

2014 SHOW ISSUE / WEARABLE DISPLAYS

# Information DISPLAY

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**SID**  
SOCIETY FOR INFORMATION DISPLAY

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## Display Industry Awards: The Future Is Flexible



**Products on Display at  
Display Week 2014**

**The Virtues of  
Quantum Dots**

**The Emerging "Sweet Spot"  
for Mobile Displays**



**Using Google Glass for  
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**Wearable Display  
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**Technology Transfer  
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Cover Design: Acapella Studios, Inc.

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- Digital Pen Technology
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- Tablets for Medical Applications
- Detail Reproduction Performance in OLED and LCD TVs

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## Welcome to Display Week

by Stephen Atwood

Welcome to San Diego, California, for our 51st annual Display Week event. This year, we continue what is expected to be a long run of Display Week meetings on the West Coast of the U.S., moving on from here to San Jose in 2015 and many following years in the Bay Area of California.

This year, we are on the harbor in beautiful San Diego, a short drive from some of the most beautiful mountains and canyons anywhere in North America. Ever since the explorer Juan Cabrillo first claimed the area for Spain in 1542, San Diego has been a much sought-after region for farming, trade, and commerce. More recently, it has become the home of many high-technology companies with numerous outstanding innovations in displays.

There are many rewarding things to do here, including visiting the San Diego Zoo, the USS Midway (site of Wednesday night's special networking event), and especially the waterfront. The city's Mission Bay Park is the largest man-made aquatic park in the country, with 4,235 acres of beaches and hiking and jogging trails. My hope is that regardless of how booked your Display Week schedule really is, you will find the time to explore at least the area near the Convention Center and enjoy what many have called one of the best climates in all of North America.

The Display Week calendar this year is jam-packed with events including the Annual Symposium Tuesday through Friday, the Business and Investors Conferences on Monday and Tuesday, the Market Focus Conferences covering interactivity and flexible displays on Wednesday and Thursday, and our outstanding keynote talks on Tuesday morning. Included in all this is the world famous Display Week Exhibition, which takes place Tuesday through Thursday, as well as countless short courses and seminars throughout the week from Sunday onwards. It's impossible to see it all, so bring your colleagues – lots of them, and divide and conquer to suit your interests.

Getting the most out of your Display Week experience involves some serious planning. Take time to review the full program and mark off the things that are most important to you. Plan your days to see as many things as you can and coordinate with colleagues to make sure the stuff you cannot see is covered by others. Usually, there are dozens of presentations and exhibits that I know I want to attend, but I also find many surprises that I can only discover if I explore as much as possible. It's a wonderful mix of the expected and unexpected that awaits you. I've never left a Display Week without at least a handful of stunning new discoveries that end up proving invaluable countless times in my day-to-day work.

This issue of *ID* can be particularly useful for your planning because it features our "Products on Display" coverage, which is assembled each year by our staff to help you get the most out of the exhibition. Also, as we do every year, we've invited a prestigious team of freelance technology enthusiasts to report on all the happenings, and they will be hard at work covering everything they can. We'll have daily blog updates on the *ID* Web site ([www.informationdisplay.org](http://www.informationdisplay.org)) and a full issue of post-show coverage later in the year. If you have a question about anything on the exhibit floor, just email us at [press@sid.org](mailto:press@sid.org) and we'll get your question to the right reporter to see what we can find out.

One of the most noteworthy happenings this year is the special event celebrating the 50th Anniversary of the Plasma Display Panel. Display Week attendees will have a

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## Panasonic Ships Final Plasma TVs

In March of this year, Panasonic shipped its last plasma display panel, bringing an end to a 13-year run that found the company's plasma TVs earning accolades from reviewers and audiophiles even as market share shrank in later years. Panasonic produced its last plasma panel in December 2013 and made the announcement that the end was near even earlier, in a press release dated October 2013.

The release read, in part: "Until now, due to the superiority of the picture, Panasonic's PDPs have received high appraisal and there has been firm demand from customers worldwide. However, due to rapid, drastic changes in the business environment and a declining demand for PDPs in the flat-panel display market, it was judged that continuing the business would be difficult and a decision was made to stop production."<sup>1</sup>

Last fall, when the release was issued, many in the industry thought it was a sign that plasma was bowing out to OLED TVs. Six months later, OLED TVs have yet to really take off; plasma's exit may have more to do with the fact that LED-backlit LCD TVs continue to improve and grow in popularity. As of this writing, both Samsung and LG, heavily invested in the LCD business, were still making plasma TVs. A year ago, Samsung's PNF8500 plasma TV won the annual Value Electronics' TV shootout, a high-profile industry indicator of high-end TV performance.


<sup>1</sup><http://panasonic.net/ir/relevant/2013/en131031-1.pdf>

## GLT Introduces Flexible and Non-Linear Light Guides

Global Lighting Technologies (GLT), a maker of edge-lit LED-based light guides, is now offering flexible and non-linear curved light guides (Fig. 1).

This new product capability was made possible through a thin-film embossing process that allows light guides to be manufactured to 0.25 mm or less in thickness, and through a change to the manufacturing process of the optical extraction features embedded in the light guides, allowing GLT to create the extraction features onto curved surfaces.

The new light guides can be integrated into a variety of products, from overhead lighting



### Special Plasma Event

Plasma technology played a vital role in making the flat-panel display industry the success it is today. To mark plasma's impact, SID is offering Display Week 2014 attendees a rare opportunity to hear from and meet some of the individuals whose groundbreaking work made plasma display possible.

At 5:00 pm on **Tuesday, June 3**, SID will host a Special Event, "**Celebration of the 50th Anniversary of the Plasma Display Panel**," following the regular plasma session. It will include talks by Professor Donald L. Bitzer, co-inventor of the plasma display panel; Tsutae Shinoda, inventor of color plasma display technology; and SID Past-President Larry F. Weber and SID Fellow Roger L. Johnson, former students of Bitzer's. Following the session, which will run from 5:00 to 6:30 pm, there will be a sponsored reception from 6:30 to 8:30 pm.

and wall sconces to automotive interior/exterior lighting such as dome lights, passenger compartment lighting, and daytime running lights, as well as household appliances and consumer-electronics devices.



**Fig. 1:** GLT's new flexible light guides can be used in flexible or mechanically curved products.

## Facebook Announces Oculus VR Acquisition; ZeniMax Launches IP Protest

Facebook recently announced that it will acquire Oculus VR, Inc., a 2-year-old immersive-reality headset maker based in California, for \$2 billion. Oculus has already generated interest from developers and has taken orders for more than 75,000 development kits for its VR headset, the Oculus Rift (Fig. 2). The headset, which is being promoted as lightweight, affordable, and high-performing, can be used to play videogames, watch movies, or operate as a computer monitor.

Shortly after the acquisition announcement, ZeniMax Media, Inc., a Maryland-based videogame maker, claimed rights to the intellectual property that powers the Oculus Rift. Oculus representatives are dismissing the claim publicly, for the time being, and the transaction is expected to close in the second quarter of 2014.<sup>2</sup>

What Facebook might do with the hardware acquisition is the subject of much speculation, but the synergies are many, according to representatives from both Facebook and Oculus. Certainly, the infusion of cash helps the startup Oculus, and the hardware helps Facebook on its (suspected) journey toward market domination.

<sup>2</sup><http://online.wsj.com/news/articles/SB10001424052702303948104579534013624548846?mg=reno64-wsj&url=http%3A%2F%2Fonline.wsj.com%2Farticle%2FSB10001424052702303948104579534013624548846.html>



**Fig. 2:** The Oculus Rift is a virtual-reality headset with low-latency 360° head tracking and an ultra-wide field of view.

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# president's corner



## Changing Times

by **Brian Berkeley**  
**President, Society for Information Display**

As of this writing, final preparations are being made for Display Week 2014, which will be held during the first week of June. The display industry and academia will gather in San Diego, California, to present, teach, learn, show, and tell about the latest technical and commercial progress in

our field. Networks will be tapped and expanded, deals will be done, press releases will announce key developments, and there will certainly be a buzz in the air as the world's biggest display event reveals this year's advancements. Our field moves so quickly, and attending the annual Display Week conference is perhaps the single best way to keep up with all of the rapid change.

In a previous column, I noted that SID was founded in California just over 50 years ago. Over the last 20 years, fully one-half of the annual Display Weeks have been held in California. This ratio will only increase in the coming years, owing to exhibitor feedback, international access, and proximity to Silicon Valley, especially considering the large concentration of companies headquartered in California that integrate and consume displays. In 2015, Display Week will be held in San Jose, right in the heart of Silicon Valley. Then, in 2016, Display Week will return to San Francisco at the Moscone Center. We look forward to welcoming you to the Golden State this year and in future years.

This article will be my last "President's Corner" column, for my 2-year term as SID President is nearing its end. I will continue serving on SID's Executive Committee as Past President. SID's bylaws, which can be found at <http://www.sid.org/About/Bylaws.aspx>, specify term limits for SID's officers. This turnover is a healthy thing for the society. The current progression through SID's Executive Committee involves 2-year terms starting as Secretary and continuing in succession through each of the roles of Treasurer, President Elect, President, and Past President. Each of these positions comes with various responsibilities. For example, the President Elect chairs the Senior Member Grade and Long Range Planning Committees, and the Past President chairs the Nominating Committee, which selects the future leadership of SID.

Although volunteering at the senior-most SID Executive Committee level involves a 10-year commitment, SID always needs volunteers at all levels. Please rest assured that you can assist at the chapter level or even with SID's international activities without making a decade-long commitment! I hope you will consider volunteering with SID. Volunteers are the lifeblood of SID, and helping to organize a local conference, referee technical papers, work on the website, or support SID in any number of other ways can be very rewarding.

The last 2 years have seen remarkable change in the world of displays, including improvements in all aspects of display performance, input technologies, materials, flexibility and form factor improvements, process technologies, cost innovation, and positive developments across the board. I am confident that this trend will continue. I am also happy to report that the past 2 years have been quite positive for SID as well, including membership growth, increased conference and publication quality, and improved operational and financial health.

During Display Week 2014, Dr. Amal Ghosh will take the reins as SID's incoming president. It has been a privilege to serve the SID membership during these past 2 years, and especially at the society's 50th anniversary. Special thanks go to Samsung for encouraging and supporting my continued participation on SID's Executive Committee.

Please give Amal your support and thank you for your membership with SID. ■

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## What's Up with Wearables?

by Xiao-Yang Huang

Wearable electronics are in the news these days and on the schedule for the Technical Symposium at Display Week 2014.

It's hard to miss the topic of wearable electronics lately. Entire Web sites, such as CrunchWear.com, are dedicated to the phenomenon. At the time this issue was going to press, Gizmag.com was updating its Wearable Electronics department about every other day, with the latest entry being a piece on LG's still-under-development G Watch, one of the next-generation "smart watches." IDTechEx had just released a new report, "Wearable Technology 2014–2024: Technologies, Markets, Forecasts." The report was accompanied by a press release from the market-research firm that poked fun at some of the latest wearable innovations (animal ears on a headband that move according to your brain waves; fitness monitors whose popularity seems to have peaked), while noting that the wearables market will still climb to \$70 billion by 2024.

Wearable electronics aren't new – hearing aids, pacemakers, iPods, and wrist-watches come to mind. But in recent years and months, the platform has clearly fired both public and industrial imaginations: new products keep arriving. One reason for their popularity is that they represent the next step in ubiquitous computing. Some wearables – those exercise monitors, for example – sync with your smartphone and also your desk computer. When done right – and manufacturers still seem to be trying to get it right – a wearable device should either augment or replace another computing platform in a useful, non-trivial way.

Another reason for wearables' popularity is that for manufacturers and retailers, they represent a new direction for innovation – and profit. And also, wearables are fun and interesting. The media will continue to cover them as a result. It's difficult to resist a story about shoes with silicon insoles that interface with a navigation system, tickling your feet to keep you heading in the right direction.

