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Publisher & Editor-in-Chief  Mark Fihn  mark@veritasetvisus.com

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The immersive experience...

by Mark Fihn

In 1983, a year out of college, I visited an old family friend in Oldenburg, Germany who was on the physics faculty at the local university – specializing in lasers. He gave me a tour of the facility and then proudly showed off one of his passions – creating holograms. The solutions he created were absolutely magical! I recall asking him, “Do you think that these will ever be created in a video format?” He said, “Oh, you mean like Princess Leia?” This, of course, was exactly what was on my mind... He presciently responded, “I think it’s possible, but computing power will have to advance tremendously”. My visit to his labs set in motion a lifelong interest in 3D technologies,

Many years later, after a career in the displays industry, I had the opportunity to start the 3rd Dimension newsletter, which started in mid-2005. And now, we’re nearing the day when computing power has actually reached a level where video holography is possible. Exciting times!

Although 3D display technologies have seen their ups and downs, we can still see the overall interest in 3D – particularly with regard to cinematic features and stereo printing. More and more, we are seeing overwhelming evidence that 3D will also play a big part in the future of augmented reality/virtual reality applications that are currently the rage.

In 2005, touch was still a bit of a step-child at events like SID. A few other events – mostly of an academic nature – like SIGGRAPH and CHI did address touch technologies, but it’s only in the past five years that touch has really been viewed as an integral part of the display ecosystem. Indeed, SID 2011 is primed to be one of the most exhaustive events ever with regard to touch and interactivity.

This “Special Edition” newsletter is being sent out to highlight the many activities going on at SID’s Display Week that relate to the immersive experience, of which 3D is certainly a component. On Wednesday, May 23, the “Immersive Experience” Market Focus Conference will feature some of the exciting new developments related to displays and markets that demand the user be immersed into the imagery. This jam-packed conference will bring to light many of the very exciting opportunities and challenges for the future in the area of augmented reality, virtual reality, project mapping, CAVES, lightfield and holographic solutions, and some magical thoughts about the future.

I am pleased to help organize this event and think we’ve put together an absolutely stellar line-up, with many of the industry’s leading innovators participating.

If you are not planning to attend SID this year – I very much encourage you to reconsider. The Immersive Experience Conference is but a small subset of the overall Display Week events and activities, but it is a milestone event that is sure to be both informative and entertaining.

One of the main reasons for publishing this newsletter is to help make sure you are fully aware of the opportunity. Equally important, however, is our goal to minimize the promotion of company-specific marketing campaigns during the conference. In order to pack as much into the event as possible, we aim to keep the discussion focused on the primary opportunities and challenges facing the market, and not on company-specific plans and roadmaps.

The Immersive Experience Market Focus Conference is designed to give delegates a glimpse at some of the amazing developments that are dynamically involving users within the visual experience, not just as observers of a
static screen. While the market is booming – to full many broadly different needs – there are still many challenges. The conference is split into five somewhat overlapping sessions:

- **Market Status**: An examination of the size and scope of each major category, including how the revenue breaks down in terms of displays, software, and other hardware.

- **Goggles and Glasses**: This session will explore the delivery mechanisms available to Immersion from goggles similar to what is on the existing market such as the Vive and PlayStation VR and the Rift, followed by the use of glasses which have been pioneered by Google and are now being adopted by Facebook, Magic Leap, Meta and DAQRI, to name a few.

- **Direct View Displays**: The future of immersive display technologies is not all about near-to-eye solutions. So much is being developed to engage people with immersive experiences related to diverse approaches, such as projection mapping, CAVEs, and not to forget – enhanced stereoscopic and autostereoscopic 3D advancements.

- **Virtual Displays**: Immersion requires a new set of requirements that is a superset of today’s resolution, response time, CR, luminance, etc. These new demands include wider FOV, solution to the merging/accommodation conflict, shadow and light sources to simultaneously display virtual and real images. New display structures are being proposed that include Light Engines and Holography, singularly and in combination.

- **Next-Generation Magic**: The final session will explore how immersive experiences will be presented. Entertainment companies already have existing programs to reach the public through new types of theatres and new types of content. A number of start-ups are trying to bring new experiences to the general public and to use the technology to change the way we educate people.

The conference will examine these segments of the market and the basics of how the display industry will need to change to cope with the demands of immersion.

The “Immersive Experience” conference will be orchestrated such that each session will build on the earlier sessions. It’s our intention that the final session will be the culmination of what we believe attendees will find to a very worthwhile experience. See you there!
The Immersive Experience
SID Market Focus Conference Series – Agenda
Wednesday, May 23, 2018: 8:30 a.m. – 5:00 p.m.

8:30 Welcome: Helge Seetzen, President, SID
8:35 Introduction: Barry Young – Conference Co-coordinator
8:40 Session 1: Market Status
- Barry Young, CEO and President, OLED Association
- Pete Ludé, CTO, Mission Rock Digital
9:20 Session 2: Goggles and Glasses
- Adrian Travis, Fellow Emeritus, Cambridge University
- Bernard Mendiburu, Director of Cinematic VR Technologies, Starbreeze Studios
- Dave Chavez, CTO, zSpace
- Keynote Address #1: Kari Pulli, CTO, Meta
10:50 Break
11:10 Session 3: Direct View Displays
- Maarten Tobias, CEO, Dimenco
- Joel Polizzi, Visualization Engineer, University of California San Diego
- Special Address: Lenny Lipton, Inventor, Leonardo IP
12:30 Lunch
1:00 Session 4: Virtual Displays
- Ruediger Sprengard, Vice President of Augmented Reality, SCHOTT Advanced Optics
- Edward Tang, Co-Founder & CEO, Avegant
- Jon Karafin, Co-founder & CEO, Lightfield Lab
- David Fattal, Founder & CEO, LEIA
- Keynote Address #2: Paul Debevec, Sr. Scientist, Google VR
2:55 Break
3:10 Session 5: Next Generation Magic
- Featured Speaker: Andrew Cochrane, VR/AR/Interactive Content, Freelance Creator
- Demian Lichtenstein, Founder & CEO, Futurism Entertainment
- Paul Dietz, CTO & Chairman of the Board, Misapplied Sciences
- Michael Ludden, Director, IBM Watson Developer Labs & AR/VR Labs, IBM
5:00 Networking
Go to [www.displaysupplychain.com/immersive-experience-2018-conference.html](http://www.displaysupplychain.com/immersive-experience-2018-conference.html) for more information. If you are interested in participating in The Immersive Experience Conference as a sponsor, media partner, or delegate, please contact Dustin Gaedtke, DSCC - Digital Marketing and Event Director at: 832/451-4909 or e-mail to: Dustin@DisplaySupplyChain.com
Speaker and company summaries

Greeting

Helge Seetzen, President, SID

Dr. Helge Seetzen, is widely considered a successful multi-media technology entrepreneur with deep experience in the university tech transfer space. He is currently the General Partner of TandemLaunch Ventures – a consumer electronics investment fund – and has held executive roles at Dolby Laboratories and at BrightSide Technologies, which he co-founded. He serves on several of boards including display-related companies such as Mirametrix, IRYSTEC and wrnch. His successes include the invention and commercial development of local dimming LED TV technology for which he received a SID Special Recognition Award and the Canadian Innovation Award from the Canadian Natural Science and Engineering Research Council. He holds more than 100 patents related to display and imaging technologies.

Market Status

Barry Young, CEO and President, OLED Association

Barry Young is president and CEO of the OLED Association, where he solves industry-wide issues, such as the development of standards for the OLED display and lighting industries. He also serves as CEO of Young Market Research (YMR) and is its primary-lighting analyst. He works with and supports the leading OLED manufacturers, tool makers and material suppliers for the entire food chain. He lobbies for the industry and develops forecasts of material usage, display shipments and revenue and lighting shipments and revenue. Each quarter the Association captures the display and lighting shipments and provides its members with a detailed analysis of the state of the industry. He also works with a group of OLED suppliers to produce the first US-based pilot line for OLED lighting. A founder of DisplaySearch, Young is one of the leading authorities on OLEDs and flexible displays, and during his tenure authored DisplaySearch’s OLED, flexible-display, small/medium-display and technology reports.

Company summary: The OLED Association (OLED-A) is an industry-based organization that provides a forum for the interchange of technical and market information. Our membership includes companies involved in small-molecule OLED technology and polymer technology (PLED or light-emitting polymers). OLED-A serves its membership by fostering the more rapid development of OLED technology and OLED products; serving as a resource on OLED markets and products for media and investors; functioning as a catalyst in the development of standards for OLEDs; and providing a forum to promote and market OLED technology products.

Organic light emitting diodes (OLEDs) offer great promise in displays of all sizes and shapes in both commercial and home lighting solutions. OLEDs, or organic electro-luminescent (OEL) devices as some call them, are already in use as mobile phone, VR, TV, Tablet and Wearable displays. In addition OLED technology lends itself to innovative solid-state lighting, as well as flexible lighting solutions and flexible displays, even displays based on organic TFTs. Several foldable mobile devices have been prototyped and will soon reach the market.
“Patience in VR/AR Expectations”: VR/AR shipment forecasts by both Market Researchers and Industry Leaders have fallen way short of expectations. In 2017, VR headset shipments actually fell from 2016 highs and AR shipments remained well under 1 million units. What will it take for VR/AR to ascend to the lofty goal of replacing smartphones as the go to device for mobile computing and is it likely to materialize?

Is virtual reality real? VR exists, whether it is real is another question…

What is your favorite AR/VR application? United Flight Simulator

Market Status

Pete Ludé, Chief Technology Officer, Mission Rock Digital

Pete Ludé is a prominent engineering executive in advanced imaging and sound. He currently serves at CTO of Mission Rock Digital, a San Francisco-based engineering firm specializing in next-generation media. Current work includes display technology for next-generation cinema, immersive sound, and interchange pipelines for VR, AR and plenoptic (light field) imaging systems. Ludé has previously been involved in pioneering broadcast facilities, laser-illuminated projectors and datacasting endeavors. He has served as Chief Innovation Officer at Real D, and before that was Senior Vice President of Sony's Silicon Valley R&D labs. Ludé is past-president of SMPTE – the Society of Motion Picture and Television Engineers – and a SMPTE fellow. Pete was founding Chairman of the Laser Illuminated Projector Association, currently serves as co-chair of the ASC Plenoptic Imaging committee and is a frequent speaker on the future of cinema, volumetric imaging systems and advanced display technology.

Company summary: Mission Rock Digital specializes in engineering development and consulting for advanced digital media systems. We have expertise in professional television production technology, digital cinema, display and sound engineering. Our experts can help you with product strategy, facilitating international standards, product testing and market analysis.

“Immersive Entertainment – Opportunities and Pitfalls”: Content producers and distributors are now in a race to unlock the secret of how new immersive imaging and sound technologies might completely alter the entertainment experience in the near future. There are debates on the technical requirements, on necessary interoperability standards and on the trade-off between interactivity and immersion for storytelling. It’s becoming clear that different types of content – such as scripted dramas, sports, concerts or hobbyist DIY shows – may require very different user experiences. What is the impact on display technology? And what applications might first appear in the market?

Is virtual reality real? VR is very real, but in its current implementation with cumbersome headgear, hefty GPU’s and significant power consumption, the market adoption will be limited. For entertainment, the emerging “location based entertainment” venues will provide an interesting bridge. As an out-of-home and professionally-managed experience, these LBE version of VR technology will afford the chance to experiment with new content types as well as enhancements in mobility, haptics, sound and smell. By the time immersive technology evolves enough to be practical for home use, we’ll be much smarter about what type of programming and user experiences will be most engaging. In the meantime, watch for some dramatic failed attempts!

What is your favorite AR/VR application? At the moment, flight simulators are lot of fun – especially where you can explore an environment with freedom and interactivity. The application that I want to be my favorite is immersive storytelling, where the viewer becomes emotionally connected with the characters, and afforded agency through some limited interactivity. I think this could be an important next step from today’s television dramas and movies – but I haven’t seen all the kinks worked out yet.
Goggles and Glasses

Adrian Travis, Fellow Emeritus, Cambridge University

Adrian Travis was a lecturer at Cambridge University from 1988 to 2007 then a scientist at Microsoft Corporation until 2017. He is a fellow emeritus of Clare College, Cambridge University.

"Why pupil steering might liberate eye-wear design": We dream of designer spectacles that produce an unlimited virtual image but even pupil expansion will struggle to deliver this. I will explain why, then introduce the concept of pupil-steering. Although ambitious, this circumvents many of the constraints of expansion and should liberate the designer to create slim curved spectacles that might better fill the capability envelope of human vision.

Is virtual reality real? It might be in niche applications but its true potential still hangs on battery and optical design.

