DISPLAY WEEK 2018 PREVIEW AND AR/VR DISPLAYS

Information DISPLAY

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SID Salutes Display Industry Standouts


Pochi Yeh


Sang Wan Lee


Hidefumi Yoshida


Vladimir Chigrinov


Seth Coe-Sullivan

DISPLAY WEEK 2018 SYMPOSIUM PREVIEW

AR/VR DISPLAYS: OLED or LCOS?

5 DISPLAY STORIES FROM CES

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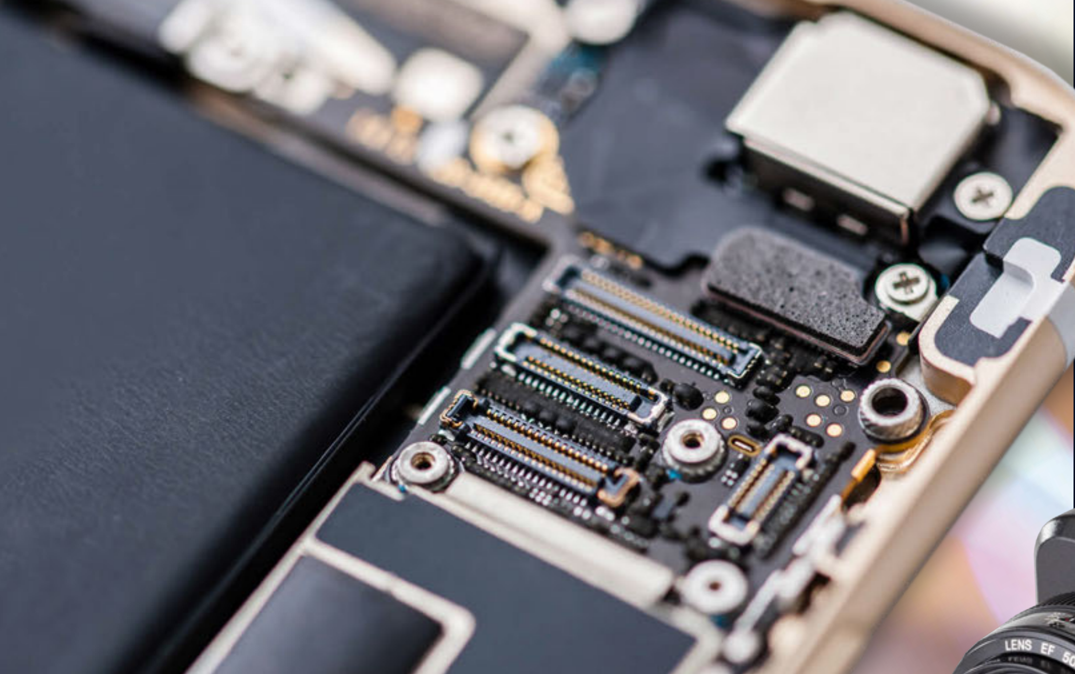


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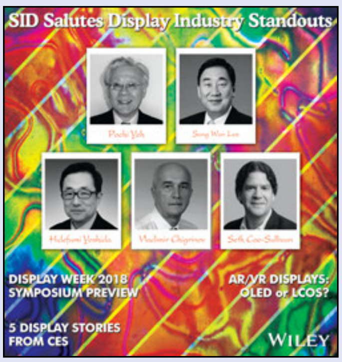
MARCH/APRIL 2018
VOL. 34, NO. 2

ON THE COVER: *The winners of this year's major awards from SID are: (top row from left to right)* ***Pochi Yeh****,* ***Sang Wan Lee****; and (bottom row from left to right)* ***Hidefumi Yoshida****,* ***Vladimir Chigrinov****, and* ***Seth Coe-Sullivan****.*



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editorial

Generations of Innovation

by Stephen P. Atwood

In spite of the rapidly growing pace of innovation, key technologies remain generational. In many cases, the things we consider ubiquitous today were probably nascent 25 to 50 years ago, or even longer. The original internet was developed in the 1960s and 1970s, and the ubiquitous web began around 1990. If you were born later than about 2000, you probably can't imagine a world without liquid-crystal displays (LCDs), the web, and real-time instant access to practically every piece of information and news you want. But there was a time, a generation or two ago, when people had to wait for the daily newspaper to come out, consult printed books and catalogs for technical data, and do computational modeling with slide rules and adding machines.

Such was the setting when George Heilmeier and associates at RCA unveiled that first LCD back in 1968. That's 50 years ago – a time when we were on the verge of a manned moon landing but were mostly watching black-and-white cathode-ray-tube (CRT) TVs and programming early computers with punch cards. Incidentally, space travel itself took several generations to evolve from amateur rocketry to a manned spacecraft that could escape the gravity of the earth.

While the principle of an LCD was solidly understood in the 1970s, the pervasive displays we know today came about only after numerous additional innovations. These include active-matrix addressing, three major generations of thin-film transistors (TFTs), optical compensation films, and various LC modes such as twisted nematic (TN), vertical alignment (VA), in-plane switching (IPS), optically compressed bend (OCB), backlight technology, and many more. This is not to mention a collective capital investment on the scale of the gross national product of several countries. It took at least 20 years for LCDs to first appear in computers and on desktops.

LCD technology today is the culmination of at least two generations of work by countless scientists, engineers, and visionary business leaders. LCDs enable virtually every major consumer and industrial product today, either directly or indirectly. They also support a gigantic global supply-chain ecosystem producing critical components and materials to make those displays. It's hard to fully imagine all the economic value fueled by the LCD industry today.

This technology platform continues to evolve, as the next generation of ambitious engineers and scientists build their careers with further innovations. Meanwhile, we have a chance to look back at some of the most seminal contributions to the field with a special event at Display Week. This May, SID is holding a 50th anniversary LCD Celebration at the show in Los Angeles. The celebration will feature a collection of LCD luminaries who have played pivotal roles in this technology. The details are described in our SID News feature, and the roster of speakers is not to be missed. This will be a wonderful chance to either reminisce if you were there for part of the history, or gain some perspective on how we got here and where this technology is going next.

Some of the people who were there along the way and made crucial contributions to the LCD industry are recognized by this year's SID Honors and Awards. As Jenny Donelan explains in our cover story for this issue, "by chance," each of the major award winners "has enjoyed a career based on or related to LCDs." Each year, the Society for Information Display honors those individuals who have made outstanding contributions to the field of displays, and if anything symbolizes the generational

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industry news

By Jenny Donelan

OLEDs March Through Peaks and Valleys

Ever since OLED displays started appearing in products like mobile phones and cameras in the early 2000s, OLED technology has experienced highs and lows worthy of a character in a novel by Charles Dickens. Even before Sony introduced the XEL 1, the first commercially available OLED TV, in 2008, emissive OLED technology was viewed by many in the industry as the successor to plasma and LCD. Sony sold its first batch of 1,300 XEL 1 TVs in one day. But for various reasons – manufacturing cost and yield challenges among them – OLED TVs did not really catch on.

It looked like OLEDs were going to find their moment in 2012, when both Samsung and LG Display announced 55-in. OLED units. These impressive, beautiful TVs were shown at Display Week 2012 in Boston, where they both received Best in Show awards from SID. In 2013, both companies followed up with curved versions of 55-in. OLED TVs. But again there were rumors of mass-production hurdles. Shortly afterward, Samsung stopped making OLED TVs, concentrating instead on quantum-dot enhanced LCD TVs (more on those below in the article about Samsung's "The Wall"). LG Display continued to develop and sell OLED TVs – and slowly, but surely, sales increased, even growing, as reported in last issue's Industry News, 133 percent year over year 2016/2017.

Of course, TVs are not the only OLED story. OLED is used for lighting, though its base has so far been high end and architectural. And it has continued to be employed in mobile devices, to the point where it is the dominant display material in Samsung's flagship smartphones. Last year, it was also used for the first time in an Apple smartphone – the iPhone X. In some ways also like a Dickens character, despite the stumbles, OLED continues to survive and even thrive. One reason is – quite literally – its flexibility. OLED offers many options to developers looking for a lightweight, flexible material for myriad new display products.

Below are just a few highlights from OLED's most recent history. (For a complete and even exhaustive account, check out the very excellent "OLED history: A 'guided tour' of OLED highlights from invention to application" from OLED-info at www.oled-info.com/history.)

- LG Display will now supply flexible OLEDs to Sony for future Sony smartphones.[1]
- LG Display is already supplying Sony with OLED displays for Sony's OLED TVs. In 2017, Sony reportedly requested LG to double its OLED panel shipments because demand for Sony's OLED TVs had been better than expected.[2]
- Since the summer of 2017, various news sources have been reporting that Sharp (acquired by Foxconn in 2016) would be creating flexible OLED panels for smartphones. In January 2018, Sharp's

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Product Briefs . . . .

Konica Minolta Introduces New Display Color Analyzer

Konica Minolta's new display color analyzer, the CA-410, improves on the accuracy, spectral sensitivity, and chromaticity readings of its predecessors, including a luminance measurement range 25 times wider than that of previous models (Fig. 1). According to Konica Minolta, the CA-410 is designed especially for the evaluation of more advanced technology, such as HDR displays.

Fig. 1: Konica Minolta's new color analyzer is designed to address the requirements posted by newer display technology. Image courtesy Konica Minolta.

Radiant Announces New AR/VR Lens for Near-to-Eye

Radiant Vision Systems has announced the release of a new AR/VR lens for its ProMetric imaging photometers and colorimeters (Fig. 2). The lens features a unique optical design specially engineered for measuring the visual quality of near-to-eye displays inside virtual-reality (VR), mixed-reality (MR), and augmented-reality (AR) headsets.

Fig. 2: Radiant Vision Systems' AR/VR lens can easily be removed and replaced with standard lenses for additional display measurement applications, such as testing displays outside of headset equipment or on the production line. Image courtesy Radiant Vision Systems.

Lenovo, Google Intro Display for Google Assistant

At CES 2018, Lenovo and Google introduced the Lenovo Smart Display with Google Assistant built in, one of several such Google-based home-assistant systems created in response to Amazon's Echo Show (Fig. 3). According to several reviewers, the Smart Display stands out from the rest of those for its functionality and good looks. The HD touchscreen display comes in both 8-in. and 10-in. IPS LCD models, with the former at 1,200 x 800 resolution and a suggested retail price of $199, and the latter at 1,920 x 1,200 resolution and a suggested price of $249. The device rotates from portrait to landscape mode and comes with a handy physical web cam shutter.

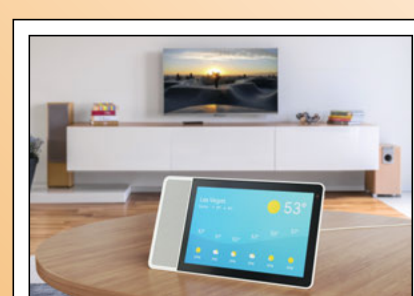

Fig. 3: The Lenovo Smart Display is a Google-based home assistant system. Image courtesy Lenovo.

guest editorial

The Race for Dominance: OLED or LCOS Microdisplays in Augmented and Virtual Reality

by Seth Coe-Sullivan

When I was invited to be the guest editor of this edition of *Information Display*, display engines for augmented reality (AR) and virtual reality (VR) came to mind, as this topic continues to be the subject of hot debate in our industry. I have colleagues residing in different camps with regard to which microdisplay will be the dominant player in this escalating market, so I reached out to Barry Young and Po King Li, both highly respected technical experts in the field who have different opinions on the subject. Our own work at Luminit leverages both of these technologies, along with LED- and laser-illuminated MEMs devices, and so we are more than a passive stakeholder in this race for dominance.

Barry Young's article, "OLED Displays and the Immersive Experience," offers a realistic view of the challenges facing the industry in creating a truly enveloping AR or VR experience. He notes that while augmented- and virtual-reality consumer products may give famous CEOs a lot of buzz, end-user acceptance is lagging, due largely to price and the awkward and bulky headsets currently available. In spite of the hardware and software challenges, however, he emphasizes the advantages of OLED microdisplays for creating a truly immersive VR experience. Advantages in latency, contrast ratio, response time, and black levels, he notes, as well as advancements in luminance, make OLED microdisplays ideal for both VR and AR.

Po King's article, "LCOS and AR/VR," paints a different picture of the liquid-crystal on silicon (LCOS) *vs*. OLED debate. He notes the advantages of front-lit LCOS and color-filter LCOS, particularly in AR, where picture quality, high luminance, small pixel size, low power consumption, and small form factor are critical. In addition, LCOS microdisplays, according to Po King, can adapt to various optical architectures, and the design flexibility solves the weight and size issues that have been barriers for consumer adoption.

Although the articles express different points of view, both authors agree that the engineering involved in designing and building consumer-friendly, affordable VR or AR devices with a large field of view (FOV) remains a challenge. In addition, the technological landscape is evolving, making the adoption of one platform even more difficult. For example, lasers are playing an increasingly important role in AR and VR, and the spatial and spectral precision of a laser light source could be a game changer for creating a highly realistic AR and VR experience. In addition, matching the light source, whether OLED, LED, or laser, to the combiner, such as waveguide, hologram, or conventional optic remains a challenge, and system-level analysis is needed to understand the best display engine for a particular device.

Some spectators may see this race for dominance in AR and VR display technology as neck and neck between LCOS and OLED. It's hard to call, because the course in this technological marathon keeps changing. Whatever microdisplay camp you've planted a flag in, I think we can all agree that in spite of the challenges that lie ahead, the potential of AR and VR devices is endless, and LCOS, OLED, and MEMs devices are all likely to play an important role in much the same way that OLED and LCD co-exist in macro displays today.

Seth Coe-Sullivan *is vice president and chief technology officer at Luminit LLC. He is also a co-founder of quantum-dot company QD Vision. He can be reached at scoe-sullivan@luminit.com.* ■

SID Salutes Display Industry Standouts

This year's winners of the Society for Information Display's Honors and Awards include ***Hidefumi Yoshida****, who will receive the Karl Ferdinand Braun Prize for his contributions to LCD technology;* ***Pochi Yeh****, who has earned the Jan Rajchman Prize for his development of matrix methods for analyzing the viewing-angle properties of LCDs;* ***Sang Wan Lee****, who will receive the inaugural David Sarnoff Industrial Achievement Prize for his leadership and contributions to the growth of the display industry;* ***Vladimir Chigrinov****, who has earned the Slottow-Owaki Prize for his educational efforts in the field of liquid-crystal devices; and* ***Seth Coe-Sullivan****, who will receive the Peter Brody Prize for his pioneering contributions to quantum-dot technology.*

by Jenny Donelan

IN this, the 50th anniversary of the liquid-crystal display (see our SID News article in this issue about the celebration scheduled for Display Week), it seems appropriate that by chance, every one of this year's Honors and Awards recipients has enjoyed a career based on or related to LCDs. Hidefumi Yoshida, this year's Karl Ferdinand Braun Prize winner, based his 40-year career on LCDs. Pochi Yeh, winner of the Jan Rajchman Prize, used his background in optics for thin films to improve the performance of LCDs. Vladimir Chigrinov, Slottow-Owaki Prize winner, became so inspired by the physics of liquid crystals that he abandoned a study of pure mathematics for a research and teaching career dedicated to LCDs. Seth Coe-Sullivan, this year's Peter Brody Prize winner, is known for his work with quantum dots, but notably chose from among their many possibilities to focus on how they might enhance LCD panels.

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

Sang Wan Lee, who has won the first-ever David Sarnoff Industrial Achievement Prize, was a different kind of LCD pioneer, a key executive behind the success of the LCD flat-panel TV. Without his persistent championship, the TV landscape might look quite a bit different than it does today. The Sarnoff Prize was created to honor individuals who may not have served the industry through hours in the laboratory, but have contributed through their efforts as visionaries and evangelists. Lee is an ideal example of such a visionary. For an exciting look at how his predictions for LCD-TV sales (viewed as somewhat audacious in 2005, when he made them) came true, see "Anniversary of a Prediction" by Past SID President Paul Drzaic in the March 2010 issue of this magazine. (In the next issue of *ID*, we will feature an article about the new award and its namesake, another television proponent from earlier days, David Sarnoff.)

Something else this year's winners have in common besides LCDs is that they saw the potential in a particular display technology and were intrigued enough by it and passionate enough about it to make it their life's work. We owe our own work and careers to their inspiration and dedication. Please join us in congratulating them for their contributions to the industry and the Society for Information Display as we know it.

> *The 2018 winners will be honored at the SID Honors & Awards Banquet, which takes place at 8:00 pm, Monday evening, May 21, 2018, during Display Week at the Intercontinental Hotel in Los Angeles.*
> *Tickets cost $100 and must be purchased in advance – they will not be available on site.*
> *Visit **www.displayweek.org** for more information.*

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2018 Karl Ferdinand Braun Prize

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

Hidefumi Yoshida, SID Fellow and research director at Sharp Corp., will receive the Karl Ferdinand Braun Prize "for his contributions to LCD technology, especially wide-view multidomain vertical-alignment LCD, the photo-alignment process, half-tone technology, and fast-response and flexible LCD architectures."

Dr. Yoshida has focused on LCD technology for his entire career – a period spanning more than 30 years. But when starting out in the mid-1980s, he nearly followed a completely different career path. Yoshida was preparing to start work at Fujitsu Ltd. (his first job after graduating with an M.S. from Tokyo University) as a dynamic random access (DRAM) engineer, when a director and supervisor at the company changed Yoshida's department and area of concentration to LCD.