### A Wearable by Any Other Name ...

In simplest terms, wearables are clothing, accessories, or other devices you can strap to your body or tote in a pocket that incorporate computers or some kind of electronics. They can be flexible, like a fabric-based display, or fixed, like a Google Glass headset. The latter category is currently more prevalent, with flexible displays, wearable or otherwise, in earlier stages of development and mass production.

Wearables are of interest to the display community because nearly all of them incorporate displays. Creating a display that will meet the demands of wearable technology requires, to different degrees, miniaturization, ruggedization, and integration. These are intriguing challenges for researchers; the Technical Symposium at Display Week 2014 received many papers in the wearables category this year. Wearable Displays have been designated as a special focus area for 2014, and three wearables sessions will be held at Display Week, as listed in the sidebar, "Wearable Display Presentations at Display Week 2014." The first two sessions deal primarily with fixed or rigid wearable technology, such as visors or glasses; the third focuses on flexible displays, such as OLEDs on textiles.

Information Display is pleased to present versions of two of these papers (edited for our readership) in this issue of the magazine. The first, "Augmented Edge Enhance-

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## Display Week 2014 Networking Events

June 1–6, 2014

*Looking to meet up with your colleagues in the display industry to discuss technology, business, or just socialize? The events below present just that type of opportunity:*

### Annual Awards Dinner, Monday:

Each year, SID recognizes individuals that have played a critical role in improving the display industry. This year's winners will be honored at an awards banquet taking place the evening of June 2 at the San Diego Convention Center.

### Business Conference Reception, Monday:

Follows the Business Conference, please note conference attendance is required for admission.

### Annual Award Luncheon, Wednesday:

The annual Best in Show and Display Industry Awards Luncheon will take place at noon on Wednesday, June 4. Both awards are peer-reviewed, such that the luncheon is well-attended by captains of industry for high-level networking and recognition of the best in the industry over the last year.

### Investors Conference:

The IC will feature presentations from leading public and private companies in the display technology supply chain and encourage questions and discussion between presenters and participants. Concludes with Drinks & Displays: Networking Reception with Presenters and Investors

### Market Focus Conference Reception, Wednesday:

Follows the Wednesday Market Focus Conference, title and program TBD, please note conference attendance is required for admission.

### Special Networking Event, Wednesday:

This year's event will be held aboard the aircraft carrier and museum the USS Midway, located in the San Diego harbor near the convention center.

Henkel is graciously sponsoring this event, which will include a light meal of drinks and appetizers.





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# 2014 SID Display Industry Award Winners

*Once again, The Society for Information Display's Display Industry Awards Committee has selected six award winners that have advanced the state of the art of display products and technology in the categories of Display of the Year, Display Component of the Year, and Display Application of the Year.*

Compiled by Jenny Donelan

**Y**OU do not need to read a word of this year's Display Industry Award descriptions to guess at a general trend – all you have to do is look at the pictures. Three of this year's winners are curved devices. Samsung's curved AMOLED panel forms the basis of the Galaxy Round smartphone, which is curved from side to side so it can easily fit in your hand. LG's G Flex OLED-based smartphone is also curved, in this case from top to bottom, to fit more easily against a user's face. LG's OLED TV makes a curvaceous statement on a large scale – 55 in. Two of this year's winners – Universal Display's green phosphorescent UniversalPHOLED emitter and Canatu Oy's Carbon NanoBud Film – are materials that support flexible and hence curved displays.

In addition, it would be wrong not to point out that four of the six winners this year are OLED based. There has been some discussion in recent months about whether OLEDs really are destined for success. Based on these products, the answer would seem to be yes. According to Display Industry Awards Chair Wei Chen, "The past year marked significant breakthroughs for OLED technology, with the commercialization of flexible OLED displays, large-sized OLED panels for TV, and the green phosphorescent emitter material, all for the first time. The 2014 SID Display Industry Awards recognize these great achievements."

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The odd product out this year is Google's Chromebook Pixel, an LCD-based laptop with nary a curve. What it has, though, are stunning imagery and great design. Not everyone has jettisoned their laptop for a tablet or a smartphone – laptops are still where a lot of the real work gets done. Kudos to Google for taking on an everyday product category and making an extraordinary product. It's this kind of imagination (and hard work) that make the display industry so dynamic. Research and innovation are alive and well.

Every year, the display industry continues to amaze and inspire us. Please join us in saluting this year's Display Industry Award winners, the best of the best.

## **Display of the Year**

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

### **Gold Award: Samsung Display's 5.68-in. Curved (Flexible) AMOLED Display**

The Samsung 5.68-in. FHD curved AMOLED display represents a major milestone for the entire display industry – the world's first truly flexible full-fidelity display technology to be mass produced and adapted for use in a mass-market product. Now being produced on a plastic substrate, the new Samsung display panel enables smartphones such as the Samsung Galaxy Round to be curved, significantly improving a user's grip.

Smartphone users will be able to comfortably hold a larger-screen version of the panel with just one hand. The smartphone has a curvature of 400 mm, while human hands have a natural curvature of about 300–500 mm. Also, the display enables a more visually immersive mobile experience with a "landscape view" aspect ratio of 1.88:1, comparable to the Vista Vision technology (1.83:1) now used in most movie theaters. In addition, the curved screen is more readable thanks to a significant reduction in light reflectance. Samsung's new curved display will later evolve into bendable and foldable displays that will further revolutionize the use of smartphones and other mobile-product form factors.

The Samsung 5.68-in. FHD flexible display used in the Galaxy Round is fabricated on a special type of plastic that is capable of withstanding high processing temperatures to ensure adequate mobility,  $V_{th}$ , and other TFT characteristics. The plastic substrate is fabricated on carrier glass, and after TFT processing and organic material deposition, the substrate is removed from the carrier glass using a proprietary liftoff process.

### **Silver Award: LG Display's 55-in. FHD Curved OLED TV Panel**

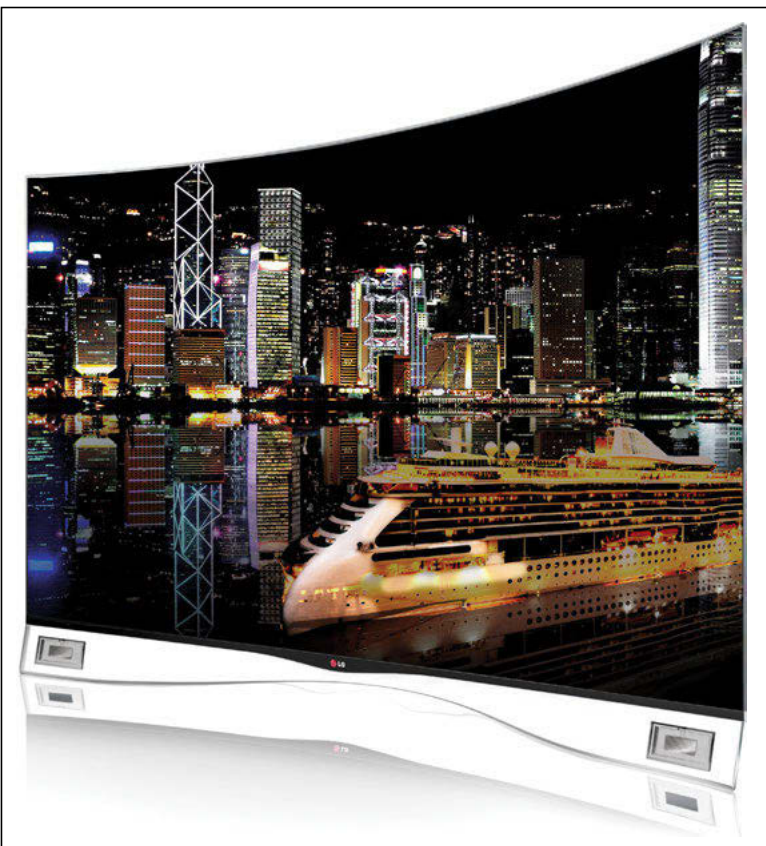
LG's curved OLED TV was introduced last year, bringing a new kind of viewing experience into the home. The TV uses LG's WRGB OLED technology with an oxide TFT backplane, the company's technical solution of choice for large-sized OLED panels. The



## DISPLAY OF THE YEAR



**Gold Award:** Samsung's curved and flexible OLED panel has been incorporated into the company's Galaxy Round smartphone.



**Silver Award:** LG's 55-in. FHD curved OLED TV panel offers exceptionally vibrant imagery in a curved format that offers viewers a comfortably immersive environment.

panel is slim – only 4 mm thick with side bezel widths of 11 mm. At 19.2 pounds, the TV is also substantially lighter than competitive products. At the same time, it offers superior picture quality, achieving remarkably rich and natural colors through 8.3 million subpixels with the addition of white subpixels – 2 million more subpixels than competitive panels. The panel also delivers clear images with less than a 0.001-msec response time, 5,000 times faster than most LCDs. Most notably, LG Display's curved OLED TV panel can realize deep and dark blacks with the capability of reproducing a wide spectrum of blacks, allowing for an optimal contrast ratio.

In addition to the vivid and enhanced picture-quality experience, the curved structure

of the new OLED TV panel offers viewing comfort. The curvature mimics a human's normal line of vision, known as the "horopter line," which makes it more eye friendly and allows viewers to feel less fatigue even when watching the screen for long periods of time. Users will also enjoy a more theater-like viewing experience because the curved screen has a wider and brighter field of view. The IMAX-like curvature of the screen minimizes visual distortion and loss of detail. LG Display's curved OLED TV panel also incorporates the company's acclaimed FPR 3-D viewing technology, which minimizes eye and body muscle strain during 3-D viewing. The added FPR 3-D film on the curved OLED TV panel offers better depth as well as a clearer 3-D effect.

### Display Component of the Year

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

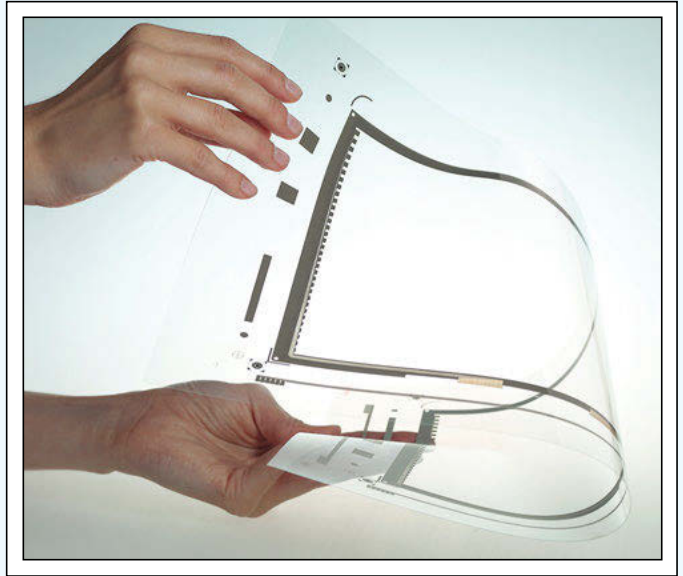
### Gold Award: UDC's Green Phosphorescent UniversalPHOLED Emitter Material

OLED displays gained a large energy efficiency boost in 2013 when Universal Display Corporation (UDC) began shipping commercial green UniversalPHOLED emitters to panel makers for incorporation into mobile products. UDC's proprietary green phos-

# DISPLAY COMPONENT OF THE YEAR



**Gold Award:** UDC's green phosphorescent UniversalPHOLED emitter material is designed to reduce an OLED device's power consumption while providing excellent color.



**Silver Award:** Canatu Oy's Carbon NanoBud (CNB) Film, made from carbon nanotubes and fullerenes, provides superior optical performance for flat, flexible, and formable touch screens and displays.

phosphorescent OLED (PHOLED) emissive system can reduce an OLED display's power consumption by approximately 25%, while providing excellent color in mobile displays. Adding green PHOLEDs to displays has increased OLED's competitiveness with LCDs for mobile applications, and this new material is expected to be a key driver in the commercialization of OLED TVs.