What is your favorite AR/VR application? Video conferencing, so that my drone can wander around the offices of my collaborators.

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We strive to supply truth (Veritas) and vision (Visus) to the display industry. We do this by providing readers with pertinent, timely and exceptionally affordable information about the technologies, standards, products, companies and development trends in the industry. Our five flagship newsletters cover:

- 3D displays
- Display standards
- High resolution displays
- Touch screens
- Flexible displays

If you like this newsletter, we’re confident you’ll also find our other newsletters to be similarly filled with timely and useful information.
Goggles and Glasses

Bernard Mendiburu, Director of Cinematic VR Technologies, Starbreeze Studios

Bernard Mendiburu

Bernard Mendiburu is a content creation technologist and artist working in interactive and immersive medias for over 20 years. His activities ranged from medical data visualization with UCLA, to stereoscopic lead artist with Disney and Dreamworks. As a stereoscopic film making expert, he wrote articles, book chapters, and lectures for industry groups and conferences like SMPTE, NAB or IBC. His reference text books like “3D movie making” was translated in 5 languages. He's currently working on the ground breaking VR headset StarVR and works in Los Angeles at the convergence of Virtual Reality devices and content production. Bernard is the director of cinematic VR technologies with Starbreeze Studios.

Company summary:

Starbreeze is an independent creator, publisher and distributor of high quality entertainment products. With studios in Stockholm, Paris, Los Angeles, Barcelona, Brussels and India, the company creates games and other virtual reality entertainment products, based on proprietary design and licensed content. Starbreeze most recent games include PAYDAY 2, John Wick VR shooter and upcoming survival co-op FPS OVERKILL’s The Walking Dead. Under its publishing initiative, Starbreeze has together with Canadian studio Behaviour Digital successfully launched horror thriller Dead by Daylight.

Starbreeze has set out to develop truly immersive virtual reality (VR) experiences by integrating software and hardware in its StarVR head mounted display, produced together with Acer. Together with wholly owned subsidiary Enterspace, Starbreeze further solidifies its presence in location based entertainment. StarVR can additionally be found at IMAX VR Centers in Los Angeles and New York.

“Visual Quality Criteria in Virtual Reality HMD”: Since the rebirth of Virtual Reality initiated by the launch of the Oculus Kickstarter, we have seen dozen of HMD project or products launches. This revolution, ignited by Cellular Phones mass production impact on technologies' price, brought us the promise of cheap presence. But cheap should be on the price tag, not on the experience. The quality of a VR experience is a weak point problem, where every node can be bleeding edge or decade-old proven technology. The presentation will list the crucial elements controlling the quality of a VR system and their respective impact.

Is virtual reality real? The technical maturity of VR is real, as prices drops and quality increases. Tens of industries are eager to increase their efficiency by using VR. When VR will to streamline itself, find the applications niches, solve the user isolation, it will bump the good-old flat display out of the picture.

What is your favorite AR/VR application? What is your favorite AR/VR application? There are so many. VR is not a usage, it's a display. Can you say what is your favorite use of a display? I cannot say there is one and only one. Going places, meeting peoples, drawing dreams. Swimming in music, shooting zombies and repairing the space station.
Goggles and Glasses

Dave Chavez, Chief Technology Officer, zSpace

David Chavez brings 20 years of experience in start-up companies, working with technologies ranging from GSM infrastructure to laptops, printers, PDAs and smartphones, in both consumer and commercial product spaces. He has managed product development teams through the full range of the product life cycle, from initial concept to volume production. David has extensive experience working with suppliers and manufacturing partners worldwide, with a particular emphasis in Asia. He has held various positions in product development organizations such as pen-based computer companies GO & EO, Hewlett Packard, and Handspring.

Company summary: zSpace combines elements of AR and VR to create lifelike experiences that inspire curiosity, create engagement and deepen understanding. Among its numerous awards and accolades, zSpace was named “Cool Vendor” by Gartner, Inc., “Best in Show at ISTE” by Tech & Learning Magazine for three consecutive years and was ranked two years in a row on the Inc. 500 list of fastest growing companies. zSpace is a privately held, venture-backed company located in Sunnyvale, California, and has been granted more than 30 patents for its innovative technologies.

“VR on the Desk”: What happens when the VR display is removed from the goggles and placed on the desk? The magic of VR can be delivered with very light eyewear, and comfortably enjoyed in a social way. A great application for such a configuration is the classroom.

Is virtual reality real? It’s about as real as can be expected. The burden of use is still too high for broad adoption.

What is your favorite AR/VR application? 3 way tie: Google translate, Richie’s Plank Experience, and Keep Talking and Nobody Explodes

Various learning situations supported by zSpace AR/VR
Morning Keynote

Kari Pulli, Chief Technology Officer, Meta

Kari Pulli is CTO at Meta. Before joining Meta, Kari worked as CTO of the Imaging and Camera Technologies Group at Intel influencing the architecture of future IPUs. He was VP of Computational Imaging at Light and before that he led research teams at NVIDIA Research (Senior Director) and at Nokia Research (Nokia Fellow) on Computational Photography, Computer Vision, and Augmented Reality. He headed Nokia's graphics technology, and contributed to many Khronos and JCP mobile graphics and media standards, and wrote a book on mobile 3D graphics. Kari holds CS degrees from University of Minnesota (BSc), University of Oulu (MSc, Lic. Tech.), University of Washington (PhD); and an MBA from University of Oulu. He has taught and worked as a researcher at Stanford University, University of Oulu, and MIT.

Company summary: Meta is a Silicon Valley company known for making augmented reality products. Their products include the Meta 1 Developer Kit and the Meta 2 Development Kit. They combine real world technology with holographic images, and unlike the Oculus Rift, which is completely virtual, Meta is still transparent and the real world can still be seen. It was founded by Meron Gribetz. Gribetz thought of starting Meta while studying neuroscience and computer science at Columbia University under tutelage of Steven Feiner. The company identifies its main competitors as Vuzix and Recon Instruments rather than Google Glass. Their initial demographic will be business use, such as product engineers and architects.

“Immersive Optical-See-Through Augmented Reality”: Augmented Reality has gained steam in the last 20 years, and is finally becoming real, powered by progress in enabling technologies such as graphics, computer vision, sensors, and displays. At Meta, we're producing an immersive optical-see-through AR headset, as well as the full software stack. We'll discuss the differences between optical vs. video see-through displays, immersion, Meta 2 optics, and the key computer vision enablers for AR. We'll conclude with discussing some of the key applications that are enabled by wearable and immersive Augmented Reality.

Is virtual reality real? In a word: no. Immersing users in a virtual universe, VR creates a physical barrier between the user and the world, separating them from reality. On the other hand, Augmented Reality offers the real deal by superimposing digital information on the world without detracting from it. With the Meta 2, users can visualize and interact with holograms, while seeing the world around them and making eye contact with collaborators.

What is your favorite AR/VR application? While the AR industry is still growing, and a killer AR app has yet to be created, design review in Augmented Reality shows real potential. Meta's Model Viewer is currently in Beta and will enable users to visualize and interact with 3D models, revolutionizing the 3D design and presentation process.
Direct-View Displays

Maarten Tobias, Chief Executive Officer, Dimenco

Maarten Tobias is CEO and co-founder of Dimenco. Prior to founding Dimenco, Tobias worked at Philips Electronics within the Philips 3D Solutions division where he was responsible for sales and business development within USA, Europe and Russia. Additionally, Tobias worked at Philips TV as strategy manager and was heavily involved in the repositioning of the Philips TV division. In June 2010 Tobias founded Dimenco together with three former Philips 3D Solutions colleagues. Dimenco is nowadays being recognized as one of the leading auto-stereoscopic technology companies in the world and was acquired by KDX in 2015. In 2017 Tobias introduced the vision and strategy of Simulated Reality at KDX, creating an experience that cannot be distinguished from Reality without boundaries, which is now being executed and first proof-points are shown to the market.

Company summary: Depth perception is created by bonding a specially developed lenticular overlay to an LCD screen, in such a way that projected light is transmitted in different directions. Introducing interference into what each eye perceives results in the perception of depth on a flat surface. The observer’s left and right eye see different images on the display, which the brain fuses into single image, without requiring cumbersome, inconvenient 3D glasses. Dimenco’s 3D technology allows viewers to sit anywhere in a room and see a customizable 3D image. This is easy on the eyes and can be watched from different angles.

In addition to the design of the lenticular overlay and optical bonding to an LCD, the technology developed by Dimenco (a subsidiary of KDX) also encompasses 3D image processing. Dimenco also offers vast experience in industrial 3D display and component manufacturing. Dimenco is moving towards Simulated Reality. The Simulated Reality vision is to create a new way to experience the world. To bring people together, enhance communication and redefine what’s possible...

At the SID Exhibition, Dimenco is demonstrating a virtual reality-like experience without glasses, hand-held devices or other wearable gear. It will also feature mid-air haptics technology, from strategic partner Ultrahaptics that will allow users to interact with simulated objects just as they do with their real-world counterparts.

“Simulated Reality”: Maarten will discuss the company’s concept for a first-of-its kind Simulated Reality (SR) display system. This technology delivers a virtual reality-like experience without glasses, hand-held devices or other wearable gear. Tobias will discuss on the future of Simulated Reality and present the company’s plans for introducing its first development kit and product launch in 2019.
Direct-View Displays

Joel Polizzi, Visualization Engineer, University of California San Diego

Joel Polizzi works with researchers, faculty, and staff for anything pertaining to media and media production at CalIt2 / Qualcomm Institute. This includes the operation and maintenance of a 200 seat auditorium, 32 screen visualization wall, CAVE VR environments, performance technical design, and technical aspects of an on site art gallery. He also dabbles in networking, Maxmsp, PD, Matlab, 3D printing, Solidworks, and Java. Currently I am working on taking computer science as well as AWS courses.

Company summary: The Qualcomm Institute is the UC San Diego division of the California Institute for Telecommunications and Information Technology (Calit2), one of four Gray Davis Institutes for Science and Innovation located on University of California campuses. The institute’s strategic vision stresses collaborative, interdisciplinary research in four core areas to benefit society: culture, energy, the environment, and health. QI also prototypes and builds enabling technologies (wireless, photonics, cyberinfrastructure, and nano-micro-electromechanical systems, or nano-MEMS). In addition, the institute plays a leadership role in the development of new institutes and research centers for the UC San Diego campus, on topics ranging from robotics and the brain to design.

“Collaborative mixed reality in CAVEs”: This presentation will be a brief overview of how we use CAVEs past/present and the various obstacles we've come across and overcome. The discussion will go into a bit of design as well, but framed around our SunCAVE which was completed and built by about 6 months ago. The talk with our short and long term goals in both our immersive experiences and how we plan to utilize the massive GPU power of our systems nodes.

Is virtual reality real? That’s a tricky question to answer. On the surface it would appear that virtual reality is not real. We are creating artificial settings that have mostly pre-determined outcomes, not dissimilar to most video games or movies (which we clearly would not consider real). Yet, I have seen applications for VR extend into digital store fronts, medical device design, nano engineering, and there’s even a realty company that has all the realtors across the nation conduct their meetings and seminars from a VR world! That sounds pretty real to me!

What is your favorite AR/VR application? Cyber Archaeology! There’s something incredible about traveling the world in VR and exploring point clouds, high res panoramas, and meshes of far off lands and artifacts from the comfort of home (or in my case a 500-megapixel CAVE).
Special Address

Lenny Lipton, Inventor, Leonardo IP

Lenny Lipton founded StereoGraphics Corporation in 1980 and was the Chief Technology Officer of Real D during the introduction of digital stereoscopic theatrical exhibition. He’s been granted 72 patents in the field of electronic stereoscopic displays and received a Smithsonian award for his invention of CrystalEyes, the original electronic stereoscopic eyewear product. He led the team that invented the ZScreen, used in 30,000 Real D theaters, and was the first to demonstrate the flicker-less projection technique used on 80,000 3D cinema screens. He has written four books, including the Independent Filmmaking (1972) and Foundations of the Stereoscopic Cinema (1982). He is a Fellow of both the SMPTE and the SPIE. He is a member of the Scientific Council of the Conservatoire des techniques of the Cinémathèque Française. While a physics major at Cornell, he wrote the lyrics of the song *Puff the Magic Dragon*. He produced and directed 25 independent films collected by the Pacific Film Archive. He is currently writing a book about the history of motion picture technology.

