Expanding Vision of Head-Up Displays: HUDs for Cars at Display Week 2017

The goal for HUDs is to provide drivers with critical situational awareness in a non-distracting way. At Display Week 2017, it was clear that manufacturers are overcoming numerous technical challenges to make this goal a reality.

by Steve Sechrist

In the automotive space, head-up displays (HUDs) allow drivers to see information such as speedometer, tachometer, and navigation system data without having to look away from the road while driving. In a conventional windscreen HUD system, this information can be projected from a system mounted in the dash onto a windshield film that provides the appearance of the information floating outside the vehicle. Next-generation windscreen HUDs called AR (augmented-reality) HUDs will project images on the street and in the environment as we drive. These images will go beyond a simple arrow indicating an upcoming turn; they will entail a series of arrows superimposed on the street and in the lane up to the turn point as we approach. This functionality requires a dramatic increase in the field of view and optics components in order to work in a realistic and reliable fashion.

Compelling as automotive HUDs are, one reason they are not more common is they are expensive. The technology is difficult to mass produce, as it must be made to conform to the complex geometries of unique car model windshields, and few (if any) models achieve the volume required to make the technology viable through economies of scale. Consequently, for decades, conventional HUD technology has been primarily relegated to high-end luxury cars and avionics applications.

Beyond cost, integration issues still loom for conventional windscreen HUD technology. These center around the competition for volume (space) in the vehicle. Two critical factors car designers face is the trade-off between HUD device package volume, which can range from 4 liters (today), to prototype AR systems that may be up to 20 liters in volume. HUD package volume directly impacts the head-up display object size and image distance (how far it floats above the hood of the car), with the potential to encompass the entire windscreen and field of view of the driver with augmented situation-awareness data (Fig. 1).

Fig. 1: *The future of windscreen conventional HUD systems includes a wide field of view that augments the entire windscreen for the driver. The arrows indicate which lane to turn into. Image courtesy of Continental.*

Stephen Sechrist *is a display industry analyst and long-time SID member since the pen computing days of Apple Newton and Go Corp. (AT&T) EO (remember?) He enjoys display industry writing and talk of the old days when a 1MB HD was hot stuff. He can be reached at esechrist@gmail.com.*

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Recent HUD design breakthroughs with lower-cost alternatives to conventional windscreen HUD systems are helping to address the need for enhanced critical situational awareness information. These new systems can deliver this information directly into the field of view of the driver, diminishing "eyes-away" distractions and enhancing driver safety. This is in concert with other auto display megatrends that include a dramatic increase in the number of sensors in vehicles.

The primary display development focus in HUD systems today (and near term) is in situational awareness and AR data display. These near-term technology additions include livestreaming of rear-view data to a mirror display from a rear-mounted wide-angle camera. Additional cameras and other sensors such as lane-change assist and warning indicators for side mirrors are available in new vehicles today.

Future "sensorization" of the vehicle includes the addition of artificial intelligence (AI) combined with connectivity between transportation and metropolitan infrastructures that will contribute both mid- and long term to the eventuality of the driverless vehicle. These advances include car-to-car communication as well as car-to-infrastructure (road and highway or building, like a parking garage). At some point in the future, our primary display focus inside the car will switch from situational awareness and monitoring to personal and social information access and entertainment.

Newer, Low-Cost HUDs Solve Windshield Conformity Issues

Recent developments in lower cost "combiner-type" HUD systems involve the projection of an image on a pop-up, see-through glass or plastic optical element. This augments the driver's field of view with critical situational awareness data, while using a relatively low-cost approach. The key difference to the driver is that the image remains inside the vehicle on the combiner element rather than appearing to float above the hood outside the car, as it does with the more expensive conventional approach. In either case, the display module includes an LED (or sometimes a laser) light source with a liquid-crystal or MEMS projection-type light engine. Critical to car designers is the volume of the module, power (in hybrids), and ruggedness, including the ability to withstand wide temperature ranges in both off state and when operational.

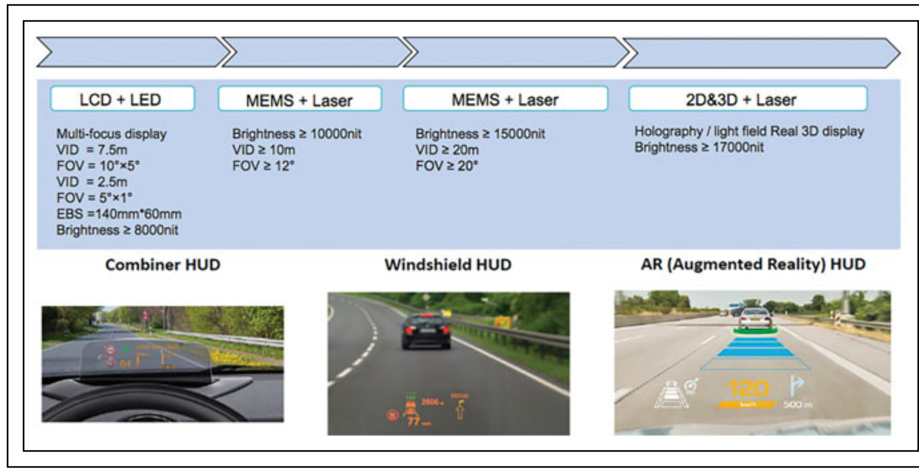

Fig. 2: BOE provided an overview of its HUD technology at Display Week's Market Focus Conference for Automotive Displays.

As evidenced at Display Week 2017, and in reports from system integrators, there is strong OEM interest in these lower-cost combiner HUD systems for B- and C-class cars that will help reduce the unit cost of the technology by leveraging its use in more models, and consequently moving the technology into the mainstream car market.

Auto Industry Requirements for Displays

The major specifications of HUD displays are mostly driven by well-established safety standards for vehicle components. In short, automotive displays require additional performance criteria compared to displays used in offices and homes, including:

Picture quality: In automotive HUD systems, the focus is primarily information (rather than entertainment and full-motion video), so higher resolutions are not a critical requirement. As recently as 2014, the HUD display requirement was relegated to a 1.x-in. WQVGA display. This was before the adoption of combiner-type displays.

High contrast/high luminance: A higher contrast ratio is required in order to provide daylight readability in the high-ambient environment of a vehicle, with luminance now being delivered above 8,000 nits.

Adjustable luminance to augment changing time of day, and day-to-night transitions: Displays must provide adjustable dimming from maximum luminance in daytime to lower luminance in evening and at nighttime to avoid interior ghosting and glare.

Color gamut: Displays must maintain color stability under sunlight conditions and in

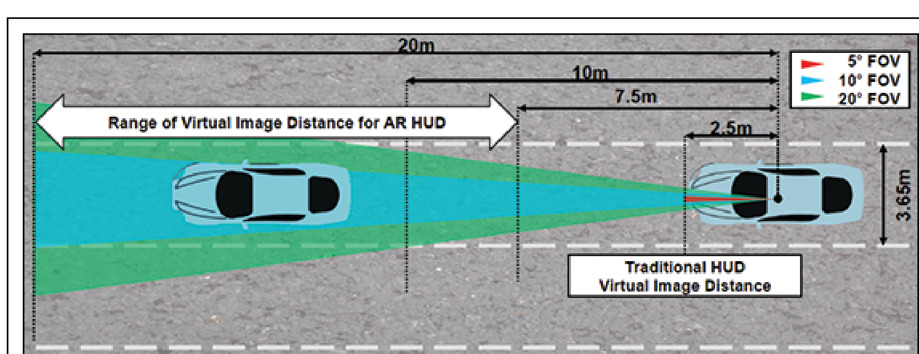

Fig. 3: TI's presentation showed conventional windscreen HUDs moving to "true AR functionality" in the future, but due to optics requirements, this will come at a cost of increased package volume.

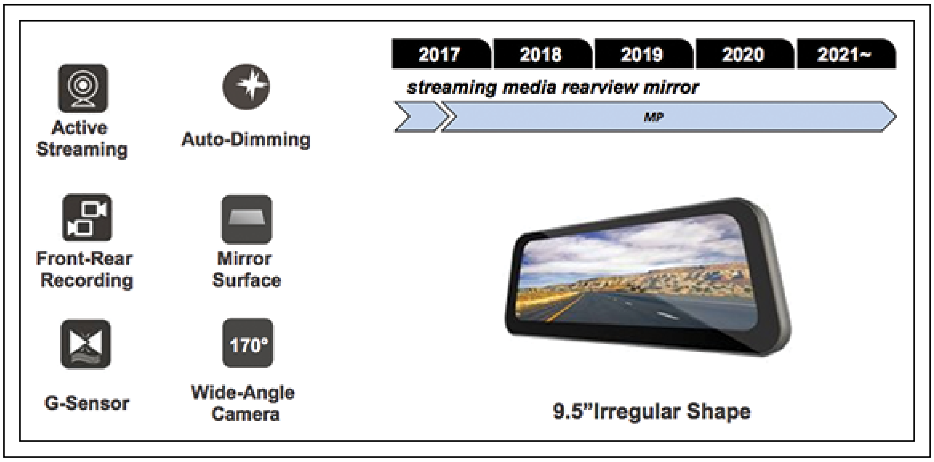

Fig. 4: A mirror display shows a streaming camera image from a rear-mounted CCD sensor with a wide-angle lens offering superior situational awareness. Image courtesy BOE.

broad viewing angles, but they do not need to produce as many or as wide a range of colors as entertainment-type displays.

Fast response time: 30 milliseconds or better response time is ideal for vehicles as well as entertainment uses that go beyond automotive.

Wide temperature range: Displays must perform consistently regardless of operating temperature; in a range from –40°C to 105°C, which is much wider than typical consumer-grade requirements.

Display Week was the ideal place to catch a glimpse of the current state of the art in automotive HUD systems. And the Market Focus Conference on Automotive Displays on Tuesday at the show was an excellent place to start.

For example, the BOE presentation at the automotive conference showed a good outline of the different types of HUD devices (Fig. 2). The lower cost combiner technology uses an LCD engine powered by LED illumination. Conventional windshield HUDs generally utilize MEMS imagers (like TI's DLP), plus laser light sources. These are currently 2D systems but long term, 3D will be added, and combined with a much longer virtual image distance that offers a more realistic AR experience than the HUD system. In the Texas Instruments presentation at the automotive conference, the company stated a minimum of 7.5 meters in virtual image distance that can extend up to 20 meters and a field of view that ranges from 5 to 20 degrees will be required for a true AR HUD image (Fig. 3).

A livestreaming video image to a rear-view mirror display represents another HUD-like display type (Fig. 4).

This irregularly shaped display technology is available this year to car makers and system integrators from BOE.

HUDs on the Show Floor

One company leading the field in automotive HUDs is JDI, which has been providing these types of products for three years now. In 2014, just two years after its founding in 2012 with the joining of display groups from Sony, Toshiba, and Hitachi, the company showed its automotive market "combiner HUD" technology in Yokohama, Japan. This display showed the image on a transparent screen inside the vehicle, rather than projecting the information onto a light field above the car hood, as would a conventional HUD.

A factor to consider is the long lead cycle necessary to get equipment such as displays into car designs. Display makers are then also burdened with long support cycles, as car manufacturers often require replacement parts to be available for 15 years or longer after product end of life.

At Display Week, the JDI booth focused on a highly transparent color display that can be used in a car as a hybrid HUD. The 4-in.

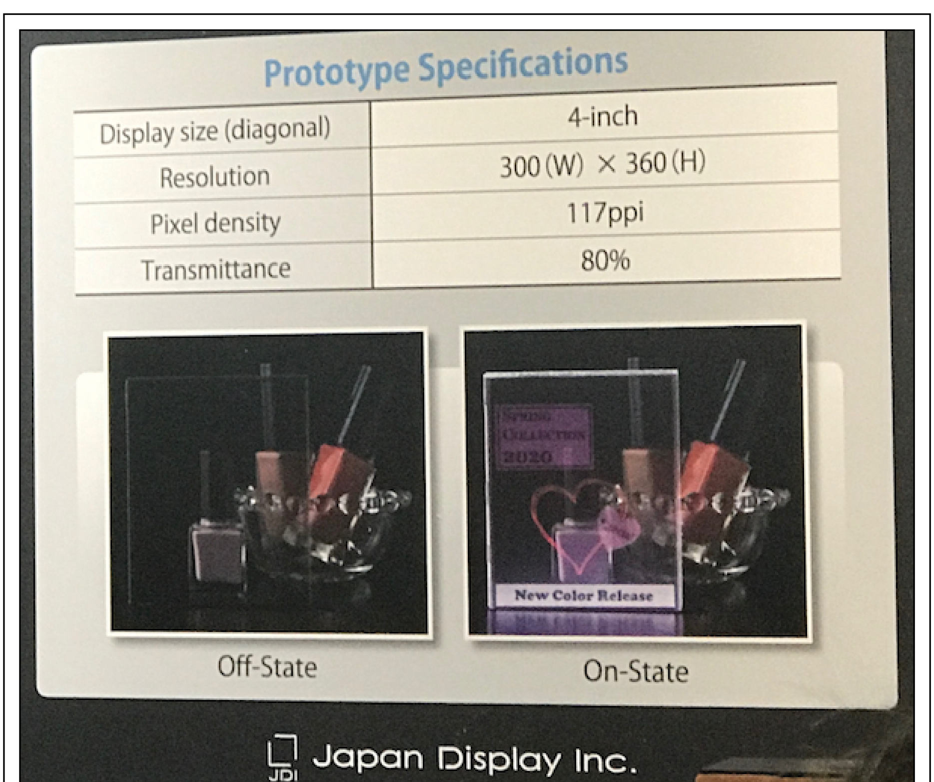

Fig. 5: JDI's display was shown in both off (left) and on (right) states on the show floor at Display Week. Photograph by Steve Sechrist.

diagonal LCD offers up to 80 percent transmittance with a 300 × 360 pixel (117-ppi) resolution sporting 16.77 million colors (Fig. 5). Background images can be clearly seen through the LCD, which requires no color filter or polarizer.