Through years of R&D work and achievements, UDC has produced UniversalPHOLED materials that provide record-breaking energy efficiencies, vibrant colors, long operating lifetimes, and manufacturing versatility. The green PHOLED emitter builds on the successful commercialization of UDC's red UniversalPHOLED emitter, first launched in commercial passive-matrix display products in 2003. PHOLED materials are expected to drive wider adoption of OLED technology and greater growth in the display and lighting markets because they significantly reduce power consumption and lower heat emission compared to prior fluorescent green OLED materials. Based on these advantages, UDC believes that all OLED products, including smartphones, tablets, TVs, and lighting panels, will benefit from the use of its green UniversalPHOLED materials.

### **Silver Award: Canatu Oy's Carbon NanoBud (CNB) Film**

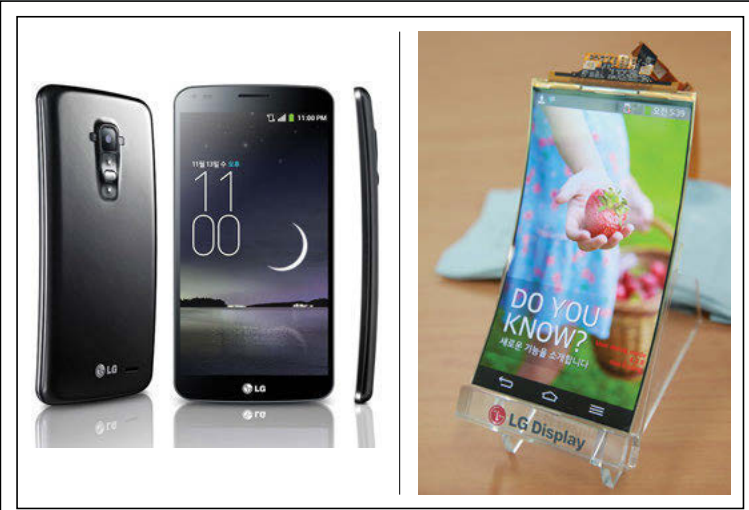
Canatu Oy's Carbon NanoBud (CNB) Film provides superior optical performance for flat, flexible, or formable touch screens, displays, and touch-sensitive surfaces. This transparent conductive film is used in capacitive touch sensors for portable devices such as mobile phones, tablets, and digital cameras, and in automobiles that require excellent display readability in outdoor and bright indoor environments. With near-zero reflectance (less than 0.2%) from the CNB touch layers, CNB touch sensors improve contrast by up to 40%, and thus enhance display readability compared to incumbent touch solutions. In portable applications, the high contrast further enables the use of lower backlight power to increase battery life by up to 20%. CNB films have the highest transmission of any carbon nanomaterials, with 96% transmission at a 150- $\Omega/\square$  sheet resistivity, practically zero haze, and almost perfect color neutrality.

CNB films are also applied in capacitive touch sensors for flexible wearable devices such as smart watches and flexible and foldable mobile phones and tablets. The films are highly foldable down to a bending radius less

than 1 mm over more than 100,000 bending cycles. Another application of CNB films is in 3-D formed capacitive-touch surfaces in smart watches, home-appliance control panels, automobile center consoles and dashboards, and mobile phones. The films and sensors are stretchable up to 100% (twice their linear dimension) and can be thermoformed and overmolded with standard industrial processes such as film insert molding or in-mold decoration.

Carbon NanoBud material is made from carbon nanotubes and fullerenes. Being carbon based, it absorbs light as opposed to reflecting as with commonly used ITO and other transparent conductive materials such as silver nanowires and metal meshes. This is the reason why CNB sensor layers have almost zero (<0.1%) haze and almost zero (<0.2%) diffuse and specular reflectance. When deposited on a substrate, CNB material forms a random network that is highly flexible and stretchable. Canatu's CNB manufacturing process is environmentally friendly and cost effective, with CNB film produced from common carbon gases in a single process step at room temperature, on rigid or flexible substrates, and in sheet or roll-to-roll form.

# DISPLAY APPLICATION OF THE YEAR



**Gold Award:** LG Display's G Flex (left) is based on a flexible plastic OLED display (right).



**Silver Award:** Google's Chromebook Pixel features an LCD panel with 239 ppi.

## Display Application of the Year

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

### Gold Award: LG Display's G Flex

LG Display's G Flex smartphone incorporates a flexible OLED panel that is based on a plastic substrate instead of glass. By applying film-type encapsulation technology and attaching the protection film to the back of the panel, LG Display made the panel bendable and unbreakable.

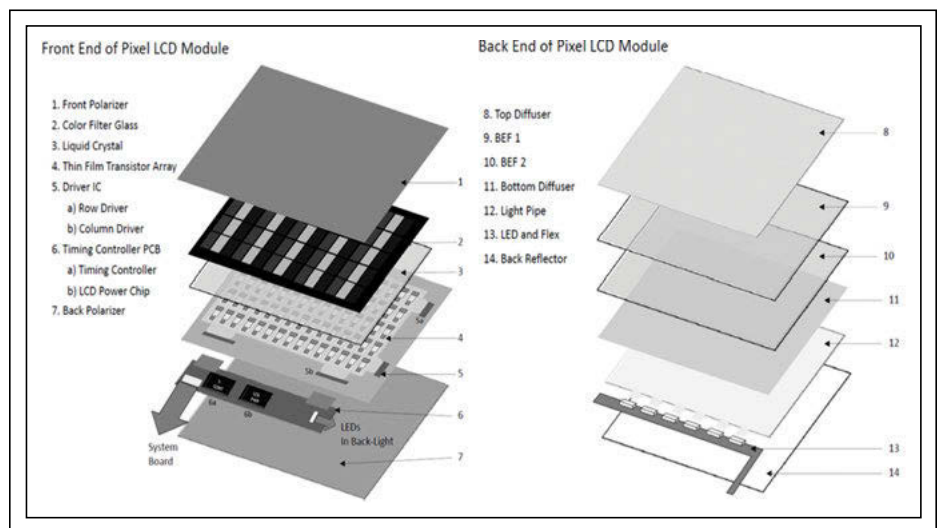
Compared to an OLED display panel based on glass, the flexible OLED panel is lightweight, thin, unbreakable, and features design flexibility. This allows for a design that naturally fits the contour of a smartphone user's face. The G Flex's OLED panel is vertically concave from top to bottom with a radius of 700 mm and only 0.44 mm thin. What's more, the panel is also the world's lightest, weighing a mere 7.2 g even with a 6-in. screen, the largest among current smartphone OLED displays.

Plastic OLED panels are made in a process similar to that of glass OLED panels; however, the former uses a plastic substrate and a different "sealing" material. First, an organic matter called Polyimide (PI) is coated on the

glass substrate. A proprietary, specially developed form of multi-layered organic and inorganic film is used to encapsulate the OLEDs and protect them from moisture. In the final process, to achieve flexibility, it is necessary to separate the glass and PI layer to remove the glass from the lower board, which can be

achieved by applying a special layer. The board is naturally weaker once the glass is removed, so the back plate is then attached to the part where the glass was removed to ensure sturdiness.

In the future, LG plans to make this process applicable to the production of large-sized



**Fig. 1:** At left is shown the stack-up of the Pixel LCD module's front end. At right is the stack-up of the module's back end.



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## best products of 2013

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**Silver Award: Google's Chromebook Pixel**  
Chromebooks are built for the way that people use computers and the Web today. They make computing faster, simpler, and more secure – for everyone. The LCD on the Chromebook Pixel is stunning, providing users with a rich, immersive experience. The 12.85-in. touch screen had, at launch, the highest pixel density of any laptop (239 ppi), and the 3:2 photographic format is specifically designed for using the Web (reducing the need for scrolling). Other statistics include a maximum brightness of 400 nits, a 60% color gamut,\* a wide (178°) viewing angle with IPS technology, and a 0.55-mm layer of touch-enabled glass fused directly to the screen (to preserve picture clarity). For users, text is crisp, colors are vivid, touch interactions are smooth – and each of the 4.3 million pixels seems to disappear into one spectacular picture.

Google used a-Si TFT technology for the pixel to reduce the cost of the glass panel. The transmissivity of its high-ppi a-Si TFT panel was lower than panels fabricated with oxide transistors or low-temperature polysilicon. To attain low power consumption using a-Si, the company optimized the remaining components (including LEDs, optical films, and light pipe). The stack-ups can be seen in Fig. 1.

The company's goal is to continue to push the laptop experience forward, working with its entire ecosystem of partners to build the next generation of Chrome OS devices.

\*Based on the gamut defined by the NTSC standard, a color TV standard developed in 1953. ■

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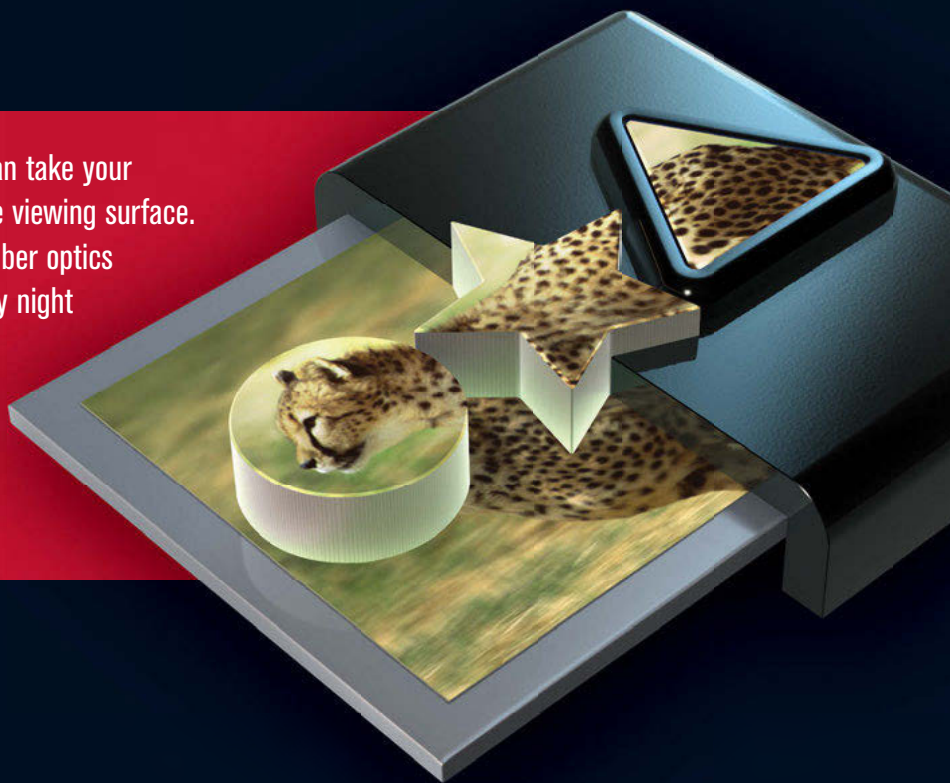
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# Augmented Edge Enhancement on Google Glass for Vision-Impaired Users

*Google Glass provides a unique platform that can be easily extended to become a vision-enhancement tool for people with impaired vision. The authors have implemented augmented vision on Glass that places enhanced edge information over a wearer's real-world view. This article is based on the paper, "Augmented Edge Enhancement for Vision Impairment Using Google Glass," to be presented at the 2014 Display Week technical symposium on Wednesday, June 4.*

by Alex D. Hwang and Eli Peli

**M**OST PEOPLE with impaired vision experience reduced visual acuity (VA) and contrast sensitivity (CS). These reduced visual functions have a large impact on the quality of life. For example, people with impaired vision are often unable to recognize faces at an appropriate distance for initial contact, which can be a great social hindrance, especially in senior-citizen communities.

A number of augmented-vision head-mounted-display (HMD) systems have been proposed and prototyped to help with various vision impairments.<sup>1</sup> Peli *et al.*<sup>2</sup> developed an augmented image-enhancement device that superimposed an edge image over a wearer's see-through view. Visibility enhancement came from the high-contrast edge aligned precisely with the see-through view. However, when the camera axis and the HMD's virtual display are not coaxial, parallax makes alignment of edges with objects at various distances difficult. An on-axis HMD-camera

configuration was subsequently prototyped and achieved good alignment across a range of distances,<sup>3</sup> but the brightness of the edge images was severely reduced by the optical combining system. Early HMD vision aid prototypes were usually bulky, requiring a separate image-processor unit that had to be carried along with a battery/power unit. They were also heavy, uncomfortable, and unattractive. Therefore, these and some commercial magnifying and light-enhancing (for night blindness) HMD systems designed as visual aids were not successful in the marketplace.