“The Paradox of VR: Big vs. Small”: About 300 years ago in Europe the urge to experience and visualize other places began to manifest itself in display technology that took two radically different forms serving as the templates for today’s similar efforts. Giant panoramas, both still and moving or scrolling, began to be used to replicate, typically, cityscapes and battle scenes. At about the same time peepshows began to be created, using small images viewed with the help of optics, for similar content. Today such efforts continue as manifested by giant projected images that lack interactivity and small head mounted displays that allow for a degree or interactivity, both approaches using binocular stereopsis and a very wide field of view.
Virtual Displays

**Ruediger Sprengard, Vice President—Augmented Reality, SCHOTT Advanced Optics**

Dr. Ruediger Sprengard studied at Universities of Mainz (Germany) and Florence (Italy). He received his PhD in Physics in 1998. Throughout his career, he worked on advanced materials and components for optoelectronic and electronic applications. Currently, he is the Vice President of the Business Field Augmented Reality at SCHOTT Advanced Optics.

SCHOTT Advanced Optics, with its deep technological expertise, is a valuable partner for its customers in developing products and customized solutions for applications in optics, lithography, astronomy, opto-electronics, architecture, life sciences, and research. With a product portfolio of more than 120 optical glasses, special materials and components, we master the value chain: from customized glass development to high-precision optical product finishing and metrology.

**“SCHOTT High-Index Glass Wafers Enabling the Next Level of Augmented Reality Experience”:** What is unimaginable today, the not so far future experience of Augmented Reality is expected to change our everyday life – at work, during our leisure time, and the way we communicate in general. SCHOTT high-index glass wafers are a key component in the optical system of AR devices, directly influencing the visual user experience, particularly increasing Field-of-View and image quality. The excellent glass wafer quality enables the best-in-class device performance. In addition the SCHOTT high-index glass wafers may come with a single or double side anti-reflective coating with tailored transmission and surface roughness.

**Is virtual reality real?** My answer is based on Augmented or Mixed reality. Is the industry real? Yes. Smart people and enormous financial resources are driving the industry making it a reality. Are the devices real? Yes, developers and commercial users can experience real devices … and start “feeling” the unlimited potential of this unprecedented experience. Is it real and mature from an end user perspective? Clearly not yet. Saturation into everyone’s daily life requires the next generation of hardware and – probably even more important – building up the software and content ecosystem.

**What is your favorite AR/VR application?** What is disruptive with AR? It is the “proximity” of the virtual world. You really can physically feel the presence of the virtual object / subject. So I am strongly convinced that any applications, benefitting from this emotion of “proximity”, will have a strong connection with the end user.
Virtual Displays
Edward Tang, Co-Founder & Chief Executive Officer, Avegant

Edward Tang is the visionary and co-founder behind Avegant, a next-generation mixed reality display company. Avegant has developed award-winning Retinal Imaging Technology to industry-first Lightfield mixed reality displays. They continually push the boundaries of near-eye display technologies to create new experiences for the industry. Born in Texas and raised in Taipei, Ed received his degree in Electrical Engineering from the University of Michigan, specializing in micro-electrical mechanical systems (MEMS), and joining the faculty full time researching and developing cutting-edge micro & nanofabrication technologies since 2001. Among a host of other entrepreneurial ventures, Edward founded Tang Consulting out of Ann Arbor, Michigan, where as President and CEO he worked for years developing technologies for the MEMS biotechnology industry in areas of autonomous surgical robots, implantable neuromodulators, and microfluidic drug devices, scribing over 20 patents along the way.

Company summary: Avegant Light Field Technology puts stunningly vivid virtual objects right in front of you, and solves one of mixed reality’s greatest technical challenges: Enabling virtual objects to appear real at distances both near and far. The clear visualization of virtual objects across multiple focal planes makes the entire experience feel natural, and opens up a universe of interactivity. Light Field Technology gives virtual objects the correct focus to match their distance, making them appear real, and opening up a wide spectrum of professional and personal uses.

“Enabling Mixed Reality: Lightfield Displays and other challenges”: Abstract: Display technologies are some of the most limiting factors to enable the next computing paradigm of Mixed Reality. Lightfield displays are critical to solve the vergence accommodation conflicts (VAC) that we see today in head-mounted displays. Solving VAC is crucial to enable the types of applications that users envision. Additionally, increasing resolution, FoV, and reducing form factors and power are further challenges for display technologies.

Is virtual reality real? Not yet.

What is your favorite AR/VR application? Interacting & holding virtual objects in your hands.
Virtual Displays

Jon Karafin, Co-founder & Chief Executive Officer, Light Field Lab, Inc.

Jon Karafin has dedicated his career to innovation in live action cinema, VFX post-production, and light field technology – transforming bleeding-edge concepts into market ready solutions. As CEO of Light Field Lab, he applies this expertise to the development of a next-generation holographic technology. Karafin has an extensive background in light field and visual effects technology, having previously served as Head of Light Field at Lytro, Vice President of Production Technology at Real D, and as Director of Production, Technology, and Operations at Digital Domain. During his tenure, he was responsible for ushering in a new era of cinematic capture through the launch of Lytro Cinema, as well as delivering technology and content for many of the all-time highest grossing feature films, including Peter Jackson’s The Hobbit, Michael Bay’s Transformers 3, and Tim Burton’s Alice in Wonderland. Karafin holds multiple graduate degrees from the Rochester Institute of Technology (RIT), as well as BFAs in multiple fields from Ithaca College.

Company summary: Light Field Lab is building the world’s most innovative holographic ecosystem. The company was founded in 2017 by Jon Karafin, Brendan Bevensee, and Ed Ibe, with the single mission to enable a holographic future by building upon the founders’ collective expertise of light field technology innovation. Based in San Jose, CA, Light Field Lab is backed by top-tier venture firms including Khosla Ventures. “Light Field Lab has the potential to change the way we view and interact with media,” said Vinod Khosla, Founder, Khosla Ventures. “This is essentially the holy grail of optical display technology, enabling things that seem like science fiction to be possible today. We are thrilled to be in on the ground floor with the team, and look forward to helping evolve this exciting technology.”

“Beyond Virtual Reality: Light Field, Holographic Display and the Roadmap to the Holodeck”: This talk will detail the very latest developments in light field and holographic display technologies including insights into the creative and technical implications for content creation, as well analyze the data requirements and solutions for streaming holographic media, and provide a glimpse into Light Field Lab's holographic technologies.

Is virtual reality real? Referring to the industry, technology, or experience? While there are certainly great applications for VR technologies, we believe that the future of entertainment is holographic.

What is your favorite AR/VR application? Tilt brush.
Virtual Displays

David Fattal, Founder & Chief Executive Officer, LEIA

David Fattal is the founder and CEO of LEIA Inc., a Silicon Valley company developing a Lightfield Display technology platform for mobile devices. He previously spent 9 years at HP Labs working on various aspects of quantum computing and photonics, and specializing in the manipulation of light at the nanoscale. He holds a PhD in Physics from Stanford University and a BS in theoretical physics from Ecole Polytechnique, France. David was named French Innovator of the year 2013 by the MIT technology Review and featured on their list of 35 Innovator under 35 that same year. He holds 90 granted patents and co-authored the text-book “Single Photon Devices and Applications”. He was awarded the French National Order of Merit in 2014 for developing the “Diffractive Lightfield Backlighting” concept.

Company Summary: LEIA Inc. is a Silicon Valley company developing a lightfield display technology platform for mobile devices. Through Nanotechnology and Software innovation, the company empowers device manufacturers and content providers in various industries to create the next digital experience for consumers. The company was founded in 2014 by David Fattal, Zhen Peng and Pierre-Emmanuel Evreux as a technology spin-off from Hewlett-Packard laboratories.

“Switchable Lightfield Displays”: Lightfield Displays are the Holy Grail of displays. They enable practical 3D Holographic applications, can be configured for privacy, and even provide means for your eyes to accommodate properly in the context of Heads-up displays. However they invariably suffer from lower resolution, which is currently a major obstacle to mass adoption. In this talk we review LEIA’s Diffractive Backlight Technology (DLB) that enables easy switching of an LCD display between a lightfield mode and a standard (high resolution, 2D, wide-angle) mode of operation. The technology is ultra-compact, power efficient, and particularly suitable for mobile devices.

Is Virtual Reality Real? Our view at Leia is there is indeed a real transformation of the digital medium but it’s happening on the smartphone, not in a head-set. When you marry inertial sensors, depth cameras, deep-learning vision algorithms and lightfield displays on a phone, you get an incredibly interesting and intuitive experience that immerses you in the Digital World in a fundamentally new way.

What is your favorite VR/AR app? Holochat – stay tuned.
Afternoon Keynote

Paul Debevec, Senior Scientist, Google VR

Paul Debevec is a Senior Scientist at Google VR and Adjunct Research Professor of Computer Science in the Viterbi School of Engineering at the University of Southern California, working within the Vision and Graphics Laboratory at the USC Institute for Creative Technologies. Debevec's computer graphics research has been recognized with ACM SIGGRAPH's first Significant New Researcher Award in 2001 for “Creative and Innovative Work in the Field of Image-Based Modeling and Rendering”, a Scientific and Engineering Academy Award in 2010 for “the design and engineering of the Light Stage capture devices and the image-based facial rendering system developed for character relighting in motion pictures” with Tim Hawkins, John Monos, and Mark Sagar, and the SMPTE Progress Medal in 2017 in recognition of his achievements and ongoing work in pioneering techniques for illuminating computer-generated objects based on measurement of real-world illumination and their effective commercial application in numerous Hollywood films. In 2014, he was profiled in The New Yorker magazine's “Pixel Perfect: The Scientist Behind the Digital Cloning of Actors” article by Margaret Talbot and worked with the Smithsonian Institution to scan a 3D model of President Barack Obama at The White House.

Company summary: AR and VR products at Google includes ARCore, Daydream, Cardboard, Jump, Tilt Brush, Blocks and more. VR video is a promising technology for exploring the world, and while they are still an experiment, light fields show a new level of how convincing virtual reality experiences can be. We hope you enjoy our “Welcome to Light Fields” experience, available now on Steam VR. Take the seven-minute Guided Tour to learn more about the technology and the locations, and then take your time exploring the spaces in the Gallery. This is only the beginning, and lots more needs to be done, but we’re excited about this step toward more realistic capture for VR. [http://store.steampowered.com/app/771310/Welcome_to_Light_Fields/](http://store.steampowered.com/app/771310/Welcome_to_Light_Fields/)

“Welcome to Light Fields for Virtual Reality”: I will discuss the technology and production processes behind “Welcome to Light Fields”, the first downloadable virtual reality experience based on light field capture techniques which allow the visual appearance of an explorable volume of space to be recorded and re-projected photo-realistically in VR enabling full 6DOF head movement. I will also provide a brief update on the use of the Light Stage systems at USC ICT in creating realistic digital characters such as "Digital Mike" for Virtual Reality and the Young Rachel character in Blade Runner: 2049.

Left: Recording a spherical light field on the flight deck of Space Shuttle Discovery, (left); Light field rendering allows us to synthesize new views of the scene anywhere within the spherical volume by sampling and interpolating the rays of light recorded by the cameras on the rig, (right)
Featured Speaker

Andrew Cochrane, Independent VR/AR/Interactive Content Creator

Andrew Cochrane is a content creator working in virtual and augmented reality, installations, live events, and mobile and web apps. Andrew has a unique ability to contribute his extensive knowledge and insight into both the creative and technological aspects of a project, offering a unique blend of narrative focus, artistic savvy, and high-tech problem solving. In 2017 he led the creation of five animated 360º art films for the “Vegas: Alter Your Reality” Experience and executive-produced a segment for The USA Today Network’s weekly VR show “VRtually There”. Other recent work includes creating a 360º skydiving experience for Intel, a VR tour of Google’s retail program, the intro for Google’s Jump 360º video platform, and a real-time dance performance using Intel’s Realsense platform featured in their 2016 Anthem commercial and at CES that year. Andrew was also the creative and technical lead on VR experiences for USA Today, Mr. Robot, The Strain, GE, Michigan Football, and several others currently in production. He has developed applications and content for projects that use technologies such as Cardboard, GearVR, PC-based HMD’s, Google’s Tango, real-time performance capture, projection mapping, data visualization, and numerous other emerging technologies.

“Everybody, Calm the **** Down: The Road to Mass Adoption”: Virtual Reality is in year 4 of its current incarnation as a consumer product. Those who are investing or trying to get investment in this emerging market often try to compare its expected adoption rate to technologies that precede it – cinema, cellphones, video games, or the internet. In reality, VR will follow an adoption curve unique unto itself, and it will only be with hindsight that we can properly understand the watershed moments that will lead to its mass adoption. This will be a multi-decade journey, and the only thing that is certain is that everyone needs to work hard and calm down, it’s going to be great.

Is virtual reality real? As in: is the industry really happening, or as in: is VR “reality”? I think the industry is definitely “real” and growing steadily, but I do not think any of the tech is good enough yet that we can genuinely convince someone that they are in the Matrix i.e. that the virtual world is “real”.