DRAM's loss was LCD's gain, because Yoshida went on to make many significant contributions to the field, including developing new display modes for vertically aligned LCDs; dividing domains by optical alignment; improving viewing angles by developing new optical or pixel configurations; creating a fast response mode with oblique field applications; and much more. He also developed both a transparent LCD and a flexible one.

"Dr. Yoshida has made significant contributions to the LCD technology process,

Hidefumi Yoshida

especially through his pioneering work on multidomain vertical alignment technology when he was at Fujitsu," says Jun Souk, a professor at Hanyang University. "He is regarded very highly as a pioneer in making VA a commercially successful technology."

In fact, one of the achievements Yoshida says he is most pleased with concerns vertically aligned (VA)-LCD photo-alignment. "When I started out," says Yoshida, "there was no equipment at our company for producing a suitable beam of UV light for substrate irradiation." He had heard that polarized UV light could be effective for creating an alignment layer, but few options existed for polarizing materials. "I concluded that for mass-production, I would need to develop a solution using non-polarized light," he says. A UV light manufacturer agreed to let him borrow its equipment, and he ended up performing experiments at its factory every week for almost half a year (each round trip to the factory took three hours). "I was able to realize the uniform alignment by irradiating with un-polarized UV, improving the alignment layer. In this case, the anisotropic irradiation was the key. If the surface of a substrate is irradiated by UV light coming from an oblique direction, the irradiation is anisotropic and the slant alignment necessary for VA is realized." In this way he was able to prove that polarized UV light was not necessary in principle. "Nowadays," he says, "better alignment is realized by using polarizers, but at the time it was not a viable approach in mass production."

Yoshida earned a Ph.D. from the Tokyo Institute of Technology in 1997 and served as a visiting scientist at Kent State University from 1994 to 1996. He joined Sharp in 2008, where he now works as a research director. The greatest challenge the LCD industry now faces, he says, is the onslaught of OLED and quantum dot technology. "In the past," says Yoshida, "there were some rivals to LCDs, but they disappeared due to their own problems or issues." Now, he notes, whatever display technologies eventually prevail, issues of reliability, manufacturability, and cost performance remain the key factors.

2018 Jan Rajchman Prize

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

Pochi Yeh, a technology consultant, will receive the Jan Rajchman Prize "for his

Pochi Yeh

contributions to the development of matrix methods for analyzing the viewing-angle properties of LCDs, and to the development of phase compensators."

Dr. Yeh, a prolific author and inventor, is perhaps best known as one of the developers of the Extended Jones Matrix Method, used in simulating the design and analysis of optical transmission in LCDs. In addition, notes Andy Ying-Guey Fuh, professor emeritus at National Cheng Kung University, "Dr. Yeh and his co-workers were among the first to propose and demonstrate thin-film compensators to improve the viewing-angle characteristics of liquid-crystal displays, including contrast ratios and color stability."

Yeh, who graduated from the California Institute of Technology with a Ph.D. in physics, was originally trained as a physicist, and started his career working in optics for thin films. In the early 1990s, he was the principal technical advisor at Rockwell Science Center, which was sponsoring a project aimed at improving the viewing quality of LCDs for avionics displays.

"In the early days of LCDs," explains Yeh, "the contrast and colors degraded significantly at large viewing angles. And at that time, Rockwell made all the cockpit displays for Boeing aircrafts." Consistent color and contrast over wide viewing angles were necessary to ensure that the pilot and co-pilot saw exactly the same information on the cockpit display. So there was a need to improve the contrast and color of Rockwell's

LCDs. "My background in thin films," says Yeh, "was useful for the development of compensators that greatly improved the viewing quality of LCDs for cockpits." That work gained momentum and distribution, as those same high-quality LCDs eventually went into households as flat-screen televisions. That work on compensators, says Yeh, led to work in further aspects of LCD optics that eventually became his career. In addition to working at Rockwell, Yeh was a professor at the University of California at Santa Barbara for nearly 30 years.

Yeh notes that technical problems that still need to be solved in LCDs include higher frame rates and 3D imagery. "The most difficult problem is the display of real 3D images and videos using holographic technology in a flat LCD panel," says Yeh.

2018 David Sarnoff Industrial Achievement Prize

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.

Sang Wan Lee

Sang Wan Lee, professor at Hanyang University and former CEO of Samsung's LCD Division, has earned the inaugural David Sarnoff Industrial Achievement Prize "for his leadership and contributions to the growth of the display industry, and especially to large-screen LCD TVs."

Dr. Lee is known for his pioneering efforts on behalf of the flat-panel display industry, and for his significant impact on the LCD industry in particular. Lee assumed leadership of the LCD division at Samsung Electronics in 1993. During his 15 years as CEO at Samsung, he led the company to grow the notebook and LCD monitor market through aggressive investment and panel-size standardization. He was the first to invest in Gen 7 fabs that made volume production of LCD-TV panels economically feasible, and which in turn made possible the era of very large-screen LCD TVs in the early 2000s.

2018 SID Fellow Awards

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

Steven Bathiche *"for his contributions to one of the first computer-vision mixed-reality computers for multi-touch and object recognition, and to the seed technologies for Microsoft Surface computers."*

Mr. Bathiche is a research director with the Applied Sciences Group at Microsoft. He has a master of science degree in bioengineering from the University of Washington.

Ioannis Kymissis *"for his sustained contributions in the application of thin-film electronics to display technologies."*

Dr. Kymissis is an associate professor in the electrical engineering department at Columbia University. He has a Ph.D. in electrical engineering and computer science from the Massachusetts Institute of Technology.

Mary Lou Jepsen *"for her contributions to display technology and product development, especially low-cost laptop and netbook displays, low-power sunlight-readable LCDs, virtual reality, and wearable displays."*

Dr. Jepsen is the founder of Openwater. She has a Ph.D. in optical physics from Brown University.

Seok-Lyul Lee *"for his invention, product development, and commercialization of fringe-field switching liquid-crystal display devices."*

Mr. Lee is senior manager/chief researcher at AU Optronics. He earned his M.S. in polymer/nanoscience technology at Chonbuk National University.

Qiong-Hua Wang *"for her contributions to the science and technology of 3D display systems based on integral imaging and lenticular lenses."*

Dr. Wang is a professor at Beihang University. She earned a Ph.D. in optical engineering at the University of Electronic Science & Technology of China.

"Professor Lee stimulated and led the LCD industry by setting a high level of targets to be achieved," says Jin Jang, director of the Advanced Display Research Center and Department of Information Display at Kyung Hee University. "For example," says Jang, "he was invited to give a keynote speech at Display Week 2005 in Boston, at which time he forecast sales of LCD TVs to increase to 100 million units per year by 2010. He called on the entire display industry to work together to achieve this goal." Although this seemed like a radical prediction at the time, it came true two years early, in 2008.

Lee explains that he grew interested in TVs in the early 2000s when he saw how quickly LCDs (already the dominant display in laptops) were replacing CRTs in desktop monitors. LCD monitor sales doubled every year from 1998 to 2001, he notes, going from 1.5 million units in 1998 to 15 million in 2001. "But," Lee explains, "the LCD-TV market was a different and very difficult one for many reasons." First, there was no suitable LCD technology for large-screen TVs at that time, including wide viewing-angle technology, a high-speed liquid-crystal driving method for moving imagery, and high gamut color. There wasn't any process equipment to make such TVs, and creating that equipment would require a huge and risky fab investment.

Undeterred and inspired, Lee drove forward. "I decided to challenge the LCD-TV panel business," he says, "and to be ahead of the other manufacturers (the early bird gets the worm strategy)." With the world's first 40-in. LCD-TV prototype announced in 2001, and the first Gen 7 fab operational in 2005, Samsung LCD was indeed able to reap the benefits of "early-bird mode," as Lee puts it. It's important to note here that while Lee wanted his company to be first to the market, he didn't wish for it to be exclusive there. "I always believed the LCD industry should grow together," he says, "and we could make the market big through the whole industry working together."

When asked what advice he would give to other CEOs in this area, Lee observes that the current situation is challenging, with the worldwide TV market near-saturated and LCD penetration close to 100 percent. He adds that there are very many players now and that "China's bold investment in Gen 10 fabs can change the market." Today's CEOs are facing difficult challenges, with fast-changing, more-diversified display dynamics, including OLED TVs, QLEDs, microLEDs, and more. But success can still be had if CEOs practice forward thinking by investing in innovative materials, says Lee.

2018 Slottow-Owaki Prize

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

Vladimir Chigrinov, professor at Hong Kong University of Science and Technology, will receive the Slottow-Owaki Prize "for his educational efforts in the field of liquid-crystal devices, as evidenced by his teaching, supervision of graduate students, and prolific publications and conference presentations."

Dr. Chigrinov got his start in the display industry after receiving his M.S. degree in applied mathematics from the Moscow Technical University of Electronics and Mathematics in 1973. But as he headed toward doctoral work, he became more and more interested in the physics of liquid crystals than in pure mathematics. "I worked in projects aimed at understanding the fundamental aspects of LCD technology," says Chigrinov, "including the special measurement techniques of LC physical parameters such as viscosity, elasticity, optical and dielectric constants, *etc*." He subsequently earned a Ph.D. in solid-state physics from the Shubnikov Institute of Crystallography at the USSR Academy of Sciences, with a thesis titled "Investigation of Instabilities in Nematic Liquid Crystals."

Throughout his career, Chigrinov has participated in making prototypes of the first

2018 SID Special Recognition Awards

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

Jae-Hoon Kim *"for his contribution to the development of LCDs and other optical and organic devices."*

Dr. Kim is a professor at Hanyang University. He earned his Ph.D. in physics at Sogang University.

Hisahiro Sasabe *"for his contributions to the science and technology of multifunctional materials realizing low-power-consumption OLEDs, and for outstanding contributions to the literature."*

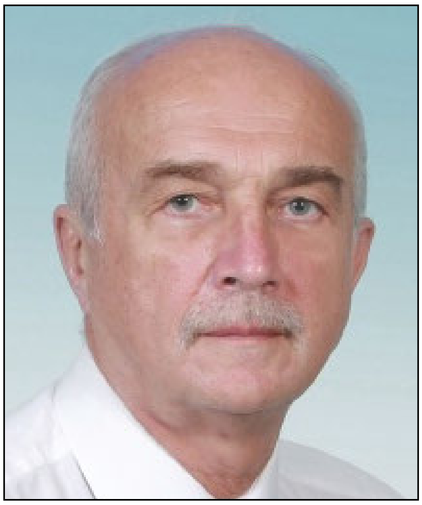
Dr. Sasabe is an associate professor at Yamagata University. He received his Ph.D. in applied chemistry from Osaka Prefecture University.

Yasushi Tomioka and Noboru Kunimatsu *"for their leading contributions to the research and development of photodecomposition-type photoalignment into mass production of planar-aligned in-plane switching and fringe-field switching LCDs."*

Dr. Tomioka and Dr. Kunimatsu are engineers at Japan Display, Inc. Dr. Tomioka received a Ph.D. in chemistry from Tohoku University. Dr. Kunimatsu received his Ph.D. in chemistry from the University of Southampton.

Katsuhide Uchino *"for his leading contributions to the research and development of designs for high-resolution AMOLED displays and micro-OLED displays."*

Mr. Uchino is a device engineer and manager at Sony Corp. He earned an M.S. in applied physics from Waseda University.



Vladimir Chigrinov

liquid-crystal displays based on dynamic scattering with electrically controlled birefringence. He also focused on computer modeling of these LC properties. Under his supervision, a unique software module was created that enabled the simulation and optimization of real LC behavior without entailing any physical experiments. In addition to this research, Chigrinov has written six books and more than 280 journal papers, and taught in various capacities at the Hong Kong University of Science and Technology since 1999.

Says physicist and inventor Martin Schadt, "Professor Chigrinov is a dedicated applied scientist with a profound understanding of liquid crystal science and technology. His well-written textbooks and original publications on LCDs are inspiring and of great value for teachers and students."

Looking back at his career, Chigrinov says he is particularly proud of pioneering LC photoaligning technology, including highly sensitive optically rewritable (ORW) photoaligning materials and superfast ferroelectric LC (FLC) materials.

Students' comments over the years on Chigrinov's lectures attest to his success as an educator. Such comments include: "deep understanding of the subject area and good attitude toward students," "very up to date with recent developments," "enthusiastic about the material, and very knowledgeable on the subject," and "very kind-hearted person" who is "easy to approach." Chigrinov's greatest satisfaction as an educator are the professional relationships he has with former students who have embarked on their post-graduate careers at universities and companies. "I still look forward to new research projects with my former students and continue to work with them on interesting future LC applications in displays and photonics," he says.

2018 Peter Brody Prize

The Peter Brody Prize is awarded to honor outstanding contributions of young researchers (under age 40) who have made major-impact technical contributions to the developments of active-matrix addressed displays in one or more of the following areas:

- *Thin-film transistor devices*
- *Active-matrix addressing techniques*
- *Active-matrix device manufacturing*
- *Active-matrix display media*
- *Active-matrix display enabling components*

Seth Coe-Sullivan, vice president of technology and chief technology officer for Luminit, will receive the Peter Brody Prize "for his pioneering contributions to quantum-dot based technologies in displays and to their impact on active-matrix display technologies."

Quantum dots (QDs) are new but now well known in the display industry, both as a material in current use as an LCD backlight color gamut enhancer, and as a material with potential to disrupt the industry with new types of self-emitting devices, including displays. Dr. Coe-Sullivan, an expert in QD materials and devices for solid-state lighting and displays, has been a major force behind the development of QDs, making exceptionally efficient use of his short 20-year-old career. His doctoral thesis at the Massachusetts Institute at Technology, where he received his Ph.D. in 2005, led to the formation of QD Vision, a company that paved the way for quantum-dot technology for displays.

Seth Coe-Sullivan

According to Larry Weber, founder of Plasmaco, "Seth's major contribution to active-matrix displays has been to develop practical ways to introduce quantum dots into manufacturable products. An example of this is his work with Sony to put the QD Vision quantum dots into the Sony 65-in. Bravia active-matrix LCD first shown at the January 2013 Consumer Electronics Show in Las Vegas. This product won the Best in Show and Best Home Theater Product at CES. Today the display industry widely accepts the concept that quantum dots are needed to make superior active-matrix LCD products."

Coe-Sullivan first learned about QDs when he was interviewing with professors at MIT, deciding which group he would join. Professor Vladimir Bulovic at MIT showed him some images he had received from Professor Moungi Bawendi, says Coe-Sullivan, and expressed his desire to make a good LED out of these materials. "Bulovic's passion was contagious," says Coe-Sullivan, "and I spent the next 17 years of my life (and counting) in the field."

When asked what achievement he is proudest of with regard to his quantum dot work, Coe-Sullivan replies, "I'm proud that we (not me alone) were able to reduce QDs to something relatively simple that adds value to the devices that you use every day. There were and are lots of incarnations that were more elegant, sexier, and flashier than using QDs as a down-conversion replacement for phosphors in LCD TVs backlights, but we stayed focused on the simple and useful, and created an industry around that innovation. Now the QD industry (there is one!) can work on those harder but cooler solutions, and bring a whole new generation of QD products to market in displays, and elsewhere." ■

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Invitation to submit review papers

The Journal is 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 invited review papers will be waived.

Herbert DeSmet
Editor-in-Chief

Announcements

Silver jubilee

JSID was first published in its present form in 1993, 25 years ago. The first Editor-in-Chief was Alan Sobel, still an active and respected member of the display research community. Please read my Editorial in Vol. 26(1) where I reminisce briefly about some changes the Journal has gone through in those 25 years.

Special issues

We will again have several special sections for expanded papers from SID sponsored conferences.
At the time of writing, '**Best of EuroDisplay 2017**' papers are being reviewed and are expected to appear in issues 2 (February) and up, but also in a virtual online issue.
Like last year we have installed an expedited review procedure for the '**Expanded Distinguished Papers of Display Week 2018**'. 44 abstracts have been nominated by the paper selection committee as 'candidate Distinguished Papers' and a large majority of the authors have submitted an expanded version to JSID. At the time of writing, the papers are being reviewed with the highest priority. The expedited review is stricter than for regular contributions, because there is not enough time to allow for major revisions to the papers. All accepted papers will be published online in a virtual issue before the start of Display Week and will be assigned to monthly issues 2-5. The Distinguished Papers will be 'open access' until the end of the year.
Finally, we are expecting a handful of **expanded selected papers from IDW'17** for publication in the July and August issues and also in a virtual online issue of JSID.

Invited review papers

A first invited review paper was authored by K. Vodrahalli and A.K. Bhowmik and published in v25(11): **3D computer vision based on machine learning with deep neural networks: A review** (DOI: 10.1002/jsid.617).

A number of other review papers are presently being prepared.

Awards

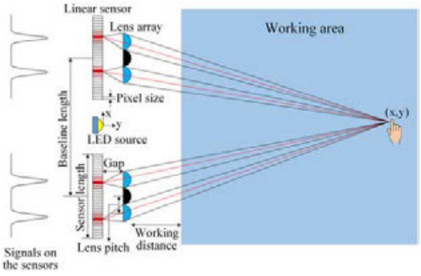
The winners of the Best Paper Award 2017 and of the Outstanding Student Paper Award 2017 will be announced during Display Week on May 22nd.

JSID social media presence

See the bottom of this page for our Twitter and Facebook coordinates.