A key benefit is the 80 percent transmittance, which allows users to see displayed images against a real-world background. (As referenced in "Materials and Other Game Changers," the materials review article in this issue, the US National Highway Traffic Safety Administration requires at least 70 percent transmissivity for an optical element that is placed between a driver and his view of the road.) This technology is targeting AR and MR (mixed-reality) environments and can be used in expanded applications such as car mirrors or even windows.

An additional display for next-generation automobile cockpits is being developed by JDI that targets auto designers' need for flexibility and content in a non-distracting way. JDI cleverly combined the driver instrument display (DID) content with a data subset displayed on the HUD combiner windscreen (Fig. 6). The technology is meant to deliver a low-cost HUD alternative to car designers by circumventing the expensive windshield HUD approach.

For more detail, we went to the company website and found this description: "JDI offers a display for next-generation automobile cockpits that increases flexibility for both interior design and displayed content to assist drivers by integrating the instrument cluster...."

For the instrument cluster, the curved "IPS-NEO" provides displays that are easily viewable to drivers. The upgraded "White Magic" achieves both a large high-definition screen and low-power consumption. In a safe head-up display that can be viewed without turning the eyes, a larger display area with increased resolution leads to the extension of data display.

In the booth this year, JDI was also featuring an LCD engine for the conventional HUD projection-based devices that have been

Fig. 6: *In 2014 JDI introduced this combiner HUD for application inside the car with data synced to the driver information display; here is a 10-in. cockpit cluster with head-up overlay.*

Fig. 7: *An example of JDI's LCD engine for conventional windscreen HUD systems uses an LED backlight. The company also supports a retractable combiner HUD like the one found in the 2016 Mini Cooper with final components assembled by Bosch.*

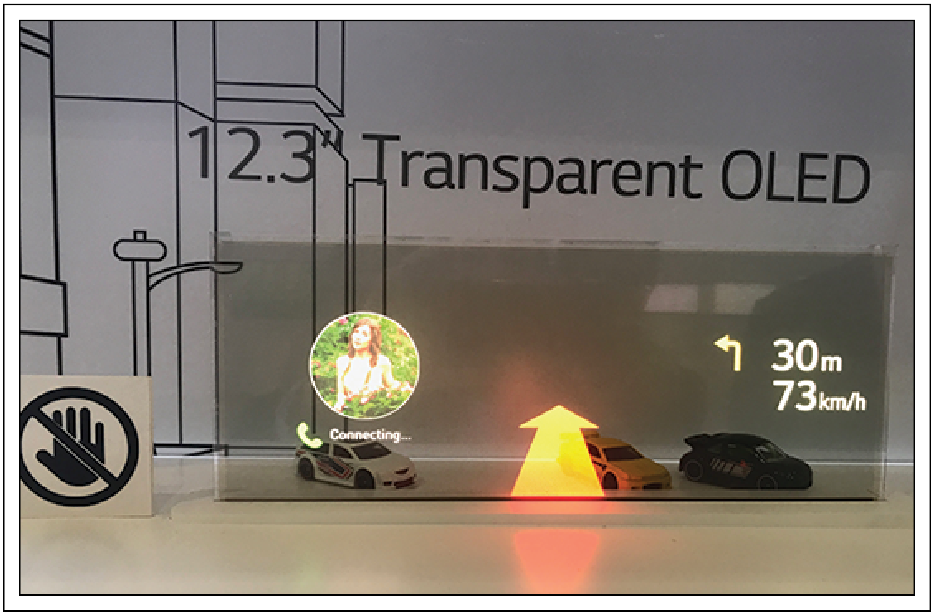

Fig. 8: LG's transparent 12.3-in. hybrid diagonal display combines both LCD and OLED elements.

around for years. These use a local dimming backlight added to the "White Magic" (added white pixel) display JDI has standardized on for the past several years (Fig. 7). The company showed how the local dimming backlight module improves traditional HUD images while lowering power by approximately 45 percent and improving luminance 35 percent.

The company also showed a curved (500-mm radius) 10-in. diagonal prototype cockpit cluster display with a head-up overlay in 2,880 × 1,080 pixel configuration (380 ppi) using an in-plane-switching based LCD. The panel sports a 1,500:1 contrast, and offers a wide gamut.

LGD's Transparent Display

On the show floor, LG's automotive exhibit featured its OLED technology and a hybrid of what the company calls MLD (multilayer display), which combines both OLED and liquid crystal in a transparent display meant for relatively low-cost (compared to windscreen-based applications) head-up use (Fig. 8).

The MLD has a front resolution of 900 × RG (BG) × 360 pixel and a rear display resolution of 1,920 × RGG × 720 pixels. Other details, like transmissivity, were not published but LG said they will be forthcoming.

LG identified three chronological trends in the automotive display space. In the first, from 2010 to 2014, displays were included as a small part of the dashboard, combined with analog instruments and growing center-stack displays. Starting in 2015, larger size displays, including full cluster displays (rather than those simply mixed in with analog instruments) and much larger center information displays (CID or center stack displays) with touch interface began to proliferate. These will continue to do so through 2019. During this period, we will also see the beginning of pervasive head-up displays. The third trend begins in 2020 and lasts to 2024, during which displays will be seamlessly integrated into the full dashboard, with the potential to include the entire vehicle – everything will be a head-up display.

LG also addresses some of the unique requirements needed by the auto industry in its display integration.

Another example of the evolving head-up display in cars is the move toward using a display and camera system to replace the rear view mirror. In fact, some see the use of traditional mirrors in the car as totally going away. At Display Week, LG showed its version of a 6.13-in. diagonal OLED that will serve as a rear-view mirror replacement. Its display sports 600 × 224 pixel resolution with 105 ppi and a reflectance of >75 percent with over 600 nits white luminance. LG Display's

Fig 9: LG Project Manager project manager J. Kang stands next to the company's 6.3-in. OLED mirror display.

J. Kang (Fig. 9) told us the OLED panel uses an LTPS backplane.

Overall, LG seems to be targeting the auto space with its OLED technology over LCD, claiming the self-emitting technology offers better auto-grade reliability, plus the ability to create various shapes (curvatures) to conform to the auto design requirements. OLED's "perfect black," high-contrast display capabilities are also in its favor.

LG's transparent OLED technology offers very high transmissivity and the ability to conform to slim window integration requirements. These displays also feature very low latency – important for situational awareness and safety – and offer a high reflectance level for use in mirror applications.

So LG's vision long term for HUD may just be display ubiquity in the car with its transparent displays placed on every traditional glass surface in the car today. As driverless (or self driving) vehicles make their way into the mainstream by the next decade, the car interior will evolve into more of a super-efficient living space where people spend time while moving from place to place. That means content consumption, and that points directly to greater use of multiple displays. And remember, this is coming from the company that also showed a 77-in. diagonal "Wallpaper" OLED display with UHD resolution, weighing in at under 3 lbs. and measuring less than 6 mm deep.

Asahi Glass Company also has a focus on automotive displays with windshield and rear view (e-mirror) technology also mentioned, along with dashboard displays (Fig. 10).

AUO's booth (and conference presentation) focused on the future of the HUD in the vehicle as a unified 360-degree glass screen where "glass is the fabric that knits the displays together." To get there, the company said what is needed is curved, molded 3D glass displays (not necessarily "flexible" ones), seamless transition of infotainment from surface to surface, integrated dynamic gesture recognition, touch and HMI, plus high-speed interconnectivity (screen to screen that includes vehicle to vehicle, vehicle to infrastructure, and vehicle to smartphone).

HUDs Up!

This is an exciting time for automotive HUD technology, whose growth is just beginning to take off. New windscreen technologies and combiner HUD systems are just the beginning. As we move forward into the realm of AR HUD systems, we see the technology growing in prominence. It is sure to be a feature in a car you drive – perhaps sooner rather than later.

From the early days of its adoption in airplane cockpits to the first use in cars dating back to luxury brands in the 1980s, the head-up display has captured the driver's imagination with the idea of a non-distracting way to update critical situational awareness. This is an idea not lost on auto safety engineers, auto insurance providers and especially cutting-edge drivers wanting that extra edge that enhances the driving experience. And after all, isn't that what it's all about? ■

Fig. 10: AGC head-up displays are combined with e-mirror display and driver information cluster.

Metrology and Image Quality Play Starring Roles at Display Week 2017

Metrology technology sessions and exhibits were much in evidence this year, highlighted by the first-ever metrology training course at Display Week. Image quality also took center stage, with high-dynamic-range (HDR) technology featured on and off the show floor.

by Tom Fiske

Display metrology at Display Week (and in the display community at large) has experienced a rise in prominence in recent years. This is due in part to the popularity of the Information Display Measurements Standard (IDMS) document published in 2012. The authors of the document, the members of the International Committee for Display Metrology (ICDM), now a part of SID, are hard at work preparing the next edition of the metrology methods standards volume, which is expected in the next year or two.

Display manufacturers and system integrators recognize the value of agreed-upon methods and definitions for display characterization. To be assured that display products adhere to display performance standards, the right measurements have to be made in the right way. It is therefore important to have up-to-date methods that are created and approved by experts in the display metrology field. The ICDM, in fact, has hosted robust discussions about various aspects of display metrology development at several of its recent meetings. Part of the Society for Information Display's charter is to encourage advances in display measurement and as a part of that effort, SID provides support for the ICDM, publishes the IDMS, and sponsors educational seminars such as the training course at this year's Display Week. In addition, SID supports the International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO), which are also working on display metrology topics.

Among the many activities related to display metrology at Display Week 2017 were the display measurement sessions in the symposium program, a display metrology track in the exhibitors' forum, several measurement companies on the exhibit floor, and a metrology seminar on Monday. And, for the first time, SID and ICDM offered an Introductory Display Metrology Training Course (Fig. 1) in parallel with the other Sunday Short Courses. The ICDM also had a booth on the exhibit floor, and the participation of many companies in the ICDM was highlighted at the exhibits.

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Display Metrology Training Course

The Introductory Display Metrology Training Course, organized by ICDM Chair Joe Miseli, featured a high-quality slate of speakers and a handful of hands-on demos of some representative types of light measurement devices (LMDs). The course was conceived as a service to the display community and to highlight the activity of the ICDM. It may be offered again in future years, depending on demand.

The introductory-level aspect was one of the keys for the first couple of presentations. Edward Kelley of Keltek Research covered basic radiometry, photometry, and colorimetry in his usual engaging style. This extremely useful information is the foundation for making any light-based measurement on devices that use light for making images for human consumption. Kelley's notes from this course are a useful compilation of definitions and formulae that serve as an essential reference.

He began with the definition of light as electromagnetic radiation and moved on to the concepts of spectra, descriptions of essential geometrical considerations, and definitions of key concepts and quantities for radiometry and photometry. Along the way, Kelley did a very good job of letting his audience know when they should pay attention to the material with notations such as "!Main Idea!" as well as when listeners could safely check their Facebook feed (*e.g.*, "Boring Alert.") Thankfully there was a lot of the former and not much of the latter. His definitions were emphatic and clear; *e.g.*, don't use the term "brightness" (a perceptual construct) when you mean "luminance" (which can be directly measured). He effectively used the concepts in the beginning of the session to describe the basics of how optical detectors work, how to

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characterize an LED, and how to understand the subtleties of characterizing color gamut and color volume.

Michael Becker from Instrument Systems, one of today's leading experts on display metrology, also gave a very informative talk on the basic framework for display metrology, reviewing the definitions of and motivations for display metrology; *i.e.*, the science of metrology as applied to electronic visual displays for the purpose of establishing the usability of a display for a particular situation. He described the main standards organizations that are most relevant to display metrology: the Commission Internationale de l'Eclairage (CIE) for fundamentals of photometry and colorimetry; the IEC for applicability of display components and systems; the ISO for usability and ergonomics; and the ICDM for practical methods and tutorials.

Becker also discussed the importance of knowing the intended application scenario for a display system. This drives which characteristics need to be measured and what thresholds should be met to satisfy the usage requirements. He reviewed the various components of a comprehensive display measurement system. One can measure electro-optical, spatial, angular, and temporal quantities as well as how these parameters vary as a function of ambient conditions (*e.g.*, temperature, age, lighting conditions). The following questions were also addressed: How should those measurements be reported? Tables, graphs, pictures, or a combination? What test patterns should be used? Becker continued with an overview of different types of measurement devices: spot meters, spatial colorimeters, and detectors for temporal and angular measurements. The last section covered best practices (*e.g.*, if in doubt, repeat the measurement) and cautions (*e.g.*, make sure the measurement conditions are well described).

Becker also gave a seminar on display metrology as part of the Monday Seminar series. Although there was some overlap of material, Monday's session included more details about pixel resolution, various types of angular and temporal measurements, and reflectance measurement considerations.

Fig. 1: *Attendees listen to a speaker at the Introductory Display Metrology Training Course at Display Week 2017. All images courtesy of Tom Fiske.*

Hands-On LMDs

The hands-on demos of different types of LMDs at the training course were well received. Represented types of LMDs included a colorimeter/photometer from Konica Minolta, a spectroradiometer from Gooch and Housego, and an imaging colorimeter from Instrument Systems (Fig. 2). This segment of the course gave attendees insight into the practical considerations of

Fig. 2: *The LumiTop 2700 from Instrument Systems, included as part of the hands-on demonstrations in the display metrology course, combines spectral accuracy with the convenience of 2D color imaging.*

how to mount displays and LMDs, as well as the trade-offs among types of instrumentation. There is no substitute for being able to try something out yourself.

Subjects that were prominent the whole week of the show also showed up in the course: augmented reality and virtual reality (AR/VR) display systems. The AR/VR display characterization session given by Tom Lianza from Photo Research was very well attended. He recounted lessons learned as he told the story of the processes he followed to eventually capture good measurements for AR and VR display systems.

Lianza began with the four distinct categories for measurement: VR (near-eye display and no ambient illumination); AR (near eye and some ambient); digital eyeglasses (near eye and full ambient); and automotive/avionics (head-up display and full ambient). All of these display types produce a virtual image – there is no physical structure producing light at the apparent image location. This is important because virtual images require more care to measure accurately due to the limited volume (aka eyebox) over which the images can dependably be viewed. Some of the most important challenges involve matching the optical characteristics of the exit pupil of the display with those of the entrance pupil of the LMD. Lianza suggested a fixed-measurement-aperture solution for some situations.