What is your favorite AR/VR application? “Keep Talking and Nobody Explodes” – hands down the single best use of VR to date. It solves the isolation and exclusivity problems and uses VR to create a fantastic entertaining experience for everyone playing.
Next Generation Magic

Demian Lichtenstein, Founder and CEO, Futurism Entertainment

Demian Lichtenstein is a producer, director and writer best known for his feature film 3000 Miles To Graceland starring Kevin Costner and Kurt Russell. Along with co-writing, producing and directing the successful #1 PAYDAY video game franchise / Net TV series, Demian has built and sold five media, VR and gaming companies.

Company summary: Futurism Entertainment makes AAA Motion Picture, Video Game, Mobile and VR/AR content. Seamless multi-platform integration of development and production groups generating synergistic revenue streams of high concept IP.

“Futurism: Where Technology and Entertainment Meet”: We are in an extraordinary time where we know that all things are possible and that in the near future completely photorealistic, totally immersive, real-time entertainment will be the norm. The combination of the story engine of Motion Picture and Television combined with real time video game engines wrapped in a virtual reality will become a new standard in which the audiences of tomorrow embrace the stories of yesterday, the heroic journeys of today, and the mind expanding adventures of tomorrow. In this nexus, there is the possibility of the expansion of human consciousness and the promise of your wildest dreams and fantasies fulfilled.

Is virtual reality real? Are you real? Am I real? Is anything we perceive in our third dimensional reality actually real? From a quantum perspective, we are nothing less than energized particles coalescing into form composed 99.9% of empty space. Musk and others have said that they believe we are actually virtual holograms inside an expansive game universe created by something or someone else. The particles of which we are made blink in and out of existence and the very nature of our action of looking at them changes the particles themselves. Einstein said, “spooky at a distance.” Since Virtual Reality is ultimately made up of the very same particles, and we can perceive it, and it can affect our physical and emotional state, then who’s to say it’s not “real.”

What is your favorite AR/VR application? Porn, haha. I have still yet to see anything better than Star VR 2010 field of view 6k resolution fully immersive HMD.

Featured SID programs about the Immersive Experience

- Fundamentals of Virtual- and Augmented-Reality Technologies – Short Course
  Sunday, May 20: 9:00 am -1:00 pm
  Achin Bhowmik, Starkey Hearing Technologies

- Computational Near-to-Eye Displays with Focus Cues – Display Technology Seminar
  Monday, May 21: 8:30-10:00 am
  Gordon Wetzstein, Stanford University

- Light-Field Displays – Display Technology Seminar
  Monday, May 21: 2:40-4:10 pm
  Nikhil Balram, Google

- Reactive Displays: Unlocking Next-Generation VR/AR Visuals with Eye Tracking
  Tuesday, May 22: 8:20-10:20 am
  Keynote Speaker: Douglas Lanman, Oculus Research
Next Generation Magic

Paul Dietz, Chief Technology Officer and Chairman of the Board, Misapplied Sciences

Paul Dietz has a long history of creating magical interface technologies. He is best known for his seminal work on touch interfaces. He holds a PhD from Carnegie Mellon and is currently CTO and Chairman of Misapplied Sciences.

Company summary: Misapplied Sciences creates “Parallel Reality” displays which allow large crowds of viewers to simultaneously share the same display, yet each see different content. No special glasses are required. These look like ordinary LED displays, and there is little hint that the person next to you is seeing something different. The ability to independently target each person in a crowd of thousands will revolutionize how we receive visual information in public places.

“Parallel Reality Displays”: The 20th century saw the rise of broadcast technologies that allowed us to instantly communicate with large numbers of people. In contrast, the 21st century has been about narrowcasting. The ability to send targeted information on a massive scale to specific individuals via their personal devices has changed how we live and created some of the most successful products and services in human history. However, our addiction to personal screens has had significant downsides. They encumber us and isolate us from each other and our surroundings. Parallel Reality displays are shared displays that can show personalized content to each viewer, even when many people are viewing the same display at the same time. No special glasses are required. This new capability allows us to imagine an alternative future, where the world itself provides the personalized information, services, and entertainment we seek.

Is virtual reality real? It feels more real than a book, and less real than a theme park.

What is your favorite AR/VR application? There’s a lot of potential for VR in gaming. For AR, I’m most fond of assistive apps, such as overlaying medical imaging data during surgery, aiding repair technicians, overlaying thermal data for firefighters, etc.

Parallel Reality is enabled by a revolutionary new pixel technology. Parallel Reality Pixels can simultaneously project up to a million light rays of different colors and brightness.
Next Generation Magic

Michael Ludden, Director—IBM Watson Developer Labs & AR/VR Labs, IBM

Michael Ludden is Director of Product at IBM Watson Developer Labs & AR/VR Labs. As passionate about solving real problems for developers as he is about Artificial Intelligence, Michael is also fascinated by all things futurist, and has been involved in ideation around emerging use cases that include Virtual Reality, conversational interfaces (digital including “chatbot” + physical including “IoT”), and generally the emerging field of AI as a service. Michael's other career highlights include tenures as Google's Developer Marketing Manager Lead at Google Play (Android - Education focus), managing a fantastic team as Head of Developer Marketing at Samsung and being a founding member of the Developer Relations team at HTC. Michael is also a frequently invited Keynote Speaker, Panelist, Master of Ceremonies and has given high profile Product Announcements at conferences around the world including the Consumer Electronics Show in Las Vegas, Mobile World Congress in Barcelona, IFA in Berlin, SXSW in Austin, the Game Developers Conference in San Francisco, TechCrunch Disrupt in New York, various Linux Foundation events including in Seoul, Budapest & New Orleans – and many more.

Company summary: “AI is going to be used left and right in VR – it already is – and we’re just hoping to play a part in the underlying technology that makes it easier for developers to do that,” said Michael Ludden. Ludden is the founder of the VR/AR Labs initiative, which is part of Watson Developer Labs at IBM. The group provides tools for developers to create new tools on the IBM platform that explore different usage opportunities for AI, VR and AR. “I’d love to see people build and advance an emotional story with a virtual partner in a game that’s story based, or something with a productivity tool where maybe you’re using Autodesk or Tiltbrush,” Ludden said. “Really, the sky’s the limit.”

“AI in XR”: During this session, attendees will learn about the intersection between the emerging fields of Artificial Intelligence and Virtual/Augmented Reality, including some of the work IBM Watson is doing with Interactive Speech Interfaces and chatbots in XR. From applications in science, training, therapy, rehabilitation, productivity, education and, yes, gaming, attendees can expect to learn some concrete examples from Michael's own experience and be presented industry trends and understand more about where AI and A/VR are going in both the near and long term future.

“In the upcoming ‘Star Trek: Bridge Crew’ by Ubisoft, a VR-native experience launching this month across Playstation VR, Oculus Rift, and HTC Vive, gamers will be able interact with virtual shipmates in natural language speech, just like their human player counterparts.”
Interview with Ross Young from DSCC

Ross Young is the CEO and Founder of Display Supply Chain Consultants and a member of the Board of Directors at UniPixel and Akhan Technologies. He was previously the Founder and CEO of DisplaySearch and also held executive positions at Samsung LCD and IMS Research. He can be reached at ross.young@displaysupplychain.com

Please give us a summary of what Display Supply Chain Consultants is all about. DSCC is about experienced analysts providing content, insights and expertise to the ever changing global display industry. We are very focused on the OLED supply chain and individual company performance, helping industry participants and investors alike navigate the inflection and turning points in the display industry.

Tell us about the DSCC linkage with SID related to the various Business Conferences at Display Week, to be held May 20-25 at the Los Angeles Convention Center: For the second consecutive year, SID has awarded their Business Track to DSCC to organize and execute. We are honored by this opportunity and will do our best to put on 4 great events. This year is slightly different in that we are also organizing the Investor’s Conference. We are changing it up as attendees will not just hear company presentations from both private and public companies, but will also hear from venture capitalists, private equity firms, investment bankers, sell-side financial analysts and market analysts.

Tell us three highlights of what you expect from each of the events DSCC is supporting at Display Week:

- Business Conference:
  - I am very excited to hear from companies presenting for the first time at this event including panel suppliers Tianma and Visionox, equipment companies Coherent and Coreflow and a leading cinematographer.
  - I also think the analyst session will be very strong with presentations from 3 analysts at DSCC and analysts from SigmaIntell, Mizuho Bank, Yole and The NPD Group.
  - I think the future technology discussions will be very interesting with presenters covering the market outlook for microLEDs, flexible and foldable OLEDs, different implementations of quantum dots, OLED TVs and much more.

- Investor’s Conference:
  - I think attendees will appreciate the analyst sessions with DSCC, Cowen, Susquehanna and Roth sharing their viewpoints on best investment opportunities in the display industry.
  - I am also excited to hear what venture capitalists and private equity firms have to say in regards to what they are looking for from their investment candidates.
  - I think the 12 private and public company presentations will be very interesting as they reveal why they would make an attractive investment and how they intend to deploy capital.

- Automotive Market Focus Conference:
  - Keynotes from Kristin Kolodge of JD Power and Roger Lanctot of Strategy Analytics giving an in-depth analyst perspective of the challenges and opportunities in the auto display market.
  - A presentation from Prof. Karlheinz Blankenbach of the German Flat Panel Forum on Displays in Autonomous Vehicles, followed by a panel Q&A with five industry experts.
  - Presenters from BMW and General Motors bringing the OEM perspective on both flat panel displays and head-up displays.

- Immersive Experience Market Focus Conference:
  - The latest market outlook from industry insiders.
Veritas et Visus
3rd Dimension – Special Edition
May 2018

- Advances in display technology for AR/VR and light field
- Next generation magic, what is coming that no one has even thought of yet.

Will attendees have access to the conference proceedings? Yes, after completing a short survey, attendees will get access to the presentations. I expect that to happen the next day.

Do participants have any special networking opportunities? Yes, we will have a networking reception for all Business Track attendees on Monday night. Tuesday night we will have receptions for the Investor and Automotive conferences. This year we will have double the bartenders, so expect shorter lines for your beverage of choice.

How much does each of the events cost? Are there special bundles for folks who attend more than one event? The cost ranges from $645 - $895 depending on the event and the timing.

Do attendees need to be members of SID? Attendees do need to be members of SID to attend the conferences.

As you prepare for Display Week, is there any one thing that you know about and are really excited to see for the first time? I am really excited to see the developments enabling easier to manufacture foldable mobile displays and emissive TVs.

Of all the things you’ve seen at Display Week in years past, is there something that stands out as being truly transformative in the display industry? Display Week has played a special role in my career. It is where I launched DisplaySearch and it is where DSCC was formed. It clearly is an important event, not just for the technical and business presentations, but the networking and deals that get done.

Is DSCC planning any other conference activities in 2018? Yes, we are. We will be holding 2 events in Japan, an event in Korea and possibly another event in the US fall. The event in Japan will take place June 20th in Tokyo and will deal with how to forecast the OLED market given the lower than expected iPhone X shipments.

Interview with Sri Peruvemba Chair of Marketing, SID

With more than two decades of experience in the technology industry, Sri Peruvemba is the Chief Executive Officer at Marketer International. His 25 years of experience in the electronics industry include marketing LCD, CRT, TFEL, OLED, LED, Plasma and ePaper displays into the mobile, industrial, medical, signage and TV markets. He earned a BSEE, a MBA and a Post Graduate Diploma in Management. Previously, Peruvemba held senior level positions at E Ink, Sharp Corp, TFS Inc, Planar Systems and Suntronic Technology. Peruvemba serves on the board of The Society for Information Display (SID) as well as the board of Visionect Inc., and also serves as advisor to technology companies in Europe, Asia and North America.

Although SID is likely known to the vast majority of display industry enthusiasts, please give us a quick overview of what SID is all about. Society for Information Display is comprised of the scientists, engineers, corporate researchers, and business people of the display industry, valued at over US$130B annually. SID was formed in 1962 to promulgate display technology, and that work continues today. SID’s annual Display Week is the world’s largest technical symposium and exhibition for emerging technologies in the high-growth global electronic display industry, expected to reach $169.2 billion by 2022. Display Week attracts more than 200 industry-leading value-add exhibitors, and more than 7,000 electronic display design, development, and engineering attendees from across the electronic information display value chain. Attendees gather from more than 50 countries to learn, source and network. They represent nearly every major industry sector, including but not limited to aerospace, automotive, consumer electronics, commercial, education, entertainment, financial, government, industrial, marine, medical, military, retail and transportation. SID has chapters located throughout the world.
Tell us how you got involved in SID’s marketing efforts. SID is a heavy tech organization and marketing had been an afterthought for many years, previous SID president Dr Munisamy Anandan realized the need to change and asked that I help SID as a volunteer. In the past 4 years, we have made a lot of progress, we brought a start-up mentality to the process, increased our email open rates from low single digits to well over 20% and in some targeted messaging, over 50%, we created eNewsletters that have been well received, our website underwent a major upgrade while retaining some legacy infrastructure, our email messages are now of higher quality than industry standard, new forums like the CEO Forum, Women in Technology were created by the marketing team and well received, we are working on increasing student involvement, we are partnering with DSCC to upgrade and make our business conferences the best they have been in the history of Display Week, we have built relationships with other societies to cross promote events and the marketing team is working closely with these organizations, I can go on and on…… I am proud of what the marketing team has accomplished. Dr Tara Akhavan, vice chair for marketing has put together a fantastic panel for the Women in Technology forum, this year. With encouragement from incoming SID President Dr Helge Seetzen, we hope to take marketing to greater heights.