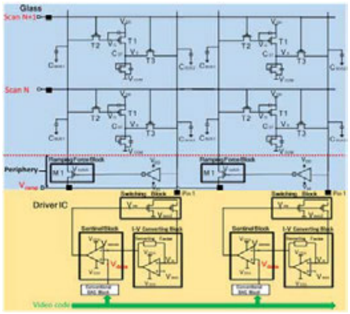
Highlighted recent papers

High-resolution and compact virtual mouse using lens arrays to capture finger images on light sensors | Zong Qin *et al.*| DOI: 10.1002/jsid.613



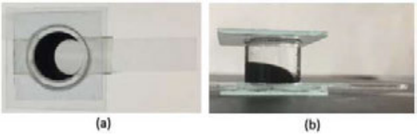
A virtual mouse using lens arrays and light sensors is proposed for finger positioning. Experiments verify a high resolution of 26 ppi over a working area of 10 cm × 10 cm. The system volume is as compact as 3.1 mm (thickness) × 4.5 mm (length) × 2, while multiple imaging paths guarantee an acceptable accuracy of approximately two distinguishable points.

An external compensation method for AMOLED using the concept of ramp-stop | Ya-Hsiang Tai and Chi-Hao Lin | DOI: 10.1002/jsid.616



An advanced circuit with only one pin per column is proposed to drive active-matrix organic light-emitting diode with real-time feedback. Without using extra memory and doubling the pin number in column, the proposed method can be implemented at lower cost than the other external compensation approaches.

Electrowetting optical switch with large aperture tuning range | Yannanqi Li, *et al.*| DOI: 10.1002/jsid.620



In this paper, we propose an electrowetting optical switch with large aperture tuning range by deforming the shape of the liquid droplet. The aperture can be largely tuned from ~0.5 to ~6.2 mm. We analyze the electro-optical characteristics such as transmission (~350:1), actuation time (~320 ms), and relaxation time (~3.6 s). Fig. 1 depicts the top-view and side-view of the fabricated device.

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LCOS and AR/VR

Companies are delivering different renditions of augmented-reality and virtual-reality products to the market, including Google Glass, Microsoft Hololens, ODG R-7, Magic Leap One, Oculus Rift, HTC Vive, and the Dell Visor. All these products have different specifications and applications. This article will discuss the differences between VR and AR, and how LCOS microdisplays can play an important role in making these applications more viable.

by Po King Li

VIRTUAL-REALITY (VR) headsets have existed for more than 30 years, but major technical breakthroughs that provide a new experience to users have only arrived in the past few years. These breakthroughs include high-resolution thin-film transistor (TFT)-LCD and OLED panels, power graphics processing units (GPUs), cloud computing, and 3D rendering software.

Augmented-reality (AR) devices are cousins to VR devices, but with different DNA. There are several differences, but the main one is that VR provides an immersive experience for users, who experience the virtual world the system provides and are not able to see the environment around them (Fig. 1). AR involves a wearable device that allows users to view the surrounding environment with an overlap of digital content. For example, a user can see his friend's face with a digitally generated hat; an architect is able to see her newly designed building at the construction site before construction has begun; a field technician can follow 3D instructions from the other side of the world to fix a copy machine; a doctor can perform heart surgery with directions from an expert in another country (Fig. 2).

Po King Li is VP of marketing & sales, LCOS displays, at Himax Display. He can be reached at poking_li@himaxdisplay.com.

AR glasses require a complex optical module to deliver the digital content overlap. We will briefly introduce these different optical architectures later in this article. The following are characteristics of AR systems:

- AR provides a see-through optical device for the user. When the AR glasses are off, the user is still able to see the environment surrounding her. AR glasses are not an immersive experience.
- AR glasses are a stand-alone device. They do not usually connect to any PC or game console. They have enough processing power to render the 3D imagery.
- The user experiences digital content as an overlap with the real environment.
- Currently, most AR applications are for enterprises, such as 3D models for architecture, warehouse management, and medical and educational applica-

Fig. 1: *The Oculus Rift is a well-known VR headset that enables users to experience immersive applications in which they see nothing of their physical surroundings. Source: Oculus*

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tions. But more gaming applications are coming.

In summation, VR provides a virtual world to the user, whereas AR adds digital content to a real-world view. This is the key difference between these two product categories.

Liquid Crystal on Silicon

Liquid crystal on silicon (LCOS) is a well-known microdisplay technology that is widely used by AR headset designers due to several key advantages that we will discuss. The liquid crystal is sandwiched between a layer of glass and a silicon wafer (Fig. 3). The silicon wafer's top metal layer has two key functions: First, it is a mirror to reflect the light, and second, the mirror's voltage drives the liquid crystal, twisting it in order to create an image. When the polarized light reflects from the mirror, the light can project through the optical system so the user can see the image.

LCOS has various applications in projectors, head-up displays (HUDs) for cars, and AR glasses. Other useful LCOS applications are in phase modulation for communication applications and holographic displays. (It would take another article to discuss phase modulation and LCOS.) LCOS projection systems offer one of the best image-quality visual systems available. Sony and JVC's top-of-the-line home theater projectors both use LCOS as the display source. Since LCOS is based on a silicon design, there is no limit on resolution. Both 4K and 8K projection systems have been implemented with LCOS.

There are several different types of these systems (two appear in Fig. 4):

- The ***three-panel LCOS system*** is used mostly for home theater projectors. It uses three LCOS panels, each projecting in red, green, and blue light provided by the optical system. The system uses a lamp, LED, or laser as a light source.
- The ***color-sequential single-panel system*** has been used in some AR glasses. The system consists of one LCOS panel, and the system projects red, green, and blue color fields sequentially. The optical system sequentially provides red, green, and blue light to the LCOS panel.
- The ***color-filter single-panel system*** integrates a color filter on the top metal layer so that the optical system requires only white light as the input. This design uses the color filters on the LCOS panel to create the colored image.

Fig. 2: *A popular AR device (which its maker refers to as a mixed-reality device) is the Hololens from Microsoft. The headset at left enables augmented-reality applications, including remote plumbing repairs, as shown at right. Source: Microsoft*

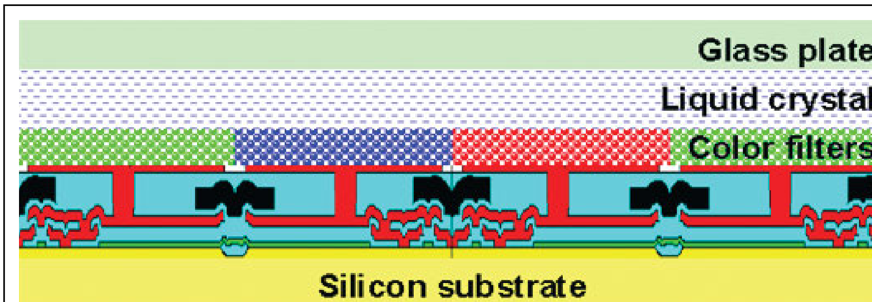


Fig. 3: *A cross-section of LCOS includes, from top to bottom, a glass plate, the liquid-crystal materials, and a color-filter layer based on a silicon substrate.*

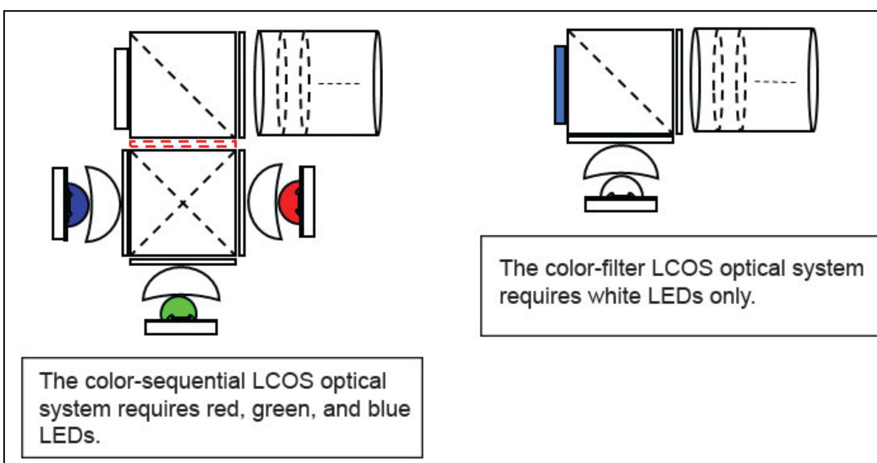


Fig. 4: *At left is a color-sequential LCOS optical system, and at right is a color-filter LCOS optical system.*

Below are major reasons for adapting LCOS as an AR display solution:

Best image quality. As we mentioned in the last section, the best home theater projectors use LCOS. With LCOS, the user is not able to distinguish the pixels – there is no "screen-door" artifact. The picture is a smooth image.

Pixel size. LCOS offers the smallest pixel of all the displays; the pixel size can be as small as 2.5 um, which makes possible a 4K panel for each eye.

Flexibility. AR glass requires a complex optical system to combine the real-world image and the digitally generated image. There are various optical architectures on the market. Since optical architectures are distinctive, the requirements of the panel size, pixel size, and resolution are different for each design. LCOS offers the flexibility to fit a variety of designs. Other microdisplay technologies have limitations in terms of lead time, resolution, and pixel size. With regard to OLEDs, the smallest OLED pixel available is around 10 µm, but LCOS pixels can be as small as 2.5 µm.

Power consumption. Power usage is one of the most critical design parameters for wearable or portable devices, since the battery size is limited. LCOS is one of the lowest-power microdisplay technologies available.

Size. AR glass can be made into a wearable-sized device. LCOS is able to deliver a small panel with high resolution. Furthermore, Himax has offered alternative LCOS solutions called front-lit LCOS. Himax is the first company to create a front-lit LCOS optical imaging system of this type.

Luminance. The LCOS optical system for AR is a projection system. The luminance of the optical engine is dependent on the optical design. Some of the applications of AR glasses require outdoor environmental support, which require display luminance as high as 30K nits from the optical system (Fig. 5).

Polarized light. Some of the optical architectures use a light guide as the eyepiece, and some of the light-guide designs use polarized light to govern the light direction (*e.g.*, a polarizing beam splitter [PBS]). The LCOS display technology is suitable for polarized-light optical systems because of the liquid-crystal layer.

Optical Architecture for AR

There are several different optical architectures for AR glasses, summarized below into the following categories:

Prism type. This is a simple design that uses a polarizing beam splitter to reflect the image into the user's eyes. The advantages of the prism design are its simplicity and high optical efficiency. One example of this architecture is Google Glass.

Projection system with combiner. An optical system projects the image onto a combiner. The user can see the digital content and the outside world through the combiner. The combiner has two functions: It reflects the projected image into the eyes and allows the eyes to see the outside world through the combiner as transparent glasses. Wearables company ODG makes products based on this architecture.

Light guide. The image is projected into a light guide, and the users see the image through the light guide. Examples of companies that use this approach are Lumus and WaveOptics.

Creating AR glasses is not a simple task, because many critical design parameters need

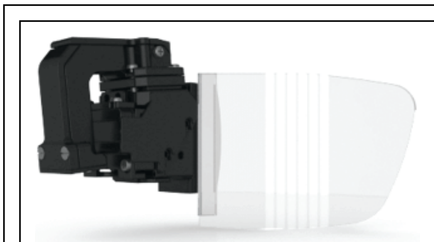


Fig. 5: *The optical engine OE50 from Lumus uses 0.37 WXGA. Source: Lumus*

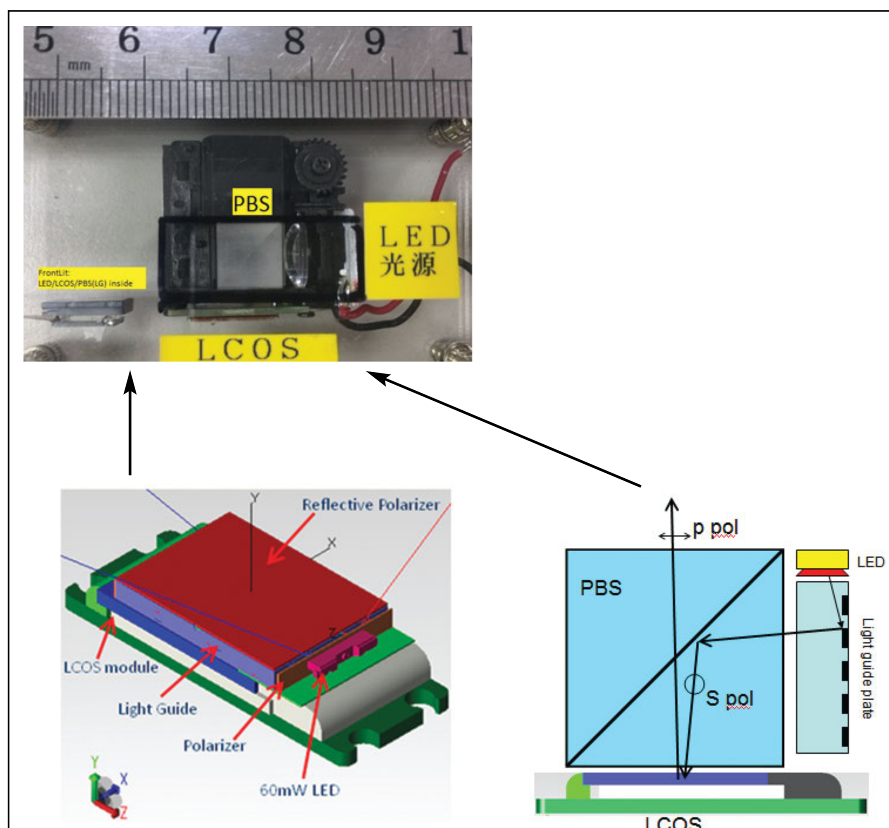


Fig. 6: *The conventional LCOS optical engine with PBS (shown in the center of the photograph at upper left in a top view) is bulky compared to the Himax frontlit LCOS engine (shown in the lower left-hand corner of the photograph in a side view). The red-topped schematic image at lower left is a top view of the Himax engine architecture. The blue schematic at lower right shows the architecture of the conventional LCOS with PBS.*

to be considered, and they may conflict with each other. For example, in the case of the resolution of the display, higher is better, but will increase power consumption for the processor and the system, due to there being more pixels to render and calculate. Critical parameters for the optical module of AR glasses are: power consumption; size and weight; latency (motion to photon); color break-up; luminance; field of view (FOV); and eye box.

LCOS as a Solution

The color-filter LCOS used by Himax Display (the author's company) provides simple solutions to some of the problems related to the above parameters; in particular, latency and color break-up. For any color sequential display, latency is a difficult problem to solve, because there is always a frame delay for converting the data from display data to color sequential data. This is achieved with an additional converter that converts the image data (RGB) into color-frame video data. (The applications processor [AP] cannot output display data sequentially yet, so the converter is needed between the LCOS and the AP.) For AR applications, latency (motion to photon) is very important, because humans turn their heads frequently. The user expects the contents to follow when and where her head is turned. Even one frame delay of latency at 120Hz refresh is too long for an AR application. Color-filter LCOS solves this difficult problem by taking away the need for conversion. It isn't necessary to send color-sequential data to color-filter LCOS, and there are no data to convert. The display data will display onto the color filter LCOS immediately after they are received from the AP.

In the case of color break-up, since color-filter LCOS is not a sequential display, there is no risk of perceived color break-up. For normal color-sequential displays, designers need to increase the frame rates high enough to reduce the perceived color break-up, but in many cases, it can still be seen.

With regard to luminance, FOV, and eye-box issues, all these parameters are dependent on the optical system design. Since LCOS is very flexible for panel size and resolution, LCOS can support most of the optical architectures for different luminance, FOV, or eye-box requirements. Although the author cannot disclose the specification of current designs, since most of them are customers' confidential information, it is fair to say that other microdisplay technologies are able to meet some of the results, but not all of them. For example, a typical AR system with an LCOS panel of .37 inches and a resolution of 720p can produce a 40-degree FOV at 30K nits luminance into an eye box measuring 10 mm × 10 mm.

For power consumption, LCOS occupies only a small percentage of the AR-system power budget. For example, a 1,080-ppi panel consumes less than 200 mW, compared to 2 W from the processor in the system. For comparison, a front-lit LCOS display can output 30K nits using 500 mW, whereas a micro-OLED requires nearly 1 W to achieve up to 1,000 nits.

In terms of size, the traditional optical engine for LCOS is not small (for example, 10-20 cc of volume, as shown in Fig. 6). This is why Himax has introduced a new front-lit LCOS optical system to reduce the optical engine size and weight. Front-lit LCOS integrates the biggest and heaviest items into the panel package – the PBS and the illumination system. This reduces the size of the optical engine by 40 percent, and the weight by 20 percent. Front-lit LCOS is based on Himax color-filter LCOS, which integrates the PBS and LED illumination system with the panel. Front-lit LCOS offers an improved solution for two of the most critical parameters for AR – weight and size. Users do not tolerate large and heavy glasses.

AR is likely to be an important new application in the near future. Every person may own a pair of AR glasses; the market could be similar to the smartphone market today. LCOS, and in particular, front-lit LCOS and color-filter LCOS, are display solution that will help solve AR design problems and help bring about the AR revolution. ■

OLED Displays and the Immersive Experience

After generating much initial excitement over the past several years, AR/VR technology deployment has hit some recent roadblocks. New applications, facilitated by OLED technology, could jump-start this technology yet again.

by Barry Young

IN 2014, Facebook founder Mark Zuckerberg plunked down a reported $US 3 billion for virtual-reality (VR) system maker Oculus and said, "We believe this kind of immersive, augmented reality will become a part of daily life for billions of people."[1] IDC, a leading technology market research firm, was so taken by the promise of a new paradigm for consumer and commercial applications that it later forecasted shipments would grow from 9.2 million units in 2016 to 67.1 million units in 2021, as shown in Fig. 1.[2]

Three years later (2017), Zuckerberg testified (in a technology theft case brought against Oculus by a company called ZeniMax Media), that VR hadn't taken off as quickly as he had anticipated and that VR sales "won't be profitable for quite a while."[3] So VR isn't as hot as everyone thought it would be, and the evidence is compelling. For most people, the cost is prohibitive: headsets start at $300 to $500, and go up from there if motion controllers, eye trackers, and other accessories are added. Plus, the headset is often tethered to a powerful computer, which costs $500 to $1,500 and limits the user's mobility.