He also discussed how the LMD had to be designed, adjusted, and used to give accurate and valid results – presenting various real-world examples that were especially useful. He emphasized a common theme in measurement practice – repeat your measurements and make sure your results are sensible for the given situation. (I can heartily endorse this practice – as learned from hard experience.)

Other topics of the day included measurement considerations for high-dynamic-range (HDR) displays, and displays for automotive applications. A special bonus session was included (with wine and cheese!) on reflectance measurements. For this presentation, Edward Kelley returned to give us a good grounding in reflectance basics and their relevance to display characterization. Kelley began with precise definitions of canonical reflection terminology, including "reflectance factor," "luminance factor," "diffuse," "specular," *etc*. It is very important to rigorously define your light source, sample, and LMD geometrical arrangements, since these will critically impact the accuracy, repeatability, and applicability of your results. Kelley also reviewed the four types of reflectance found in a display context: specular, diffuse, haze, and matrix scatter.

The bidirectional reflectance distribution function (BRDF) is the complete geometrical and wavelength-dependent description of how an object reflects light. Unfortunately, high-resolution BRDF is very difficult to fully characterize. Fortunately, the reflective characteristics of a display can be adequately measured in many situations with much simpler methods. Kelley's practical guidelines for the acceptability of such methods are that they must be robust, reproducible, and unambiguous. He finished his presentation by describing many different reflectance-measurement methods and ranked them against these criteria. It was another great talk and the material provided will prove to be very useful reference information.

HDR Displays

HDR was a popular topic at Display Week. Judging from the technical presentations at the show, no one technology or company has a lock on HDR displays, the HDR ecosystem, or even on how to describe HDR performance. Standard-dynamic-range (SDR) displays (the ones that we're used to seeing every day on our TVs, PCs, tablets, and phones) have a maximum luminance of around 300 to 500 candelas per square meter (cd/m^2) and a black-to-white luminance range of about 1,000:1 for LCDs – OLEDs can be much higher. HDR promises more realistic and exciting images with more black-to-white luminance range and wider color gamut. The main technology contenders are OLED displays, dual-modulation LCDs, and dual-modulated projection light-valve systems. The ecosystem includes Dolby Vision and ACES encoding and delivery schemes, among others. The measurement protocols and standards for HDR are still in development.

OLED displays are still fairly new (and therefore expensive), but deliver a superb HDR experience. The black levels are amazing and almost unmeasurably low. The peak luminance can be up to several hundred cd/m^2, but those values are limited to lower average picture level (APL). The dual-modulation techniques for LCDs generally use a local dimming backlight (*i.e.*, a backlight that has areas with individual luminance control) as the second modulation source. These require sufficient backlight spatial "resolution" (*i.e.*, controllable areas) for good HDR performance. Depending on implementation, halo artifacts can be a problem. A second LCD panel (with a normal backlight) can also be used as the second modulation source. Projection systems need an additional light valve in the optical path as the second modulation source to render HDR images. Direct-backlit LCDs have the advantage of high peak luminance at any APL since the light level is nominally independent of the image-forming function. Wide color gamut (WCG) is realized in OLEDs due to the inherent narrow spectral bandwidths of the RGB color primaries. LCDs achieve wide color gamut by using LED backlights with quantum-dot technology to get color primaries with narrow spectral bandwidths.

All this is to say that HDR and WCG will not be inexpensive to realize. The display devices are new, the workflow is not quite settled, and the pipelines – from acquisition, processing and content delivery – are bigger and more complicated than those for SDR content.

A few items of note around HDR at Display Week: LG Display showed off a beautiful (and thin – 6 mm!) "Wallpaper" 77-in. ultra-high-definition (UHD) OLED display at its booth on the exhibit floor (Fig. 3). In fact, this display won one of SID's 2017 Display of the Year awards. It provides a truly stunning HDR image, with black levels at an amazingly low luminance and highlights up to 800 cd/m^2 at 10 percent APL. This panel will also retail at around $20,000, so it won't be for everyone. LGD executives showed me around the rest of the booth, where they had an impressive array of display technologies and applications, including flexible and curved displays, 8K resolution, HDR, displays with integrated speakers, and transparent displays.

In the technical program, authors from the University of Florida and AU Optronics delivered a paper, "High-Dynamic-Range LCD With Pixel-Level Local Dimming," which describes a system with a fringe-field-switching (FFS) LCD cascaded with a twisted-nematic (TN) LCD with no color filter to give 1,000,000:1 contrast ratio (CR) and good angular performance. The display boasts a bit depth of more than 14 bits. A polarization preserving diffuser is introduced between the panels to eliminate moiré effects and maintain CR. There are still some challenges to

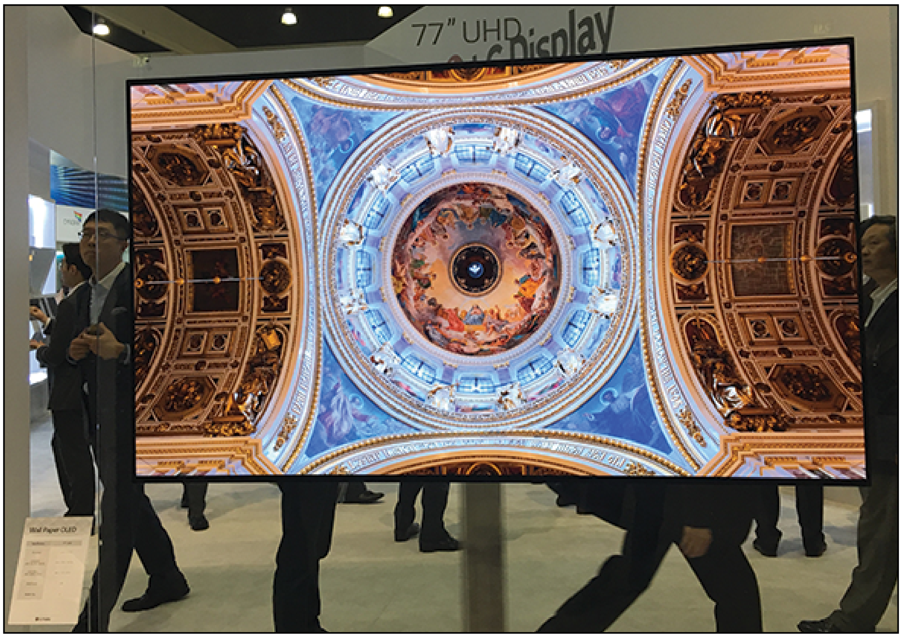

Fig. 3: LG Display's 77-in. "Wallpaper" OLED was difficult to miss on the Display Week 2017 exhibit floor.

address, such as cost, misalignment issues, decreased efficiency, and system thickness, but this approach could be a promising method for implementing HDR.

Dolby Laboratories authors delivered the invited paper, "Prediction of Overall HDR Quality by Using Perceptually Transformed Display Measurements." Using a local dimming LCD system, measured parameters such as maximum luminance, minimum luminance, backlight resolution, color gamut, and bit depth were used in two different models to predict HDR display performance as compared to subjective ranking across variations in the above parameters. The physical model used the directly measured parameters. The perceptual model was based on a perceptually transformed set of analogous parameters. The authors provided a compelling case for an HDR quality metric that uses the perceptually transformed parameters. I would like to see this work extended beyond local dimming LCDs to include OLEDs as well.

Dolby authors also delivered a good Monday seminar on HDR. Dolby is obviously invested in a particular HDR ecosystem (Dolby Vision) and technology (dual-modulated LCDs). However, the company's proposals and positions are always well presented and are backed by top-notch human factors research and display metrology. This is much appreciated.

A couple of other noteworthy HDR papers from a session called "Visual Quality of HDR Displays" included one from Samsung on the "Visual Quality of a Global Dimming Backlight with High-Contrast Liquid-Crystal Panel for High Dynamic Range Displays" and one from University of Central Florida on "Reproducing High-Dynamic-Range Contents Adaptively Based on Display Specifications." The Samsung paper showed that a system with a global dimming backlight with a high CR LCD was preferable to one with a local dimming backlight with a moderate CR LCD. The UCF paper showed that an SDR display can reasonably render HDR content with an appropriate gamma and color-mapping algorithm and a dynamic range of 0.1 to 640 cd/m^2.

HDR remains an active field of research and development. This is true on a few fronts: display technology, the delivery pipeline, and the most effective description of visual performance. So, no matter what your favorite flavor of HDR is or how you want to describe it, it looks like there's still opportunity to make a contribution.

It's still too early to tell which HDR ecosystem and workflow model will be widely adopted. For the consumer's sake, one hopes that the industry will settle on a solution that has enough commonality to avoid a Blu-ray/HD-DVD debacle. Apart from which technical implementations, ecosystem, and workflow models prevail, the metrology around HDR needs some development. Pursuant to that need, there is a large group within the ICDM that is hard at work on defining and standardizing HDR measurement methods.

Among other areas the ICDM will address in the coming months is metrology in AR/VR displays. This will definitely be a hot area, as evidenced by the interest in AR/VR during the metrology course on Sunday and the prominence of the AR/VR papers during the symposium sessions. There is an obvious need for manufacturers of HDR and AR/VR technology to support the advancement of display metrology that will enable the delivery of great customer experiences in these areas. So get involved and contribute to the work of the ICDM and submit those groundbreaking technology papers to Display Week and the *Journal of the SID*. ■

show review

Digital Signage at Display Week 2017

Projection, LCD, direct-view LED, and other technologies represented the state of the art in digital signage at the show in Los Angeles.

by Gary Feather

Digital signage, which now represents a sizable segment of the display market, includes the indoor LED direct-view signage business at $2 billion (growing to $4 billion by 2021); outdoor LED at $2 billion; projection at $3.5 billion; professional LCDs at $1.9 billion; and video cubes at $.45 billion. The market has evolved significantly over the past decade in terms of both technology and applications. Static displays, which replaced many nondigital roadside signs, are being replaced in turn by those offering full-motion and full-color video. Pixel pitches of 25 mm have shrunk to below 0.9 mm.

Display Week 2017 was an excellent place to learn about these and other trends; the show floor highlighted direct-view LED and reflective displays, and the technical program featured presentations on how to overcome challenges specific to digital signage. (Since all displays are technically "digital signage," this article focuses primarily on products that are bigger than 90 inches diagonal and have a luminance higher than 500 nits.)

Large-Area Display Systems: Narrow Pixel Pitches and Direct-View LEDs

Some background may be helpful in better understanding the digital-signage developments at Display Week. In the early 1990s at Texas Instruments (TI), researchers imagined a better solution to the CRT direct-view and CRT three-gun projection systems that were prevalent at the time. The vision was a 2,048 × 1,152 reflective spatial light modulator (SLM) that could be refreshed using pulse-width modulation (PWM) to create full-motion, full-color video with a luminance of more than 4,000 nits and a bit depth greater than 10 bits per color. TI demonstrated the first HD cinema prototype in 1993 in Seattle at Display Week. (See Fig. 1 for a schematic of the chip on which that prototype was based.) The Texas Instruments SLM was operated in a digital mode and was very fast. The product was patented as a DMD, both Digital and Deformable Mirror Device. In 1994 the company decided that a market name would be helpful for product applications, and thus was born digital light processing, or DLP.

After this, large-area projection systems became a standard for indoor digital signage, as high-luminance, full-color, and full bit-depth images were now realizable.

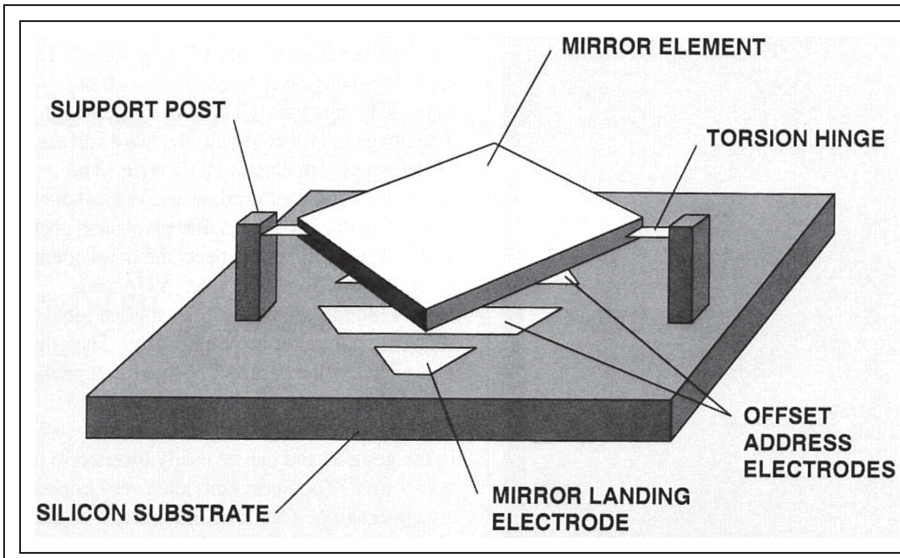

***Fig. 1:** This schematic originally appeared in the 1993 July/August issue of* Information Display. *It depicts a chip (one of thousands) used to power TI's HD cinema prototype, which was shown at Display Week in 1993.*

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In 2003, after years of development, Sharp launched an affordable line of LCD TVs with 15-in. and 20-in. diagonals worldwide. While the industry scoffed at the possibility of ever building larger-format LCD TVs with HD resolution and image quality, Sharp (and eventually other companies) pushed forward to launch >30-in. LCD TVs in 2004. In 2005, LCD TVs were in every major manufacturer's booth at the Consumer Electronics Show (CES). Digital signage makers took note and began to incorporate LCD into stand-alone solutions as well as tiled video walls. By 2016, LCD video walls had hit sales of ~$2 billion. Manufacturers are working hard to sustain that growth through new features including narrow bezels (lines) and self-calibration for uniformity.

Meanwhile, direct-view LED signs have, for the past 15-plus years, represented the ever-improving large outdoor displays we see along our roadsides. Those direct-view LED displays started moving indoors a decade ago and are now competing with LCD and DLP technology in both image quality and pixel pitch.