Google Glass, a wearable computer with an optical see-through HMD that was first announced in 2012, provides a unique hardware and software development platform that can be easily extended to vision enhancement devices for visually impaired people. The Google Glass package is attractive and substantially more comfortable than the aforementioned designs, and, therefore, more suitable to social interactions. Google Glass has a wide-angle camera, a small see-through display, and enough mobile CPU/GPU power to handle the necessary image processing. Although a full Glass API has not yet been provided, its Android-based operating system supports OpenGL ES and camera access.

## Goals for Google Glass

Several challenges were apparent to the authors when they began working with Google Glass on creating a new augmented-vision edge-enhancement visual aid. To provide an augmented view that overlaid enhanced edge information accurately over the wearer's real-world view, spatial alignment between the augmented and real view had to be resolved for the Google Glass hardware configuration. The inherent parallax was not as large as in earlier devices because the Glass camera is close to the display optics (a horizontal displacement of 18 mm). The edge-enhancement method and level of enhancement needed to be user selectable because these depend on factors such as type and degree of vision loss (which can be progressive or variable), the task at hand, scene content, and image clarity. The user interface to control the device parameters has to be simple, intuitive, and quick.

## Google Glass Hardware

Google Glass has a camera with a relatively large field of view that can capture  $75.7^\circ \times 58.3^\circ$  of the world with a resolution of  $2528 \times 1856$  pixels [see Figs. 1(a) and 1(b)]. During video recording, the upper and lower portions of the captured image are cropped to fit the more

*Alex D. Hwang and Eli Peli are with Schepens Eye Research Institute at the Massachusetts Eye and Ear Institute, Harvard Medical School. Prof. Eli Peli is a Fellow of the SID and can be reached at [eli.peli@schepens.harvard.edu](mailto:eli.peli@schepens.harvard.edu).*



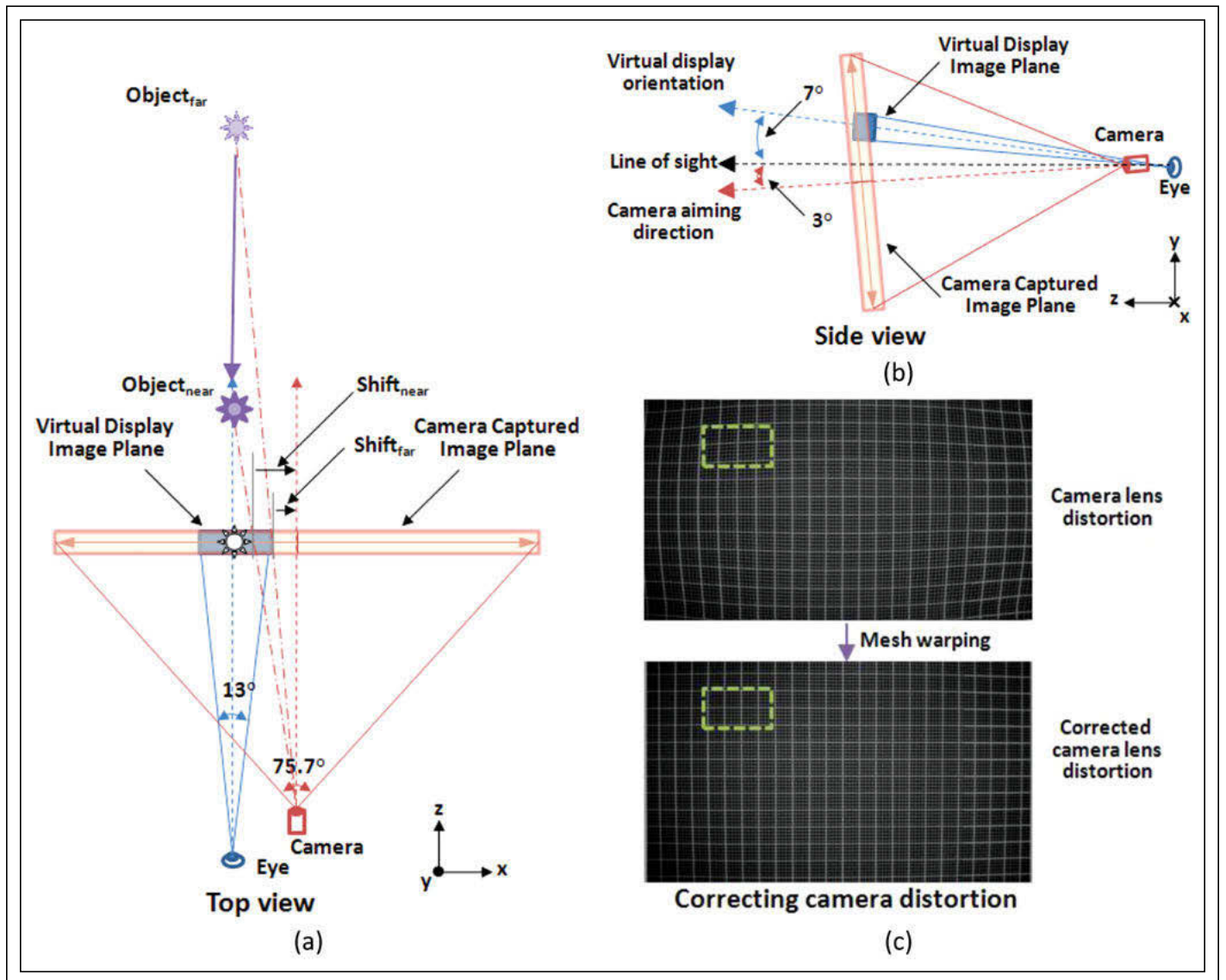
conventional 16:9 screen ratio and encoded at  $1280 \times 720$  pixels, 30 fps (720p). The display, only available for the right eye, spans a visual angle of  $13^\circ \times 7.3^\circ$  at a  $640 \times 360$  pixel resolution (see Figs. 1(a) and 1(b)). The camera and display optics are encased in a single rigid compartment, so that adjusting the display position also changes the camera's aiming angle. The camera is set to aim  $10^\circ$  downward relative to the display direction. The display is angled at  $7^\circ$  above the wearer's

line of sight; thus, when a Google Glass wearer looks straight ahead, the camera is aiming  $3^\circ$  downward [see Fig. 1(b)]. The alignment process is simpler when the virtual display plane is perpendicular to the line of sight. In the case of Google Glass, in order to use it as an augmented-reality device, the user has to tilt his/her head down and look  $7^\circ$  upward. The wearer's active eye and head movements naturally align the virtual display with the center of the wearer's visual field,

bringing the display plane perpendicular to the wearer's line of sight.

### Fixing Camera Distortion

The Google Glass wide-field camera inevitably introduces distortions, especially at high eccentricities. Therefore, image alignment starts with correcting the captured image distortion so that the acquired image represents a correct orthographic projection. We measured the camera distortion and generated



**Fig. 1:** (a) The above schematic shows the Google Glass hardware configuration (not to scale). The top view illustrates the required 2-D translation dependency on the distance to the aimed object of the projected image. (b) The side view identifies the angular compensation needed between the virtual-display orientation and the camera aiming direction. In (c), the Google Glass camera lens distortion is corrected. Note that only a small portion of the captured image (marked here as a green dashed rectangle) needs to be rendered.

a corrective mesh. Then, the corrective mesh was used to warp the captured image to match it to the ideal image plane projection [see Fig. 1(c)]

### Correcting Image Zoom and View Point

The camera field of view of  $75.7^\circ$  is displayed on the  $13^\circ$  display. Therefore, the captured image has to be cropped and scaled up in size when it is displayed. Then, the image is projected onto a display plane that is rotated  $10^\circ$  upward (rotation around the x-axis) to compensate for the relative angular difference between the camera aiming direction and the virtual display orientation. With the image projection correction, an additional 2-D translation must be applied to bring the center of the captured image in alignment with the center of the display [see Figs. 1(b) and 1(c)]. Note that the horizontal displacement between the camera and the virtual display causes parallax and image misalignment between the projected and captured images that depends on the distances to the objects in view. Since near objects (less than 10 ft. away) are easier to recognize for most visually impaired people, a default operational correction for parallax at

10 ft. is applied. The user can select other parallax settings by swiping along the touch-pad on the Google Glass.

### Implementation

Google Glass (currently) runs on Android 4.4 and fully supports OpenGL ES 2.0. Our prototype application utilizes the 3-D graphic hardware pipelines of the Google Glass by using vertex and fragment shaders. Camera distortion is corrected by using an image-warping mesh and image projection that controls the rotation and translation of the image and is modulated by the vertex shaders. Since edge enhancement is implemented at the fragment shader level, only the visible portion of the captured image (about  $328 \times 185$  pixels from the original preview image's  $1920 \times 1080$  pixels) is processed for edge enhancement. This effectively reduces the overall image processing load by a factor of 8.4 and allows the system to achieve high performance, reaching an acceptable real-time frame rate of 30 fps.

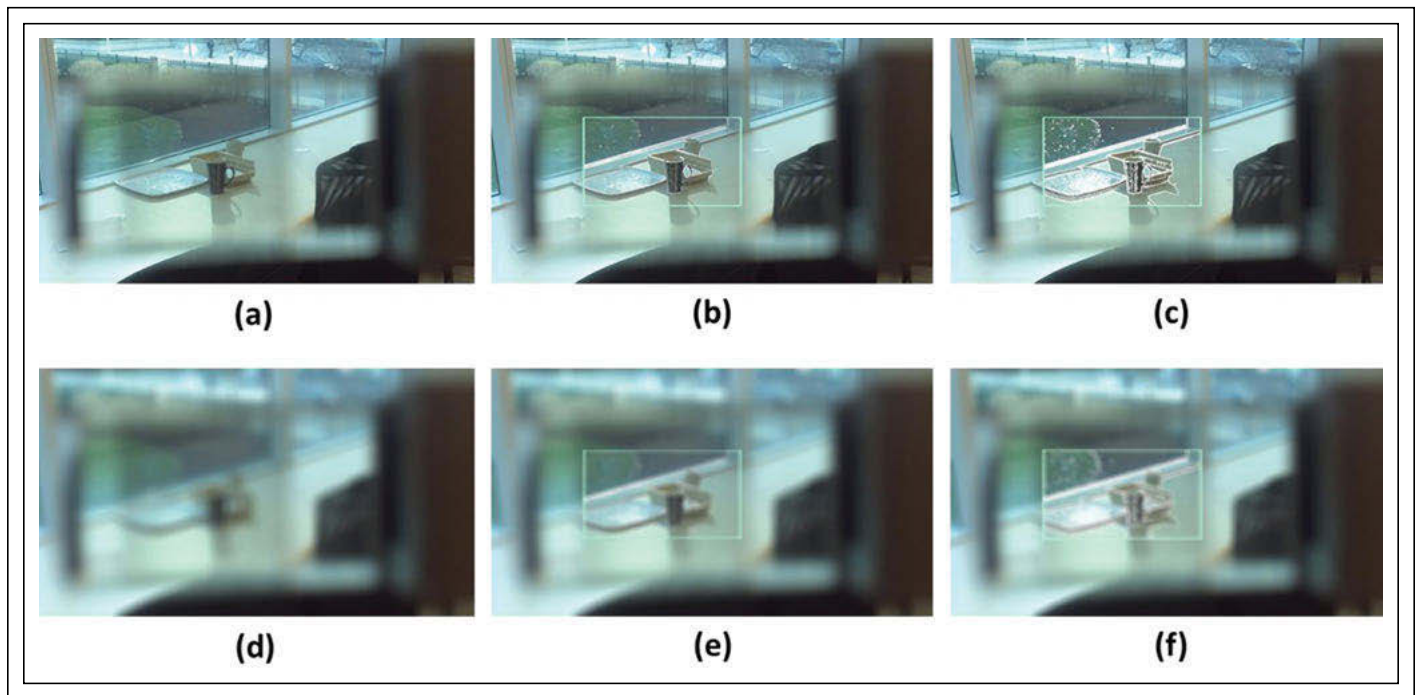
### Edge-Enhancement Control

The usual implementation of edge-detection algorithms enhances all edges in the scene, in

proportion to the local contrast. As a result, clearly visible edges of the scene are often over-emphasized, and may interfere with overall visibility. Our current implementation of the edge-detection algorithm has double thresholding, so that the user can reduce the enhancement of strong edges by applying a two-finger pinch gesture on the touch pad (see Fig. 2).