Sony's PlayStation VR, designed to work with the tens of millions of installed PlayStation 4 consoles, was expected to set the industry on its ear, but early enthusiasm quickly dissipated for both the games and the content. Google's well-publicized Glass never reached the masses and is now relegated to industrial applications.

Barry Young *is CEO of the OLED Association. He can be reached at barry@oled-a.org.*

Mixed Terminology

When comparing the build-up to the reality, it may be useful to consider that neither augmented reality (AR) nor VR has reached the growth levels experienced by smartphones in the early years of their growth, as shown in Fig. 2. In addition to the reasons listed above, the failure of this technology to take off is also due to the way that experts have confused consumers with terms like virtual, mixed, and augmented reality, or immersive computing, without clearly defining these terms. (In short, virtual reality immerses the user in a digital world; he cannot see anything but that world. Augmented reality lets the user see the real world, but overlays that physical view with digital content. For more about the differences between AR and VR, see the article "LCOS and AR/VR," also in this issue).

So despite all the hype, we still don't have the "next big thing," although we seem to have pretty much defined it: a lightweight, always-on device that obliterates the divide between the real world and the one created by our computers.

"We know what we really want: AR glasses," said Oculus's chief scientist Michael Abrash at Facebook's F8 developers' conference in April 2017. "They aren't here yet, but when they arrive they're going to be the great transformational technologies of the next 50 years." He predicted that in the near future, "instead of carrying stylish smartphones everywhere, we'll be wearing stylish glasses." And he added that "these glasses will offer AR, VR, and everything in between, and we'll wear them all day and we'll use them in every aspect of our lives."

About AR/VR

Augmented reality/virtual reality (AR/VR) are also expected to re-energize 3D after the

Product Category	Segment Group	2016 Units	2016 Share	2021 Units	2021 Share	CAGR% (2016–2021)
Augmented Reality	Commercial	110,512	68.0%	20,454,18	83.3%	184.1%
Augmented Reality	Consumer	51,946	32.0%	4,114,598	16.7%	139.7%
Total AR Headsets	**–**	**162,458**	**100.0%**	**24,568,76**	**100.0%**	**172.9%**
–	–	–	–	–	–	–
Virtual Reality	Commercial	1,838,19	19.9%	18,141,76	27.0%	58.1%
Virtual Reality	Consumer	7,399,36	80.1%	48,963,87	73.0%	45.9%
Total VR Headsets	**–**	**9,237,434**	**100.0%**	**67,105,53**	**100.0%**	**48.7%**

Fig. 1: *Worldwide AR and VR headset shipments are forecasted here to increase dramatically from 2016 to 2021. Source: IDC*

0362-0972/2/2018-016$1.00 + .00 © SID 2018

failures of the film and TV industries. While commonly used apps like Facebook, texting, and FaceTime are 2D, VR/AR is a 3D space phenomenon. Web design must change if instead of up/down and left/right scrolling, the actual web page takes up a 3D space. Instead of studying pictures of human anatomy, all parts of a human body – inside and out – would be available, including a more natural interface, as we physically operate in 3D. Some believe that AR/VR will not have "arrived" until we do mundane and boring things with it and some industries are already adapting:

- Certain medical studies have shown that VR can be more effective than morphine for pain management in burn units.[4]
- Following a year of VR therapy, paraplegics participating in a study at Duke University began to regain certain functions, such as bladder control.[5]
- GE is training workers in tasks such as jet engine repair using Glass (formerly Google Glass) and AR technology, as shown in Fig. 3.[6]

AR/VR Functionalities

AR/VR products require a range of functionalities that go far beyond the typical display on an advanced smartphone, including:

Stereoscopic Vision: Creates the perception of depth and 3D structures. To achieve this, the system has to generate separate images for each eye, one slightly offset from the other, to simulate parallax as shown in Fig. 4. The system should operate at a minimum frame rate of 60 frames per second, to avoid any perceived lag that might break the illusion or, worse, lead to the nausea that is often associated with poorly performing systems.

Optics: A pair of lenses that augments the eyes, allowing them to converge the images, rendering something like the image in Fig. 5. The lenses converge and correct distortions so the brain perceives images with a sense of depth.

Motion Tracking: The art of tricking the brain to believe it is in another place by tracking movements of the head (Fig. 6) and updating the rendered scene without any lag.

Array of Sensors, Such as Gyroscopes, Accelerometers,* etc.*: These are used to track the movement of the head. The tracking data is passed to the computing platform to update the rendered images accordingly. Apart from head tracking, advanced VR/AR systems targeting for better immersion also track the position of the user in the real world.

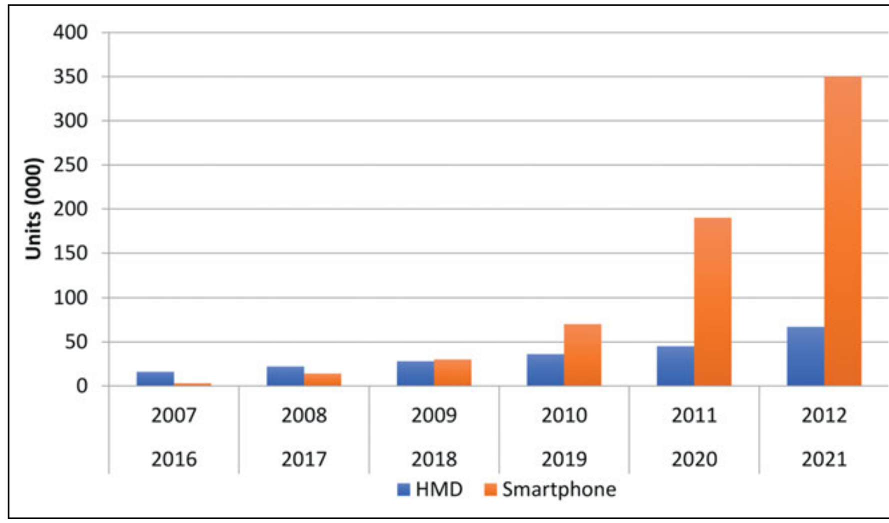


Fig. 2: *The VR/AR market from 2016 to 2021 has not even begun to keep pace with the smartphone market from 2007 to 2012. Source: Canaccord Genuity, Trendforce, OLED-A*

The head-mounted display enables the user to view superimposed graphics and system-created text or animation. Two head-mount design concepts are being researched – video see-through systems and optical see-through systems. The video see-through systems block

Fig. 3: *A company called Upskill, which received backing from GE Ventures, has started working with Glass (formerly Google Glass) and GE Aviation to build an AR solution that connects a smart torque to perfect all of the steps in building a jet engine that require tightening nuts. Source: GE Reports*

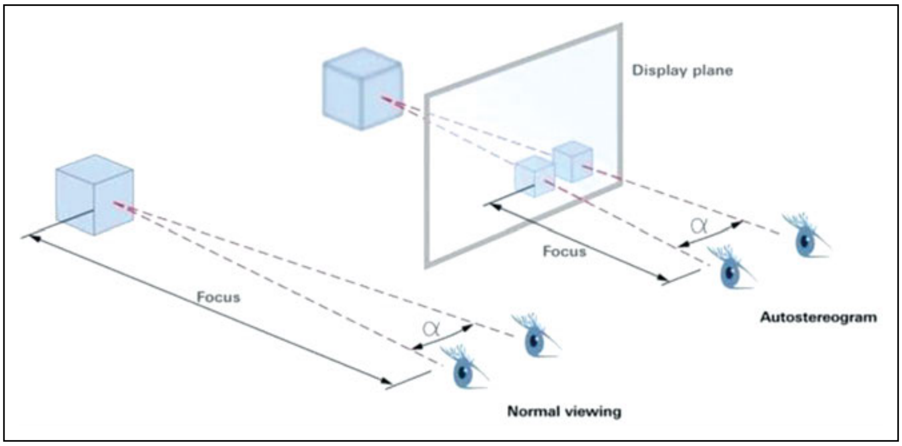


Fig. 4: Normal "naked-eye" viewing (at left) is compared with an autostereoscopic viewing system at right. Source: Samsung

out the user's view of the outside environment and play the image in real time through a camera mounted on the headgear. Latency in image adjustment whenever the user moves his head is an issue. Optical see-through systems, on the other hand, make use of technology that "paints" the images directly onto the user's retina through rapid movement of the light source. Cost is an issue, but researchers believe this approach is more portable and inconspicuous, holding more promise for future augmented-reality systems.

Tracking and Orientation: The tracking and orientation system includes GPS to pinpoint the user's location in reference to his surroundings and additionally tracks the user's eye and head movements. Major hurdles to developing this technology include the complicated procedures of tracking overall location and user movement, and adjusting the displayed graphics accordingly. The best systems developed still suffer from latency between the user's movement and the display of the image.

Fig. 5: Stereoscopic systems show two images to users. The images converge to create the perception of depth. Source: Oculus

Computing Platform: Available mobile computers used for this new technology are still not sufficiently powerful to create the needed stereo 3D graphics. Graphics processing units like the NVidia GPU by Toshiba and ATI Mobility 128 16MB-graphics chips are, however, being integrated into laptops to merge current computer technology with augmented-reality systems.

AR in Action

For a prime example of how AR could ideally function, we need go no further than a product built years ago by Lockheed for fighter pilots: helmets with amazing capabilities (Fig. 7)! These helmets, specially designed for the US military, allow fighter jet pilots to "see through their planes," eliminating blind spots and giving pilots an extra edge. The headgear, which is specifically used by pilots flying the Lockheed Martin F-35 Lightning II, displays images from six cameras mounted throughout the fighter, providing the pilot with a good look at the outside world without the need for extra equipment. An array of lights on the back of the Lightning II help guide a head-tracking system that keeps projected information in close sync with head movements; a pilot caught in a dogfight doesn't have to wait crucial moments for flight information to drift into view. The images that are projected in the helmet's screen correspond to points in the planes the pilots would typically not be able to see, like the sky behind them. A pilot "can look between his legs and can see straight to the ground" instead of the plane's floor, test pilot Billie Flynn said, noting the helmet gives the pilot "situational awareness."[7] The helmets take all the information that is typically displayed on various screens, including speed and altitude readings, and bring it inside the mask, Flynn said. Of course, the consumer isn't seeking a big helmet, six cameras, oxygen, and a $400,000 price tag.

The Display Industry Tackles Immersiveness

The challenges to reaching total immersive experiences are huge, but the display industry appears to be up to its portion of the task. There are two display technologies vying for this market: LCDs and OLEDs, both in direct view and utilizing projection optics. The characteristics of these displays are shown in Table 1.

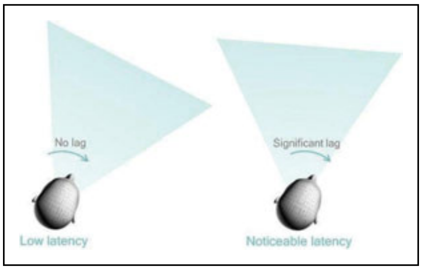


Fig. 6: *Latency is an important consideration for motion-tracking systems. Source: OLED-A*

OLEDs are the technology of choice for VR due to their advantages in latency, contrast ratio, response time, and black levels. They are used in all the popular VR headsets (Vive, Rift, and PlayStation VR). It is assumed that since AR requires high luminance (it operates in any ambient condition), liquid-crystal-on-silicon (LCOS) through a projection prism optic would be the best display medium for AR. But due to improvements in material lifetimes, transparent direct-view OLEDs can operate at >1,000 nits and are suitable for AR as well.

Table 1: Current Maximum Performance Spec Comparison. Source: OLED-A

		Direct View		Micro Display	
Characteristic	**Units**	**OLED**	**LCD**	**Micro OLED**	**LCOS**
Pixel Density	(ppi)	~1000	~1000	~2000	~2000`
Pixel Pitch	µm	25	25	10	10
Response Time	millisec	0.1	5	0.1	5
Contrast Ratio		∞	1500:1	∞	1500:1
Luminance	cd/m^2	1200	2500	2000	2500
Backplane		p-Si	p-Si	c-Si	c-Si
Mobility	cm^2/vsec	~100	~100`	~1,000	~1,000
Optimal Viewing Distance	inches	1.6	1.6	0.8	0.8

LCOS = liquid crystal on silicon

The challenge is how to make displays that provide comfort for near-to-eye use, have a wide field of view (FOV), support 3D, and operate in any ambient environment – dark or bright. The use of microdisplays helps because of the smaller pixels and higher ppi, which eliminate the screen-door effect caused by insufficient resolution for the distance between the eye and the display (Fig. 8).

In search of such a display, the author went to Newton, MA, just outside of Boston to visit Kopin, a small public company. Kopin is a worldwide leader in LCOS and recently announced a new OLED microdisplay. The company is well positioned in the AR industry, as it is the primary supplier of microdisplays for Google's Glass and provides the LCOS displays for the F-35 Lightning II helmets. Dr. John Fan, CEO of Kopin, explained that if the helmets were designed today, he would probably use OLED microdisplays due to their fast response time and higher contrast. Kopin believes that in order to attract the consumer and thereby reach the billions of units/year, a successful AR product must:

- Be smaller and more like glasses than current headsets
- Have higher resolution – probably 3K to eliminate the screen-door effect of current displays
- Support fast refresh rate and response time to eliminate any latency – 90Hz to 120Hz with µs response
- Be untethered from a high-end PC. The smartphone would be a good substitute, but graphics processors need to reach to the next level of performance to handle the bandwidth
- Support luminance >1,000 nits to handle all the artifacts, even in a partially light-controlled environment
- Include built-in motion controller, eye trackers, and other accessories

Fig. 7: *The F-35 Lightning II helmet offers powerful AR capabilities but isn't feasible for the consumer marketplace. Source: Lockheed Martin*

- Incorporate batteries designed with flexible substrates and possessing double the current capacity

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

Fig. 8: *The "screen-door effect" with lower resolution appears at left. Source: eMagin*

Fig. 9: *eMagin's 2K × 2K OLED-based micro display allows the design of more streamlined headsets than standard direct-view ones. Source: eMagin*

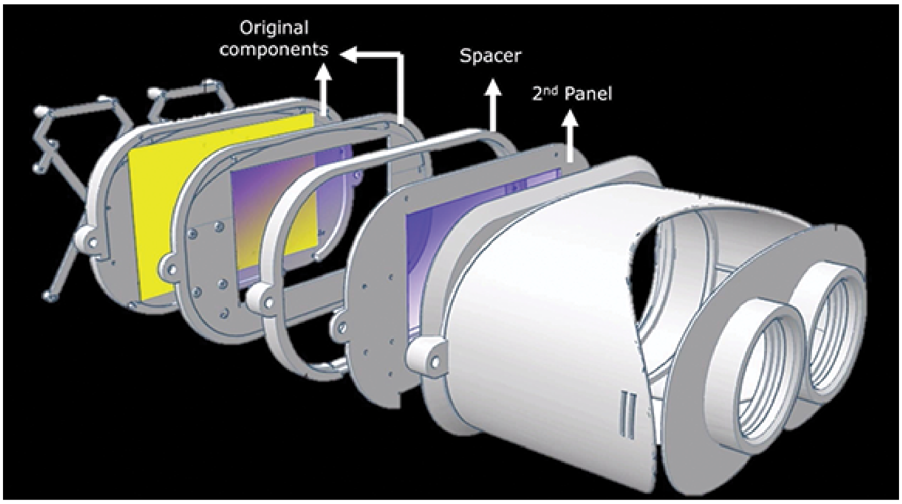


Fig. 10: *This light-field headset includes an embedded LCD. Source: Stanford Labs*

Further Opportunities

Related AR solutions include light-field displays and holograms. A hologram is a photographic recording of a light field, rather than of an image formed by a lens, and is used to display a fully 3D image of a "holographed" subject. However, in these types of designs, a basic imaging device such as an OLED or LCD is still necessary as shown in Fig. 10 (which uses an LCD but could also use an OLED).

Perhaps the most highly publicized startup ever, Magic Leap, a company with a >$US 2 billion valuation before it even had a product and that *Wired* called "the World's Most Secretive Startup," recently announced an AR product to be released in 2018 as shown in Fig. 11. The design is so secret that the display technology – OLED, LCD, or something else – has not been announced.

Brave New World

The chasm between where we are today and where we need to be to achieve the lofty goals of immersion can be understood by comparing the VR/AR experiences we can achieve today and what's needed to create experience-simulation systems like those depicted in the movies *Inception* or *The Matrix*. To achieve true, reality-like immersive experiences, the human body must be modified, and computers connected directly to the brain. It won't happen until we can integrate prosthetic eyes/ears/limbs with the nervous system, something that is still very much in the experimental stage. Devices and signal transceivers have to be

(continued on page 36)

Looking Forward to the 2018 Display Week Technical Symposium

This year's technical program shines a spotlight on AR/VR, microLEDs, and wearables – the hottest topics in the display industry right now. But there is so much more to discover – amazingly efficient OLEDs, state-of-the-art automotive displays, ultra-high resolutions. Read this handy preview to find out which papers belong to that absolutely can't-miss category. But first, a note from this year's technical program chair, Yi-Pai Huang.