Display Week 2018 is coming up – May 20-25 – at the Los Angeles Convention Center. Tell us about a few of the highlights. If electronic displays are mission-critical to an enterprise then Display Week 2018 at the LA Convention Center is their once a year opportunity to get current, keep up, and stay ahead. Highlights during the May 20-24th Display Week includes:

1. Sunday short courses on AR/VR, MicroLEDs and Flexible OLEDs
2. Monday seminars on various display technologies
3. The main symposium will have 400 speakers on almost all display related topics
4. On the commercial side, we have the
   a. Business Conference
   b. Investor Conference
   c. Automotive Display Conference and
   d. Immersive Experience Conference
5. Student job fair
6. The main exhibit runs Tue-Thu, its bigger this year than previous year
7. I-Zone features 50+ startup companies
8. Women in Technology forum returns with an impressive panel
9. We will celebrate the 50th anniversary of LCD technology with a special event
10. CEO Forum: Lessons learned is a new feature to Display Week
11. There are always a lot more…. See: http://www.displayweek.org

About how many attendees do you expect at Display Week 2018? How does this compare to past years? Our pre-registration numbers are up significantly over last year as well as the previous year so we are expecting well over 7000 industry professionals to attend.

How many exhibitors do you expect at this year’s Exhibition? We have over 200 exhibitors signed up, the number of exhibitors as well as the floor space, are already larger than last year, there are a few more last minute sign ups that will make the show even bigger. In addition to this we expect to have about 50+ startup companies and universities at the I-Zone.

One of my personal favorite parts of Display Week is the I-Zone. What should we expect to see this year? The I-Zone committee led by Harit Doshi has once again done a great job in attracting some of the emerging technology start-ups and university initiatives to Display Week. They have received record number of entries and have selected about 50 applicants who would have the opportunity to showcase their technologies. We should expect to see new, emerging display technologies, materials, touchscreens, covering a variety of applications. mailto:http://www.displayweek.org/2018/Program/I-Zone.aspx
As you prepare for Display Week, is there any one thing that you know about and are really excited to see for the first time? There are actually four events that I am very excited about: The Women in Technology forum promises to be awesome, the LCD 50th anniversary event will bring back some great memories for those of us that have been in the industry for a long time, I get to moderate the first ever CEO forum and finally, this years’ Investor Conference has a lot of what the industry has been asking for. For all of us in the electronic display industry, this is the highlight of our year; it will be hectic but very satisfying.

This year, SID is celebrating the 50th year since LCD technology was first introduced. Anything special going on at Display Week? Yes, we are celebrating this occasion with a special event. Industry pioneers and luminaries will gather on May 22 at 2 p.m. to celebrate and discuss LCD’s history, future and impact on our world. Dr. S-T Wu will chair this session. [http://www.displayweek.org/2018/Program/LCD50thAnniversary.aspx](http://www.displayweek.org/2018/Program/LCD50thAnniversary.aspx) The talks will feature:

- Martin Schadt, Ms. High Tech Consulting: From Dynamic Scattering to Field-Effect Liquid Crystal Displays
- Fang-Chen Luo, Adviser, AU Optronics: Development of TFT LCDs
- Koji Suzuki, former CTO, Toshiba Corp.: Development of a-Si TFT-LCD and Low temperature p-Si TFT-LCD
- Kenji Okamoto: Technical Innovation of Wide-Viewing Angle LCD
- In-Jae Chung, former CTO, LG Display: Opening the New Era of Large-Size LCDs
- Jun Souk, former CTO, Samsung: The First 40-inch LCD TV Prototype in 2001/Initiation of the Large-Size LCD-TV Race
- Dr. Mark Verrall, Sr. Vice President, Research & Development, Merck: The (R)evolution of Liquid Crystals
- Terry Scheffer, LCD Consultant: The STN Story
- Dr. J. William Doane, Co-Founder and Senior Advisor, Kent Displays, Inc.: PDLCs: Development and Display Applications

Usually very popular are the Display Week keynote addresses. Please give us a preview of this year’s talks. We have three very impressive speakers that will discuss blue LED, AR/VR and future of OLEDs:

- **Deqiang Zhang**, CEO, Visionox – “OLED Leading to the New Experience of Display”
- **Douglas Lanman**, Director of Computational Imaging, Oculus Research, -- “Reactive Displays: Unlocking Next-Generation VR/AR Visuals with Eye Tracking”
- **Hiroshi Amano**, Nobel Laureate/Director, Center for Integrated Research of Future Electronics/Professor, Institute of Materials and Systems for Sustainability, Nagoya University – Blue LEDs and Transformative Electronics for Developing Sustainable Smart Society
One of the new features at Display Week 2017 was a “Women in Tech” Forum. Back again this year by popular demand – can you tell us a little about what to expect from this year’s “Women in Tech” Forum?

Display Week’s second annual Women in Tech forum brings together female innovators, scientists, executives and experts at the forefront of the field who will share how they’ve navigated - and succeeded in - the unpredictable world of technology. mailto:http://www.displayweek.org/2018/Program/WomenInTech.aspx

Robinne Burrell, Chief Digital Product Officer, Redflight Mobile/Redflight Innovation; Poppy Crum, Chief Scientist, Dolby Laboratories; Rosalie Hou, CEO, ELIX Wireless Charging Systems; Nadya Ichinomiya, Director of Information Technology, Sony Pictures/Co-founder, Women in Tech: Hollywood, Jeanine Jue, Head of Developer Evangelism, Samsung SmartThings Cloud; Tara Akhavan, Moderator/Founder and CTO, IRYStec/Marketing Vice-Chair, Society for Information Display

A new event this year is a “CEO Forum”. Tell us about it. Learning lessons is a part of growth, both personally and professionally. Sometimes it’s a difficult process, but our CEO Forum: Lessons Learned event is sure to make it easier for you to sidestep some landmines on your way to the top. We expect a great panel discussion with these global leaders who will share how successes, as well as not-so-successful ventures, led them to where they are today.

Frank Christiaens, Chairman and CEO, CLEARink Displays; Helge Seetzen, CEO and General Partner, TandemLaunch/President-Elect, Society for Information Display; Paul Travers, Founder, President and CEO, Vuzix; Ross Young, Founder and CEO, Display Supply Chain Consultants; Sri Peruvemba, Moderator/CEO, Marketer International/Board Member, Society for Information Display
Technical papers related to the Immersive Experience
Display Week Symposium, May 20-25, 2018

AR/VR I: Display Systems

Tuesday, May 22 / 11:10 AM - 12:30 PM / Room 515A
Chairs: David Eccles, Rockwell Collins, Salt Lake City, Utah; Vincent Gu, Apple, Inc., Cupertino, California

• VR Standards and Guidelines (11:10 AM - 11:30 AM)
  Matthew Brennesholtz, Brennesholtz Consulting Pleasantville, New York
  Virtual Reality is a new technology end-to-end, from content creation through distribution to display. The differences between VR and systems such as television, cinema or streaming video have led to the development of many new guidelines and standards that can be potentially confusing. This paper will attempt to reduce this confusion.

• An 18-Megapixel 4.3-in. 1,443-ppi 120-Hz OLED Display for Wide Field-of-View High-Acuity Head-Mounted Displays (11:30 AM - 11:50 AM)
  Carlin Vieri, Grace Lee, Nikhil Balram, Google, Mountain View, California
  Sang Jung, Joon Yang, Soo Yoon, In Kang, LG Display Co., Seoul, South Korea
  The world’s highest resolution (18-megapixel, 1,443-ppi) OLED-on-glass display was developed. 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. Foveated driving logic for VR and AR applications was implemented.

• Resolution-Enhanced Light-Field Near-to-Eye Display Using E-Shifting Method with Birefringent Plate (11:50 AM - 12:10 PM)
  Kuei-En Peng, Jui-Yi Wu, Yi-Pai Huang, National Chiao Tung University, Hsinchu, Taiwan
  Hsin-Hsiang Lo, Chuan-Chung Chang, Coretronic Corporation, Hsinchu, Taiwan
  Light-field near-to-eye displays (LFNEDs) can produce lightweight devices and address the accommodation-convergence conflict. However, their low spatial resolution creates a poor immersive experience. In this paper, a new method is proposed to enhance image resolution by using a birefringent plate. The results show that the proposed method improves the resolution of an LFNED.

• Doubling the Pixel Density of Near-to-Eye Displays (12:10 PM - 12:30 PM)
  Tao Zhan, Yun-Han Lee, Shin-Tson Wu, University of Central Florida, Orlando, Florida
  A fast-switching liquid-crystal phase deflector is fabricated to boost the pixel density for AR/VR displays. Through synchronizing and computational factorization, the authors could double the pixel density. This compact image shifter can be integrated into wearable devices to display more pixels per degree and reduce the screen-door effect.

• RGB Superluminescent Diodes for AR Microdisplays (12:30 PM - 12:50 PM)
  Marco Rossetti, Antonino Castiglia, Marco Malinverni, Christian Mounir, Nicolai Matuschek, Marcus Duelt, Christian Velez, Exalos, Schlieren, Switzerland
  Red, green, and blue super-luminescent LEDs (SLEDs) offer benefits like high color gamut, high efficiency, high directionality, and low temporal coherence in the field of displays for augmented reality. This paper briefly reviews the history of the topic to provide a context in which to report recent advances.
3D Holographic and Volumetric Displays Applications

Tuesday, May 22 / 11:10 AM - 12:30 PM / Room 501
Chairs: Jae Hyeung Park, Inha University, Incheon, Korea; Brian Schowengerdt, University Of Washington, Seattle, Washington

- **Computer-Generated Hologram Accelerated by Using Hybrid Iterative Fourier Transform Algorithm (HIFTA) on Phase-Modulator LCOS** (11:10 AM - 11:30 AM)
  Shang-Ting Wu, Shang-Hao Huang, Huang-Ming Chen, Yi-Pai Huang, National Chiao Tung University Hsinchu, Taiwan
  To reduce blur or non-smoothness of the reconstructed images of the iterative Fourier transform algorithm (IFTA) or the symmetrical iterative Fourier transform algorithm (SIFTA), the authors present a hybrid iterative Fourier transform algorithm, which uses three constraints on the area of the target image. Better image quality was achieved in the same number of iterations.

- **High-Contrast Encoding Method for Amplitude-Only Computer-Generated Hologram** (11:30 AM - 11:50 AM)
  Jungkwuen An, Bongsu Shin, Chang-Kun Lee, Chil-Sung Choi, Chorong Yoo, Geeyoung Sung, Højung Kim, Hoon Song, Jae-Seung Chung, Juwon Seo, Kanghee Won, Sung-Hoon Lee, Sunil Kim, Wontaek Seo, Yongkyu Kim, Young Kim, Yun-Tae Kim, Hong-Seok Lee, Duckhyung Lee, Samsung Advanced Institute of Technology, Suwon, Korea
  Burch’s encoding methods for amplitude-only computer-generated holograms have been used for over 50 years. However, the results are noisy due to the offset, making none of the data less than zero, meaning that the electric field of zero amplitude is mapped to the medium gray level in a spatial light modulator. The authors introduce encoding methods that can map the zero amplitude to the zero gray level, which increases the contrast ratio by reducing unnecessary scattering and stray light.

- **A Large-Scale Multi-Projection Light-Field Display Based on Multi-View Sampling Calibration** (11:50 AM - 12:10 PM)
  Lixia Ni, Zhenxing Li, Haifeng Li, Rui Wang, Xu Liu, Zhejiang University, Hangzhou, China
  The authors designed and built a 360-degree large-scale multi-projection light-field 3D display system, including 360 projectors and a cylindrical diffuser, which is 1.8 m high with a radius of 3 m. This system can reconstruct the light field of models in real space and the content can be observed by multiple viewers from different positions simultaneously.