While enhancement using light and dark edges can be implemented with conventional displays,<sup>4</sup> with an optical see-through system, edge enhancement can only be implemented with bright/white light, contributing to visibility enhancement mostly over darker portions of the scene because a dark/black edge becomes transparent in a see-through optical system.<sup>5</sup> As a result, current edge enhancement shows minimal effect over the brighter area. Note the lack of enhancement on the handle of the mug in Figs. 2(e)–2(f).

It is hard to measure exactly how bright the AR edges are due to the HMD optics. However, the Google Glass display produces more than bright enough light indoors and those edges remain apparent outdoors, thanks to the photochromic coating applied to the outer sur-



**Fig. 2:** (a) Photo of a scene through the Google Glass simulates normal vision (NV). The other photos show: (b) a view with moderate edge strength on the display with NV; (c) a view with full edge enhancement with NV; (d)–(f) simulated views of the scene with the level of enhancement in (a)–(c) by a user with impaired vision (IV) (blurred). Note improved visibility of details with enhanced edges.

face of the see-through display (transmission is reduced with exposure to ultraviolet light). Our pilot experiment with subjects using the described application on the Google Glass showed that people with contrast sensitivity worse than 1.50 from a Pelli-Robson contrast sensitivity test<sup>6</sup> may receive a benefit from the AR edge enhancement using the current system without any modification.

### Effectiveness of the Small Visual Field Edge Enhancement

The small span of the display limits the angular extent of the augmented edge enhancement, but this does not limit the effectiveness of the device. The user with impaired vision frequently has normal peripheral vision, which is available to guide the direction of the virtual display and direct the edge enhancement to objects of interest by scanning through the scene with head movements. This mode of operation is similar to the function of normal vision, where the peripheral vision, which naturally has low VA or CS, guides foveal gaze<sup>7</sup> and ego/exocentric motion perception.<sup>8</sup> Once the target of interest is selected, detailed inspection is mainly carried by the foveal area, which has high VA and CS. Similarly, the visually impaired users use the highest sensitivity area on their retina to examine the enhanced image.

### Potential Impact

We demonstrated that augmented vision enhancement can be efficiently implemented on Google Glass, providing a visual aid for people with impaired vision. This is an approach that we evaluated with earlier devices, and Google Glass shows improved performance. The compact and aesthetically pleasing hardware design of Google Glass is also more readily accepted by the general population. We believe this demonstration is encouraging with respect to the possibility of developing an HMD-based vision enhancement device for people with impaired vision at reasonable cost and high functionality.

We are currently implementing and testing additional applications using Glass, such as a scene magnifying app that provides functionality similar to that of the spectacle mounted (bioptic) telescopes that are commonly used by people with impaired vision, but with controllable magnification levels and a cartoonized scene minifying app for people with restricted peripheral (tunnel) vision.

Such a system has been previously shown to be beneficial for patients.<sup>5</sup> We are also developing Google Glass apps for other specific tasks that people with visual impairments have difficulties with, such as distant face recognition and collision judgment and avoidance.

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# New Shoes? No Problem. Creating Dynamic Fashion with Wearable Displays

*A research team used an e-Paper display to create a color and pattern-changing shoe. Their paper on this project, “Wearable Display for Dynamic Spatial and Temporal Fashion Trends,” will be presented at Display Week’s technical symposium on Wednesday, June 4.*

by Wallen Mphepö, Jiaqi Gao, Miao Li, Justin Wang, Mega Mengmeng, Tian Dan, Hanson Zhao, Guilan Yang, Yirui Liu, and YinLei Liu

ACCORDING to recent research, approximately 13 billion pairs of shoes are sold each year. The average woman in developed countries owns approximately 19 pairs of shoes at any given time. The same research shows that of these 19 pairs of shoes up to 75% are rarely worn, usually because they do not match the owner’s outfits. Our research team determined that wearable flexible-display technology could be used to provide a new and dynamic fashion paradigm (while also freeing up needed space in people’s closets!). In this article, we describe a prototype high-heeled shoe that can change colors and patterns via a smartphone, electronics, and a flexible customized e-Paper display.

## In the Service of Fashion

The term wearable display brings to mind images of Google Glass or clothes with flashing LEDs patched on them – technology statements rather than fashion statements. It would be short sighted to imagine these as the

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best realms for wearable displays. From the beginning, our team strove to create technology that would serve fashion, not the other way around.

In the display industry, there is currently an understandable emphasis on full color, extremely fast video refresh rate, and higher than retina resolutions. For our project, we chose to concentrate on e-Paper – a display technology that is monochrome, has slower refresh rates, and lower resolution – potential advantages that are often overlooked and underutilized. In fashion, there are many products that commonly occur in plain black, white, gray, or brown. If the reader will simply assess a random sample of shoes, belts, wallets, bags, etc., wherever she or he is right now, this will be confirmed. A glance at furniture, appliances, vehicle surfaces, and so forth tells the same story. In addition, these surfaces rarely require a video refresh rate!

If we had chosen instead to use a flexible display based on current OLED technology, we could have provided full color, high resolution, fast video refresh rate, an infinite contrast ratio, and so forth. While the result would have been impressive and trendy in terms of displays, it would not have sold for an affordable price, nor would consumers, after paying a handsome amount, be satisfied with its very short battery life. With e-Paper,

we still achieved a final product demonstration that offers dynamic functionality and falls squarely in the middle of the price range of current conventional high-fashion shoes (\$150 – \$250 range)

## A New Display Platform

There are many parameters that affect the quality and comfort of a high-heeled shoe. Figure 1 shows a couple of points of interest that need to be taken into consideration.

Of particular importance to note in high heels is the area where the foot bends at the



*Fig. 1: A high heel was not necessary to house the electronics, but the researchers determined that a fairly high-heeled (9.5 cm) shoe would showcase the fashion aspect of the project to the best possible extent.*

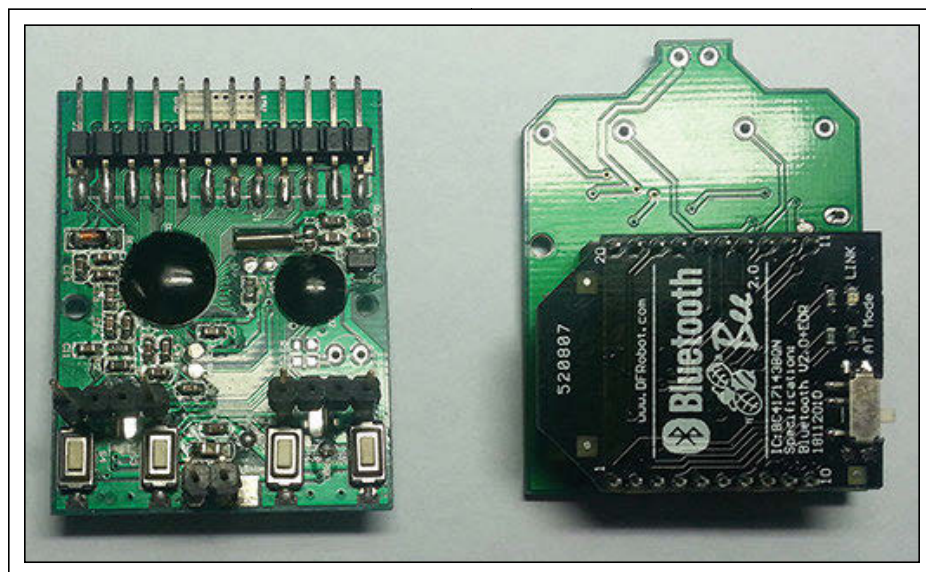
base of the toes. A shoe can be made to be both comfortable and aesthetically pleasing even with a 9-cm heel height as long as the angles and the materials are chosen carefully. This height was chosen to demonstrate that with good design one can achieve some daring heel heights without the shoe being uncomfortable to the wearer or unusable for the technology. The technology we developed works with different extremes of this challenging form factor. For example, the latest electronics board we have developed is just 4 cm long  $\times$  3 cm wide  $\times$  0.5 cm high. It can fit into most flat shoe heels without a problem. However, a high heel seemed like a challenge that would more visibly illustrate the versatility and fashion-forward nature of our project.

Wearable displays on unconventional surfaces such as shoes do require careful planning and execution. After we chose a high-heeled shoe for our application, we proceeded to check the various parameters that would affect the displayed image quality on such curved surfaces with obvious and not so obvious mechanical stress and strain points that might affect the display's performance. In particular, we considered the impact on image contrast ratio, viewing angle, and image distortion due to deformations. Our choice of display substrate was made on the basis that it would not suffer greatly from the impact of walking or dirt. Our choice of display-cell sealing method was influenced more by the necessity of protecting it from water. (The exact materials and methodologies used to create this display are the subject of an upcoming paper.)

### The Electronics and the Display

An understanding of shoe mechanics enables one to choose the most appropriate location to place the electronics to both drive the display as well as perform other wearable computing functions. Minimizing the volumetric size of the electronics is crucial for most wearables. From our design and iterations, we calculated that a volume of 4.5 cm  $\times$  4 cm  $\times$  1.5 cm would just be small enough to suffice for a women's size 38 shoe and would fit inside the heel of the shoe.

To achieve this, we employed a well-known prototyping board, the Arduino, and customized it with additional chips (Fig. 2), including a Bluetooth chip for wireless communication with the user's smartphone. We



*Fig. 2: The front of the customized printed circuit board placed in the heel of the shoe is shown at left and the back is shown at right.*

wrote an Arduino script and uploaded it to the custom board. We then built an Android app to send the commands to the board via Bluetooth in order to control the displayed images we had previously photographed with the smartphone camera and transfer them to the shoe display.

For this prototyping purpose, we used a customized flexible e-Paper display powered by a rechargeable 3-V lithium-ion battery. The battery had sufficient power for the rest of the electronics as well. It should last from 6 months to 2 years depending on usage.

### Smart-Shoe Issues and Challenges

Figure 3 shows sample screenshots from a demo video of a user operating our custom Android app to control the shoe's appearance at the click of a button. xPatterns are also possible. Some of the challenges we faced in realizing this "smart shoe" stemmed from the fact that the display itself had to be a custom shape and use custom substrates that work well with conventional leather shoes. The shoe itself had to be designed from the ground up to seamlessly incorporate the display, the display wiring, and the display powering. It took a few iterations to settle on the recipe, as both display properties and shoe properties had to be meshed just right. A compromise in either the shoe's or the display's properties would not do if it meant the result was neither pretty nor functional.

The impact of this rather slow, monochrome, and low-resolution display is evident. The ability to dynamically change the appearance of the footwear to match various outfits has value both in terms of fashion and practicality. Ad-hoc self-expression and personalization do not need to look tacky or awkward. With this design, there is no hint that the electronics are there.

However, with new platforms come new quandaries. One topic that has emerged is the ease with which trademarked art, patterns, and logos might be scanned and redeployed on other merchandise. This is but one of the many potential topics that this frontier in wearable technologies and wearable displays in particular will make it necessary to address. However, as with the movie industry and the music industry before it, disruptive platforms do not necessarily bring about the doom that many analysts predict. Indeed, both the music and movie industry are alive and well years after Sean Parker introduced the MP3 format, although both industries have seen a shift in terms of business models.