Compiled by Jenny Donelan

Dear Friends and Colleagues,

On behalf of the Society for Information Display's program committee, I am pleased to invite you to participate in Display Week 2018, which will be held from May 20 to May 25 at the Los Angeles Convention Center.

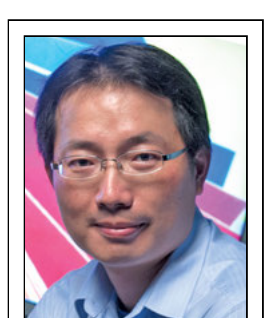
The technical program begins on Sunday with the Short Courses and is followed by the Monday Seminars. The Display Week Symposium, the main event, takes place from Tuesday to Friday. This year's symposium features 83 technical sessions consisting of nearly 450 oral and poster presentations, including about 85 invited talks.

Augmented reality/virtual reality (AR/VR), microLEDs, and wearables are the three special hot topics this year. In AR/VR, the technical tracks will cover systems, optical design, human factors, and even artificial-intelligence applications. For microLEDs, manufacturing and materials are the two major issues under discussion. In the wearables area, presentations will focus not only on displays, but on stretchable electronics and devices.

Of course, active-matrix thin-film transistors (TFTs), liquid-crystal (LC) technology, and organic-light-emitting diodes (OLEDs) are still the most important fields, and most of the paper submissions belong to these categories. But there are papers of interest in all areas. In addition to the above three, there are sessions based on Emerging Applications, Applied Vision, Display Electronics, Display Manufacturing, Display Measurement, Display Systems, Emissive Displays, e-Paper and Flexible Technology, Lighting, Touch and Interactive Displays, and Automotive/Vehicular Displays.

Additionally, SID will celebrate LCD's 50th anniversary during Display Week. This once-in-a-lifetime event honors the technology that opened a new era of small-to-large display-related products and helped shape today's industry. This celebration will feature LCD pioneers sharing their experiences from earlier days in both R&D and commercialization and marketing sectors. Don't miss it! (For more information about the 50th Anniversary LCD Celebration, see this issue's SID News.)

In light of past successful events, we expect 7,500 or more participants from all over the world to attend Display Week this year. Your participation has always been vital to the success of SID's Display Week. We sincerely look forward to seeing you in Los Angeles this May!



Respectfully yours,

Yi-Pai Huang, Ph.D.
SID Display Week 2018
Program Chair

0362-0972/2/2018-022$1.00 + .00 © SID 2018

The New Reality

Augmented reality and virtual reality are the biggest story for the 2018 program. "I see a clear trend in AR/VR," says Wei Yao, chair of the Display Electronics subcommittee. "There are lots of papers in this area." His observation was echoed by many of the chairs, with AR/VR-related papers appearing in almost every segment of the symposium – from head-up products to manufacturing solutions to metrology for near-to-eye displays. There are so many great AR/VR papers (approximately 60), says Technical Program Chair Yi-Pai Huang, that they appear on all four days of the symposium in multiple sessions.

What this boom in AR/VR research portends for the consumer market is only partially clear. "I think a lot of companies are trying to replace the mobile phone with Google-type glasses," says Huang. Yet consumers aren't on the whole clamoring for augmented-reality glasses to wear full time, or for virtual-reality headsets to take them out of the here and now. So this push toward AR/VR could be a case of the tail wagging the dog. On the other hand, consumers don't always know what they want before they get it. Twenty years ago, few of us knew we'd depend on our smartphones to the point of looking at them before we go to bed at night and when we wake up in the morning.

One thing is clear: For AR/VR technology to get to that smartphone-level of ubiquity, it has to get better. And that's something that the researchers delivering papers at Display Week are working toward. "For consumer applications in AR/VR, there's a very big technology gap," says Huang. "And there is also a price *vs*. quality gap. AR/VR systems are very complex in terms of integration." So the industry still needs solutions in terms of hardware – comfortable headsets, immersive displays that are comfortable to use – and in terms of software – applications that are useful, accessible, and compelling enough that people turn to AR/VR devices on a regular basis, not just for niche uses or entertainment.

David Hoffman, chair of the Applied Vision subcommittee, says, "We're seeing lots of interest in image manipulation and color processing, as well as in studying human factors with AR/VR. One of the recurring issues is how to balance quality with bandwidth."

Each of the following three papers provides an example of how AR/VR developers are taking on the challenge of making the headgear more usable – balancing image quality against bandwidth, providing higher resolution OLEDs, and reducing motion blur.

- "Visually Lossless Compression of High-Dynamic Range Images: A Large-Scale Evaluation" by Aishwarya Sudhama of York University in Canada tackles the quality/bandwidth issue. The author writes: "High-dynamic-range (HDR) displays provide impressive image quality but require markedly higher bandwidth. Here, we report results from the first large-scale subjective assessment of HDR image compression."
- "An AMOLED Pixel Circuit for 1,000 ppi and 5.87-in. Mobile Displays with AR and VR Applications" by Oh-Kyong Kwon of Hanyang University describes the creation of a prototype AMOLED pixel circuit consisting of three TFTs and two capacitors, designed for 1,000-ppi AR/VR mobile displays, simulating emission current and crosstalk errors.
- "Fast Motion-Picture Response Color-Filter LCOS for Wearable Applications" by Yuet Wing Li of Himax Display, Inc., proposes an image-blur-free color-filter LCOS equipped with 1.9-ms liquid-crystal response time; analog frame buffer; and a 480-frame-per-second refresh rate. The author explains, "The display system for AR applications has to update images promptly in order to cope with the user's head movement or any environmental change. This requires both low latency of the image data and fast image response on the display itself. Image blur becomes noticeable if the motion-picture response time (MPRT) of the AR display is longer than 1.5ms." The MPRT of the Himax device is reported as <1.5ms.

Measuring AR/VR

In addition to addressing image artifact problems such as sparkle and image retention, this year's metrology papers cover a range of display technology that indicates what's cutting edge in the industry. "The measurement papers we see each year tend to reflect the new display problems that people are trying to solve," says Display Measurement Subcommittee Chair Stephen Atwood. "In order to know if you have made a significant performance improvement, you need robust optical metrology methods, and the papers in this year's lineup reflect the most pressing needs for developers now and in the future." Measurement topics therefore include reflective e-paper, light-field displays, high-dynamic-range (HDR) displays, and of course, near-to-eye displays for AR/VR, as in the Sustar-Optics paper below:

- "Requirements for Lenses in Measuring Systems Evaluating Near-to-Eye Displays" by Norbert Schuster of Sustar-Optics proposes that imaging luminance and color measuring devices (also called array detectors), combined with adapted measuring lenses, provide effective one-shot solutions for evaluating near-to-eye displays.

A Higher Plane

According to Huang, the most surprising, exciting thing you will see this year at Display Week and nowhere else is a profound increase in resolutions across all types of displays. "Everyone keeps pushing the boundaries of resolution," he says. "LG and Google have an OLED that's more than 1,400 ppi. It's very hard to imagine that!" That paper is:

- "An 18 Megapixel 4.3-in. 1,443-ppi 120Hz OLED Display for Wide-Field-of-View High-Acuity Head-Mounted Displays" by Carlin Vieri of Google LLC. According to the author, this is the world's highest resolution (18-megapixel, 1,443-ppi) OLED-on-glass display yet developed. A white OLED with a color filter structure was used for high-density pixelization, and an n-type LTPS backplane was chosen for higher electron mobility compared to mobile phone displays. A custom high bandwidth driver IC was fabricated, and foveated driving logic for VR and AR applications was implemented.

Two technical sessions are entirely devoted to ultra-high resolution this year, and every paper should be highly informative. Two samples:

- "Large-Area Ultra-High-Density 5.36-in. 10K 2,250-ppi Display" by Hyun Sup Lee of Samsung Display Co. describes a new pixel architecture that integrates TFTs, contact holes, and data/gate lines in the smallest pixel pitch yet reported on glass. A new driver system including a new IC design has also been developed for this 10K resolution display, which the author sees as ideal for VR/AR and holographic displays.

Display Week 2018 Overview

Los Angeles Convention Center, Los Angeles, California, USA

May 20–25, 2018

TIMES	Sunday May 20: Short Courses	Monday May 21: Seminars	Monday May 21: Business Conf.	Tuesday May 22: Symposium	Tuesday May 22: LCD 50th Anniversary Celebration	Tuesday May 22: Market Focus Conference	Tuesday May 22: Exhibits Exhibitors Forum Sessions / I-Zone	Tuesday May 22: Investors Conf.	Wednesday May 23: Symposium	Wednesday May 23: Exhibits Exhibitors Forum Sessions / I-Zone	Wednesday May 23: Market Focus Conference	Wednesday May 23: CEO Forum / Women in Technology	Thursday May 24: Symposium	Thursday May 24: Exhibits Exhibitors Forum Sessions	Friday May 25: Symposium
8:00 AM			Business Conference	Session 1: SID Business Meeting						Student Job Fair 8:30-9:30					
8:30 AM		Seminars SE1 - SE3		Session 2: Welcome / Keynote Addresses											
9:00 AM	Short Courses S-1 & S-2								Oral Sessions 23-29	Exhibits / Exhibitors Forum / I-Zone /	Market Focus Conference: Immersive Experience		Oral Sessions 44-50	Exhibits / Exhibitors Forum / I-Zone	Oral Sessions 72-78
9:30 AM															
10:00 AM															
10:30 AM		Seminars SE4 - SE6		Ribbon Cutting Ceremony					Oral Sessions 30-36				Oral Sessions 51-57		Oral Sessions 79-85
11:00 AM				Oral Sessions 3-9		Market Focus Conference Automotive (11:00-5:30)	Exhibits / Exhibitors Forum / I-Zone	Investors Conference							
11:30 AM															
12:00 PM			Lunch	Lunch					DIA & Best-in-Show Awards Luncheon				Lunch		Author Interviews
12:30 PM															
1:00 PM		Seminars SE7- SE9	Business Conference										Oral Sessions 58-64		
1:30 PM															
2:00 PM				Oral Sessions 10-16	LCD 50th Anniversary Celebration				Designated Exhibit Time						
2:30 PM	Short Courses S-3 & S-4														
3:00 PM		Seminars SE10 - SE12		Oral Sessions 17-22					Oral Sessions 37-43			CEO Forum	Oral Sessions 65--71		
3:30 PM												Women in Technology			
4:00 PM															
4:30 PM													Author Interviews		
5:00 PM		Seminars SE13 - SE15	Bus. Conf. Recept.	Author Interviews					Author Interviews				Poster Session		
5:30 PM															
6:00 PM									Special Networking Event						
6:30 PM															
7:00 PM															
7:30 PM		Honors and Awards Banquet													
8:00 PM															
8:30 PM															
9:00 PM															
9:30 PM															

Display Week 2018 Symposium at a Glance

2018 SID Display Week Symposium at a Glance – Los Angeles Convention Center

Day	Times	Petree Hall	Room 515A	Room 515B	Room 502A	Room 502B	Room 501	Room 503	Room 518
Tuesday, May 22	8:00 – 10:20 am	SID Business Meeting and Keynote Session (Concourse Hall 151-153)							
Tuesday, May 22	11:10 am – 12:30 pm		3 AR/VR I: Display Systems (Joint with Display Systems and Emerging Technologies and Applications)	4 Quantum-Dot and Emissive Materials Synthesis (Joint with Emissive Displays)	5 Integrated Drivers	6 OLED Materials I	7 3D Holographic and Volumetric Displays	8 Image-Artifact Characterization	9 Emerging Flexible Electronics and Displays (Joint with Wearable Displays, Sensors, and Devices)
Tuesday, May 22	2:00 – 3:20 pm	Special Session: Celebration of the 50th Anniversary of LCD	10 AR/VR II: Light-Field HMDs (Joint with Display Systems)	11 Emerging Quantum-Dot Applications (Joint with Emerging Technologies and Applications)	12 Oxide TFTs I	13 OLED Materials II	14 Backlight Systems	15 Topics in Display Measurement	16 Emerging Technologies and Applications
Tuesday, May 22	3:40 – 5:00 pm		17 AR/VR III: Waveguide Optics (Joint with Display Systems)	18 Perovskite Materials and Devices (Joint with Emissive Displays)	19 Oxide TFTs II	20 OLED Materials III	21 3D Light-Field and Autostereoscopic Displays		22 Emerging Medical Applications
Tuesday, May 22	5:00 – 6:00 pm	Author Interviews (Concourse Hall)							
Wednesday, May 23	8:30 – 8:50 am								
Wednesday, May 23	9:00 – 10:20 am		23 AR/VR IV: Display Electronics (Joint with Display Electronics)	24 Flexible Barrier Materials	25 Digital Signage (Joint with Emerging Technologies and Applications)	26 OLED Devices I	27 Advances in Automotive Displays	28 Integrated Gate Drivers	29 New Alignment Technologies I
Wednesday, May 23	10:40 am – 12:00 pm		30 Input Technologies for AR/VR	31 Flexible Materials and Substrates	32 Emissive Display Materials	33 OLED Devices II	34 Automotive Display Systems and Functional Safety	35 OLED Driving and Compensation	36 New Alignment Technologies II
Wednesday, May 23	2:00 – 3:30 pm	Designated Exhibit Time (Exhibit Hall)							
Wednesday, May 23	3:30 – 4:50 pm		37 Artificial Intelligence and Machine Learning	38 Stretchable and Printable Electronics/Displays	39 Novel TFT Applications	40 OLED AR/VR (Joint with Artificial Intelligence and Augmented Reality and Virtual Reality)	41 Quantum-Dot LCDs (Joint with Automotive/Vehicular Displays and HMI Technologies and Emissive Displays and Liquid-Crystal Technology)	42 Novel Display Circuits	43 Smart Windows with LC Technology
Wednesday, May 23	5:00 – 6:00 pm	Author Interviews (Concourse Hall)							
Thursday, May 24	9:00 – 10:20 am		44 Fast-Switching LCDs for AR/VR I (Joint with Liquid-Crystel Technology)	45 Micro-LED Epitaxial Semiconductor Materials & Manufacturing (Joint with Emissive Displays)	46 Ultra-High Resolution I	47 OLED Processes	48 e-Paper and Reflective Displays	49 Image Processing	50 TFT Manufacturing Trends
Thursday, May 24	10:40 am – 12:00 pm		51 Fast-Switching LCDs for AR/VR II (Joint with Liquid-Crystel Technology)	52 Micro-LED Device Processing and Hetero-Integration (Joint with Emissive Displays)	53 Ultra-High Resolution II	54 Flexible OLED Displays (Joint with e-Paper and Flexible Displays)	55 Automotive Head-Up Displays (Joint with Artificial Intelligence and Augmented Reality and Virtual Reality)	56 Novel Display Technologies	57 Advanced TFT Manufacturing Processes
Thursday, May 24	1:30 – 2:50 pm		58 High-Resolution LCDs for AR/VR (Joint with Liquid-Crystal Technology)	59 Micro-LED Microdisplays (Joint with Emissive Displays)	60 Flexible TFTs (Joint with e-Paper and Flexible Displays)	61 Novel OLEDs	62 Automotive HMI Trends for Connected and Autonomous Cars	63 Projection: Image Improvement	64 Ink-Jet Printing for Display Manufacturing
Thursday, May 24	3:10 – 4:30 pm		65 Human Factors in AR/VR Systems (Joint with Applied Vision)	66 Micro-LED System Integration and Applications (Joint with Automotive/Vehicular Displays and HMI Technologies and Emissive Displays)	67 Flexible Active-Marix Devices (Joint with e-Paper and Flexible Displays)	68 OLED Displays	69 Capacitive-Touch Displays	70 Projection: Screen Technology	71 High Image Quality
Thursday, May 24	4:30 – 5:30 pm	Author Interviews (Concourse Hall)							
Thursday, May 24	5:00 – 8:00 pm	Poster Session (Petree Hall)							
Friday, May 25	9:00 – 10:20 am		72 Measurement Challenges for Near-to-Eye Displays (Joint with Display Measurement)	73 QD Electroluminescence I	74 High Ambient Contrast Ratio I	75 High-Resolution OLED-Display Manufacturing	76 Fingerprint Sensing and Optical Sensing Displays	77 Advances in LED Lighting	78 Color Gamut
Friday, May 25	10:40 am – 12:00 pm		79 Enhancements to AR/VR (Joint with Emgerging Technologies and Applications)	80 QD Electroluminescence II	81 High Ambient Contrast Ratio II	82 Flexible-Display Manufacturing	83 Interactive Displays	84 OLED for Lighting and Imaging	85 Image Quality
Friday, May 25	12:00 – 1:00 pm	Author Interviews (Concourse Hall)							

TECHNOLOGY TRACKS KEY

Active-Matrix Devices	Applied Vision	Artificial Intelligence and Augmented Reality and Virtual Reality		Automotive/Vehicular Displays and HMI Technologies	Display Electronics
Display Manufacturing	Display Measurement	Display Systems	Emerging Technologies and Applications	Emissive Displays	e-Paper and Flexible Displays
Lighting	Liquid-Crystal Technology	OLEDs	Quantum Dots and Micro-LEDs	Touch and Interactive Displays	Wearable Dispalys, Sensors and Devices

- "4,032-ppi High-Resolution OLED Microdisplay" by Takuma Fujii of Sony Semiconductor Solutions Corp. covers the development of a 0.5-in. UXGA OLED microdisplay with 6.3µm pixel pitch that is described as suited to near-to-eye display applications, especially viewfinders.