AR/VR II: Light-Field HMDs

Tuesday, May 22 / 02:00 PM - 03:20 PM / Room 515A
Chairs: Nikhil Balram, Google Inc., Mountain View, California; Brian Schowengerdt, University Of Washington, Seattle, Washington

- **Toward Varifocal Augmented Reality Displays using Deformable Beamsplitter Membranes** (2:00 PM - 2:20 PM)
  David Dunn, University of North Carolina - Chapel Hill and NVIDIA Research, Chapel Hill, North Carolina;
  Praneeth Chakravarthula, Qian Dong, Henry Fuchs, University of North Carolina - Chapel Hill, Chapel Hill, North Carolina;
  Kaan Aksit, NVIDIA Santa Clara, California
  In this paper, the authors extend the evaluation of gaze-contingent wide-field-of-view varifocal AR near-to-eye layout by evaluating the optical characteristics of resolution, luminance, and eye box. The most recent prototype dramatically reduces form factor while improving maximum depth-switching time to under 200 ms.
• A Deep Depth-of-Field Near-to-Eye Light-Field Display Utilizing Varifocal Lens and Dual-Layer LCDs (2:20 PM - 2:40 PM)
Mali Liu, Haifeng Li, Xu Liu, Zhejiang University, Hangzhou, China
The authors proposed a deep depth-of-field near-to-eye light-field display utilizing an LC lens and dual-layer LCDs. An optimization scheme was proposed to determine the parameters and a prototype was constructed. This result achieved high resolution, a simple form factor, and improved depth of field, which overcame the convergence-accommodation conflict.

• Design of a High-Performance Optical See-Through Light-Field Head-Mounted Display (2:40 PM - 3:00 PM)
Hekun Huang, Hong Hua, University of Arizona, Tucson Arizona
This paper presents a high-performance integral-imaging-based optical see-through light-field head-mounted display that offers a spatial resolution of 3 arc minutes over a depth range of 3 diopters and a wide see-through view of 65° by 40°. The authors experimentally demonstrate the optical performance in terms of spatial resolution, depth of field, and focus-cue accuracy.

• Stereoscopic / Light-Field Hybrid Head-Mounted Display by Using Time-multiplexing Method (3:00 PM - 3:20 PM)
Chun-Ping Wang, Ping-Yen Chou, Hsin-Hsueh Lee, Jui-Yi Wu, Po-Yuan Hsieh, Yi-Pai Huang, National Chiao-Tung University, Hsinchu, Taiwan; Eng Sik Yee, Hsu-Sheng Hsu, Tsang-Hong Wang, Li-Wei Shih, Jiin-Jou Lih, AU Optronics, Hsinchu, Taiwan
A stereoscopic/light-field hybrid head-mounted display has been proposed that avoids accommodation-convergence conflict and improves the resolution of the light-field image. This new system generates images in light-field and 2D mode, producing higher resolution hybrid images through the persistence of human vision.

AR/VR III: Waveguide Optics

Tuesday, May 22 / 03:40 PM - 05:00 PM / Room 515A
Chairs: W. Hendrick, Rockwell Collins Optronics, Carlsbad, California; Brian Schowengerdt, University Of Washington, Seattle, Washington

• A Flat-Panel Holographic-Optical-Element System for Holographic Augmented Reality Display with a Beam Expander (3:40 PM - 4:00 PM)
Pengcheng Zhou, Yan Li, Shuxin Liu, Quanming Chen, Yunfeng Wang, Sida Li, Yueda Liu, Yikai Su, Shanghai Jiao Tong University, Shanghai, China
We demonstrate and experimentally verify a compact design for an augmented reality (AR) display which uses two holographic optical elements (HOEs) and no traditional optical elements. The two HOEs, which are set in a flat-panel form, are used as beam expander and see-through eyepiece optics simultaneously.

• Shearing Bragg Gratings for Slim Mixed Reality (4:00 PM - 4:20 PM)
Adrian Travis, Clare College, Cambridge University, Cambridge England; James Clegg, Andreas Georgiou Microsoft Research, Cambridge, England; Jinsoo Jeong, Seoul National University, Seoul, Korea
The authors suggest a mixed-reality display in which the eye box follows the eye’s pupil by shearing of the holographic combiner. Tests on Bragg gratings show a switching extinction ratio of 35:1 for an extrapolated shear of several microns, and switching energy of milliJoules or less.

• A Plastic Holographic Waveguide Combiner for Light-weight and Highly-transparent Augmented Reality Glasses (4:20 PM - 4:40 PM)
Takuji Yoshida, Kazutatsu Tokuyama, Yuichi Takai, Daisuke Tsukuda, Tsuyoshi Kaneko, Nobuhiro Suzuki, Akira Yoshikai, Katsuyuki Akatsu, Akio Machida, SONY, Atsugi, Japan; Takafumi Anzai, Sony Global Manufacturing & Operations, Atsugi, Japan
A full-color eyewear display using a novel plastic volume-holographic waveguide has been developed. The waveguide provides over 85 percent high see-through transmittance, and increases the eyewear design flexibility to expand the market for augmented reality (AR).

- **DigiLens AR HUD Waveguide Technology** (4:40 PM - 5:00 PM)
  Jonathan Waldern, Alastair Grant, DigiLens, Sunnyvale California; Milan Popovich, DigiLens, Leicester, England
  DigiLens Switchable Bragg Gratings enable digitally reconfigurable waveguides with form factors and fields of view surpassing those of other technologies. The waveguides can be laminated to integrate functions such as color and eye-tracking seamlessly, with minimal impact on form factor.

- **High-Efficiency Reflective Polarization Volume Grating for Waveguide-Based AR Displays** (5:00 PM - 5:20 PM)
  Kun Yin, Yun-Han Lee, Shin-Tson Wu, University of Central Florida, Orlando, Florida
  A high-efficiency reflective liquid-crystal polarization volume grating (PVG) for augmented-reality display applications is demonstrated. Its angular reflection follows the Bragg condition, and its transmittance for the environment light is high, with negligible scattering. By stacking three PVGs with different periods, a broadband waveguide can be assembled.

## 3D Light-Field and Autostereoscopic Displays

Tuesday, May 22 / 03:40 PM - 05:00 PM / Room 501
Chairs: Shinichi Uehara, Asahi Glass, Tokyo, Japan; Brian Berkeley, Highlight Display LLC, Saratoga, California

- **Reducing Image-Quality Variation with Motion Parallax for Glassless 3D Screens using Linear Blending Technology** (3:40 PM - 4:00 PM)
  Motohiro Makiguchi, Hideaki Takada, Taiki Fukiage, Shin'ya Nishida, NTT, Atsugi, Japan
  Linear blending of viewing zones is desired to reduce the number of projectors for a multiview 3D screen. To preserve image quality when transitioning between adjacent viewpoints, a new method, phase-based disparity, is used to generate viewpoint images for linear blending. Image quality evaluation demonstrates effectiveness of the new method.

- **Toward Direct-View Accommodative Light-Field Displays** (4:00 PM - 4:20 PM)
  Graham Woodgate, Jonathan Harrold, Real D, Oxford, England; Michael Robinson, Benjamin Ihas, Robert Ramsey, Real D, Boulder, Colorado
  Progress is reported on a programmable imaging backlight for a glasses-free light-field display (LFD). Dynamic backlight steering plus a microlens array are used to optimize image quality while reducing data loading with potential for compensating for vision deficiencies. A resolution optimization analysis for the microlens LFD is provided.

- **Super-Multiview Display with Time-Division Multiplexing Parallax Barrier** (4:20 PM - 4:40 PM)
  Hideki Kakeya, University of Tsukuba, Tsukuba, Japan
  A full-HD resolution super-multiview autostereoscopic display is proposed. Time-division multiplexing is used instead of a lenticular lens in order to maintain resolution with many views. Eighteen views (nine for each eye) are realized by time-division sextuplexing, in which the orders of color filters in the two LCD panels are reversed to realize three-fold views.

- **Light-Field Display with Ultra-Wide Viewing Angle and High Resolution** (4:40 PM - 5:00 PM)
  Takeo Koito, Keiichi Saito, Shuji Hayashi, Keiji Takizawa, Japan Display, Ebina, Japan
  A new ultra-wide viewing angle high-resolution light-field display has been developed. High performance viewing angle and resolution properties have been achieved by the use of a new barrier design in conjunction with arrangement of viewing points.
AR/VR IV: Display Electronics

Wednesday, May 23 / 09:00 AM -10:20 AM / Room 515A
Chair: Mainak Biswas, Google, Fremont, CA US

- **An AMOLED Pixel Circuit for 1,000 ppi and 5.87-inch Mobile Displays with AR and VR Applications** (9:00 AM - 9:20 AM)
  Nack-Hyeon Keum, Seong-Kwan Hong, Youn-Sik Kim, Oh-Kyong Kwon, Hanyang University, Seoul, Korea; Chong Chul Chai, Samsung Display, Yongin, Korea
  An AMOLED pixel circuit consisting of three TFTs and two capacitors was proposed for 1,000-ppi mobile displays with AR and VR applications. To verify the performance of the proposed pixel circuit, the emission current and crosstalk errors were simulated and a prototype display panel was fabricated.

- **A Novel Low-Power OLED-Driving Method Based on Gaze Tracking** (9:20 AM - 9:40 AM)
  Jeong-Sik Kim, Seung-Ryeol Kim, Byung-Chang Yu, Seung-Woo Lee, Kyung Hee University, Seoul, Korea
  This paper introduces a new low-power driving method based on gaze tracking for organic light-emitting diode (OLED) displays. In the proposed method, the image data becomes darker as it is farther from the gaze point. It was verified through a psychophysical experiment that the proposed method can reduce power consumption by about 27 percent without degradation in quality of experience (QoE).

- **Deep Tone-Mapped HDRNET for High-Dynamic-Range Image Restoration** (9:40 AM - 10:00 AM)
  Gwon Hwan An, Siyeong Lee, Yong Deok Ahn, Suk-Ju Kang, Sogang University, Seoul, Korea
  This paper proposes deep tone-mapped HDRNET for high-dynamic-range (HDR) image generation in a target display. The proposed network learns the relationship between a single low-dynamic-range (LDR) image and a tone-mapped HDR image. It then restores saturated and black region details, which are lost information in existing images.

- **High-Slew-Rate Low-Static-Power Dynamic-Bias Rail-to-Rail Output Buffer for OLED-on-Silicon VR Microdisplay** (10:00 AM - 10:20 AM)
  Jinyuan Wen, Binjie Liu, Tianyu Zhou, Hesheng Lin, Min Zhang, Peking University, Shenzhen, China
  In this paper, a high-slew-rate low-static-power rail-to-rail output buffer with dynamic bias has been proposed. When input voltage is stable, this buffer can automatically shut down its output transistors so as to reduce the static power consumption. When input voltage changes, it triggers the proposed feedback to supply more tail current. Thus, faster slew rate and superior system stability are achieved. Based on 0.25 µm process, the simulation results show that the proposed buffer with feedback is more stable and can support a wider range of output loading, and the slew rate is 22.8 V/µs, which is 2.6 times larger than that of the buffer without feedback.

Input Technologies for AR/VR

Wednesday, May 23 / 10:40 AM - 12:00 PM / Room 515A
Chair: William Cummings, Microsoft, Clinton, Washington

- **Cyclopean-Eye-Based Binocular Orientation in Virtual Reality** (10:40 AM - 11:00 AM)
  Zhenping Xia, Suzhou University of Science and Technology & Harvard Medical School, Suzhou, China; Eli Peli, The Schepens Eye Research Institute, Massachusetts Eye and Ear, Department of Ophthalmology, Harvard Medical School, Boston, Massachusetts
  Currently, the individual variability in the cyclopean eye’s position is not considered when presenting virtual-reality content. A novel perceptual space model for virtual-reality content is proposed, based on the location of the cyclopean eye. The proposed methodology may improve the viewing experience of stereo display.
  Add to Calendar
• Implementation of a Real-Time Eye Gaze Tracking Solution for ASIC Based On VR Display (11:00 AM - 11:20 AM)
Quan Yang, Gaoming Sun, Yang Gao, Zhenkun Song, BOE Technology Group, Beijing, China; Hongzhen Xue, Beijing BOE Display Technology, Beijing, China
We implemented an ASIC-oriented, real-time eye gaze tracking solution without calling ARM, DSP, calculation IP cores and external memories. Prototype validation on Xilinx kintex-7 platform showed that the sampling rate of the system can be above 380Hz and the accuracy is ±1.5 degree at 200MHz frequency.