Direct-View LED Joins LCD and DLP Projection

Today, LED video walls have many advantages although they also face a number of challenges they must overcome if they are ever to surpass LCD video walls. From a total market-growth perspective, many analysts predict the compound annual growth rate (CAGR) for direct-view LED displays in the fine-pitch and ultra-fine-pitch area to be greater than 36 percent compared to a mere 10 percent for LCD. By 2020 the sales revenue of fine-pitch LED video will match that of LCD video walls.

The pixel pitch for an LCD with a 60-in. panel at HD resolution is about 0.75 mm. For most large-area digital signage applications, that pixel pitch exceeds the capability of the viewer's eye at a normal viewing distance to appreciate and value the resolution. LED digital walls are therefore specified to a pixel pitch in which the user gets the maximum content but does not see the individual pixels.

Direct-view LED has been moving quickly into the classic LCD space. One advantage of LED displays is that they can be made in any extended size without the noticeable borders or "mullions" associated with multiple conjoined LCDs. Also, the display is calibrated as a full display rather than individual displays, which aids in image uniformity. LCD video walls have a cost advantage, which will help them maintain their current position in the market. The current 2.5-mm LED pixel pitch is competitive with the best-of-class narrow bezel LCD, and if the resolution (in pixels per inch) is sufficient, the LED is the superior choice.

Direct-view LED digital signage has offerings in many pixel pitches and any practical resolution size. The market has 2.5-mm, 1.87-mm, 1.6-mm, 1.5-mm, 1.25-mm, and now 0.9-mm RGB pixel-pitch solutions in production. The building-block approach to direct-view LED displays makes them adaptable to practically any shape, any size, and any resolution. So with worldwide sales of LED fine-pitch (less than 2.5-mm pixel pitch) digital signage moving from $1 billion today to more than $2 billion in 2022, the challenge ahead will be to educate the market on performance and reliability capabilities so that customers purchase technology that aligns to their needs during this transition of display technologies.

The future of digital signage will be heavily affected by technical, performance, and cost improvements in coming years.

Display Week 2017 Perspectives

Display Week 2017 brought together leading industry experts and top researchers for an array of invited papers and technology presentations. Among the questions posed and sometimes answered in these discussions were:

- Will projection-display applications based on DLP continue to shift to direct-view LED, or is the cost and visual-performance advantage of DLP maintained through most current applications?
- Will LCD maintain its place in the digital signage industry, or will direct-view LED continue to grow its share as a better match to large-format applications?
- Will digital cinema ever move to a direct-view LED display?
- Are there applications for reflective technologies for outdoor and indoor applications?
- What new development in any of the technology areas can create new market growth?

The three sessions and eleven presentations covering digital signage at Display Week 2017 touched on many of the top areas of technology and product opportunity spaces.

SMT RGB LED Display Emitters

In a paper from Cree, Jovani Torres covered details on the release of the 1-mm × 1-mm surface-mount technology (SMT) red-green-blue (RGB) LED for the finer pixel-pitch patterns. Current performance shows support of luminance and color control along with efficacy to address the needs of 1.25-mm pixel-pitch LED display products currently on the market. The output luminance supports displays in the 500-nit-candelas-per-square-meter (cd/m^2) range, which is a match for the needs of the industry at this time. Improvements in the contrast ratio are attained through the masking of reflective elements, and the new "sandwich design" supports the low profile required for the tighter pitch. With all the improvements in this RGB LED offering, the industry requirements for next year will be much greater. With current pixel pitches passing 0.9 mm and demonstrations at 0.7 mm, it will be very important for this 1-mm 1010 (refers to package size) LED to continue to be reduced in size. The 0.9-mm pixel pitch requires an 0606 RGB SMT LED (36 percent of the 1010) with all the same optical performance and reduced output flux proportionately. Likely the final requirement for discrete LED SMT packaged solutions will be 0.7-mm pixel pitch, so packages may need to become a little smaller.

Transmissive Displays

National Chiao Tung University's Zong Qin provided much-needed insight into the proper implantation of transparent displays in the paper, "Pixel-Structure Evaluation Regarding See-Through Image Quality for Transparent Displays: A Study Based on Diffraction Calculation and Full-Reference Image-Quality Assessment." The transparent display has captured imaginations and won some implementations in the past five years. The open issue is that it has proved difficult to design a "system" solution that makes the display perform at maximum visual impact. The methods and algorithms in Qin's paper clearly outlined the considerations for addressing image quality and the viewer perception of a transparent digital sign. This is an exciting opportunity in transparent displays, and we hope that implementations based on these design parameters will grow more compelling in the years to come.

Reflective Displays

There are no deployed solutions in reflective digital signage that are getting much attention, and yet there is a great interest in the potential for this technology. Outdoor displays in specific use forms may work best if based on reflective technology. The advantages of reflective technology are in relation to its low power usage and its readability in the outdoor sun. If reflective light management is managed properly, the display will avoid thermal issues as well.

At Display Week 2017, there were three presentations of interest in the reflective color space. In a paper titled "Development of a Novel Reflective Display System with Multi-Primary Color for Digital Signage," Tatsuya Yata of JDI presented an LCD-based design for reflective outdoor signage with a focus on multiple primary colors. These examples were limited in size to that of a typical LCD panel, but the reflective solution removes the need for super-bright backlights. These displays also supported moving images. The challenges to overcome include cost and long-term reliability in high ambient light.

Another LCD-derived reflective panel, described by JDI's Tadafumi Ozaki in the paper "Development of New Error-Diffusion Dithering Method for Reflective Memory-In-Pixel (MIP) LCDs," discussed image quality with dither. The implementation and validation showed useful results. Again, the challenges of the added cost vs. benefits are still in the details of the application.

A unique solution using micro-electrical mechanical systems (MEMs) technology was proposed by Zhong Ji of Yuanse Technology in the paper "Large-Pixel Reflective-Color Display for Outdoor Applications." While in early feasibility stages, the approach and described method offer a possible path to a prototype. The large pixel size lends itself to outdoor applications. Yet the display is limited in size and doesn't allow for seamless tiling. It could, however, be considered for particular applications.

In addition to these three presentations, there were three related booth exhibits that sparked interest. From E Ink, we saw the larger-format reflective display with near-full-color performance (Fig. 2).

These displays demonstrated on the floor at Display Week were complete and ready for applications. Most outdoor signage that can be viewed by a moving car is not video but changing static displays; that use aligns to this display. While the size is a smaller format, a number of installations in outdoor environments only need smaller-format displays.

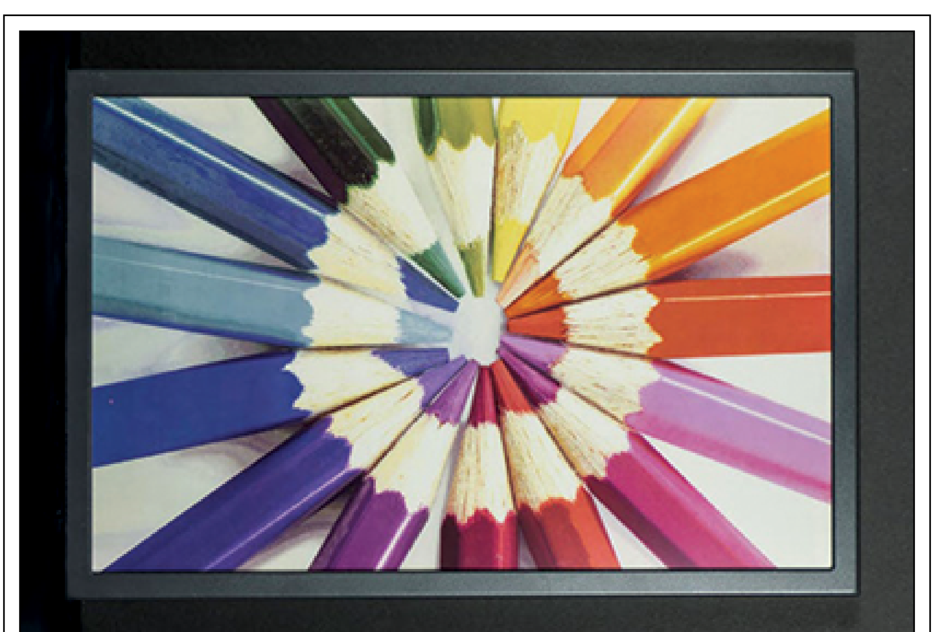

Fig. 2: E Ink showed new versions of its Advanced Color Display at Display Week. The displays can be tiled.

E Ink was pushing the display for direct-sunlight applications. Marketing of the product is in progress.

The reflective-digital-signage offering from New Visual Media Group was a macro-sized MEMs device. With a manufacturing process that is validated, the system provides shutters that can provide a reflective display through a dither and switching solution. While it is only a prototype test unit at this point, many on the show floor were very interested in the technology and intrigued by the possible system and addressing schema that might make this useful.

CLEARink surprised many on the exhibition floor with a video-capable electronic paper display. The technology touted e-book applications, and a key feature was sunlight readability and reflectivity. Still in the early stages with regard to larger-format signage, this CLEARink solution has the potential to be another player in outdoor information and entertainment products. (For more about CLEARink, see the Materials article in this issue.)

Signage Market Overview

As an invited speaker for the first Digital Signage session of the Symposium, Samantha Phenix of Planar/Leyard took a step back to discuss all aspects of the digital-signage industry. The key takeaways from her presentation were that market growth, technology evolution, and possible revolutions are all yet to come. The vast availability of video content and the return on investment in bringing displays to the public in any of the growing markets will lead to an additional $1 billion in sales over the next four years. While Phenix discussed LCD solutions (large and tiled), the spotlight was on LED business growth. Trends involve the finer pitches (below 2 mm) and standardization on HD (2K) and now UHD 4K, which are being met with smaller SMT RGB LEDs (1010 to 00505). There are no technical barriers for implementation; the focus now is on better-quality displays and lower costs. In addition, the technology changes to uLED solutions and active-matrix LED (AMLED) backplanes open another huge growth area with regard to performance and cost reductions over the next five years.

"Active Backplane Design for Digital Video Walls," a presentation by D.R. Dykaar of DifTek Lasers, Inc., laid out the path toward an AMLED backplane. This scalable active-matrix backplane leveraging single-crystal silicon spheres opens the door to a targeted project for early introduction of the next generation of direct-view LED and possible OLED solutions.

OLED and LCD Tiling

Digital signage is usually a large display, often bigger than a single-panel solution for OLED or LCD. Minimizing the gaps (or mullions) from tiling LCD and OLED panels (2 × 2, 3 × 3, *etc.*) was addressed by Seijin Lee of LG Display with the paper "Development of a Zero-Bezel Display Utilizing a Waveguide Image-Transformation Element." The solutions are focused on both the optical management and the data management of a display matrix to reduce the visibility of the gaps between the panels. Panel displays have reduced the bezel to 0.9 mm; it's not enough to be good enough. Both of these presentations are an attempt to electronically shift the image and the light to a spatial position to effectively "fill in" the gap. The results are effective in reduction of the gap, but unfortunately complete elimination remains elusive.

Display and Image Quality

An invited paper from Jorge Perez Bravo of NanoLumens on image quality actually dared to consider matching and improving on the display quality from the best large-format LED and OLED displays. A demonstration of products now shipping in HD and UHD clearly showed the capabilities in the industry. The paper identified the display elements that create limitations to video quality, presented methods to mitigate those limitations, and discussed the competitive capabilities of LED as compared with LCD. Of course, LED has the advantage over LCD when it comes to building a very large display (10 ft^2 to >1,000 ft^2) without any mullions. This is only offered by LED.

The details of artifacts or characteristics of the LED drive that cause some limitations in display quality were addressed clearly in a paper from ELDIM. Both on the exhibition floor and in the technical presentation, the system approach to presenting information on the display to avoid visual (temporal and spatial) artifacts was a clear improvement.

Digital Signage Continues to Gain Momentum

Display Week 2017 opened the door to more information on digital signage than ever before. With the growing market and the considerable advancements in technology, it is clear that companies focused on these technologies can expect significant demand for their products in this market segment. Figure 3 shows one example of the kinds of applications that are now possible. Combining the inventions with the innovations and the implementations at the system level will assure digital-signage displays will lead to greater demand and higher value. ■

Fig. 3: This 4K cinema installation for Telstra in Sydney, Australia, represents but one possible direction for digital signage. Image courtesy of NanoLumens.

Best in Show and I-Zone Winners

The Society for Information Display honored five exhibiting companies with Best in Show Awards at Display Week 2017 in Los Angeles: Samsung Display, JDI, BOE, LEIA, and CLEARink. The winner of the Best Prototype Award in the I-Zone was IGM, University of Stuttgart, in partnership with Hella KGaA Hueck & Co.

Compiled by Jenny Donelan

THE winners of this year's highly coveted Best in Show awards were chosen from a wide array of truly great exhibitors showcasing the wealth of innovation that is alive and flourishing in our industry. The many and varied sights at Display Week 2017 featured some outstanding exhibits distinguished by creativity, energy, and ingenuity. The line at Samsung's booth to see its 2-dimensional, stretchable active-matrix organic light-emitting diode (AMOLED), hidden in a dark alcove, both reflected and generated a special kind of excitement (see below). BOE won this year not for any single product but for many excellent products across a wide range of materials and applications. These awards recognize the effort the winning companies invested in making not only their exhibit successful, but the exhibition as a whole.

Even the selection process bears mentioning because of the extensive effort put forth by the members of SID's Display Industry Awards Committee. They spend the better part of opening day on the exhibition floor, visiting the booths of all the nominated companies and many others as well. That night, they convene to select the winners of the Best in Show awards so the winners can be recognized at the annual luncheon the next day, and display their award ribbons for the rest of the show. This year's five Best in Show winners were selected from more than 200 exhibitors. The awards were presented in three categories of exhibit size: large, medium, and small. This year, there were three large-exhibit winners and one each in the medium- and small-exhibit categories.

Large-Exhibit Winners

BOE received a Best in Show award for its multiple advanced display technology demos.

These included a 27-in. 8K LCD, a 55-in. UHD wireless flat-back module (Fig. 1), a 15.6-in. curved (R = 1,000 mm) FHD LCD with 1,000 cd/m^2 and in-cell touch, and 5-in. and 14-in. panels based on electroluminescent quantum-dot LEDs (QLEDs). Among the standouts was BOE's 27-in. 8K iGallery ADSDS LCD designed to show paintings (Fig. 1, right). This panel's special optical design allows exceptionally wide-angle viewing and anti-glare, anti-reflective properties. Other highlights were flexible OLEDs, bezel-less panels, and a foldable, touch-enabled OLED display. The company's booth was a great example of how to help attendees understand the breadth of available display technology.