Smaller Is Better: Quantum Dots and MicroLEDs

Quantum dots and microLEDs are potentially disruptive display materials that everyone in the industry should learn more about, and there's no better place than Display Week's technical symposium to do so. Quantum dots are already in widescale commercial use as a complementary material in LCDs, whereas microLEDs are viewed by many people as "the next big thing" in display materials. In order for microLEDs to live up to their promise, however, many manufacturing issues need to be addressed.

"There are no commercial display devices built on microLEDs at this time," says Display Manufacturing Subcommittee Chair Chi Woo Kim. "We don't know the right answers about how to manufacture them yet." You can find out about the state of the art, though, in the following paper from Veeco:

- "MicroLED Displays: Key Manufacturing Challenges and Solutions" by Christopher Morath of Veeco explains that while microLED displays offer potential advantages such as high brightness and low energy consumption, mass adoption requires that higher manufacturing yield and lower cost targets be met. In this presentation, the author explores key manufacturing requirements and presents solutions for epitaxy and mass transfer to enable microLED display adoption for consumer applications.

Emissive Displays Subcommittee Chair Seth Coe-Sullivan notes that microLED papers of all kinds have proliferated at Display Week. "We have four sessions on microLEDs," he says, "which is twice as many as last year, which was twice as many as the year before that." The quality of the papers is also quite high, with approaches like the aforementioned manufacturing paper from Veeco that seem likely to lead to breakthroughs.

In other emissive topics, progress is being made on true quantum-dot LEDs (QLEDs). Instead of using quantum dots (QDs) to enhance LCDs, this approach would make the QDs, or rather QLEDs, the primary display material.

"What's exciting about this paper," says Coe-Sullivan, "is that it's a 14-in. QLED display that is entirely ink-jet printed. And it's easily scalable to bigger sizes."

- "Developing AMQLED Technology for Display Applications" by Yanzhao Li of BOE describes the current state of the active-matrix (AM) QLED display technology and analyzes the ways this technology can be developed for mass production, with a discussion of material requirements, device structures, and the electrical and optical properties of quantum-dot light-emitting diodes (QLEDs). The author makes the argument that QLEDs can provide a compelling alternative to OLED- and LCD-based panels in the near future.

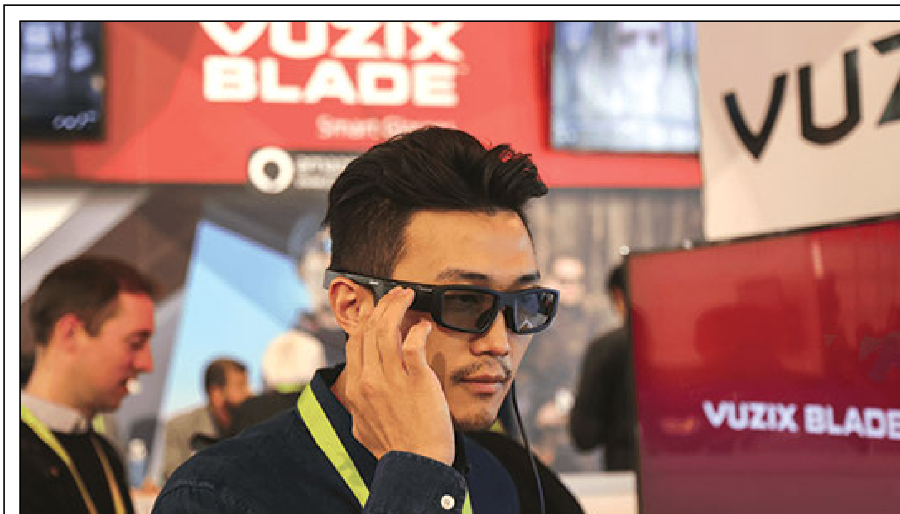
Stretchable (Inspirational) Sensors

This year's special focus area of Wearable Displays, Sensors, and Devices features several papers on biometric sensors that retrieve data via an interface with human skin. The committee invited these authors in the hopes of inspiring the wider display community. "We believe this topic is going to open the minds of future display engineers," says Wearables Subcommittee Chair Bo Ru Yang. One example is:

- "Stretchable Electronics for Wearable Microvolt Biosignal Monitoring Systems" by Tsuyoshi Sekitani of Osaka University, in which the author discusses sensors for patch-type biosignal monitoring sheets with high measurement accuracy and wireless sheet-type electroencephalogram (EEG) and fetal electrocardiogram (ECG) monitoring systems for next-generation telemedicine.

Light Shaping and Tunable Lighting

Tunable lighting can produce a range of correlated color temperatures – from cool to warm illumination as well as a change in intensity of light. Many of this year's lighting papers focus on OLEDs and LED tunability, according to Lighting Subcommittee Chair Marina Kondakova. One paper from the Light-Emitting and eXcitonic Organic Semiconductors Group at the University of Dresden describes a new OLED structure with controllable angular emission (light shaping). "The manipulation of emission profile is important. With it, the OLED light can be directed where it has the most functionality while maintaining high light quality," says Kondakova. "We haven't seen much on this topic before, especially for OLED. Its further development can create new applications for OLED displays and lighting."



If the technology development at this year's technical symposium is any indication, products like the Vuzix Blade, a pair of augmented-reality smart glasses with proprietary waveguide optics and built-in Alexa, will be appearing more frequently in our future. Source: Vuzix

- "Organic Light-Emitting Diode Beam Shaping: Pixel Design for Variable Angular Emission Profile Control" by Sebastian Reineke, Technische Universität Dresden. Once integrated with a certain layer architecture into the backplane layout, OLED's emission color and angular distribution are set by the optical properties of the layered system. In this paper the author demonstrates a pixel design that allows for actively controlled variation of the angular emission profile of the individual vertical pixel.

Fingerprint Sensing

Two major trends appeared this year in the Touch and Interactivity area: fingerprint sensing and capacitive touch on a large scale. "Big is the final frontier," says Jeff Han, chair of the Touch and Interactivity subcommittee. There are four capacitive-touch papers focused on large-scale displays. The fingerprint sensing papers point to a new direction: "They are truly integrating fingerprint sensing into the display, not just in a panel on the side," says Han. One example:

- "Optical Fingerprint Sensor Based on TFT Technology" by Hong Zhu of Shanghai OXi Technology Co., Ltd., reports on optical fingerprint sensors based on hydrogenated amorphous Si TFT technology, enabling "thin optical touch," "hidden optical touch," and "hidden under display" sensor technologies, depending on the application.

OLEDs Get More Efficient

"Two things jump out in OLEDs," says OLEDs Subcommittee Chair Michael Weaver. "Efficiency – how you get beyond the status quo. And dipole alignment – trying to orient the molecules in the film to make them less random [like LCs]." An efficiency paper of note:

- "Highly Efficient Deep-Blue Fluorescent Dopant for Achieving Low-Power OLED Display Satisfying BT.2020 Chromaticity" by Yusuke Takita of Semiconductor Energy Laboratory Co., Ltd. The author has succeeded in developing a stable, deep-blue fluorescent dopant that has a shorter emission wavelength and higher emission efficiency than conventional pyrene-based dopants. A demonstration shows that the power consumption of a panel using this novel dopant is lower than that of a conventional one.

LCD Technology Never Stops Evolving

The top trends for LCDs, unsurprisingly, are AR/VR and fast-switching, and super high resolution, according to Liquid Crystal Technology Subcommittee Chair Michael Wittek. He also cites high ambient contrast in ambient light as important for displays in general and especially for digital signage. "There's a Sharp paper on reduced reflectivity," says Wittek, "that is very important."

- "Sunlight-Readable Low-Reflection FFS-LCD" by Yuichi Kawahira, Sharp Corp. The author writes: "A novel wide-view LCD with reduced reflection has been developed to enhance ambient contrast ratio. By combining a fringe-field switching (FFS)-based new LC mode with a circular polarizer, our 12.3-in. prototype has successfully shown excellent outdoor visibility without boosted backlight brightness."

Automotive Displays: More, Better, Bigger Business

The automotive industry will do its part to keep display makers in business for at least the foreseeable future. "In-car displays will be a $25 billion business by 2025," says Rashmi Rao, chair of the Automotive/Vehicular Displays and HMI Technologies subcommittee. "There have been huge display enhancements in cars and in HMIs. There will be more screens, and better ones. Displays are no longer reverse-engineered – most are created directly for customers." Here are just two of the many notable automotive display papers to check out.

- "Active Polarizer Dimmable Lens System" by Paul Weindorf of Visteon Corp. "Deadfront" or "secret until lit" displays are desirable in vehicles for aesthetic reasons. Display units that utilize a dimmable smart lens may be utilized to reduce the required display luminance compared to a smoked neutral density lens to provide a hidden display appearance. A lens configuration that utilizes an active polarizer in conjunction with a linear polarizer is explored.
- "Holographic Grating to Improve the Efficiency of a Windshield HUD" by Philippe Coni of THALES Avionics SAS looks at the creation of a windshield head-up display (WHUD) using an embedded transparent holographic optical element film (THOE) film to improve system efficiency.

And There's More

While the technical symposium is the core of Display Week, make sure to save time for the other major events: the Sunday Short Courses; the Monday Seminars; the Business, Investors, and Market Focus Conferences; the new CEO Forum; the second annual Women in Tech panel; the Wednesday night Special Networking event at the California Science Center; and, of course, the exhibition and the I-Zone. Don't wait – start building your Display Week 2018 schedule now. See our schedules at a glance in this issue and visit www.display.org for more details. ■

Five Short Display Stories from CES 2018

OLEDs, car cockpits, quantum dots, and really big TVs were all part of the narrative at this year's Consumer Electronics Show in Las Vegas.

by Ken Werner

Increasingly, the annual Consumer Electronics Show in Las Vegas is neither about consumers nor about electronics. More and more, it is about artificial intelligence (AI), cloud-based systems, and the like. This is not necessarily a bad thing, but it makes it harder to find unadulterated display technology stories … harder, but not impossible. Some of the five stories that follow were found behind closed doors, but some were on the show floor for anyone to see (Fig. 1).

Story #1: The Empire Strikes Back

A year ago, at CES 2017, Samsung introduced its Q Series of super-premium, quantum-dot-enhanced LCD TVs. Samsung offered the sets at prices that were comparable to those of LG sets with equivalent screen size and features.

Analysts, including this one, were enthusiastic, but Samsung had set itself a high bar. By pricing Q Series sets comparably to OLED TVs, the company was implying that the picture quality was comparable, too. Over the following weeks and months, it became clear that in at least one important way, this was not the case.

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In striving to make sets of nearly OLED-like thinness, the company used edge lighting. This limited the sets to local dimming using a small number of large, stripe-shaped zones. When bright images were shown against dark backgrounds, this had the effect of raising the dark levels in the zones containing the bright images. The resulting "halo effect," which involved a reduction of the local contrast ratio, was very noticeable with certain kinds of content. LG and LG Display lost no time in demonstrating the relative performance differences of the QLED sets against their own OLED TVs.

At CES 2018, Samsung struck back. At two analyst/media-only events, Samsung introduced its new and improved 2018 high-end Q technology side by side with both its 2017 set and an LG OLED set. With the content used by Samsung, the halo effect was dramatically reduced on the set using 2018 technology, and images looked comparable to those on the OLED TVs.

Fig. 1: *A popular entrance to the LG Electronics exhibition was through this impressive OLED tunnel. LG has had multi-tiled OLED tunnels, ceilings, and walls at CES, and has constructed a variety of them in South Korea, but this was the most impressive I've seen. (Photo: Ken Werner)*

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So what has Samsung done? The company has replaced the edge light of 2017 with a full two-dimensional-matrix backlight that will feature between 100 and 500 dimming zones in the production versions. Samsung has also modified the optical stack and reduced the black level. At the SID LA Chapter's One Day Conference in early February, Samsung revealed that the full-matrix enhancement will be incorporated in the 2018 Q8 and Q9 models, but not in the Q6 and Q7 models. The 2018 full-matrix set is only slightly thicker than the 2017 edge-lit set, said Dennis Choi, senior engineer in Samsung Electronics' R&D team for the visual display business. Samsung also showed an 8K technology demonstration with 10,000 dimming zones, which produced a remarkable combination of adjacent bright and dark areas for an LCD.

Story #2: The Harman Acquisition Generates Synergy – Really

Whenever one company merges with or devours another, it predicts that a cornucopia of synergistic value will result. More often than not, it doesn't, but since Samsung completed its acquisition of Harman in March of last year, the companies have worked hard to combine Samsung's display expertise with Harman's knowledge of advanced automotive systems.

As seen at Harman's invitation-only exhibit at the Hard Rock Hotel and Casino during CES, this cooperation has produced developmental systems incorporating OLED and local-dimming QLED displays, both separately and in combination. As Harman's Tom Rivers put it, the company is bringing consumer electronics technology into automotive systems as it expands its advanced driver assist systems (ADAS) and security offerings. He also said Harman is "moving from device centric to consumer centric."

On display was a Maserati with a Harman 28-in. QLED local-dimming infotainment display and OLED instrument cluster. Harman's Rashmi Rao explained that for a high-end car like the Maserati, Harman selected the best-performing display technology for the critical cluster, while the large QLED display still offers very good performance at a significantly lower cost than OLED. Rao commented that the performance of the QLED is good enough that it integrates visually with the OLED. A conventional LCD would present an obvious visual mismatch with the OLED. The system is fully functional but is not yet in a shipping automobile.

The Maserati system can customize interior lighting and integrate Bixby (and/or Alexa and Google). Through the voice interface, drivers can ask the system to check their own calendar, check the dealer's schedule, and set up a service appointment. Other Tier 1 suppliers are offering a similar feature.

Harman also showed a QLED instrument cluster and infotainment display integrated in a single unit for the MINI (Fig. 2). Cluster and infotainment are driven by the same controller, which simplifies the system, reduces power consumption, and saves weight. The unit incorporates a smart surface beneath the display, and permits control from contextual knowledge and the steering wheel. The system integrates Android Automotive with the smart cluster and provides inductive wireless phone charging.

Harman also used a QLED display for a concept called MoodRoof (Fig. 3), which is part of an audio system called Moodscape. Moodscape is intended to provide a multi-sensory environment to keep you relaxed (or stimulated) while your autonomous car of the future drives itself to your destination.

Story #3: Presenting the Automotive Cockpit of Tomorrow – or Maybe Next Week

The automotive display focus at CES was less on the display technology itself than on how displays could be integrated into next-generation cockpits that support connectivity, environmental awareness, ADAS, autonomous driving, and vehicle sharing. Advanced vehicle sharing implies that vehicles not only will come when you call them but will automatically customize themselves to your preferences and operate at a very high duty cycle,

Fig. 2: Harman designed this demonstration QLED cluster for the MINI dashboard to combine instrumentation (in the outer ring) and infotainment in the center. The user can change the infotainment part of the display but not the instrumentation part. The secondary display, showing a clock in the photo, changes content as the outside ring is turned. (Photo: Ken Werner)

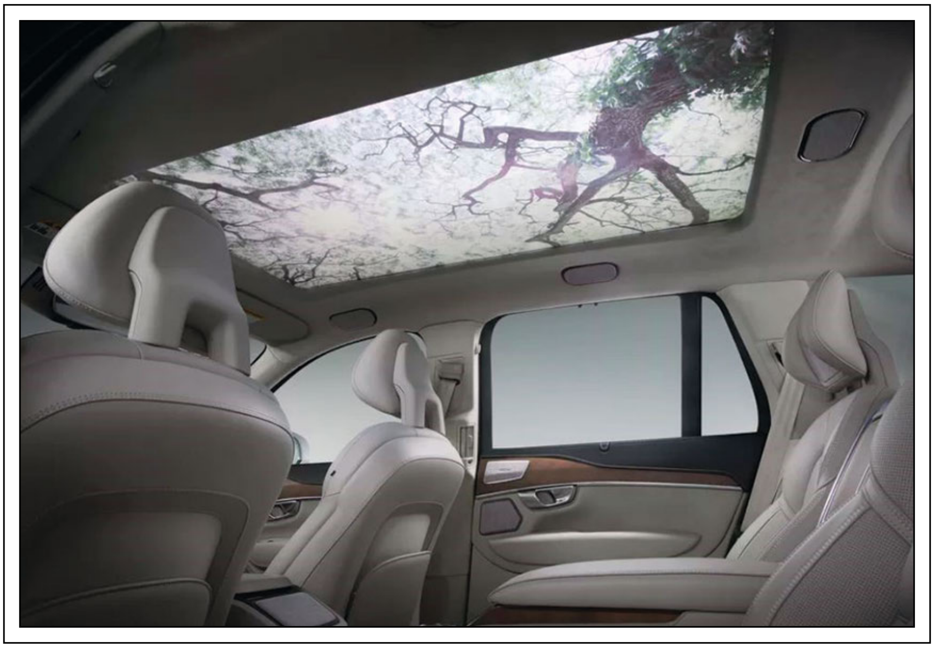

Fig. 3: *The QLED MoodRoof will change displayed content along with audio from a sound system. The intended application is autonomous vehicles. (Photo: Harman)*

unlike the vast majority of personal vehicles today. These considerations have major implications for the ways in which vehicles are designed, built, and priced – and for their cockpit designs and display suites. Let's look at some of the cockpit designs shown at CES, some of which are concepts and some of which are appearing in current vehicle models.

Mercedes showed the Mercedes-Benz User Experience (MBUX), the company's new infotainment system that learns user preferences via artificial intelligence (AI) and can update itself with over-the-air downloads (Fig. 4).