• Ultra-High-Speed 6DOF SLAM Using Optical Compression (11:20 AM - 11:40 AM)
Klony Lieberman, Daniel Greenspan, Ouriel Moses, Gilad Barach, Sixdof,Space Jerusalem, Israel
The authors present a novel positioning and localization system that is lightweight enough to perform high-speed, low-latency, inside-out tracking on mobile computing platforms without dedicated hardware. Using optical-domain compression with multiple sensor orientations, the researchers demonstrate an approach capable of running full 6-degrees-of-freedom (6DOF) visual simultaneous location and mapping (SLAM) at 1KHz with sub millisecond latency.

• Semantic Simultaneous Localization and Mapping for Augmented Reality (11:40 AM - 12:00 PM)
Bing Yu, Yang Li, Chao Ping Chen, Nizamuddin Maitlo, Jiaqi Chen, Wenbo Zhang, Lantian Mi, Shanghai Jiao Tong University, Shanghai, China
The authors propose semantic simultaneous localization and mapping (SLAM) for AR, which combines SLAM-based navigation and you-only-look-once (YOLO)-based object detection. They demonstrate that their solution can simultaneously create sparse map points and annotate them with detected objects.

OL ED AR/VR
Wednesday, May 23 / 03:30 PM - 04:50 PM / Room 502B

• Next Generation Virtual Reality Displays: Challenges and Opportunities (3:30 PM - 3:50 PM)
Kunjal Parikh, Jim Zhuang, Kim Pallister, Jun Jiang, Marshall Smith, Intel, Santa Clara, California
High ppi compact form factor requirement is being described using micro-display as key enabler. The trade-off between FOV, size and scalability to meet price targets will be discussed. Overview of system impact using novel display design with Intel’s key technologies will be presented to give holistic view about product vision.

• Microdisplays for Augmented and Virtual Reality (3:50 PM - 4:10 PM)
Gunther Haas, MICROOLED S.A.S., Grenoble, France
Compare existing and upcoming microdisplay technologies with respect to their specific advantages and disadvantages for AR and VR applications. A second part is dedicated to present recent advances in OLED based microdisplays for AR and VR, namely with respect to high brightness, very high resolution, and ultra-low power consumption.

• Gate-Tunable Electron-Injection-Based OLEDs for VR Applications (4:10 PM - 4:30 PM)
Huaping Li, Atom Optoelectronics, Inglewood, California
Differing from conventional microOLED displays controlled with CMOS cuitry, gate-tunable electron-injection-based OLED displays directly modulate the electron injection from cathode to emissive layers by applying an external field effect. This new device structure will remarkably reduce fabrication cost and power consumption.

• Effect of Evaporation Stagnation on the Performance of OLED Devices (4:30 PM - 4:50 PM)
Li Xiaohu, Zhu Haibin, Liu Tun, Jiao Zhiqiang, Yuan Guangcai, BOE Technology Group, Beijing, China
Due to the constraints of sequential evaporation, the evaporation substrate can be in buffer waiting for a period of time. In this study, it was found that stagnation of evaporation during OLED manufacturing decreases the performance of devices, while optimizing the device fabrication process can greatly improve device performance.

- **High Frame-Rate 1” WUXGA OLED Microdisplay and Advanced Free-Form Optics for Ultra-Compact VR Headsets (4:50 PM - 5:10 PM)**

Philipp Wartenberg, Bernd Richter, Stephan Brenner, Uwe Vogel, Fraunhofer FEP Dresden Germany; Marina Buljan, Pablo Benitez, Limbak, Madrid, Spain; Gunther Haas, Microoled S.A.S, Grenoble, France; Mike Thieme, X-FAB, Dresden, Germany

VR glasses are increasingly popular, but they have usually been heavy and oversized. Large-area OLED microdisplays combined with advanced free-form optics are expected to change that, because they make it possible to provide ergonomic and lightweight VR glasses. We report on an 1” WUXGA (1920 × 1200, 2300ppi) 120Hz OLED-on-Silicon microdisplay, as well as ultra-compact optics with the ability to seamlessly combine multiple display chips per eye enabling very high effective display resolutions and a wide field of view (>100°) for immersive VR sensation. Both components have been specifically designed to meet VR application performance needs, e.g., with respect to high frame rates and schemes necessary to avoid visual or balance discomfort, e.g., flickering or motion sickness.

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### Fast-Switching LCDs for AR/VR

**Thursday, May 24 / 09:00 AM - 10:20 AM / Room 515A**

Chairs: Michael Wand, LC Vision, LLC, Boulder, Colorado; Jian Gang Lu, Shanghai Jiao Tong University, Shanghai, China

- **Motion-blur-free LCD for High-Resolution Virtual-Reality Displays (9:00 AM - 9:20 AM)**

  Fangwang Gou, Haiwei Chen, Shin-Tson Wu, University of Central Florida, Orlando, Florida; Ming-Chun Li, Seok-Lyul Lee, AU Optronics, Hsinchu, Taiwan

  The authors report on a new LCD with fast response time, high transmittance, and low voltage for virtual-reality applications. When driven at 120 Hz with 20 percent duty ratio, the motion-picture response time is 1.34 ms, similar to a CRT's, leading to indistinguishable motion blur. This device also enables high-resolution density because only one TFT per pixel is needed.

- **Fast Response Time Advanced High Performance In-plane Switching (AH-IPS) Mode for High Resolution Application (9:20 AM - 9:40 AM)**

  Soo In Jo, Sang-Soon Yoon, Seung Ryull Park, Joun-Ho Lee, Myung-Chul Jun, In-Byeong Kang

  LG Display Seoul South Korea

  The authors propose a fast-response AH-IPS LCD panel suitable for high-resolution and low-latency applications. By developing a new LC and electrode configuration, they obtained a fast response time without the use of over driving or BLU scanning scheme (gray to gray avg /GTGmax = 4.2/6.5 msec).

- **Large Area Multi-Layer Liquid Crystal Phase Modulators Enabled by Two-Photon Polymerization (9:40 AM - 10:00 AM)**

  Daniel Franklin, University of Central Florida, Orlando, Florida; Yun-Han Lee, Ziqian He, Debashis Chanda, Shin-Tson Wu, College of Optics and Photonics, University of Central Florida, Orlando, Florida

  A multi-fold speed enhancement method of liquid crystal phase modulators was demonstrated by laser written sub-micron scaffolds. The versatile fabrication process allows devices with arbitrary liquid crystal alignment and, therefore, polarization dependence. And the prospects of the technology for large area (>0.5 in2) spatial light modulators was discussed.
• **New Liquid Crystals Enable High-Frame-Rate LCoS for Augmented-Reality Displays** (10:00 AM - 10:20 AM)
  
  *Yuge Huang, Ziqian He, Shin-Tson Wu, University of Central Florida, Orlando, Florida*

  Three kinds of new LC mixtures were applied to enable 240-Hz spatial modulators and 1-kHz intensity modulators. A $2\pi$ phase change and 2-ms response time can be achieved at 5.38V with a homogeneous aligned phase modulator. For intensity modulation using a 90° MTN LCOS, a 0.90-ms average gray-to-gray response time at 5V can be achieved.

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**Fast-Switching LCDs for AR/VR -- II**

Thursday, May 24 / 10:40 AM - 12:00 PM / Room 515A

Chairs: Koichi Miyachi, JSR Corporation, Mie, Japan; Shui Chih Lien, CSOT, Shenzhen, China

• **Optimal Fast-Response LCD for High-Definition Virtual Reality Head Mounted Display** (10:40 AM - 11:00 AM)
  
  *Toshiharu Matsushima, Kenta Seki, Shunichi Kimura, Yasushi Iwakabe, Yoshihiro Watanabe, Shinichi Komura, Makoto Uchida, Takashi Nakamura, Japan Display, Mobara, Japan; Tatsuya Yata, Japan Display, Higashiura, Japan*

  A fast-response LCD is necessary for high definition and high-refresh rates in virtual-reality head-mounted displays. In this study, fast-response properties were achieved by SLC-IPS. High transmittance and stable switching were obtained using a one-side branch structure with small irregularities in the electrode.

• **Development of Super-Fast-Response LCD for VR HMD** (11:00 AM - 11:20 AM)
  
  *Takashi Katayama, Shinpei Higashida, Atsuko Kanashima, Kazutaka Hanaoka, Hidefumi Yoshida, Shinji Shimada, Display Device Company, Sharp, Tenri, Japan*

  The authors developed a fast-response LCD. The fabrication process was the same as for a conventional FFS mode. A diamond-shape slit was fabricated for applying the fringe field. The resulting response time was half that of conventional mode. A 2.89-in. diagonal LCD with the resolution of 706 ppi for a VR-head-mounted display (HMD) was developed.

• **High-birefringence Liquid Crystal for Phase-only Spatial Light Modulators** (11:20 AM - 11:40 AM)
  
  *Ran Chen, Shaanxi Normal University & University of Central Florida, Xi'an, China; Yuge Huang, Shin-Tson Wu, University of Central Florida, Orlando, Florida; Jian Li, Minggang Hu, Juanli Li, Xi'an Modern Chemistry Research Institute, Xi'an, China; Zhongwei An, Shaanxi Normal University & Xi'an Modern Chemistry Research Institute, Xi'an, China*

  The authors report a high-birefringence and high-resistivity LC mixture for augmented-reality and virtual-reality displays. When employed in a phase-only liquid-crystal-on-silicon, the measured response time is 2.95 ms, which enables 240 Hz operation without using complicated overdrive and undershoot circuitries.

• **Fast Moving-picture Response-time LCD for Virtual Reality Applications** (11:40 AM - 12:00 PM)
  
  *Chang-Hung Li, SSu-Hui Lu, Szu-Yen Lin, Wei-Hung Kuo, AU Optronics, Hsinchu, Taiwan; Tsung-Ying Hsieh, Ko-Shun Wang, iboson Technology, Hsinchu, Taiwan*

  A 2-in. AHVA LCD with a moving picture response time (MPRT) of 1.1 ms and 0.9 ms at 75Hz and 90Hz frame rates was demonstrated by optimizing the timing of the global backlight technology. Such a fast MPRT for an LCD presents a CRT-like display with crystal-clear motion-image quality.

• **Fast Motion Picture Response Color Filter LCOS for Wearable Applications** (12:00 PM - 12:10 PM)
  
  *Yuet-Wing Li, Wen-Hsu Chen, Chi-Wen Lin, Kuan-Hsu Fan-Chiang, Hung-Chien Kuo, Hsien-Chang Tsai, Himax Display, Tainan, Taiwan*

  An image blur free Color Filter LCOS (CFLCOS) for augmented reality (AR) applications is proposed, combining 1.9 ms liquid crystal response time; analog frame buffer and a 480 fps refreshing rate. The MPRT of such a device can be less than 1.5 ms.
Automotive Head-Up Displays

Thursday, May 24 / 10:40 AM - 12:00 PM / Room 501
Chairs: Rashmi Rao, Harman International, Mountain View, California; Haruhiko Okumura, Toshiba, Kawasaki, Japan

- **Superiority of Monocular AR when Continuous Viewing is Required** (10:40 AM - 11:00 AM)
  Akihiko Kitamura, Yasunori Kinosada, Kazumitsu Shinohara, Osaka University, Suita, Japan; Takahiko Kimura, Kansai University of Welfare Sciences, Kashiwara, Japan; Takashi Sasaki, Haruhiko Okumura, Aira Hotta, Toshiba, Kawasaki, Japan
  We compared binocular augmented reality (AR) presentation and monocular AR presentation in a situation where continuous viewings of AR images were required. In the monocular presentation, participants could detect more changes in their peripheral field of view than the binocular presentation. Observers might be able to acquire more information in the monocular presentation.

- **Volume Optimized and Mirror-Less Holographic Waveguide Augmented Reality Head-Up Display** (11:00 AM - 11:20 AM)
  Bjoern Richter, Continental Automotive, San Jose California; Wolff von Spiegel, Continental Automotive, Babenhausen, Germany; Jonathan Waldern, DigiLens, Sunnyvale California
  Trust in highly autonomic driving cars increases by intuitive dialogues between the driver and driving assisting systems. Predestined are augmented reality head-up displays (AR HUD) able to display virtual images in large projection distances in front of the driver in context with the environment. In this presentation a volume optimized mirror-less AR HUD solution will be presented, based on a disruptive holographic waveguide technology with first results based on a real demonstrator.

- **Holographic Grating to Improve the Efficiency of a Windshield HUD** (11:20 AM - 11:40 AM)
  Philippe Coni, Jean-Luc Bardon, Natacha Damamme, THALES Avionics, Merignac, France; Seth Coe-Sullivan, Fedor Dimov, Luminit, Torrance, California
  A windshield head-up display (WHUD) using an embedded transparent holographic optical element (THOE) film to improve system efficiency is presented. The reflectance efficiency of today's HUDs is very poor, at less than 20 percent. With an efficiency of up to 80 percent, THOE uses four to five times less power, in a more compact size, and has a lighter weight and longer lifetime.