In a random survey conducted by the authors, an overwhelming majority – 98% – of women were in favor of fashion products and accessories that can be dynamically changed with a smartphone app to match their desired ensemble. Out of 240 women, 236 were in favor; the other four were not sure



**Fig. 3:** The image at left shows the shoe in a neutral white design. At right, the shoe has been changed to a black design to match a hypothetical user's outfit.

what it meant to change the appearance of their accessories using a smartphone app because they could not imagine it. Of those in favor, their condition was that it should not look, feel, weigh, or smell like a fashion product compromised to accommodate electronics. Designers will have to tread a fine line between efficiency and appearance in order to avoid the spectacle of “geek fashion.”

We are still cautiously exploring what custom information content to allow while we retain control over the technology for now. As with most technologies, especially new ones, we are aware that this could be abused, *ala* SnapChat, before it settles into conventional legitimate intended uses. Some parties have already come to us with requests for the ability to display on demand their dating status, job searching status, horoscope signs, personal codes and QR codes, *etc.* It is, in particular, the personal codes and QR codes that can easily be abused since they can point to a Web site or half a page's worth of text that can be set arbitrarily by the user to anything, including test answers, formulas, photos, *etc.*

### A Foot in the Door

We are pleased that we were able to develop a prototype that is a regular shoe in all aspects except it has a hidden technological capability to change its patterns and colors *via* a smartphone app. This technology is product modular and applicable to other markets as well. We have already been approached by representatives from a couple of companies that prefer not to be named as they are still in the very early stages of designing luxury concept

vehicles. As for the clothing market, we are already in the process of customizing the technology to work with a variety of women's dresses. Purses and bags, on the other hand, are just a simple modification of the current shoe platform.

As of writing this magazine article, we are finalizing a collaboration agreement with a division of Intel's Wearable Technology R&D (<http://www.intel.com/content/www/us/en/do-it-yourself/edison.html>). We have just signed an agreement with the European shoe brand United Nude ([www.unitednude.com](http://www.unitednude.com)) to implement our updated platform into four of their designer product lines. We have already signed an agreement with Dragon Innovation, Inc. ([www.dragoninnovation.com](http://www.dragoninnovation.com)), the company that assisted Pebble in reaching a record Kickstarter funding of \$10 million to help us with Crowdfunding campaign preparation services. The crowdfunding pledges will enable us to keep pushing boundaries until we secure funding to fully scale.

We envision that at some point most clothes will come with wearable technology by default.

Clearly, this is not going to happen overnight nor is it guaranteed. We are determined to stay true to our startup vision of wearable technology that is powerful, ubiquitous, yet largely invisible behind the true design form factor.

### Special Acknowledgments

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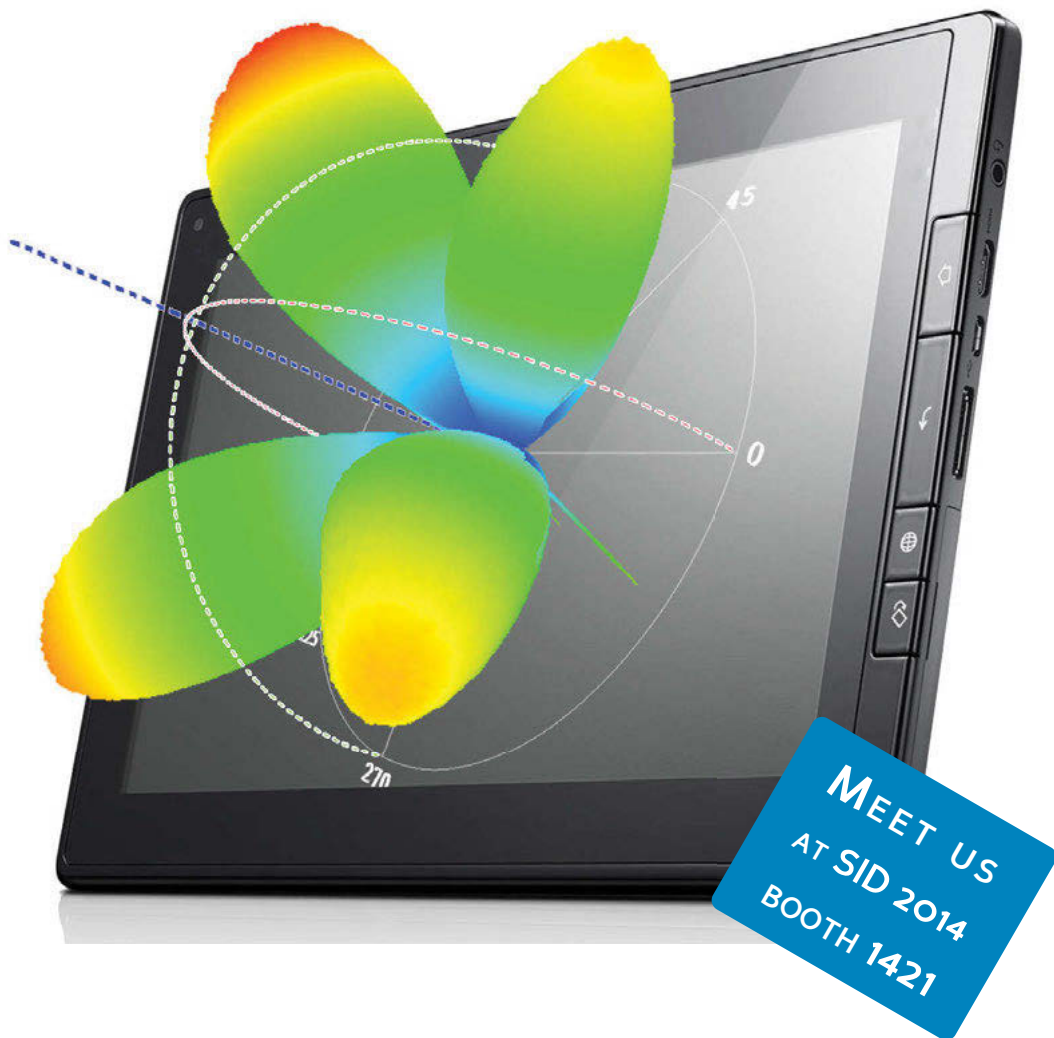


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# The Virtues of Quantum Dots

*When used in conjunction with LED backlighting, quantum dot technology can make LCD performance meet or exceed that of OLED displays.*

by Seth Coe-Sullivan

TODAY's consumers have access to a wide variety of image and video content, and their expectations for performance, most especially picture quality, are high across all delivery platforms. As a result, display suppliers are motivated to push the limits of exceptional picture quality on any and all consumer devices, from small-screen mobile phones to the largest-screen TVs. Meeting the different needs and challenges of this wide range of display devices, where one size certainly does not fit all, requires constant assessment of new technologies.

From an industry trends perspective, resolution improvements seem to be offering diminishing returns as we approach the limits of the human eye. Color gamut seems to be ripe new territory, offering consumers a visually appealing quality difference over what they are used to. While the Adobe RGB standard is gaining traction in the prosumer monitor space, the DCI color-gamut standard is increasingly the target for home-theater TVs. Furthermore, future standards such as UHD-1 will include gamut specs that are considerably wider than HD's Rec. 709, based on the BT.2020 definition.

Displays that can render 100% of the colors within any of these wider-gamut standards are therefore full-gamut displays. Several technologies exist today that enable full-gamut displays, including lasers, OLEDs, and quantum dots (QDs). While laser-based displays have been much discussed, they remain a curiosity due to the lack of an efficient green light

source. For this reason, we will focus this article primarily on the comparison between the most viable technologies for full-gamut displays: OLEDs and quantum dots.

TV makers have long touted OLED displays as the ultimate in picture quality because they can produce saturated colors with extremely high contrast ratios and virtually no motion blur. OLED displays are certainly impressive to look at! LCDs using QD-enhanced backlights are a relative newcomer to displays, but are challenging OLED in market segments such as TV as a high-quality alternative. LCDs with QD backlights meet or exceed OLEDs in a number of display metrics, while offering an easier upgrade model for display makers and consumer-electronics companies alike.

## QD and OLED Basics

Quantum dot semiconductor nanocrystals are tiny chunks of crystalline inorganic luminescent material that emit saturated light in colors depending on both the material composition and size of the dots themselves. QDs are a part of the light engine [the backlight unit (BLU)] in today's liquid-crystal displays (LCDs), generating the red and green primaries by downconverting a part of the blue light emitted by a blue inorganic light-emitting device (LED) (Fig. 1).

In contrast, OLED displays directly emit light from each pixel, and hence have no corresponding BLU component. An OLED is an organic light-emitting device in which the emissive electroluminescent layer is a film of amorphous organic (or organometallic) material that emits light in response to an electric current. The OLED structure is a rather com-

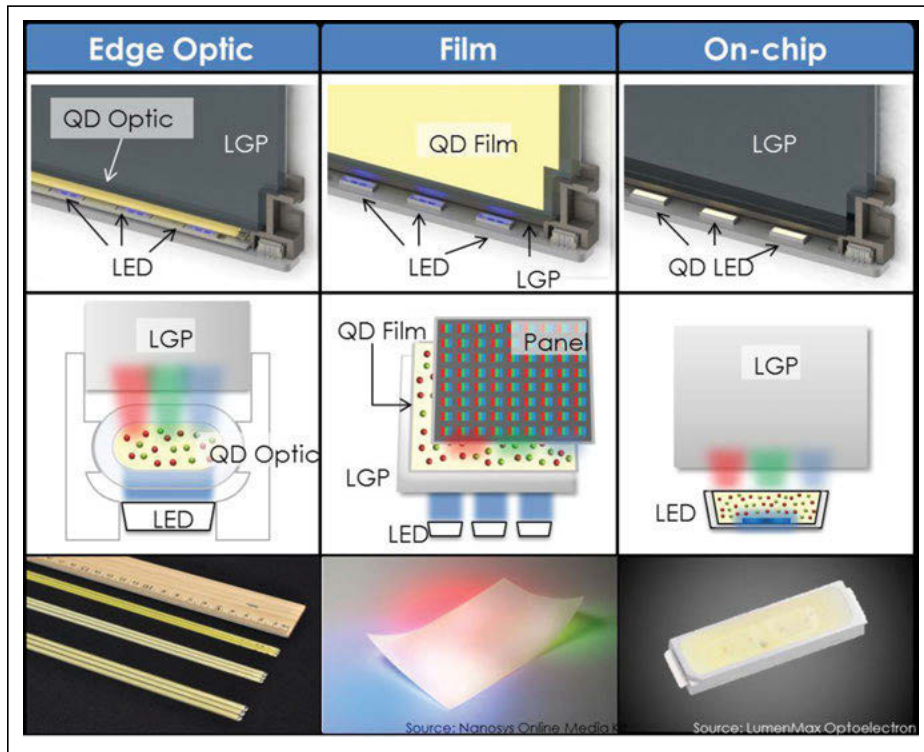
plex multilayer film stack in which the molecular design of each layer is dependent on the adjacent layers, nanometer thickness control is essential, and the organic molecules themselves are quite expensive due to the multistep syntheses required. Due to the interdependency of this technology and the intellectual property barriers that are in place, manufacturers have been only slowly making progress on the requisite and numerous manufacturing challenges. On the other hand, LCD construction is more modular with less interdependency between the various functions, and so the modularity of LCDs has allowed the massive industry's infrastructure to separately optimize and reduce the cost of each component, resulting in tremendous year-over-year cost reductions that have been achieved for well over a decade.

## Color Gamut

Mobile-OLED-display color performance is universally praised, and it provides a significant improvement over that of typical mobile LCDs. Several different OLED modes of operation are currently in use, and hence the color performance of mobile OLED displays, as well as TV-sized OLED displays, made by different panel makers can vary. Despite these differences, the >90% of NTSC gamut\* achieved by all of them is a beautiful-to-behold improvement over LCDs using white LEDs as the backlight source.

\*Based on the gamut defined by the NTSC standard, an older but still widely used color TV standard developed in 1953.