Japan Display Inc. (JDI) also won in the large-exhibit category, with the display committee noting two products for the award: the company's highly transparent full-color LCD

Fig. 1: *BOE won a Best in Show award this year for its lineup of excellent products that were displayed in excellent fashion (left). One outstanding example was the 27-in. 8K iGallery ADSDS LCD, which is optimized to show paintings (right).*

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and its narrow-bezel, trademarked FULL ACTIVE LCD (Fig. 2).

Achieving high light transmission has been an ongoing challenge for developers of transparent displays. According to JDI, its 4-in. color transparent LCD achieves transmittance as high as 80 percent, which is an industry record to date, and an important feature for applications such as automotive. This feat is achieved by having the LEDs directly illuminate the panel through the edge of the substrate, rather than from a traditional backlight unit. This technology also permits the removal of the color filter and polarizer layers from the transparent LCD. The transparent displays are still in the R&D stage, but will eventually be available in sizes even larger than 4 inches, according to JDI.

Fig. 2: At left is is JDI's color transparent display. At right is its FULL ACTIVE LCD panel featuring a narrow bezel on all four sides. Photos courtesy of JDI.

JDI's 6-in. narrow-bezel LCD panel has a bottom bezel that is nearly as narrow as those on the other three sides. This is possible, according to the company, via a new high-density wiring layout as well as new processing and module assembly techniques. The 1,080 (×RGB) × 2,160 display has an aspect ratio of 18:9. Products based on this technology are now commercially available under the FULL ACTIVE brand name.

Samsung Display won a Best in Show Award for its 9.1-in. stretchable AMOLED display (Fig. 3), an example of compelling technology demonstrated in a compelling way. As *ID* Executive Editor Stephen Atwood wrote in his Editor's Note last month, "There was a long line at the [Samsung] booth, and I debated whether to wait in it on the first day of the exhibition. Something was being shown in the back room of the booth that was obviously interesting to people, but there was almost no hint of what it was from the front." What that "something" turned out to be was a stretchable OLED prototype being continuously deformed from its center region. (It was worth the wait, according to Atwood.)

Samsung Display notes that what is unique about this stretchable OLED panel is that it can be flexed in two directions. If pressed from above, for example, it depresses like a rubber balloon, then returns to its original flat shape. The display will maintain its original image quality even while the screen is deformed as much as 12 mm. According to Samsung, the prototype is designed as flexible, scalable, next-generation technology for use in future wearable, automotive, and artificial intelligence applications. The company is unable to say when the technology will advance from the prototype stage as first seen at Display Week 2017 to the commercial stage, but certainly market forces will encourage it to move quickly.

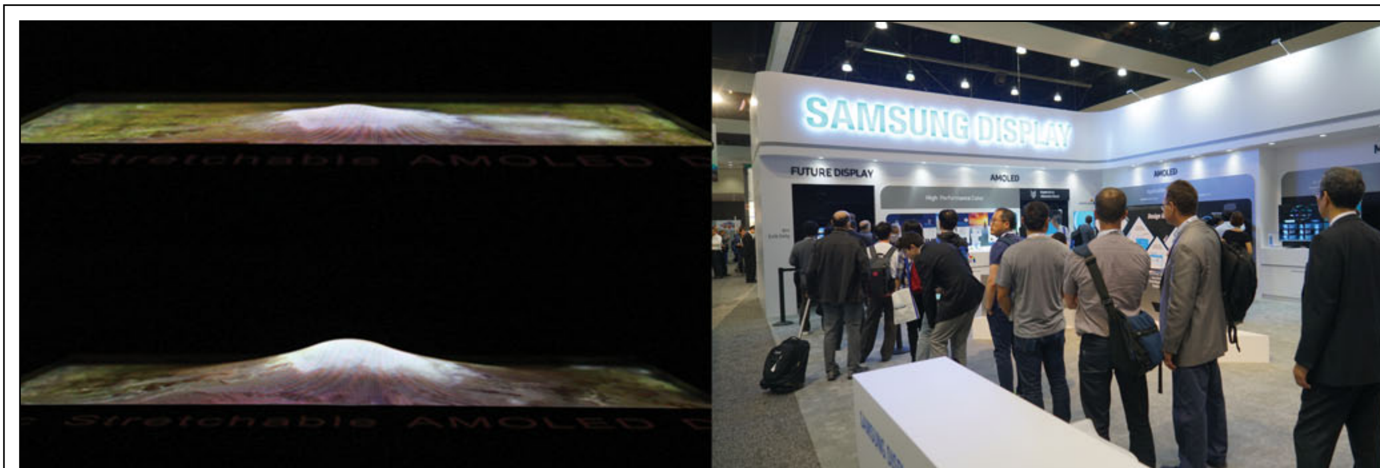

Fig. 3: Samsung's stretchable AMOLED prototype (left) was demonstrated at Display Week in a dark alcove at the back of the booth, where people lined up to see it (right) throughout the three days of the show. Photos at left courtesy of Samsung.

Fig. 4: LEIA's Diffractive Lightfield Backlight (DLB) technology is designed to produce holographic-type imagery on demand from a 2D display. Conceptual rendering courtesy LEIA.

Medium-Exhibit Winner

Silicon Valley start-up ***LEIA Inc.*** won a Best in Show Award for its light-field-based multi-view display (Fig. 4). Readers may recall *ID*'s Q&A with LEIA CEO David Fattal in our January/February 2017 issue. The technology depicted in Fig. 4 was also on the cover of that issue.

At Display Week 2017, LEIA showcased its Diffractive Lightfield Backlight (DLB) technology, designed to give LCDs the ability to project multiview "holographic" light-field content and switch back to standard "2D" mode on demand. These light-field holographic images can be viewed from any direction (portrait or landscape). They also exhibit depth as well as look-around qualities. Standard 2D images are able to use the full resolution of the underlying LCD panel with no visible artifacts or penalty in terms of power consumption.

LEIA demonstrated its DLB technology at the show in two different form factors: a 5.7-in. QHD smartphone running Android that featured interactive games and light-field movie clips, and a 15.6-in UHD 4K laptop display, running a virtual fashion show and a space battle game with immersive 3D audio. Content was chosen to highlight the 3D depth and parallax capability of the display, but also its unique ability to render complex light effects. The fashion show demo in particular was chosen to show how it rendered the complex lighting of a runway and reflections off the animated fabric.

Fig. 5: CLEARink's Electrophoretic Total Internal Reflection display excited Display Week visitors because it breaks new ground by providing video and color in an e-paper display. Image courtesy CLEARink.

Small-Exhibit Winner

CLEARink was recognized at SID's Display Week with a Best in Show Award for its video-capable e-paper display (Fig. 5).

The company's Electrophoretic Total Internal Reflection displays have the desirable "printed paper" attributes of electrophoretic displays – they are thin, light, sunlight readable, and ultra-low power – yet unlike e-readers, are able to show color and video at 33 frames/second. Color has been a challenge for many e-paper technologies, but the CLEARink display has an 83 percent white-state reflectance and uses an RGB color filter to create a reflective color display that is vivid outdoors and can also be used in complete darkness using a low-power front light. To enable fast enough movement for video, CLEARink features a clever implementation of electrophoresis that uses an optical plate and lenslets combined with the traditional moving black-ink particles. In the white state, incoming light experiences total internal reflection (TIR) and returns to the viewer. Lurking behind the optical plate is an "ink" containing black particles that are moved toward or away from the plate. When the particles touch the plate (actually, when they get close enough to interfere with the evanescent light wave), the TIR is defeated and light at that point is absorbed. This approach requires the particles to move only a very small distance (~0.5 microns) and therefore can enable update rates compatible with video images.

Applications for this technology include e-books (especially schoolbooks), wearables, video-ready electronic shelf labels, and general signage and automotive applications.

I-Zone Best Prototype Award

The I-Zone is a special component of the exhibition that provides a forum for live demonstrations of emerging information display technologies in a special exhibit area within the main exhibit hall at Display Week. It was created six years ago to showcase cutting-edge demos and prototypes from start-ups and research labs that might not otherwise be ready to exhibit at Display Week. For this reason, the I-Zone is often the most exciting part of the entire conference – there is where you may discover the disruptive technology that will revolutionize the industry in years to come.

This year, I-Zone had many more applicants than ever, and twice the number of participating companies (approximately 50) than in 2016. So for 2017, the I-Zone committee selected not just a Best Prototype winner but two additional honorees.

This year's winner of the Best Prototype Award in the I-Zone was ***IGM at the University of Stuttgart,*** which partnered with ***Hella KGaA Hueck & Co.*** to develop a novel headlamp with fully adaptive, driving beam technology that incorporates both active-matrix LCD and LED technologies (Fig. 6).

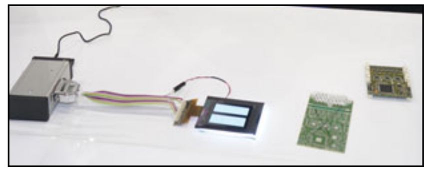

Fig. 6: *Novel LCD/LED headlamp technology earned IGM at the University of Stuttgart, in partnership with hella KGaA Hueck & Co., the 2017 I-Zone Best Prototype Award.*

The VoLiFa2020 headlamp provides a fully adaptive driving beam with 30K switchable pixels, 16 gray scales, and a contrast ratio up to 490:1 on the street, without requiring mechanical elements and using only 25 LEDs. According to its makers, this novel headlamp incorporates the first active-matrix LCD (AMLCD) ever used in a mass-producible headlight module. The AMLCD was developed and manufactured at the IGM, University of Stuttgart, to provide top performance while withstanding simultaneous long-term exposure to high illuminance (≥20Mlx) and high temperature (≥80°C) inside the headlamp module. It is currently being tested in a Porsche Panamera test vehicle.

This year's two I-Zone honorees were:

- ***Jasper Display Corporation*** and ***glō*** for a megapixel silicon backplane (4K × 2K) and spatial light modulator technology for microdisplays.
- ***Turtle Beach*** and ***Nepes Display*** for HyperSound Glass, the world's first highly directional and transparent parametric speaker.

The Jasper and glō technology is a digital electro-optics platform for developing various applications. These applications are based on its X-on-silicon technologies, such as MicroLED on Silicon (µLEDoS), Liquid Crystal on Silicon (LCoS), OLED on Silicon (OLEDoS), and Cell on Silicon (CELLoS). µLEDoS technology is applied to AR/VR, HUDs, and wearable devices. In addition, LCoS technology is applied to microdisplays, holographic displays, SLM, dynamic optics, biotech, and more.

The Hypersound transparent, flat-panel loudspeakers from gaming headphone maker Turtle Beach and Nepes Display are capacitive, and the vibrating layers are driven by two signals; the first is 100 kHz and the second is 100 kHz plus the audio sideband. The audio portion of the signal is constructed in the space in front of the speakers. In this way, just two speakers are able to construct a surround-sound field of remarkable clarity and precise location.

Looking Forward

Once again this year, the annual Display Week exhibition was a resounding success and a must-see event. This year's award winners well represented the diversity and innovation of our industry, and promise a great future ahead. ■

At Display Week with Universal Display Corporation

In Los Angeles last May, ID frequent contributor and industry expert Ken Werner spoke with Universal Display Corporation's Janice DuFour about UDC's thoughts and plans regarding the OLED industry. Later on, he took in a forward-looking OLED presentation by UDC's Mike Hack.

By Ken Werner

Note: If you're talking about OLED materials, and Ken was (check out his feature article on materials at Display Week 2017 in this issue), you need to talk to Universal Display Corporation (UDC). UDC, founded in 1994, currently owns or has rights to more than 3,000 patents for the commercialization of phosphorescent OLEDs (PHOLEDs) and other types of OLEDs for both display and lighting applications. UDC's technologies and materials are licensed and supplied to companies including Samsung, LG, AUO, and Konica Minolta. – ID Editors

At the time of this writing, UDC was a Wall Street darling, with its share price having risen from about US $50 last November to roughly US $117 in Q2 2017. The rise of 27 percent in May alone was attributed to strong Q1 earnings. (Full disclosure: This author owns UDC shares.) The company's 2016 acquisition of the privately owned contract research organization (CRO) Adesis was also regarded favorably by analysts (read more about Adesis below).

UDC predicts even greater growth in the OLED displays market, and has said that its next generation of emitters is now being adopted by customers. However, many experts now doubt that OLED will completely displace advanced LCD as the television display of choice (although it has made considerable inroads with mobile devices), and there is increasing speculation about TADF as an eventual competitor to UDC's phosphorescent OLED (PHOLED).

On the Monday of Display Week, I sat down on a flight of stairs at the Los Angeles Convention Center for an interview with Janice DuFour (formerly Janice Mahon) of UDC. DuFour is vice president of tech commercialization and general manager of the PHOLED material sales business for UDC. *(Note: DuFour's answers are paraphrased, except when included in quotes.)*

Ken Werner: You've announced that a new generation of PHOLED emitters are now being adopted by your customers. How are the materials evolving?

Janice DuFour: We introduced a new set of materials in 2016, and new emitters are currently in design cycles with some customers. There are improvements in lifetime and efficiency, but the big difference is that we are now designing for customer requirements instead of just releasing a new emitter once in a while. A lot of what we are doing is customizing our materials for a specified output.

In general, customers want high dynamic range and high luminance to compete with quantum-dot LCDs, but the emphasis does change. Lifetime can be the high priority one year, and efficiency the next.

KW: Do you see synergy in the acquisition of Adesis (which does R&D and specialty manufacturing for the pharmaceutical, chemical, and catalysts industries), or was this primarily a portfolio expansion?

JD: Adesis has been a CRO supplier for us. R&D programs were suggested by Julie (UDC CTO Julie Brown) or by new chemistries. Adesis was such an important part of our research and development that acquisition made sense for us. And Adesis was looking for growth and personal security for the owners.

There is a meaningful CRO business for Adesis, both in OLED and in other areas. They provide support for difficult chemistries in pharma, agriculture, synthesis, and other market areas. Early-stage mass production is their specialty, and they have space to grow. They will pursue more OLED business in the future.