The system includes intelligent voice control with natural speech recognition. The voice system is activated by saying "Hey Mercedes." (I am not making this up.) Here's the display part: a high-resolution LCD widescreen cockpit with touchscreen operation and a navigation display with augmented reality. MBUX is not designed as a high-end solution; instead, it will be used in in M-B's new generation of compact A-Class cars, the first of which will be introduced this year.

In its invitation-only suite, LG Display was showing automotive displays, along with many other displays, some of which are described in Story 4. LGD's focus was on plastic OLED (pOLED) and low-temperature polysilicon (LTPS) backplanes for pixel densities over 200 ppi in displays up to 16.2 inches for now. One cockpit demo featured a nice integration of the sideview "mirror" displays on the large cluster display, which simplifies the display suite significantly (Fig. 5).

Panasonic, a leading Tier 1 supplier both to automotive OEMs and to aircraft manufacturers, was showing its "smart design cockpit," which combines high technology with premium materials. The cockpit incorporated a high-performance graphics engine that simultaneously controlled four displays. Controls were touch activated, and "smart materials" allowed surfaces like wood, leather, fabric, and stone to support capacitive touch and backlit graphics. This cockpit, in my opinion the most beautiful and well integrated at the show, is designed for semi-autonomous vehicles (Fig. 6).

Pioneer showed its Advanced UX Cockpit concept for Level 3 autonomous driving, in which the car drives itself under favorable conditions and passes control to the driver when conditions move beyond the envelope deemed safe for autonomous operation. By my count, the cockpit contained five displays plus a laser head-up display (HUD) and a GoPro camera. The cockpit, according to Pioneer, contains a driver monitoring system, facial recognition camera for driver condition and status, heart rate monitor, steering wheel sensor, seat sensor, and "seat vibration to improve level of alertness."

When people in the automotive-display world talk about 3D displays, they are generally not talking about images that hang in the air. Most often, they are referring to a display with layers, such as a mechanical indicator over a displayed 2D background. And 3D touch generally does not mean holographic

Fig. 4: *The Mercedes-Benz MBUX offers a wide-screen display that is both modern and modest, which is appropriate for its intended application in M-B's new generation of compact A-Class cars. (Photo: Ken Werner)*

Fig. 5: This LG Display cockpit concept is notable for the nice integration of the various displays and the positioning of the side-view images on the same display as the instrument cluster. (Photo: Ken Werner)

buttons that are actuated by "touching" them in 3D space. Continental's "3D touch surface display" consisted of a molded lens in front of the display, with touch-sensitive areas in the 3D contours of the lens that allow the driver to find the touch buttons by feel. Haptic feedback tells the driver when the button has been actuated. As you would expect from Tier 1 supplier Continental, this was a well-thought-out and well-implemented concept (Fig. 7).

Among the products Visteon showed in its tent in the Las Vegas Convention Center's Central Plaza was a 4K x 1K instrument cluster with driver monitoring and ADAS visualization. The 20.3-in. free-form display featured local dimming with 32 × 8 (256) zones and a pixel density of about 200 dpi. Visteon is not, of course, ignoring OLEDs. The company showed a pOLED instrument cluster with a hot-formed glass lens and another on cold-formed glass.

Fig. 6: Panasonic's Smart Design Cockpit offers superb display integration, luxurious materials, and smart-touch surfaces where you wouldn't expect to find them. (Photo: Ken Werner)

Also on exhibit was a dimmable lens display. Ordinarily, an automotive LCD is dimmed by reducing the backlight luminance. But if the OEM wants to have a flush display that is integrated with its surroundings and matches the luminance of lights and other displays, dimming by adjusting the transmissivity of the lens provides a solution.

Visteon is the leader in combiner-type head-up displays, and the company is now getting more active in windshield-type HUDs. The company has patents on windshield HUDs that can be viewed with polarized glasses. In addition to simple HUDs, Visteon was showing an augmented-reality (AR) windshield HUD, which might appear in 2018 or 2019 in a car from a premium German manufacturer.

Because an AR HUD occupies a large volume beneath the dash, Visteon sees this solution as being limited to large cars and SUVs. The company does not foresee in the near future a technology that would shrink AR HUDs enough to allow them to be incorporated in smaller vehicles.

Story #4: Your New OLED TV Doesn't Have to Be an LG

Henry Ford famously said of the Model T, "You can have any color you want as long as it's black." Two years ago, you could have any brand of OLED TV you wanted as long as it was LG, but that is changing, and changing rapidly. What hasn't changed is that no matter the brand of the TV, the OLED glass will have been made by LG Display, and that's an important part of the story. But before we look at the OLED TVs shown at CES 2018 that did not have an LG brand on them, let's take a quick tour of the OLED TVs LG Display was exhibiting in its invitation-only suite in the Las Vegas Convention Center's North Hall. After all, most OLED TVs will be built around LGD glass (or plastic) for the immediate future.

Notably, LGD showed a 65-in. rollable OLED TV (Fig. 8), which the company identified as its featured technology this year.

The OLED TV was repeatedly rolled into and out of a rectangular housing that sat on a flat surface. One clever feature was that if the display was rolled into the housing just enough to present a 21:9 area (for instance), the electronics automatically presented a 21:9 image to the screen.

LGD President and CMO Eddie Yeo said the rollable OLED was fabricated on 80-

Fig. 7: *Continental's 3D Touch Surface Display won a CES Best of Innovation Award. (Photo: Ken Werner)*

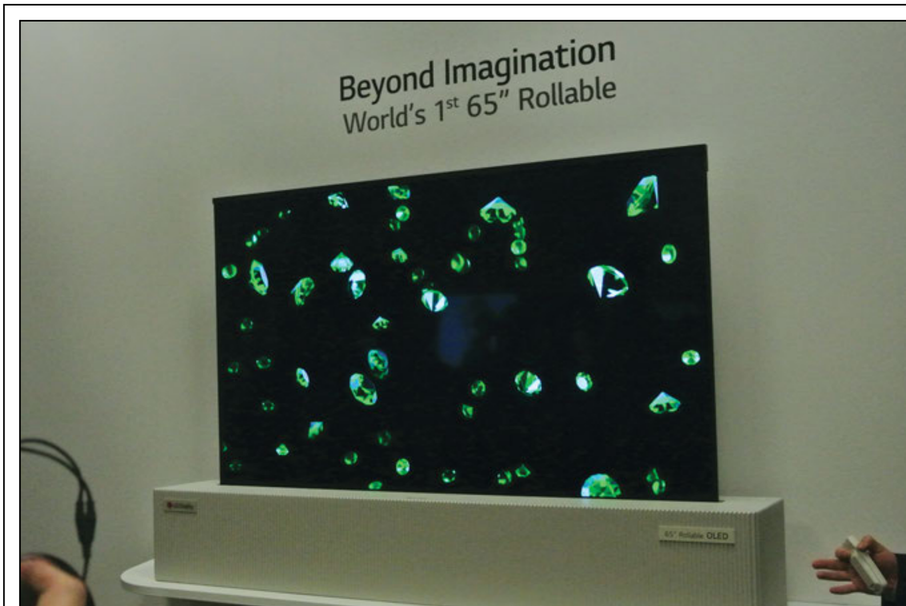

Fig. 8: *LGD's 65-in. rollable OLED TV was a highlight of the display technologies shown in LG Display's by-invitation-only suite. (Photo: Ken Werner)*

micrometer-thick flexible glass. Fabrication on a plastic substrate is coming, he said, and will allow the screen to be rolled more tightly. Yeo said he expects commercial introduction of the technology in two to three years.

Also featured in the LGD suite was an 88-in. 8K OLED TV with 7,680 × 4,320 pixels. LGD specifies the luminance as 800 nits at an average picture level (APL) of 10 percent; 500 at 2 percent; and 150 at 100 percent. Color gamut is specified as 99 percent of DCI and 129 percent of sRGB. LGD showed 2K, 4K, and 8K imagery side by side on the 88-in version.

As we have observed with other 8K displays, at a viewing distance of three feet or so there is a clear difference between the 4K and 2K imagery but only a subtle difference between 4K and 8K. Yeo said the 8K media is upconverted from 4K, so the visible difference in quality between 4K and 8K is not as great as it should be. LGD is working with NHK of Japan to develop true 8K media, Yeo said, which should significantly increase the perceived difference.

LGD also introduced the latest version of Crystal Sound, its actuator-based audio system that uses transducers to turn the screen itself into a speaker. This year's version uses thinner exciters for a much slimmer TV, Yeo said. There are now three exciters for 3.1 channel sound.

On the show floor, LG Electronics was showing its lineup of 2018 OLED TVs. These are the TVs that were most like the OLED TVs being shown by other brands.

Panasonic noted in its press conference that the company made its first TV 66 years ago, although it did not mention that it currently sells no TVs in North America (the company withdrew from the market two years ago). Michael Moskowitz, president of the Panasonic Consumer Marketing Company of North America, said the company was introducing two new series of OLED TVs. He said the OLED TVs (with LG panels) are already being used as monitors in post-production. Interestingly, he said the sets support the HDR10+ dynamic metadata protocol. HDR10+ is the approach developed by Samsung; LG supports Dolby Vision, along with HDR10 (not HDR10+) and HLG. The Panasonic booth contained no TV sets of any kind.

Last year at CES, Sony introduced a very nice OLED TV. It was notable for its well-implemented Acoustic Surface – Sony's version of Crystal Sound – which effectively localized sound to the portion of the screen from which it was supposed to emanate. This year, the set was even more refined, as was the marketing. Acoustic Surface is now described as "The greatest sound you've never seen."

Major Chinese manufacturer Changhong, not satisfied with displaying its short-throw laser projectors (a largely irrelevant category in North America although apparently significant in China), seemed to be pulling a lot of OLED panels from the LGD parts bin. There were, among others, a Pure Sound OLED TV and a 77-in. "Wall Paper" OLED TV.

Another Chinese manufacturer, Skyworth, had a major OLED TV exhibit in the Las Vegas Convention Center's South Hall. Skyworth, too, was showing OLED wallpaper TVs ("wallpaper" for Skyworth; "wall paper" for LGD and most other vendors) and Crystal Sound OLED TVs.

So why is LG Display working so energetically to create potential competitors for its sibling company LG Electronics? When I visited LGD's headquarters in Paju last summer, SooYoung Yoon, LGD vice president and director of the company's laboratory, said that LGD expected to bring costs and prices down significantly in 2018 through new manufacturing capacity, greater volume, and improved supply chain management. He specifically said that these reductions would be done without a change to solution processing, although the company is working on that for the future.

Clearly, LGD and LGE have decided that the necessary cost targets could not be reached by expanding LGE OLED TV sales alone. They needed TV-manufacturing partners. Interestingly, Samsung has come to a similar conclusion regarding its premium QLED quantum-dot LCD TVs. Samsung has said that anyone making a quantum-dot-enhanced TV can use the QLED name. At CES, lots of companies were doing so. But that's a story for another time.

Story #5: The Nanosys Express Has a Schedule – and Sticks to It

Nanosys is responsible for virtually all of the quantum dots that appear in today's commercial quantum-dot-enhanced LCD TVs, either by manufacturing the dots itself or by licensing the technology to others. What is remarkable about Nanosys today is the lack of drama. The company seems to know where it is going and just how long it will take to get there.

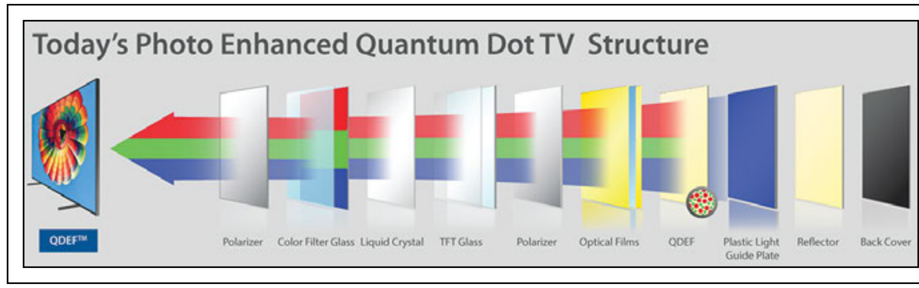

***Fig. 9:** Current quantum-dot-enhanced LCD TVs use this structure, in which a quantum-dot-enhancement film (QDEF) replaces the diffusion film in the optical stack. (Graphic: Nanosys)*

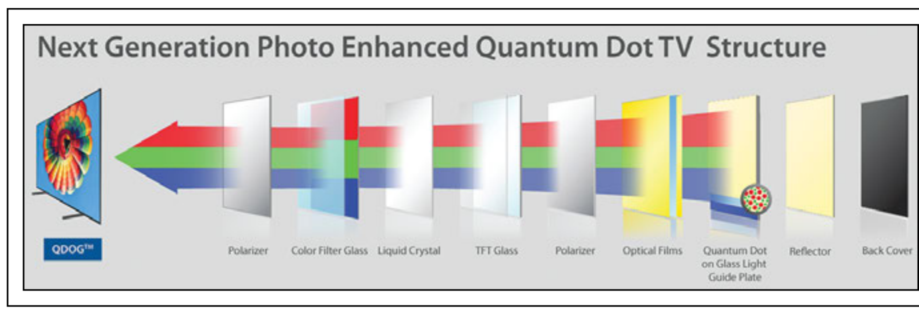

***Fig. 10:** The soon-to-appear QDOG structure will coat the QDs directly on a glass (not plastic) light-guide plate. (Graphic: Nanosys)*

In the company's suite at the Westgate Hotel, Nanosys executives discussed the company's roadmap for new quantum-dot (QD) versions to support new LCD-TV architectures, and their schedule for supporting each version.

The current QD-TV structure is based on quantum-dot enhancement film (QDEF), as shown in Fig. 9.

The initial supplier of QDEF was 3M, but in response to investigative reporting 3M revealed just after SID Display Week 2017 that it was going end of life on QDEF. However, Nanosys has arranged with at least four Asian filmmakers to manufacture QDEF, two of which have been announced: Hitachi Chemical and Exciton Technology of China.

The benefits of the QDEF structure, says Nanosys, is a color gamut of greater than 90 percent BT.2020, "premium HDR" with greater than 2,000 nits peak luminance, and low cost because the fabrication process leverages the existing LCD manufacturing infrastructure. QDEF is a multilayer film that protects the QDs from moisture and oxygen.

If you can passivate the dots individually you don't need to embed them in a film or protect them from the environment. Nanosys has developed such air-stable QDs, which are used in the next QD structure, "quantum dot on glass," or QDOG (Fig. 10).

With QDOG, a glass light-guide plate (LGP) replaces the polymer LGP typically used in the current generation of edge-lit LCDs, and QDs are coated directly on the glass. The benefits, says Nanosys, are a very thin structure of less than 5 mm, greater than 90 percent BT.2020, "true HDR" of greater than 1,000 nits peak luminance, and low cost. Although a glass LGP is considerably more expensive than an acrylic one, Corning says that the system costs are similar. Nanosys says that QDOG TV sets will be available in 2018.

The next structure is the quantum-dot color filter (QDCF), shown in Fig. 11.

In this structure, the venerable matrix-color filter that uses dyes or pigments to convert the white light from the backlight into colored subpixels is replaced by a patterned red and green (RG) matrix of quantum dots, which is possible because the dots are air-stable. Here, light from a blue backlight is converted into red and green for the red and green subpixels, and light for blue subpixels passes through an area containing only an uncolored diffusive film.

The advantages, according to Nanosys, are an improvement of power efficiency or luminance of up to three times, "perfect viewing angle," and QDCF manufacturing that is compatible with both photolithography and inkjet printing. QDCF TV sets should be available in 2018 or 2019.

All of these structures are photo-emissive: the quantum dots are excited by light. But the holy grail for Nanosys and its leading customer, Samsung, is to make electro-emissive QDs, the inorganic version of OLEDs (Fig 12). Samsung has announced it intends to leapfrog OLED and move to electro-emissive QDs.

Nanosys calls this architecture QDEL, and predicts it will be available in 2021 or 2023. Benefits, says Nanosys, are perfect black levels; perfect color and viewing angle; rugged inorganic materials; true HDR luminance and improved reliability; and low cost due to solution processing via inkjet, transfer, or gravure printing.

For the first time, Nanosys showed an inkjet-printed quantum-dot color filter (QDCF). The QDCF was made by partner DIC Corp. of Tokyo. DIC is collaborating with Nanosys to make QD inks.

We asked Nanosys's Jeff Yurek if batch processing of QDs posed any limitations. Yurek said they like batch processing. The company uses big reactors, said Yurek, adding that the plant looks like a brewery. And it's easy to build new lines, so there is no motivation to go to continuous reactors.