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**Fig. 1:** 3-D, 2-D, and photographic images of three different quantum dot form factors for enhancing color saturation in LCD backlights appear in the top, middle, and bottom rows, respectively. Edge optic, film, and on-chip form factors are shown from left to right. (The on-chip photo is a WLED product representative of a QD-LED form factor since no QLED on-chip products are currently on the market).

LCDs are for the most part transmissive displays, and utilize backlights to illuminate the LCD panel to produce the image. A color-filter array is used to create the three-color primary channels that reach the viewer. QDs can be used to maximize the LCD color performance with existing filter arrays by creating spectrally narrow red and green color channels to obtain a wide color gamut and high-power efficiency from a display's blue LEDs. Compared to conventional backlight sources, QDs offer display manufacturers the ability to reach full-gamut color by producing saturated red, green, and blue colors in the display's backlight (Fig. 2). By creating the primaries with saturated light at the BLU level, full gamut is realized with the best possible efficiency, thereby reducing the power needs, battery volume, and component and heat sink costs otherwise associated with these higher performing displays.

Despite the vast differences in their implementation, the end result is that today's QD-

based LCDs and OLEDs have similar color gamut and color purity, both large improvements over conventional LCD technology. Given the trend toward more colorful standards, and the steady improvement in QD material quality (in both efficiency and bandwidth), the long-term edge (in this author's opinion) will likely go to QD LCDs in terms of the color quality they can offer to consumers

### Response Speed

OLED turn-on is a purely electronic process, and hence can be extremely fast, typically quoted in microseconds. LCD response is limited by the rotational switching of the liquid-crystal molecules, and hence is measured in milliseconds, or 1000 times slower. However, the speed and timing factors limiting viewing quality are also measured in milliseconds – many consumers are aware of their TV being specified as 60, 120, or 240 Hz, corresponding to 16, 8, and

4 msec per frame. With LCDs now capable of 240-Hz operation, the limitations of display performance are dictated far less by the overall response speed of the technology, and instead by subtle effects, such as jitter and jutter. For the average consumer, and even for the display guru, both OLED displays and LCDs offer satisfactory response speed, with any remaining limitations being more a matter of digital image processing than the display panel.

### Viewing Angle

Historically, the degraded performance of transmissive LCDs when viewed from oblique angles was a major performance limiter. However, LCD technology has demonstrated a combination of new LC modes (e.g., IPS), thinner LC cell gaps, and new optical control films (e.g., WV film) that makes LCD TVs good enough for most viewing scenarios. OLED TVs may look better in the store when viewed from well off of center, similar to plasma displays, but offer little practical benefit over LCD TVs when viewed in a typical living room. Interestingly, curved TVs, should they become a trend, could accentuate this difference – which may be one of the reasons why this feature is being pushed by OLED manufacturers, with LCDs as fast-followers.

### Thickness

The LED-BLU edge-lit designs that were established at the end of the last decade resulted in LCDs offering a thinness and lightness that closely approached that of OLEDs. This was a marked improvement over the CCFL-backlit TVs that were dominant in the middle of the decade, reducing thickness from a few inches to less than an inch.

### Power Efficiency

The LEDs used in LCD backlights are far more efficient today than the OLED pixels themselves, but the many losses built into the LCD stack (polarizers, color filters) make the LCD system efficiency lower than the individual pixel efficiency of an OLED display. However, when comparing display systems to each other, one must also factor in the OLED power losses from their own circular polarizers, as well as resistive and capacitive losses associated with the current-driven technology. It is for these reasons that OLED mobile displays consume more power than liquid-



crystal-based mobile displays, despite running at lower peak brightness. These same factors get far worse as one increases screen size and screen resolution to a point where OLED TVs on the market are consuming two or even three times that of an equivalent LCD TV. (Colegrove's Touch Display Research, *Touch and Emerging Display Monthly Report*, August 2013, pp. 9–14.)

Looking forward, OLED displays have pending improvements from the roll-out of phosphorescent green emitters, and, perhaps one day, blue. However, LCD improvements are easily keeping pace with those of OLED displays, gaining efficiency every year, and with new film and materials technologies continuing to improve overall LCD light throughput.

### OLED and QD Technology: Differences

The real difference between OLED and QD technology lies in how they are made. OLEDs are made from complex organic materials that are expensive to make and purify. Manufacturing OLED displays is also an expensive and complicated vacuum production process, requiring the deposition of many layers of precisely controlled thin films of organic molecules on a substrate, and nearly hermetic packaging of the devices.

QD materials, on the other hand, are made from abundant inorganic substances using a two-step synthesis process. The QD components can be integrated into standard LCDs with no changes required to the LCD fab infrastructure whatsoever. Incremental improvements in LCDs and the persistence of

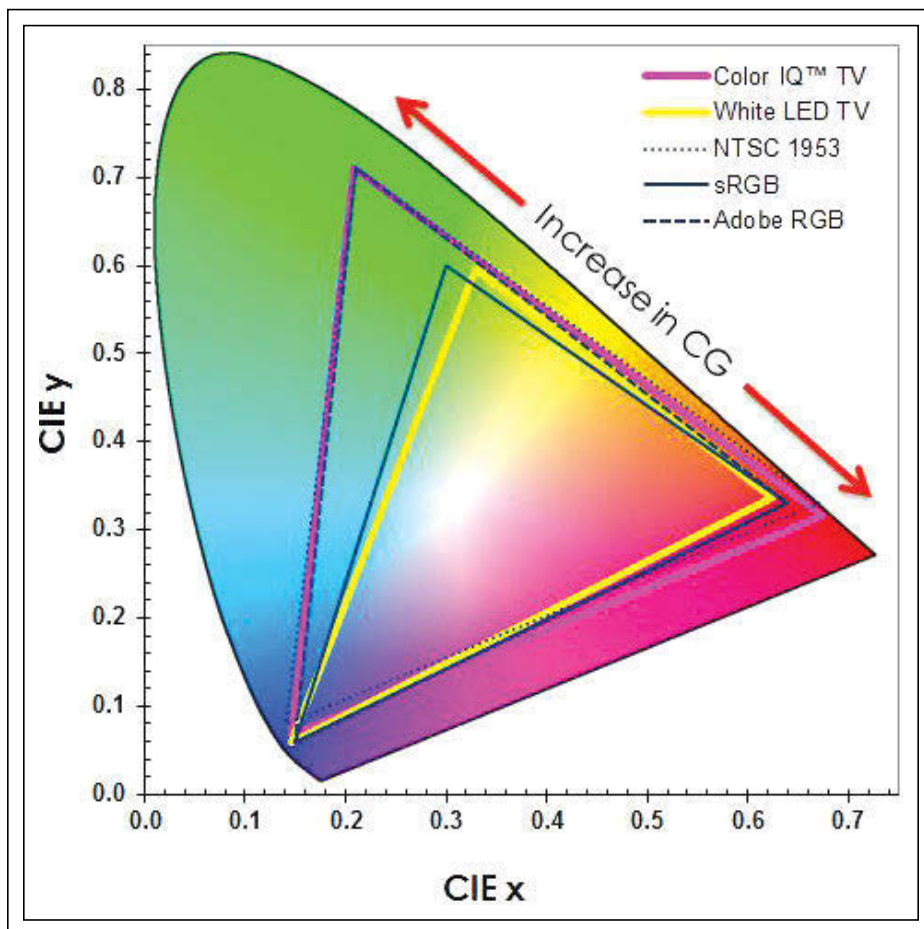
low volumes in OLED manufacturing have resulted in OLED display's bill-of-material (BoM) being greater than that of LCDs. And that is before the significantly lower yield of OLED displays compared to LCDs is taken into account.

The argument has been made that “new” OLED manufacturing processes, such as ink-jet printing, laser transfer, nozzle jet, and OVJP, will reduce material waste and improve yields, making OLED display costs lower than that of LCDs. These arguments are now 15 years old, and still these techniques are in the R&D stage. Indeed, we first saw an ink-jet-printed OLED TV demo at Display Week in 2004, will see them again in 2014, and have yet to see a single commercial product result, despite what is, no doubt, more than a billion dollars invested in the intervening decade.

### Contrast Ratio

Contrast ratio is strongly dependent on how dark a black level a display can produce. In most LCDs, the backlight is always on, and so the black level is related to how completely the liquid crystals can block the light. This “off” state is imperfect, and so LCDs produce a perceptible glow even when attempting to show a completely “black” screen in a dark room.

OLED displays do not require backlighting to function. OLED pixels are independently lit, like tiny red, blue, and green light bulbs. To represent “black,” the pixels can be literally turned “off.” In low ambient light conditions, such as a dark room, an OLED display screen can achieve a higher contrast ratio than that of an LCD screen. This is a truly beautiful image, and today the clearest example of a quality difference between an OLED display and an LCD. However, in normal ambient light conditions for watching TV, this black state of an OLED display is difficult to achieve. The front-of-screen reflection of ambient light dominates the contrast ratio in most home-viewing experiences. In addition, there is a growing trend in LCDs toward so-called “2-D dimming” – this is a direct-lit backlight unit with separate zones that can have their brightness reduced (or eliminated) if there is no brightness in that zone of the image. In this way, LCDs can also produce a true “off”-state black, provided the black is present not just in one pixel but in the entire dimming zone. As this technology improves, the number of zones increase and the cost and



**Fig. 2:** This CIE diagram shows how Color IQ (QD Vision's quantum dot technology) increases the range of colors that a display can show. The Color IQ gamut is essentially identical to the NTSC 1953 and Adobe RGB gamuts, while white LED shows only a portion of the sRGB standard and ~70% of the NTSC/Adobe standards.

thickness are reduced; this technology may allow LCDs to neutralize even the OLED display contrast advantage.

### Hype vs. Reality

There has been a lot of excitement in the market about OLED TV, as well there should be considering the picture quality the technology can provide. But the argument that OLED display technology offers significant advantages over existing LCD technology no longer holds true, particularly since the introduction of quantum dots. Quantum dot-enhanced LCDs provide better color gamut than OLED displays and reduce power consumption, all at a minimal increase in cost over conventional LCDs.

More importantly, quantum dots are commercially available today, while, despite heavy investments in OLED displays for well over a decade, there still has been little progress in terms of using the technology for mass-producing large-sized applications on an affordable basis, due to the manufacturing costs involved. With OLED TV not progressing as fast as hoped (estimated by DisplaySearch to be at best 100,000 units sold in 2014, in contrast to a few hundred-million mobile phone displays; *NPD DisplaySearch Quarterly TV Design and Features Report*, April 2014) and LCD makers needing extra features to justify UHD prices, this looks like the right time for QD full-color gamut capabilities to become a key product feature and motivator for consumer television upgrades.

Analysts are already predicting rapid growth in design wins for quantum dots in 2014, with penetration increasing rapidly in the following years. While conventional LCD TVs with white-LED backlights are dominant, and LCD TVs with quantum dot-enhanced backlights are becoming a major force already, the future of OLED TV is less certain. ■

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# Development of Konica Minolta's New Color Luminance Meter Equipped with an Interference Filter

## 1. Introduction

Recent advancements in display technology have led to improvements in image quality. As the popularity of the display technology used in smartphones, tablets, and PCs increase, major manufacturers continually seek out methods for improving the image quality, particularly in small-sized displays. Large-sized display development is steadily progressing towards high resolution such as 4K and 8K, and to new display devices such as organic EL.

Resolution is one element that determines the image quality, but color reproduction and contrast are important elements as well. Therefore, high-quality management is required in the adjustment and inspection of luminance and chromaticity. In order to achieve it, the performance of the color luminance meter in use becomes an important factor. In fact, there are cases where conventional color luminance meters cannot meet performance expectations that guarantee the quality of a display accompanied with the new device. Konica Minolta has developed the CA-310 Display Color Analyzer aimed at providing a solution in the adjustment and inspection process, assuring high quality of the new displays.

This white paper will explore conventional measurement methods while highlighting the features of the CA-310 Display Color Analyzer from the perspective of image-quality improvement of displays.