Ken Werner is principal of Nutmeg Consultants, specializing in the display industry, manufacturing, technology, and applications, including mobile devices and television. He consults for attorneys, investment analysts, and companies re-positioning themselves within the display industry or using displays in their products. He is the 2017 recipient of the Society for Information Display's Lewis and Beatrice Winner Award. You can reach him at kwerner@nutmegconsultants.com.

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KW: Is TADF a threat to PHOLED?

JD: "TADF is an interesting technology but it is not a meaningful threat in the short to medium term. It takes a lot of time to get efficiency, life, and color right all at the same time, and then move into manufacturing. And once a company is tied into a system, it's hard to move." Adesis worked on TADF for quite a while, so the technology is not new to us.

KW: What about blue emitters? *(Note: Despite years of work, a fully achieved, deep-blue PHOLED emitter with appropriate efficiency and lifetime has eluded researchers, including those at UDC. This step is considered crucial for an all-phosphorescent OLED display.)*

JD: "Internal momentum is building," thanks in part to the BASF patent portfolio we acquired in 2016. The portfolio enhances our strength in chemical modeling and digital chemistry. The team we have working on blue is expressing "exciting positive momentum."

KW: Is there anything else I should have asked you?

JD: "We are also doing more work on OVJP [organic vapor jet printing] technology. Samsung and LG are happy with what we are doing. OVJP combines VTE [vacuum thermal evaporation] and IJP [ink-jet printing]." We're in R&D, but we are also building a pilot-scale tool and looking for partners. There is potential for large-scale TV screens.

The Business Outlook for OLEDs

Immediately after I spoke with DuFour, I took in a paper presentation, "Color Is Universal; New Opportunities for Phosphorescent OLED Displays," by UDC VP for Business Development Mike Hack as part of the SID/DSCC Business Conference. In addition to addressing several of the topics covered in the interview above, Hack also addressed the topic of luminance and lifetime requirements by explaining that if a cell phone produces 1,000 nits of peak white luminance, it means that some sub-pixels must emit 5,000 or 10,000 nits. Hack said that UDC's red PHOLEDs maintain over 98 percent of an initial 3,000-nit luminance for 500 hours; green maintains over 98 percent of 10,000 nits for 500 hours; and yellow maintains over 98 percent of 3,000 nits for 500 hours. He added that matching the emitter and host materials is central to achieving commercial lifetime performance.

Hack described OVJP in some detail. Despite a lot of work, he said, developers of solution-based-processed OLEDs have not been able to achieve the performance of vacuum-thermal evaporation (VTE) deposited materials. OVJP, he said, combines the advantages of both approaches. Steve Forrest (then at Princeton University, now at University of Michigan) invented OVJP around 2005. The method evaporates emitter material (as VTE does), then jets the vapor onto a substrate in the desired pattern (as IJP does). Recent work at UDC, said Hack, has produced the necessary line width.

Hack also described a pixel architecture in which only blue and yellow OLED emitters are used. Blue and yellow sub-pixels are viewed directly, while portions of the yellow sub-pixel pass through red and green color filters. Since the architecture relies either on a competitor's fluorescent blue, or on a phosphorescent blue or TADF blue (neither of which currently exists), this structure doesn't seem to make much sense at first look.

But if the point of comparison is not an RGB structure (which Hack calls an SBS – for side-by-side – structure), but LGD's color-by-white OLED-TV structure, B-Y suddenly does make sense. The LGD structure mixes yellow and blue OLED emitters to make an un-patterned white light source, which is filtered through an RGB color matrix filter, much as is done in an LCD. This throws away two thirds of the light, or roughly one half if a RGBW structure is used.

The unfiltered B and Y of the UDC structure can be used to construct many unsaturated colors, said Hack, with the filtered R and G being used only for the smaller gamut of saturated colors, increasing efficiency over color-by-white. In addition, only half the normal resolution of a fine-metal-mesh mask is needed if the emitters are applied with VTE, which would permit a stronger mask than might be usable for TV-sized substrates. Since Hack emphasized this aspect, it is reasonable to view the B-Y architecture as a fallback for making more economical OLED-TVs if OVJP doesn't pan out.

All this indicates that while there are a lot of OLED displays being produced today and a lot of interest in displacing LCD in large-panel markets, there are still obstacles to overcome. But if developers attain the goal of large OLED displays that are cost-competitive with LCDs, their efforts will be rewarded. ■

Lasers Improve Display Glass Cutting

Non-contact glass cutting by laser offers an attractive alternative to mechanical methods in display fabrication. There are several laser technologies and processing techniques in actual use, each with its own characteristics and advantages.

by Jürgen Serbin and George Oulundsen

Displays for handheld devices, such as smartphones and tablets, increasingly utilize thinner glass, as well as chemically strengthened glass. In addition, screens with curved corners, contoured shapes, and cutouts are becoming more common. These trends make traditional mechanical glass cutting a less-effective method during display fabrication, and a variety of laser-based techniques have appeared to replace this older technology. This article provides an overview of laser glass-cutting methods and is intended to help readers choose the most appropriate method for a specific application.

Traditional Methods

The traditional technique for cutting glass, used in various forms for centuries, involves scribing the surface of the glass with a hard, sharp tool (typically a diamond or carbide wheel), followed by the application of mechanical stress to propagate the crack completely through the glass. In automated systems, this separation is usually implemented by using a "chopper bar" that descends on the glass.

This method has certain drawbacks, particularly for the aforementioned very thin substrates that are increasingly being employed in flat-panel displays (FPDs). In particular, the mechanical force of the scribing tool produces microcracks in the material, and the subsequent breaking step yields small chips and debris, as well as an edge not necessarily perpendicular to the glass surface. Furthermore, mechanical cutting leaves significant mechanical stress in the finished edge. (In fact, it becomes difficult to use mechanical cutting with substrates below about 1 mm in thickness because the glass is so easily broken.) To prevent further cracking or breaking of the glass after the original cut, it may be necessary to grind or polish the cut surface. Also, a post-process cleaning step may be required to remove debris that could interfere with subsequent processes, such as circuit formation.

For the display manufacturer, various edge-grinding and cleaning steps represent additional production time and costs. They may also have negative environmental impacts, like the generation of debris that cannot be easily disposed of, or large amounts of waste water required for cleaning. In addition, mechanical glass cutting doesn't readily support the production of curved edges, which are increasingly desirable, especially in FPDs for portable devices.

Laser-Cutting Advantages

There are several different laser technologies currently being used for glass cutting, and these are deployed in a variety of methods. However, all laser glass-cutting techniques offer some similarities in their main benefits.

First, all laser methods are non-contact processes that largely eliminate the problems of microcracking and chipping. Laser-cutting

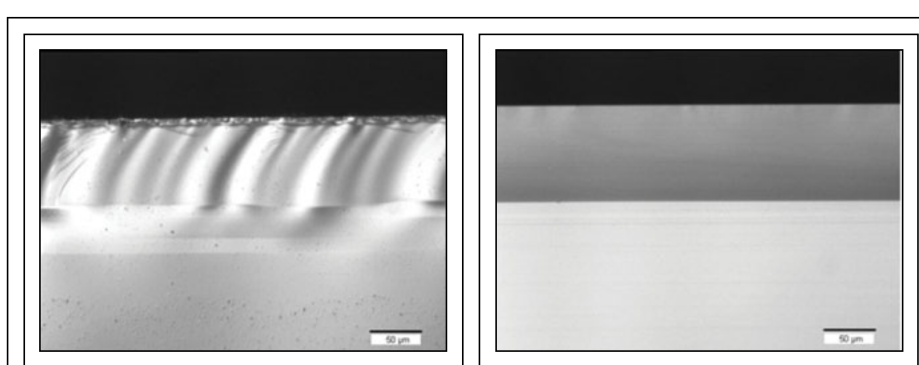

Fig. 1: *Above are microscopic views of mechanically cut (left) and laser-cut (right) glass. The mechanically cut glass shows significant residual stress, and substantial debris from the cutting process.*

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0362-0972/5/2017-038$1.00 + .00 © SID 2017

methods minimize residual stress (to varying degrees) in the glass, resulting in higher edge strength. This is critical, because even when force is applied to the center of a glass panel, any break usually initiates at the edge. Consequently, laser-cut glass can typically withstand two to three times as much force as mechanically cut glass.[1]

Laser cutting can also reduce the number of process steps, since it requires few, if any, subsequent cleaning or grinding stages. So while the capital cost for a laser cutting station is higher than for a mechanical system, the overall investment in laser cutting can be lower than for mechanical processing if an additional grinding machine can be eliminated. The reduced need for post processing and cleaning also makes laser-cutting greener than mechanical methods, and reduces or eliminates the need for water.

Finally, some laser-cutting methods enable the production of curved cuts in glass. The demand for curved cuts is increasing, especially in mobile phones, where many manufacturers would like to produce more complex geometries in their screens, including holes to accommodate buttons, controls, LEDs, and camera lenses. Laser cutting is the only clean and contact-free method to produce these complex curved features. Figure 1 compares mechanically cut and laser-cut glass.

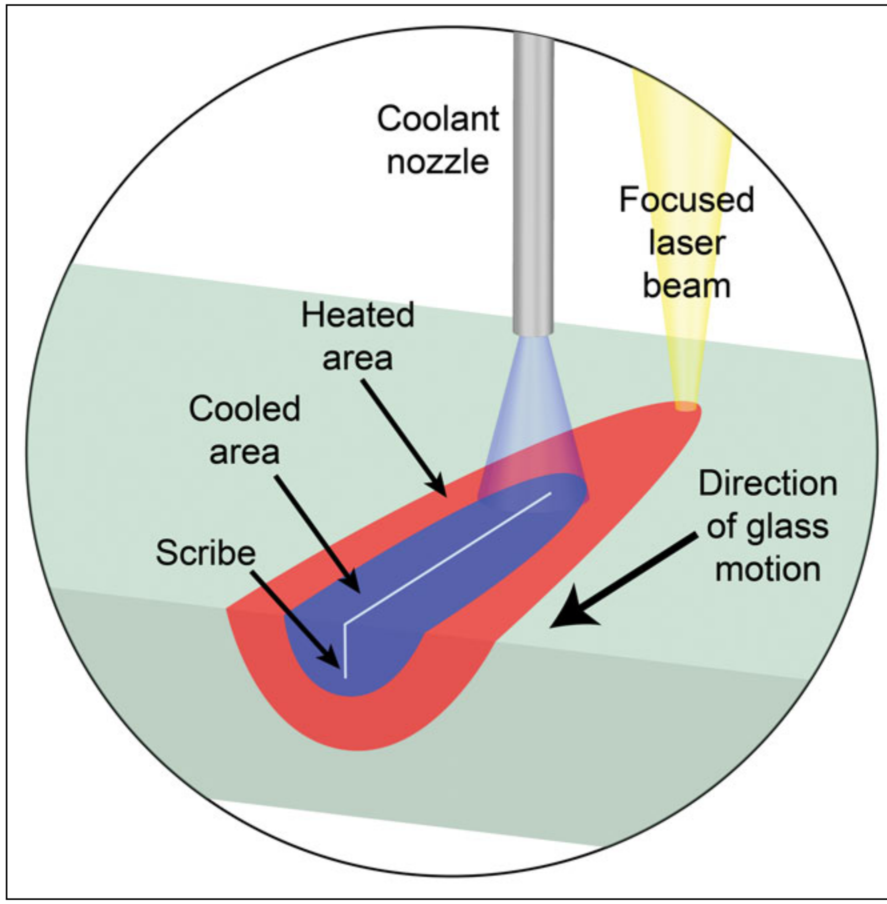


Fig. 2: This schematic illustration of CO_2 laser scribing shows the motion of the glass beneath the laser beam.

CO_2 and CO Lasers

Carbon dioxide (CO_2) lasers have been used in glass cutting for many years. In contrast, carbon monoxide (CO) lasers, which were first introduced as practical, industrial tools by Coherent in 2015, are just beginning to be deployed in this application. Both CO_2 and CO lasers offer rapid glass cutting and high process throughput. The key improvement, however, is in the differing wavelengths of the CO *vs*. the CO_2 lasers.

The CO_2 and CO lasers are infrared sources that process glass by causing intense, local heating. Specifically, all types of glass absorb strongly at the 10.6-µm CO_2 laser wavelength, so a focused laser beam causes rapid heating at or near the surface of the glass. To produce a cut, the glass is translated relative to the beam, and either liquid or air is delivered by nozzles onto the glass to quickly cool it. The resulting thermal shock produces a continuous crack. Depending upon the glass thickness, this crack can be propagated all the way through the substrate to complete the cut; this is called full body cutting. Alternatively, for thicker glass, a second step, either laser or mechanical, is used to finish the break; this is called laser scribing (Fig. 2).

Because of the high absorption of glass at the 10.6-µm CO_2 wavelength, the beam is formed into a long, thin line on the work surface, rather than a circle (which is the way laser beams are most commonly focused). This is necessary in order to adequately distribute the intense heat generated by the laser. However, this geometry means that the glass is always being heated along a line segment, and thus precludes the ability to cut short radius curves.

The overall process is much the same with the CO laser. However, glass absorption of the 5-µm to 6-µm output of the CO laser is significantly lower, allowing the light to penetrate much farther into the bulk material. Thus, heat is introduced to the bulk glass directly and does not rely on diffusion from the surface. Testing at Coherent has shown that this produces even lower residual stress than CO_2 cutting, yielding a stronger cut piece, together with a wider process window for the manufacturer.

The other exciting aspect of CO lasers in glass cutting is their ability to support the cutting of curves (Fig. 3). This is because the lower absorption of the CO laser allows its round beam to be used directly without adverse heat effects. In addition, the CO laser can cut chemically strengthened glass.