Despite CES's continuing evolution into a B2B technology systems show, there was still a lot of display technology to be uncovered, much of it behind the scenes. If we display nerds can get used to the idea that displays will increasingly play a critical but supporting — rather than central — role in sophisticated automotive, aircraft cabin, and other systems, then we will be able to find plenty of display stories at future CES shows. This year, across many technologies and products, there were eight million stories at CES. You have just read five of them. ■

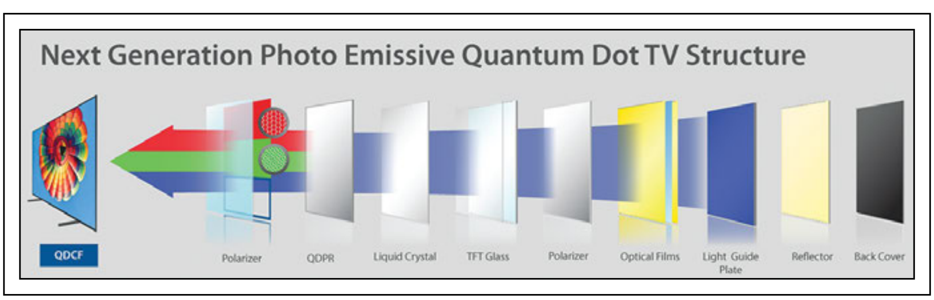

Fig. 11: Now that QDs can be individually passivated and do not have to be sealed between films for moisture and oxygen resistance, they can be directly patterned and used to replace color filters in LCD TVs. (Graphic: Nanosys)

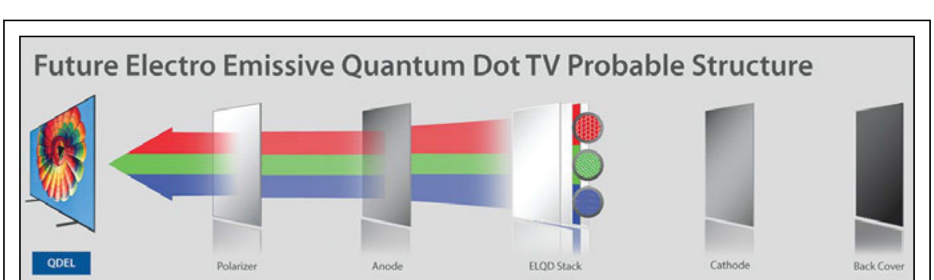

Fig. 12: When fully developed in perhaps five years, electro-emissive QLEDs could be a superior alternative to OLEDs. (Graphic: Nanosys)

Q&A with Jasper Display Corp.

Jasper Display Corp. is a leading designer of spatial light modulators (SLMs) and microdisplays for both LCOS and microLEDs. In 2017, Jasper and partner glō received an I-Zone Best Prototype Honorable Mention from SID for their megapixel silicon backplane (4K × 2K) and spatial light modulator technology for microdisplays. Information Display *recently had the chance to speak with Jasper's vice president of marketing and engineering, Mike Stover.*

Information Display: Tell us a little about Jasper Display Corp.

Mike Stover: Jasper Display Corp. (JDC) has been around since 2010. We see ourselves as a leader in high-resolution backplanes, primarily for liquid-crystal-on-silicon (LCOS) devices. These are active-matrix digital backplanes with digital storage, featuring high bandwidth and flexible addressing. The controllers support very flexible backplane addressing to handle a wide array of modulations.

In the past couple of years, we've expanded the space beyond LCOS through a program called "X-on-silicon." As a result, we found several different ways to enable the use of microLEDs on our backplane silicon so that they are compatible with our controllers and modulation resources.

We've been working on this project with several different microLED suppliers, and we've made the most progress with a company called glō.

Mike Stover

ID: That's the company you received the I-Zone award in conjunction with, correct?

MS: Yes, glō. This is a company based in California and Sweden, which develops RGB direct-emitting display panels based on gallium-nitride (GaN) nanowire-based microLEDs. This company had the ability to produce microLEDs in different wavelength formulations, and to transfer them onto a substrate. Getting a large collection of them to light up wasn't possible with passive-matrix approaches, and this is where our active-matrix backplane came in. Additionally, trying to get the right color (or wavelength), and combining light from three microLEDs to produce a known color palette is a big challenge for most microLED companies. So we provided glō with a backplane and controller and modulation methods, as well as our knowledge and experience, and together we achieved the results that won that honorable mention.

There are lots of uses for these backplanes. That next generation of this microLED approach that may have some legs involves augmented-reality (AR) devices. AR displays tend to be used outside, so the added brightness that you get with microLEDs is an advantage.

ID: Do you still consider Jasper a startup?

MS: We do consider ourselves a startup of sorts. We're small, with about 45 people. We're somewhere between 15 and 20 here in the Santa Clara Valley, with the rest in Taiwan.

ID: What's that like, being a cross-continent company?

MS: It's an unusual arrangement. Our headquarters are in Taiwan, and that's where most of the manufacturing takes place, but the R&D and the primary drivers behind the company are all here in California. We were founded in the US.

ID: How has that worked for the company?

MS: It's been pretty good for us, because we do take advantage of the manufacturing environment in Asia. In the US, we have a close association with the technical community here in Santa Clara/Silicon Valley.

ID: What have you been doing in terms of marketing efforts?

MS: Our marketing efforts are primarily through word of mouth. We don't advertise very much. We think the display community

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

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is pretty small and by the time we attend Display Week and various Optical Society of America conferences, we're pretty well covered.

ID: Did the I-Zone, and especially winning an I-Zone award, have an effect on your business or potential partners?

MS: It's had a very positive impact on our business and partners. End users liked what they saw and are now willing to put effort and resources behind these kinds of projects to make future displays with greater luminance and saturation that are also more color-correct. These are attributes people are willing to spend money on.

ID: How much are you a licensing company *vs*. a maker of devices?

MS: While we are a maker of devices, we also recognize that we don't want to limit a potential market or ramp-up opportunity, and so we will provide the portion that we are really good at, and let other factories and ODM suppliers take over to get the economies of scale they are good at.

ID: What is the biggest challenge that your company faces right now, be it operational or sales or technology?

MS: The biggest challenge is that most of these technologies are really multidimensional and so they require not only the electronics, including the display and the drivers, but optics, and there are a lot of choices to be made in that area. Companies' optical systems are all different, and this is particularly true for AR, where you are trying to package everything near-to-eye and volume and power are at a premium.

ID: So there's not a homogeneous approach at this point?

MS: That's correct. No matter if we're talking about Microsoft, Google, Apple, or any of the big Chinese companies – everyone is trying to figure out how they want to approach the problem: there's not a unified way to do it. Everyone wants to do something different right now.

ID: What plans does the company have for the future?

MS: We will continue to make LCOS backplane technology and also microLED backplane technology that can be customized on a per-project basis. Our specialized silicon capabilities make our products suitable for applications ranging from low-power AR headsets all the way to automotive headlights. We're especially excited about high-luminance microLEDs, which solve a key problem that AR glasses and HUDs face – namely, viewability in sunlight. There are more advanced circuit techniques and optical techniques that we're going to be able to use to move beyond the current demonstrated luminance and color-point control, and we think that with certain partners we can enable a new generation of display devices and projector devices that will be very interesting for personal use in the outdoor space.

ID: Do you have advice for anybody in a startup at the same stage of evolution as Jasper is right now?

MS: Yes, stick with it. At the same time, you need to realize that as the company gets bigger, what you're going to be doing when you really start to be successful is probably not what you started out doing.

Hardware is also a challenge. A lot of people these days are specialists on the software side. They can often quickly get to a successful startup based on an app, for example. With hardware, that's much harder to do, especially hardware that has both integrated circuit hardware and optics hardware associated with it. ■

AR/VR outlook

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Fig. 11: The Magic Leap AR headset has been much discussed, but isn't yet widely understood. Source: Magic Leap

surgically implanted. A responsive, Matrix-like simulation with the resolution or detail needed to completely fool the human brain is well beyond the reach of today's hardware and software. Ray Kurzweil, in his book *The Singularity Is Near*, projects these capabilities around 2035, less than 20 years from now.

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50th Anniversary of the LCD

It may be difficult to imagine, but the first liquid-crystal display was revealed to the public only 50 years ago. Liquid crystals themselves were discovered in Austria in the 1880s, but approximately 80 years went by before someone sandwiched the LC material between two pieces of glass and applied voltage to create a display of a glowing electronic numeral, as shown below (Fig. 1).

George Heilmeier and associates at RCA unveiled that first LCD back in 1968. They knew they were onto something big, but could anyone have dreamed that 40 years later, more than 100 million LCD-based televisions would ship in one year? (See our Honors and Awards profiles in this issue for more about the sales history for LCDs.) Or that LCDs would form the basis of products ranging from calculators to watches to oven timers to smartphones to computers to televisions? Even now, with OLEDs and e-paper cutting into LCD's dominance a bit, any one of us probably has at least a dozen and possibly a hundred LCD-based devices in our home. SID has flourished along with the LCD – our society, founded in 1962 back when the cathode ray tube (CRT) was the dominant display technology, has been greatly shaped by the ascendance of liquid-crystal displays.

To honor the LCD and those who made it possible, the Society for Information Display is holding a 50th anniversary LCD Celebration on Tuesday, May 22, at Display Week in Los Angeles. The celebration will feature a roster of LCD luminaries who have played pivotal roles in this technology. According to Erica Montbach of Kent Displays, spokesperson for the event along with Linghui Rao of Microsoft, the presenters will talk about how the industry got to where it is today and describe some of the key innovations made along the way. The speakers and topics are:

- Martin Schadt, MS High-Tech Consulting: "From Dynamic Scattering to Field-Effect Liquid-Crystal Displays"
- Fang-Chen Luo, Adviser for AU Optronics and co-inventor (with Peter Brody) of the active-matrix LCD: "Development of TFT LCDs"
- Kouji Suzuki, former CTO of Toshiba Corp.: "Development of a-Si TFT-LCD and Low temperature p-Si TFT-LCD"
- Kenji Okamoto: "Technical Innovation of Wide-Viewing-Angle LCD"
- Injae Chung, former CTO of LG Display: "LG Display Opened New Era of Large-Sized LCDs with State-of-the-Art Technologies"
- Jun Souk, former CTO of Samsung Display: "The First 40-in. LCD TV Prototype in 2001: The Initiation of Large-Sized LCD TVs"
- Mark Verrall, senior VP, research & development at Merck: "The (R)evolution of Liquid Crystals"
- Terry Scheffer, LCD consultant and co-inventor of super-twisted-nematic liquid crystals: "The STN Story"
- J. William Doane, co-founder and senior advisor to Kent Displays, Inc., and co-inventor of polymer-dispersed liquid-crystal systems: "PDLCs: Development and Display Applications"

A short video about the LCD celebration can be seen on the Display Week YouTube channel at www.youtube.com/watch?v=YZZ-GvX4kCE. Please join us in Los Angeles this May for this very special event. ■

Fig. 1: This early LCD (with inventor George Heilmeier) may look primitive, but it was a revelation back in the 1960s.

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nature of innovation, this year's honorees certainly do. Here at *ID* we do our best to capture the essence of their achievements in the biographies and citations thoughtfully compiled by Jenny. But nothing we write can come close to documenting the lifetimes' worth of ideas, challenges, setbacks, inspirations, and successes that these individuals have weathered on behalf of our industry.

I am especially pleased this year to see the addition of a new award, the David Sarnoff Industrial Achievement Prize, which goes to those who have had a profound, positive effect on the display industry over a period of many years, and are broadly recognized across the industry. This year's recipient, Sang Wan Lee, professor at Hanyang University and former CEO of Samsung's LCD Division, gave a keynote speech at Display Week 2005 in Boston that was truly inspiring. His vision, combined with his position of influence, truly changed the velocity of LCD-TV development over the past 18 years. I also want to say congratulations to Seth Coe-Sullivan, vice president of technology and chief technology officer for Luminit, who will be receiving the Peter Brody Prize. Seth got his Ph.D. from MIT up here in New England and was a frequent speaker at our New England chapter of SID events during his time at QD Vision. While the SID honors are being bestowed on these leaders of the display industry, the real honor goes to those who have had the privilege of knowing them, working with them, learning from them, and using their innovations to build better products that enrich people's lives.

Once again, we're just a couple months away from Display Week 2018. This year, the big show is once again in sunny and warm Los Angeles, beginning on May 20 and spanning the entire week with short courses, seminars, business and market focus conferences, the international symposium, some great keynotes, and the world-class Display Week exhibition. I'll have more to say about this later on, but if you have not yet made your plans to visit, you should! I'm sure by the time you read this, the winter rains will have ended and the southern California landscape will be vivid, bold, and as welcoming as ever.

This year's technical program features nearly 450 papers, including about 85 invited talks. There are a total of 83 technical sessions. I mention the numbers because they provide a context to the scale and depth of the event, which in fact is just one part of the overall Display Week program. If you are looking for proof that innovations are plentiful in the world of displays, this will certainly do it. Aside from the sheer numbers, the rich array of technical focus areas such as AI/AR/VR; Quantum Dots and microLEDs; and Wearable Displays, Sensors and Devices will surely make for one of the most exciting symposiums ever. Starting with the seminars on Sunday, May 21, this year will pack more technical and business content into one week than any other display industry event in the world.

To start planning your visit, consult the Display Week web site http://www.display-week.org/2018/Attendee/Registration.aspx to register, then sit back and enjoy our Symposium Preview compiled by Jenny Donelan. Of course, I'm always partial to the metrology papers because I'm also the subcommittee chair for display measurement, but this year's lineup of AR/VR papers could be the roadmap for predicting the future of this space. I'd also suggest looking closely at microLEDs and quantum dot LEDs (QLEDs), both emissive technologies with a great deal of promise for a new generation of displays. And oh yeah – don't forget the stretchable electronics and wearables papers – and also… well you get the idea! It's a lot to cover, so bring some friends and make sure you divide and conquer to hear and see all the great symposium presentations.

Our technical theme for this issue is Displays for AR/VR applications, and we have two broad-reaching articles addressing the advantages of OLED and LCOS microdisplays assembled by our Guest Editor Seth Coe-Sullivan. You should read Seth's excellent guest editorial, "The Race for Dominance: OLED or LCOS Microdisplays in Augmented and Virtual Reality," first to get a good context of these two topical features. The first, "LCOS and AR/VR," by Po King Li, VP of marketing and sales for LCOS displays at Himax Display, presents a compelling case for the future of LCOS in creating lightweight and high-luminance AR glasses. The second, "OLED Displays and the Immersive Experience," by long-time *ID* supporter Barry Young, CEO of the OLED Association, presents a great overview of the important considerations for development of these platforms, along with the role OLED technology can play in enabling commercial success. I can say from personal experience that head-worn displays for AR and VR are another clear example of a generational technology, one that has periods of initial excitement, some down times, then intermittent periods of resurgence as supporting technologies evolve. We're in one of those periods of new energy now, with greatly advancing computational power and evolving choices for displays as well. I was very involved in the development of LCOS displays for glasses and goggles in the late 1990s, but several pieces of the puzzle were missing at that time that prevented mainstream success with these products. Incidentally, I can't promise that being a guest editor for *ID* will lead to receiving an SID award, but the evidence this year suggests it doesn't hurt your chances either. Feel free to contact us if you are interested and we'll put in a good word with the awards committee!

At CES this year, displays were everywhere, and yet not nearly as much a part of the show as they used to be – as we learned from author Ken Werner, whose Show Review, "Five Short Display Stories from CES 2018," covers the highlights for us. The interesting stories range from TVs to automotive displays, rollable OLED panels, and quantum dots. My favorites are some of the new concepts for automotive displays and the rollable full-size OLED TV display. I called Best Buy, but they said mine is not ready yet. Soon, I hope. I can't wait to see these hit the market!

Our Business of Displays feature this month looks at the market for silicon backplanes for microdisplays by way of a Q&A with Mike Stover, vice president of marketing and engineering for Jasper Display Corp. Jasper, with partner glō, won an I-Zone Best Prototype Honorable Mention from SID for its megapixel silicon backplane (4K × 2K) and spatial light modulator technology for microdisplays. Jenny spent some time with Mike on the phone talking about his company, the technology, and some of the challenges for backplanes in this evolving market of AR and VR devices. Jasper is part of the new generation of suppliers making key building blocks for a rapidly growing eco-system around microdisplays. I'm sure you will enjoy Mike's insights.

This wraps up our March/April 2018 issue. Our next issue hits the streets just in time for Display Week and I hope I will see many of you there in LA. In the meantime, I wish everyone prosperity, peace, and safe travels. ■

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CEO confirmed these reports, saying that the company will commence production in Q1 2018 and will introduce its new OLED smartphones in June or July of 2018.[3]

- Universal Display Corporation announced in January 2018 that Sharp Corporation has signed an extended and updated evaluation agreement with UDC. Under the new agreement, UDC will supply its phosphorescent OLED materials and technology to Sharp for use in the company's OLED displays. Details and financial terms of the agreement had not been disclosed at press time.[4]

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Samsung Debuts 146-in. microLED TV

Until now, Samsung's premium TV offerings have been based on its quantum-dot enhanced LCD technology. These units have most recently been marketed as QLED TVs, and while they do contain both quantum dots and LEDs, some display purists might expect a QLED TV to be an emissive device that is built solely on quantum-dot LEDs, an emissive technology also referred to as QLED. In any event, Samsung's QLED TVs are undeniably of high quality and no doubt the average consumer enjoying a football game cares very little about the underlying material creating the great picture.

Into the mix, however, comes a new kind of TV from Samsung that actually is based on emissive technology – microLEDs. At CES 2018, Samsung announced a 146-in microLED-based TV called The Wall (Fig. 4). This 4K device is based on self-emitting technology that, according to many who saw it, rivals OLED in terms of vibrant imagery, deep blacks, *etc*.

The Wall, which consists of a series of bezel-less modules (sizes not currently available), will be on the market in August of 2018, according to a recent report in *The Verge*[5], at a price as yet not announced.

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[5]https://www.theverge.com/circuitbreaker/2018/3/7/17092000/samsungs-146-inch-the-wall-modular-tv-available-august

Fig. 4: *Dave Das, general manager and senior vice president of consumer electronics product marketing at Samsung Electronics, helps introduce Samsung's new 146-in. microLED TV, The Wall, at the Consumer Electronics Show in January 2018. Image courtesy Samsung.*

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