High-Resolution LCDs for AR/VR

Thursday, May 24 / 01:30 PM - 02:50 PM / Room 515A
Chairs: Philip Chen, National Chiao Tung University, Hsinchu; Linghui Rao, Microsoft, Redmond, Washington

- **High-Resolution IPS-LCDs Fabricated with Transparent Polyimide Substrates** (1:30 PM - 1:50 PM)
  Shinichiro Oka, Yosuke Hyodo, Lu Jin, Yohei Yamaguchi, Shinichi Komura, Japan Display, Mobara, Japan; Genki Asozu, Emi Higano, Toshiyuki Higano, Japan Display, Nomi-gun, Japan
  Plastic film IPS-LCDs were fabricated with transparent polyimide (PI) substrates. Conventional transparent PI substrates have a large coefficient of thermal expansion and cause high retardation in thickness direction. We developed a new fabrication process and sheet design that improves upon these characteristics.

- **High-Performance Displays for Wearable & HUD Applications** (1:50 PM - 2:10 PM)
  Akheelesh Abeeluck, Edmund Passon, Compound Photonics, Chandler, Arizona; Andrew Iverson, Howard Goetz, Compound Photonics, Vancouver, Washington
  This paper will introduce a scalable, fully digital platform for AR/MR that supports up to 4K resolution and provides low diffraction loss and high contrast. The new software-definable drive architecture is optimized for real-time AR/MR & HUD applications, where high frame rates, low latency & short persistence are critical.
- **Sub-KHz 4,000-ppi LCOS Phase Modulator for Holographic Displays (2:10 PM - 2:30 PM)**
  Jhoo-Pu Yang, Huang-Ming Chen, National Chiao-Tung University, Hsinchu, Taiwan; Yuge Huang, Shin-Tson Wu, College of Optics and Photonics, University of Central Florida, Orlando, Florida; Cynthia Hsu, Lily Ting, Ron Hsu, Jasper Display, Hsinchu, Taiwan
  A 4,000-ppi phase-only liquid-crystal-on-silicon spatial light modulator (LCOS-SLM) filled with UCF-L1 NLC was assembled and evaluated. The resulting LCOS panel demonstrated 1.59 ms of linear full-phase-modulation response time at 45 °C. A low-latency driver solution based on 1,920 x 640 at 240 Hz frame rate and 720 Hz data frame rate was presented.

- **Active-Matrix Field-Sequential Color Electrically Suppressed Helix Ferroelectric Liquid Crystal for High-Resolution Displays (2:30 PM - 2:50 PM)**
  Liangyu Shi, Abhishek Srivastava, Alex Cheung, Tsz Kin Ho, Hoi Sing Kwok, Vladmir Chgrinov
  The Hong Kong University of Science and Technology Kowloon Hong Kong; Chia-Ting Hsieh, Ching-Lang Hung, Ching-Hsiang Lin, Ching-Huan Lin, Norio Sugiuara, Chia-Wei Kuo, AU Optronics, Hsinchu, Taiwan
  A 3-in. 250-ppi active-matrix field-sequential color electrically suppressed ferroelectric liquid-crystal (ESHFLC) display has been successfully made. The response time is ~10µs at 6.67V/µm. The contrast ratio is more than 10K:1. A 3T1C pixel circuit provides analog grayscale via pulse-width modulation. This display behaves as an IPS/FFS device and has many advantages over IPS/FFS, such as lower color shift and much reduced image blur.

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**Human Factors in AR/VR**

Thursday, May 24 / 03:10 PM - 04:30 PM / Room 515A
Chairs: Yuning Zhang, Southeast University, Nanjing, Jiangsu, China; Takashi Shibata, Tokyo University of Social Welfare, Gunma, Japan

- **Maximum Comfortable Luminance of Head-Mounted Displays Under Various Surround Illuminations (3:10 PM - 3:30 PM)**
  Hyeyoung Ha, Youngshin Kwak, Ulsan National Institute of Science and Technology, Ulsan, Korea; Hyosun Kim, Young-jun Seo, Seungbae Lee, Sung-Chan Jo, Samsung Display, Yongin, Korea
  The comfortable luminance for head-mounted displays (HMDs) was investigated under four different surround illuminations. Participants adapted to a surround illumination and then viewed a white uniform field in an HMD at several luminances. Subjective comfort was positively correlated with surround luminance, suggesting the need for adaptive luminance control of HMDs.

- **Sensitivity to Peripheral Artifacts in VR Display Systems (3:30 PM - 3:50 PM)**
  David Hoffman, Zoe Meraz, Eric Turner, Google, Mountainview, California
  The authors evaluated the visual system’s sensitivity to different classes of image impairment that are closely associated with rendering in VR systems. In the far periphery, the visual system was sensitive to volatile down-sampling solutions. Temporally stable down-sampling in the periphery was generally acceptable, even with sample spacing up to half a degree.

- **The Quantization of Cybersickness Level Using EEG and ECG for Virtual-Reality Head-Mounted Display (3:50 PM - 4:10 PM)**
  Yi-Tien Lin, Yu-Yi Chien, Hsiao-Han Wang, Fang-Cheng Lin, Yi-Pai Huang; NCTU, Hsinchu, Taiwan
  Cybersickness is a problem of virtual-reality (VR) applications. An objective method to quantize cybersickness using electroencephalography (EEG) and electrocardiography (ECG) is described. Higher levels of cybersickness are correlated with the amplitude of the gamma band (>32Hz) and increased heart rate. These biosignals predict cybersickness and could be used as a warning system for VR devices.
• **Ergonomic Approaches to Stereoscopic and 360 Images** (4:10 PM - 4:30 PM)
  *Takashi Kawai, Waseda University, Tokyo, Japan*
  Where people look when viewing stereo pair imagery and 360 images that are two dimensional their eye scanning pattern can change. This paper explores the differences between these two distinct viewing modes.

• **Resolving the Vergence Accommodation Conflict in VR and AR via Tunable Liquid Crystal Lenses** (4:30 PM - 4:50 PM)
  *Yoav Yadin, Shamir Rosen, Yariv Haddad, Yuval Vardi, Itamar Grutman; Deep Optics, Petach Tikva, Israel*
  In real 3D vision, vergence and accommodation are strongly correlated, such that adjusting one of them triggers the other. The mismatch between the two in VR and AR often causes nausea and fatigue. We present integratable electrical lenses which allow dynamically adjusting the focal plane to match the virtual distance.

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**Measurement Challenges for Near-to-Eye Displays**

Friday, May 25 / 09:00 AM - 10:20 AM / Room 515A
Chairs: Michael Becker, Display-Messtechnik&Systeme, Rottenburg am Neckar, Germany; Chuck Yin, Oculus, Menlo Park, California

• **Requests to Lenses in Measuring Units Evaluating Near-to-Eye Displays** (9:00 AM - 9:20 AM)
  *Norbert Schuster, Sustar-Optics, Heilbronn, Germany; Udo Krueger, Tobias Porsch, TechnoTeam Bildverarbeitung, Ilmenau, Germany*
  Imaging luminance and color measuring devices (ILMDs, ICMDs) with adapted measuring lenses provide effective one-shot solutions to evaluate modern near-to-eye displays. Basic parameters of those lenses depend on the near-to-eye arrangements under test. The application of two new measuring lenses shows a way to generate a series of measuring lenses.

• **Standardizing Fundamental Criteria for Near-to-Eye Display Optical Measurements: Determining Eye-Point Position** (9:20 AM - 9:40 AM)
  *Russell Draper, Rupal Varshneya, U.S. Army CERDEC, NVESD, Ft. Belvoir, Virginia; John Penczek, National Institute of Standards & Technology, Boulder, Colorado; Paul Boynton, National Institute of Standards & Technology, Gaithersburg, Maryland*
  The fundamental criteria for measuring the near-to-eye display eye point are evaluated in terms of their impact on device performance. Several eye-point determination techniques are used to illustrate how the various derived eye-point locations affect primary display characteristics such as angular alignment, field of view, and center resolution.

• **Contrast, Resolution, and Parallax Measurements of Near-to-Eye and HUDs** (9:40 AM - 10:00 AM)
  *Richard Austin, Robert Calpito, Bruce Denning, Gamma Scientific, San Diego, California*
  The authors give a detailed investigation of the effects of rotation of a large (5-mm) diameter entrance pupil positioned in the qualified viewing space (QVS) on resolution and image distortion measurement results. Rotation such as would occur in the human eye is highlighted.

• **Head Movement-Based Motion-Blur Measurement System for HUDs** (10:00 AM - 10:20 AM)
  *Keon-Woo Kang, Min-Woo Seo, Suk-Ju Kang, Sogang University, Seoul, Korea; Sang-Lyn Lee, Ho-Chul Lee, Eui-Yeol Oh, Jong-Sang Baek, LG Display, Paju-si, Korea*
  This paper proposes a head movement-based motion-blur measurement system for head-mounted displays (HMDs). The proposed system simulates head movement to consider the physical rotation applied to HMDs. Motion blur is quantitatively measured by calculating the moving-picture response time (MPRT) from images taken with a high-speed camera.
Enhancements to AR/VR

Friday, May 25 / 10:40 AM - 12:00 PM / Room 515A
Chairs: Susan Jones, Nulumin Corporation, Bellevue, Washington; Fang-Cheng Lin, Apple, Cupertino, California

- **Accommodative AR HMD Using Birefringent Crystal** (10:40 AM - 11:00 AM)
  Byoungho Lee, Jong-Young Hong, Seokil Moon, Gang Li, Seoul National University, Seoul, Korea
  A near-eye augmented display is proposed, using a birefringent crystal, to provide accommodation. The birefringent crystal has polarization-dependent property, depending on the refractive index. It is been used to accommodate head-mounted display by making multiple image planes. Two near-eye display systems are analyzed for interpolation method between multiple image planes.

- **Compact See-Through Near-to-Eye Display with Depth Adaption** (11:00 AM - 11:20 AM)
  Yun-Han Lee, Guanjun Tan, Kun Yin, Tao Zhan, Shin-Tson Wu, University of Central Florida, Orlando, Florida
  Based on the recent development of Pancharatnam-Berry deflectors and lenses (PBDs and PBLs), the authors propose a compact and lightweight near-to-eye display system with depth adaption. The compact design results from the polarization selectivity of PBD waveguide couplers, and the fast-switching PBLs can be exploited for generating correct light fields.

- **Color Adjustment for Video-See-Through AR and Camouflage Application** (11:20 AM - 11:40 AM)
  Yu-Kai Chen, Chun-Ho Chen, Yi-Pai Huang, National Chiao-Tung University, Hsinchu, Taiwan
  The authors realized a color-adjustment system with a commercial camera and a borderless LED panel for video-see-through AR and camouflage applications. Using a high dynamic range (HDR) and color-mapping technique, CIE XYZ of a real scene can be effectively obtained. The CIEDE2000 as evaluation indicator was 3.01 and indistinguishable visual perception was achieved.

- **A Plastic Electrochromic Dimming Device for Augmented-Reality Glasses** (11:40 AM - 12:00 PM)
  Akio Machida, Koji Kadono, Yui Ishii, Tadahiro Kono, Hidehiko Takanashi, Akihito Nishiike, Kazumasa Nomoto, SONY, Atsugi, Japan; Hidetada Suzuki, Yasuro Nakagawa, Kuniaiki ANDO, Daisuke Kasahara, Ayari Takeda, Sony Global Manufacturing & Operations, Aichi, Japan
  The authors have developed an electrochromic dimming device on a plastic substrate with high transparency modulation from 70 percent to 10 percent and bending radius below 30 mm. It worked with >10,000 endurance cycles and in high temperature and humidity conditions. Its application to an AR glass enables clear image visibility for indoor and outdoor use.

- **Ultra-Thin Variable Transmission Smart Window by One-Step Patterned Photoalignment** (12:00 PM - 12:10 PM)
  Su Pan, Cuiling Meng, The Hong Kong University of Science and Technology, Hong Kong, China; Man Chun Tseng, Shu Tuen Tang, Hoi Sing Kwok, The Hong Kong University of Science and Technology, Hong Kong, China
  Smart windows are attractive because of their numerous advantages such as elegance in construction design and energy conservation. Smart windows with variable transmission are especially desirable for obvious reasons. The simplest way to make a variable transmission smart window is to use two patterned polarizers, and control the transmission by changing the relative position of the two polarizers. We have demonstrated a high-dichroic-ratio polarizer by photoalignment and proposed a simple one-step photo-copy method to realize a continuous axis varying polarizer. The patterned polarizer shows high optical performance, and its thickness is as thin as 100 nm, which is favorable in practical window applications.
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