While CO_2 lasers are employed in a very wide range of commercial materials-processing tasks, from cutting thin films for food packaging up to welding thick steel plates, most readers are probably not familiar with CO laser technology. CO lasers were invented

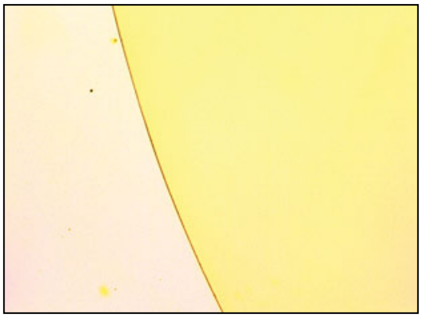


Fig. 3: *A CO laser with only 9W of output power produced this clean, curved cut (6-mm radius circle) in thin glass (50-μm thick) at a feed rate of 140 mm per second. This photo (which is not an illustration) shows the laser-cut edge of the piece of glass. The yellow part is the glass, and the face-on view shows the cut.*

decades ago, but never commercialized due to practical considerations involving very limited lifetime and reliability caused by difficulties in cooling the laser. In fact, the first CO lasers required cryogenic cooling, which kept them from being used in any commercial applications. Coherent recently developed new technology that has enabled the manufacturing of sealed CO lasers, which operate at very high output powers, with excellent efficiency at room temperature, and which demonstrate lifetimes in the thousands of hours. Because CO lasers offer distinct advantages for glass cutting, this was one of the first commercial applications pursued for this technology.

Laser Ablation

Laser ablation relies on a completely different mechanism to process glass than do CO_2 and CO lasers, which utilize thermal shock to create a crack. Ablation is the actual removal of material, with high precision, to create the scribe. Ablation occurs when laser power is sufficiently high to produce intense local heating (thermal ablation), or at very high peak powers, to directly break interatomic bonds (photo-ablation).

Ablation is accomplished using either solid-state lasers with pulse widths in the nanosecond range, or ultra-short-pulse (USP) lasers with pulse widths in the picosecond, or even femtosecond, range.

There are several different variations on the way laser ablation is used to cut glass, but in all of them, each laser pulse blasts away the glass in the form of microscopic chips. Generally, there is a direct correlation between pulse width and the size of these removed particles. Chips in the single-digit micron size range are produced by nanosecond pulse-width lasers, and USP lasers yield even smaller particles – hundreds of nanometers in size. This process does require cleaning – although the particles produced by the laser are much, much smaller than those produced by mechanical cutting. And the advantage of laser cutting is better edge quality, which directly translates into bend strength.

Nanosecond pulse-width lasers, operating in either the green (532-nm) or ultraviolet (355-nm) bands, usually enter through the top of the transparent substrate and are focused bottom surface to top surface, sequentially. In this so-called "bottom-up" approach, ablated chips fall out of the material interaction zone due to gravity. Scribes or cuts of virtually any edge profile, including tapered slots, holes, trenches, bevels, and chamfers, can be generated by moving the beam focus up through the substrate and then along it to create the desired contour (Fig. 4).

Processing speeds for this type of ablation are relatively slow compared to other methods. For example, it takes about 1 second to drill a 1-mm diameter hole in 3-mm-thick soda lime glass. The cutting speed for free contours is in the single-digit mm-per-second range. Other drawbacks are that this method cannot process strengthened glass, and the edges typically show significant chipping from about 10 μm to 50 μm from the processed edge.

With USP lasers, scribing is most commonly performed with the laser initially focused on the top surface of the substrate, then the beam focus is adjusted to work down through the material. This is because the very small particles generated don't readily fall out of the scribe on their own (although there are methods to remove them) and therefore it is challenging to use USP lasers for bottom-up drilling or cutting. In addition to limited cutting speed and some edge roughness, the other limitation of topside scribing using an USP laser is that a taper always remains on the scribe or hole, usually in the 8° to 12° range.

Filamentation Cutting

Glass cutting can also be accomplished through a specific form of internal modification called filamentation, which again utilizes the very high-power densities achieved with focused, USP lasers. In this case, the high laser intensity produces self-focusing of the beam due to the nonlinear Kerr optical effect. This self-focusing further increases power

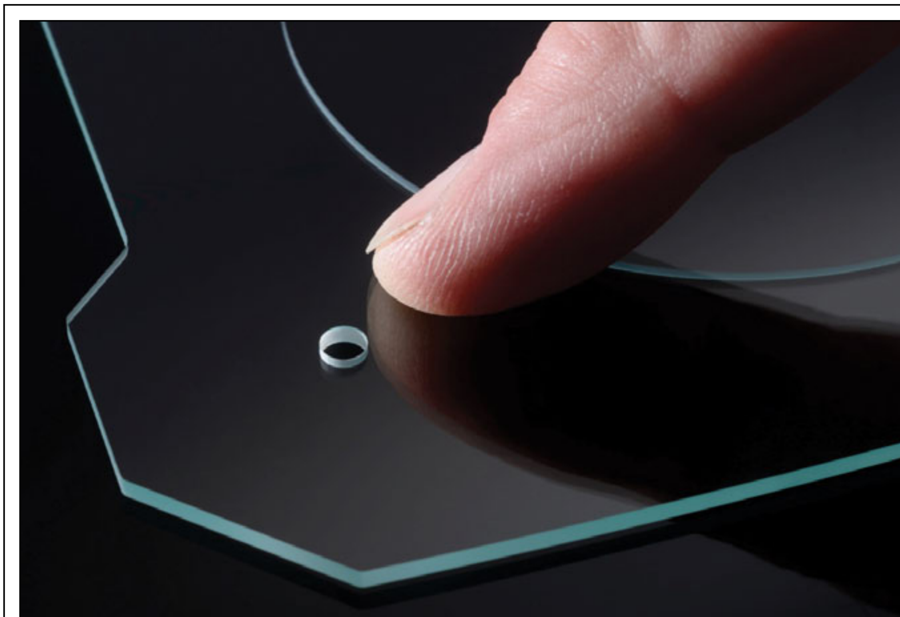


Fig 4: *This example shows a through-hole produced by bottom-up processing in glass.*

density until, at a certain threshold, a low-density plasma is created inside the material. This plasma lowers the material refractive index in the center of the beam path and causes the beam to defocus. If the beam focusing optics are properly configured, this focusing/defocusing effect can be balanced to repeat periodically and form a stable filament that extends over several millimeters in depth within an optically transparent material. The typical filament diameter is in the range of 0.5 µm to 1 µm. An example appears in Fig. 5.

In order to achieve effectively zero-gap cutting or perforation lines, these laser-generated filaments are produced close to each other by a relative movement of the work piece with respect to the laser beam. Cutting speeds of 100 mm/s to 2,000 mm/s can be achieved, depending on the material thickness and the desired cut geometry.

Coherent|Rofin's embodiment of the filamentation technology is called SmartCleave. It pairs process technology acquired and further developed by Rofin, together with advanced industrial USP lasers from Coherent. The resulting process enables high-speed cutting of arbitrary shapes, including curves, freeform cuts, and insets, without taper, into transparent and brittle materials from 0.05-mm to 10-mm thickness (Fig. 6). SmartCleave delivers smooth surfaces, with an average roughness (Ra) of less than 1 µm, which are essentially free of chips and debris. This yields bend strength in the cut parts that is markedly superior to mechanical processes.

With chemically or thermally strengthened glass, internal stress within the part provides for automatic separation of outer contours after the filamentation process, without an

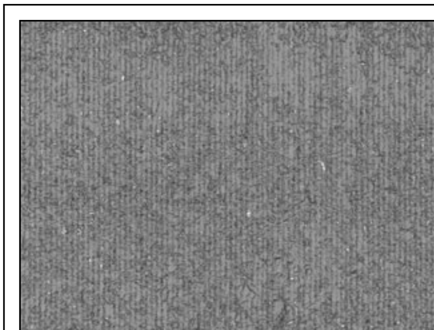


Fig. 5: Laser filamentation creates a series of parallel voids in 0.5-mm-thick sapphire.

Fig. 6: The SmartCleave filamentation process enables high-speed cutting of curves and insets into glass, e.g., as used for substrates of displays.

additional step. For non-strengthened transparent materials, such as soda lime, borosilicate, and alumino-silicate glass, as well as sapphire, a separation step must follow filamentation. This can be accomplished with a small mechanical or thermal force. For example, the latter can be provided by heating with a CO_2 laser.

Coherent|Rofin supplies products to enable this filamentation processing in a variety of integrated configurations. This begins with laser sources, and continues through subsystems that integrate a laser with beam delivery optics and control electronics. These can also be configured as a so-called "black box" subsystem, in which the particular configuration to enable and optimize a specific process has already been optimized, validated, and programmed.

In conclusion, lasers have proven to be superior to traditional glass-cutting techniques in a wide range of different applications. In general, lasers are most useful when mechanical means fail to deliver the cut quality or characteristics required, or when older methods become too expensive due to the extensive post processing required, or to downstream yield reduction. However, laser glass cutting is actually a broad term covering a variety of different techniques, each with its own unique characteristics and advantages. Thus, it is important to understand the advantages and limitations of each technique and to work with a vendor supporting several techniques in order to choose the optimum one for a specific application.

Reference:

[1]A. Abramova, M. Blacka, and G. Glaesemanna, "Laser separation of chemically strengthened glass," *Physics Procedia* **5**, 285–290 (2010). ■

SID Announces New David Sarnoff Industrial Achievement Prize

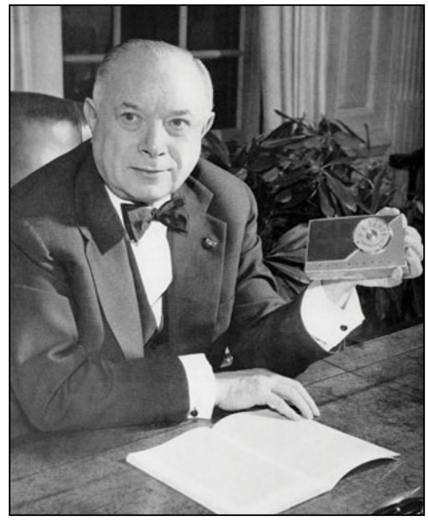
The Society for Information Display (SID) has announced the designation of a new award to honor individuals for long-term and significant leadership and/or exceptional contributions to the advancement of the information display industry. The award is named after the late David Sarnoff, a pioneer of American radio and television who served as Radio Corporation of America (RCA) president and chairman for many years.

Mr. Sarnoff, who joined RCA in 1919 and retired in 1970, was a visionary who recognized the long-range potential of numerous radio and television technologies and championed their subsequent development. At RCA, Sarnoff drove R&D and manufacturing of the practical electronic TV system during the 1930s and 1940s, and was also the driving force behind the development of the practical full-color TV system, as demonstrated by researcher Alfred Schroeder's shadow mask CRT in 1947. Sarnoff was instrumental in the development of flat-panel displays, promoting a research environment that ultimately resulted in the LCD, the thin-film transistor, and active-matrix addressing.

The David Sarnoff Industrial Achievement Prize is designed to honor outstanding recipients who would not qualify for one of SID's technical achievement awards but who nonetheless have had a profound, positive effect on the display industry over a period of many years, and are broadly recognized across the industry. Winners of the David Sarnoff Industrial Achievement Prize will receive a $2,000 stipend, made possible through the generosity of BOE.

The award joins the lineup of prestigious honors bestowed by SID to outstanding innovators in the field of information displays, including the Karl Ferdinand Braun Prize for outstanding technical achievement in or contribution to display technology; the Jan Rajchman Prize for outstanding scientific or technical achievement in or contribution to research on flat-panel displays; the Otto Schade Prize for outstanding scientific or technical achievement in or contribution to the advancement of the functional performance and/or image quality of information displays; the Slottow-Owaki Prize for outstanding contributions to personnel training in the field of information display; and the Peter Brody Prize to honor young researchers for outstanding contributions to active-matrix-addressed information displays.

The deadline for nominations for the 2018 awards is **Oct. 15, 2017**. For more information on any of the SID Honors and Awards, including how to submit nominations, please visit www.sid.org/About/Awards/IndividualHonorsandAwards.aspx. ■



Although David Sarnoff's contributions to the display industry were considerable, he was also an audio pioneer who helped established the AM radio infrastructure. Here he is shown holding a state-of-the-art RCA transistor radio in 1956.

continued from page 2

You might wonder why I did not just mention head-up displays (HUDs) in the past paragraph. It's because there was so much to talk about that we separated the topic into its own review article and convinced well-known analyst Steve Sechrist to survey it all for us in his contribution, "The Expanding Vision of Head-Up Displays: HUDs for Cars at Display Week 2017." It always feels like the promise of a virtually augmented view through the windshield is just a little beyond the technical frontier when the concept people describe all the really compelling possibilities. Well, as we look at what Steve found, you might conclude that a lot of moving parts, including ergonomic requirements, hardware concepts, and implementation ideas, are all finally starting to converge into an ecosystem that is not that far away.

One of my first passions in display work was optical metrology. Fresh out of college, I was privileged to work in a well-equipped lab facility where I learned not only the mechanics but also the subtleties of crafting good measurement methods to produce results that were meaningful to end users. That passion has stayed with me and fueled my enthusiastic support for the work of the International Committee for Display Metrology (ICDM).

The dedicated people involved in this effort also helped organize the first-ever Display Metrology Training Course. Well attended and well organized, this event will surely be popular again in the future. Tom Fiske, a key leader of the ICDM and SID Standards Committee, graciously agreed to cover this subject area with his article, "Metrology and Image Quality Play Starring Roles at Display Week 2017." Tom did a great job explaining how the new technologies that are developing today directly affect the work being done in metrology. It's an exciting time to be part of this field.

Digital signage is everywhere. From retail sites, to sports venues, to public areas, and more, electronic displays are being deployed for targeted public messaging. And, as in any other tech field, there are some disruptive evolutions moving the platforms first from projection and CRT screens to LCD screens, from low-resolution bulbs and LEDs in billboards to very high-resolution LED panels. In "Digital Signage at Display Week 2017," author and entrepreneur Gary Feather provided both a short history of the platforms and marketplace and a great survey of where we are today supported by the papers and exhibits at Display Week. There are many new innovations emerging, including high-resolution, low-power, reflective displays and ultra-high luminance fine-pitch LED building blocks. The really cool thing about this subject area is that you don't have to look far or spend a lot to enjoy the real products – the industry wants to bring them to you as fast as it can!

Best in Show Awards

Each year at Display Week, the members of the Display Industry Awards Committee recognize the best exhibitions by conveying on them the Best in Show Awards. Who won this year? Well, you can guess a few by looking at our cover, but to know the whole story, read our coverage of the "Best-in-Show and I-Zone Winners" written by Jenny Donelan. It's always a privilege to take part in this process alongside some of the best-credentialed people in our industry. These highly coveted awards have become a mainstay of the event.

OLED Business

Along with great technology, there is always a lot of business going on at Display Week. Every technical field in play has a business case behind it, and in many cases, a very complex history of strategies, entrants, successes, and, well, sometimes a lack of successes. One company that has navigated the challenges in the OLED space and built up a truly impressive patent portfolio as part of its business strategy is Universal Display Corporation (UDC). During the show, Ken Werner gathered inputs from UDC VPs Janice DuFour and Mike Hack to understand more about the moving parts of their business and technology investments.

For those paying attention, UDC has been on the forefront of OLED material development as a research company, often making significant leaps behind the scenes while working with some of the biggest commercial display developers in our field. With over 3,000 patents and about 23 years of work behind it, UDC can easily be seen as a standard bearer for innovation. Ken's questions included probing the future of OLED materials lifetimes, new technologies for blue emitters, investment strategies, and where the efforts need to focus in the future. It's a nice wrap-up for our Display Week review package, but for this issue, we're not done yet…

Glass-Cutting Advances

Have you ever tried to cut glass? People have been doing it for centuries, and of all the key steps in making displays, I would have thought this one would be fairly well matured. But just like many other things, there are always compromises and disadvantages to the status quo. For example, mechanical scribe and break cutting is generally limited to straight lines and edges. Exotic features such as curves must be achieved by grinding, and holes need to be drilled. Scribing, grinding, and drilling processes make lots of debris and display makers hate debris. Dust, glass particles, and all manner of dirt can wreak havoc on yields in multi-billion-dollar fabrication lines.

Hence, the recent interest in refining and improving the technology for cutting glass with lasers. Different lasers (frequency, power, beam patterns, *etc.*) have different properties and can be used in different ways to improve the process for cutting glass, especially into complex shapes and patterns much in demand for innovative display formats.

Authors Jürgen Serbin from Rofin and George Oulundsen from Coherent broke this all down for us and provided a very informative survey in their Making Displays Work for You feature, "Lasers Improve Display Glass Cutting." I'm sure you will find it very informative. Take a moment while reading it to imagine what new and creative display-panel formats you could create with this capability. I think this is a great way to wrap up this issue, which is sure to inspire you with new ideas for your own field of work.

Welcome to Fall

With that we bring our fully packed September–October issue to an end. As you enjoy your late-summer/early-fall season, I hope something you read here inspires you to find new ways to achieve great things in your own endeavors. Inspiration and fresh ideas can come from almost anywhere, and hopefully the work our great team of contributors has done here will help provide that inspiration for you. ■

Journal of the Society for Information Display

Invitation to submit review papers

The Journal is presently soliciting review papers on any display-related topic. If you have a great idea for a review paper, please contact the editor at **editor@sid.org**.

Page charges for review papers will be waived.

Herbert DeSmet
Editor-in-Chief

Announcements

Impact Factor increase

JSID's Journal Impact Factor has gone up by 42% compared to last year and is now at 0.877. Our aim is to continue this trend in the coming years.

Expanded Distinguished Papers of Display Week 2017

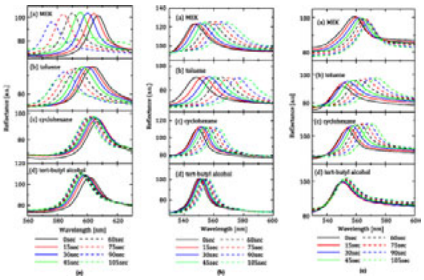
All peer reviewed expanded versions of the Distinguished Papers of the SID Symposium are now published, in the February through April issues of JSID**.** A **virtual JSID issue** containing the 20 Expanded Distinguished Papers is **openly accessible** until December 31st at **http://tinyurl.com/edpdw17**.

Like! JSID on your social timeline

We already had the Twitter hashtag **#JSIDINFDISP**, but now our new Associate Editor, Abhishek Srivastava, has also created a Facebook page for our Journal: **http://tinyurl.com/jsidfb.**

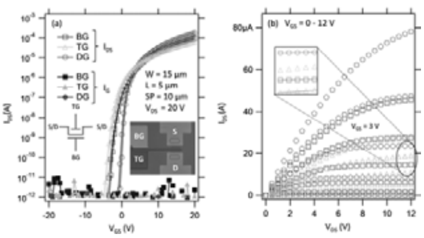
Highlighted recent papers

Editors' pick of June: Chemical gas sensors using chiral nematic liquid crystals and its applications | Khai Jun Kek *et al.*| DOI: 10.1002/jsid.560



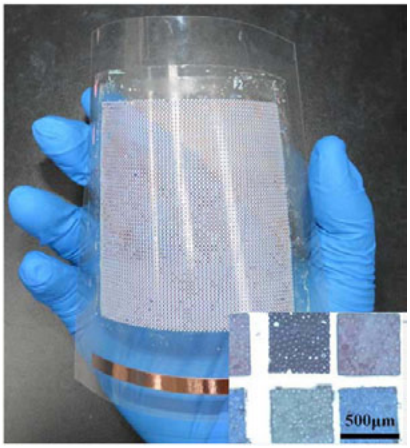
This paper clarifies the relationship between the molecular structures of chiral nematic liquid crystals and the shift in their reflection spectrum resulting from contact with volatile organic compounds (VOCs). We propose a mechanism to explain the red or blue-shift in the peak wavelength upon contact with VOC vapor. Enhancement of the sensitivity of this method of VOC detection is discussed.

Characteristics improvement of top-gate self-aligned amorphous indium gallium zinc oxide thin-film transistors using a dual-gate control | Manoj Nag *et al.*| DOI: 10.1002/jsid.558



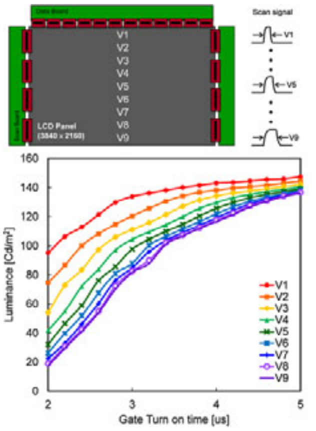
In this work, we have reported dual-gate amorphous indium gallium zinc oxide thin-film transistors. With dual-gate control, the parameters such as on current (I_{ON}), sub-threshold slope (SS^{-1}), output resistance, and bias-stress instabilities are improved in comparison with single-gate control amorphous indium gallium zinc oxide thin-film transistors.

Transfer printing for fabrication of flexible RGB color e-paper | Li Wang *et al.*| DOI: 10.1002/jsid.562



A tape assisted transfer approach was utilized to fabricate the multi-color e-paper with the structure of subpixel array. Unlike the color filter array, the color microcapsules containing two kinds of color particles were adopted to form subpixels. This transfer method may pave a new way to realize the commercially available color e-paper which have a good color performance.

Line-time optimization technology for ultra-large and high-resolution liquid crystal displays | Seung-Hyuck Lee *et al.*| DOI: 10.1002/jsid.561



Line-time optimization technology for ultra-large and high-resolution liquid crystal display (LCD) televisions is proposed. With the application of the proposed method, drivers at the bottom or top of the screen could be eliminated, which can lead to manufacturing cost reduction. Furthermore, the proposed method offers the advantages of greater freedom of placement of the control boards of displays.

Information about the Journal

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continued from page 4

phone based on the emissive technology. Sources also say that while the LCD models will be immediately available, there may be a delay of several months for the OLED device.

Alongside this information exists a swirl of rumors about features that will or will not be included in the iPhone 8 – touch ID, facial ID, virtual home button, astronomical price tag, fast charging, new colors, old colors, etc. So while we do know there will be new phones announced this fall, and that one of them will almost certainly be Apple's first OLED iPhone, we'll have to wait for the big reveal to find out more.

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[1]www.forbes.com/sites/gordonkelly/2017/08/15/apple-iphone-8-specs-camera-price-release-date/#40fd8a3416c1
[2]www.cnet.com/products/apple-iphone-8/preview ■

show review materials

continued from page 6

luminance, a 20 to 30 percent increase in efficiency, sharp cut-off, and wide viewing angle.

A Lively Evolution

Innovations in materials and processes are at the core of non-trivial improvements in displays and modules. At Display Week 2017, we saw materials developments that guarantee a lively display evolution over the next few years. ■

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2017 Editorial Calendar

Issue	Editorial Coverage	Ad Closing Date
January/February	**Applied Vision** **Special Features:** Reducing Stereoscopic Artifacts, Realizing Augmented and Virtual Reality, New Display Frontiers, Cool New Devices for a New Year **Markets:** Game developers, medical equipment manufacturers, research institutions, OEMs, software developers, wearable designers, entertainment industry research and developers	December 28
March/April	**Display Week Preview, Display Materials** **Special Features:** SID Honors and Awards, Symposium Preview, Display Week at a Glance, MicroLEDs, Progress in OLED Manufacturing, Disruptive Materials, Nine Most Important Display Trends from CES **Markets:** OEMs, deposition equipment manufacturers, entertainment industry research and developers, display and electronic industry analysts	February 27
May/June	**Display Week Special, Automotive Displays** **Special Features:** Display Industry Awards, Products on Display, Key Trends in Automotive Displays, Head-up Designs for Vehicles, Novel Interfaces for Automobiles **Markets:** Consumer products (TV makers, mobile phone companies), OEMs, research institutes, auto makers, display module manufacturers, marine and aeronautical companies **Bonus Distribution: Display Week 2017 in Los Angeles**	April 18
July/August	**Wearable, Flexible Technology and HDR & Advanced Displays** **Special Features:** Flexible Technology Overview, Advanced Displays Overview, Wearables Round-up, Overcoming HDR Challenges **Markets:** Research institutions, OEMs, OLED process and materials manufacturers, entertainment industry research and development, measurement systems manufacturers	June 16
September/ October	**Display Week Wrap-up, Digital Signage** **Special Features:** Display Week Technology Reviews, Best in Show and Innovation Awards, Digital Signage Trends, Ruggedization Challenges for Digital Signage **Markets:** Large-area digital signage developers; in-store electronic label manufacturers, advertising and entertainment system developers, consumer product developers, retail system developers	August 22
November/ December	**Light-field and Holographic Systems** **Special Features:** Real-world light-field applications, holographic approaches, solving problems of next-generation displays **Markets:** OEMs, Consumer product developers, research institutes, auto makers, entertainment and gaming developers; measurement systems manufacturers	October 20

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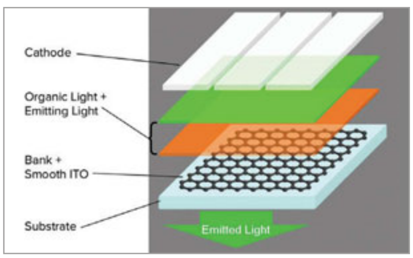
NLT Technologies
Noritake Itron Corp.
Nvidia
Oculus
Panasonic
POLOMO
Rolic Technologies
Sakai Display Products
Sharp Corp.
SpectraTek
TDMDA
Teijin Films Solutions Ltd.
TFD, Inc.
Thine
TLC International
Tokyo Ohka Kogyo Co.
UICO
Universal Display Corp.
US Micro Products
Vestel Electronics
Vigor Gas Purification Technologies
Visionox
WaveOptics
Westar Display Technologies, Inc.
Yazaki Europe Limited
YUASA SYSTEM Co., Ltd.

THIN FILM DEVICES

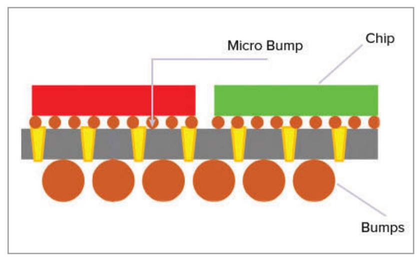
Economical and Superior Coatings and Products

Foundry Capability for MEMs, OLED, Banks, OPV, Dye Cell, Interposer, Chip on Glass & Others

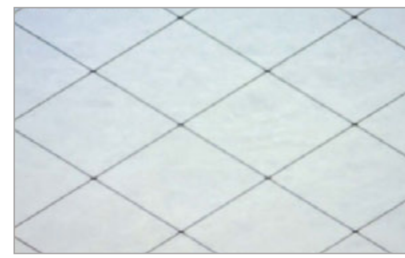
PHOTOETCH & PATTERNING CAPABILITIES: SMALL TO LARGE SCALE



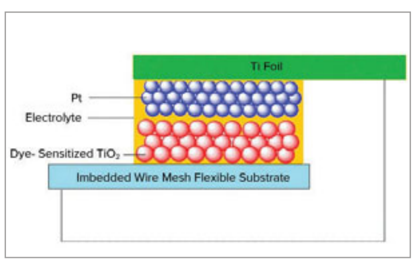
OLED + Bank



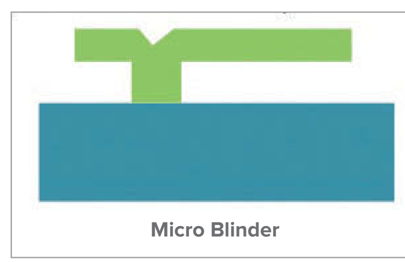
Glass Interposer



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



Flexible Dye Cell



MEMs

STANDARD COATING & SERVICES:

- STD TCO's ITO/IZO/AZO/FTO & WRTCO™
- BBAR 200μm – 12μm Multiple Range
- IMITO™ (EMI & Heaters) Several Types
- Hot & Cold Mirrors Several Types
- Black Mask: Black Cr, Nb or Resist
- Custom P-Caps Several Types
- Color Filters (Resist Type) Several Types
- Lamination: Ruggedization, Glass to Glass, Anti-Vandal, Filters, EMI/Heater to LCD

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Phone: 714.630.7127
Fax: 714.630.7119
Email: Sales@tfdinc.com

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Group International
jeanne-giil@hotmail.com

Korean Manufacturing:
Ion-Tek
ion-tek@hanmail.net

Taiwan Manufacturing:
Acrosense Technologies