## 2. Color Luminance Meter and Display Image-Quality Evaluation

Adjustment and inspection evaluations are vital in monitoring the quality of displays including white balance adjustment, color pattern inspection, and contrast inspection. Color luminance meters are used for carrying out these evaluations. High accuracy is required for white-balance adjustment and color-pattern inspection, while high sensitivity is required for contrast inspection in order to achieve high measurement reproducibility with a low luminance level. In white-balance adjustment, a process is repeatedly performed in sequence of pattern output, measurement, and then adjustment for a display to recognize targeted color output. Therefore, fast measurement speed is required for obtaining a large number of measurements. When measuring a light source of low luminance, measurement speed largely depends on the length of light receiving time. Fast-speed performance comes from the light capturing efficiency in a short period of time. In other words, the instrument performs with high sensitivity. In summary, high accuracy and high sensitivity are required features of a color luminance meter.

## 3. Color Luminance Meter Features and Challenges

Color luminance meters can be broadly classified into two types, depending on the measuring method; spectral type and color-filter type. In general, a spectral-type color luminance meter calculates the luminance and chromaticity from the spectral data. A color luminance meter can accurately match its spectral response to the CIE color-matching functions. Therefore, it can realize high accuracy in luminance and chromaticity measurement. However, there is a tendency for the optical system to become complicated in principle so that it may reduce efficiency

in guiding light to the sensor, which will then result in low sensitivity. To compensate for this, some countermeasures need to be taken such as adopting a sensor with a cooling device. This approach may result in a larger more costly instrument.

A filter-type color luminance meter estimates its spectral response to the color-matching function with its multiple color filters on the optical paths to the sensor unit. In this method, the optical system is simple and high sensitivity can be achieved even with a small body. However, the challenge still remains in making a combination of color filters to accurately estimate the spectral response to the color-matching function. Generally, the accuracy is lower than that of the spectral-type instrument.

Figure 1 shows an example of the spectral response from a filter-type color luminance meter. It can be observed that not all of  $x(\lambda)$ ,  $y(\lambda)$ ,  $z(\lambda)$  matches with the color-matching function with high accuracy. In display manufacturing, small-sized instruments and affordable cost are priority. However, there has not been an instrument satisfying the needs of both high accuracy and high sensitivity.

## 4. Color Luminance Meter in Measurement Process and Its Challenges

In display manufacturing, low-accuracy conditions found in filter-type instruments have been resolved by using the user calibration function. Calibration is carried out with the following procedure.

To begin, the pattern on a display is measured by using a spectral-type instrument. (Measured values  $X$ ,  $Y$ ,  $Z$  are to be  $X_0$ ,  $Y_0$ ,  $Z_0$ .) The same display pattern is measured using a filter-type instrument. (Measured values  $X$ ,  $Y$ ,  $Z$  is to be  $X_1$ ,  $Y_1$ ,  $Z_1$ .) When measuring a display with the filter-type color luminance meter, measurement value  $X, Y, Z$  is used by multiplying  $X_0/X_1$ ,  $Y_0/Y_1$ , and  $Z_0/Z_1$ .

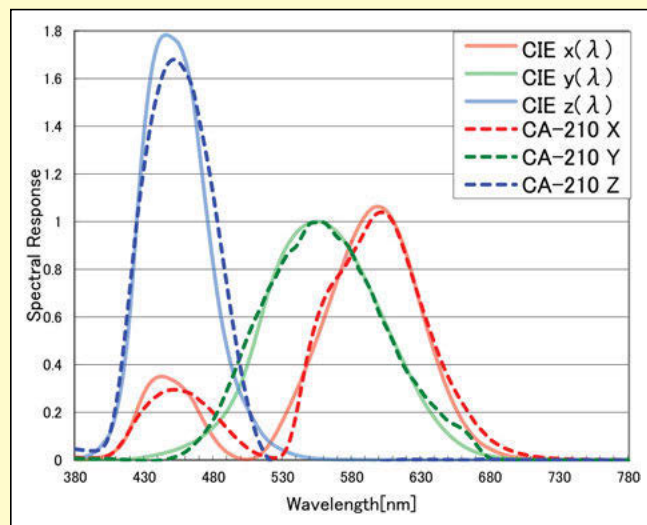


Figure 1: Spectral response of a filter-type color luminance meter.

By utilizing this method, the same level of measurement accuracy can be obtained by a filter-type instrument as with a spectral-type instrument. In order for the procedure to work properly, the display under test must be close enough in spectral distribution with the target display used for user calibration. In other words, the accuracy of the measurement value would not improve if the display under test has different spectral distribution from the target display. For example, in an LCD with a CCFL backlight, the difference in the spectral distribution among the same models is so small that the user calibration function is effective. However, new types of displays are starting to enter the market. These include LCD panels with LED backlighting or edge lighting and OLED displays.

Figures 2-1 and 2-2 show the spectral distribution (white screen) of these displays. Even though the data was obtained using the same model, spectral distribution varied among displays. Table 1 shows data differences held by the same display model measured by a filter-type instrument (accuracy simulation data based on spectral data). The instrument was calibrated by one of two displays in Figures 2-1 and 2-2, and then another display of same model was measured. Chromaticity difference  $\Delta x$ ,  $\Delta y$  was observed at the level of 0.001 and 0.006, respectively. For white color, the human eyes can distinguish color difference when the chromaticity difference is from about 0.006 to 0.007. Therefore, the required accuracy level of an instrument used for adjustment and inspection is about 0.003, which is less than half. The measurement value shown in Table 1 exceeds this required level; therefore some may claim that the instrument performance is insufficient.

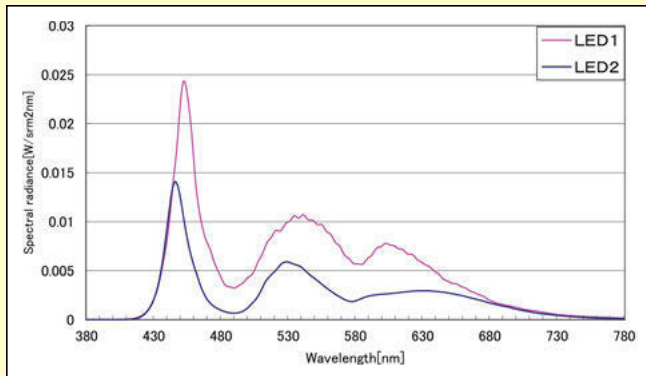


Figure 2-1: Spectral distribution of an LCD with an LED backlight.

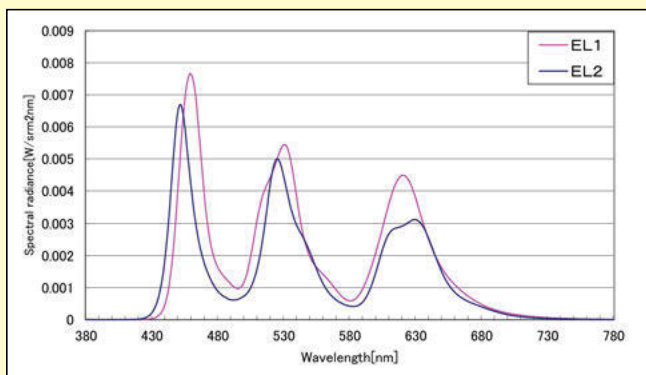


Figure 2-2: Spectral distribution of OLEDs.

Table 1: Data difference after user calibration.

	$\Delta x$	$\Delta y$
LCD with LED backlight	0.0000	0.0060
OLED	0.0010	0.0052

This scenario depicts a new type of filter-type color luminance meter with higher accuracy needed to replace the conventional filter-type color luminance meters in order to comply with the needs of adjustment and inspection in the production of new-generation displays.

## 5. Issues in the Measurement of New Types of Displays and Features of CA-310

The main cause of the issues described thus far is the approximation accuracy of the instrument's sensor part to the color-matching function which is decided by the transmissivity of the optical filter and the spectral response of the sensor. In order to solve this issue, Konica Minolta successfully developed the CA-310 Display Color Analyzer, which has improved the filter portion of the color luminance meter.

A new filter with high accuracy is mounted in the instrument. The optical filter of a conventional color luminance meter is composed by a combination of absorption-type filters which are made of glass or gelatinous. The difference is that the CA-310 uses an interference filter.

With the use of a multi-layered interference filter, the design flexibility of the spectral transmissivity improved greatly, resulting in high approximation of the sensor part to the color-matching functions. Meanwhile, the disadvantage of using an interference filter is that there is an issue of ripple in spectral transmissivity, which is generated when incident light is received from a single direction. A test was performed using incident light from multiple angles as shown in Figure 3-1. Figure 3-2 shows the spectral transmissivity of each incident light. In this test, ripples are mainly observed in the wavelength range of 400–500 nm. The amplitude of ripple is large enough to affect the spectral response of the sensor part. Therefore, it is necessary to reduce the amount of ripple in order to achieve high approximation of the sensor part to the color-matching func-

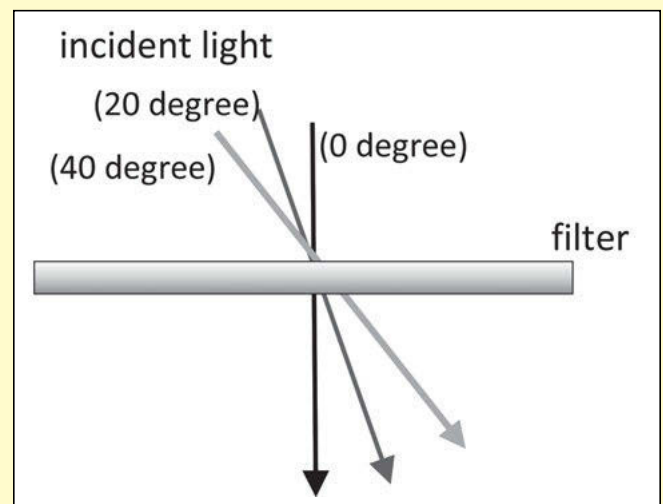


Figure 3-1: Incident light from multiple angles.



tions. As shown in Figure 3-2, attention was focused on the position of ripple in the wavelength, which changes according to the direction of incident light. By transmitting incident light to the filter from multiple angles and by adjusting the incident angle and intensity properly, ripples were offset and it became successful to adjust overall spectral transmissivity in order to realize an high approximation of the spectral response to the color-matching functions at sensor part (Figure 3-3).

Further, since the interference filter is produced by depositing it on a base plate glass, its spectral transmissivity performance is less affected by temperature and humidity than conventional filters formed by gelatinous filter. The filter provides long stability which largely improves the instrument's significant feature reliability.

### 5.1 Accuracy in Spectral Response

Figure 4 shows the spectral response of CA-310 to the color-matching functions. Figure 5 shows the amount of deviation of the spectral response from the color-matching functions for CA-310 and for CA-210, a conventional filter-type instrument.

The spectral response of the CA-310 shows large improvement in the approximation to the color-matching functions. At the same time, generation of ripple, regarded as a disadvantage of the interference filter, has been controlled to a minimal level.

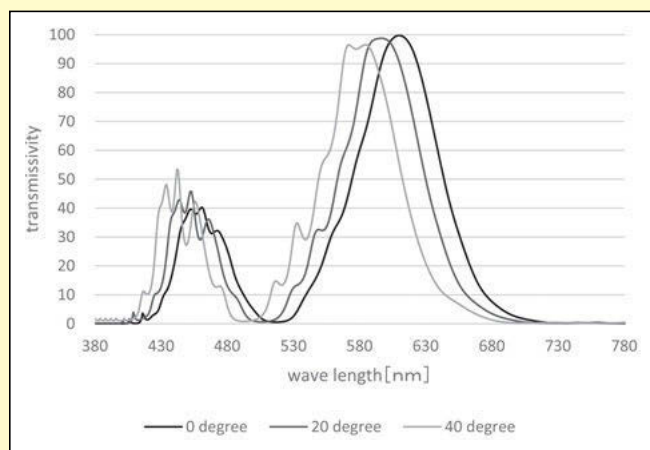


Figure 3-2: Spectral transmissivity by incident angle.

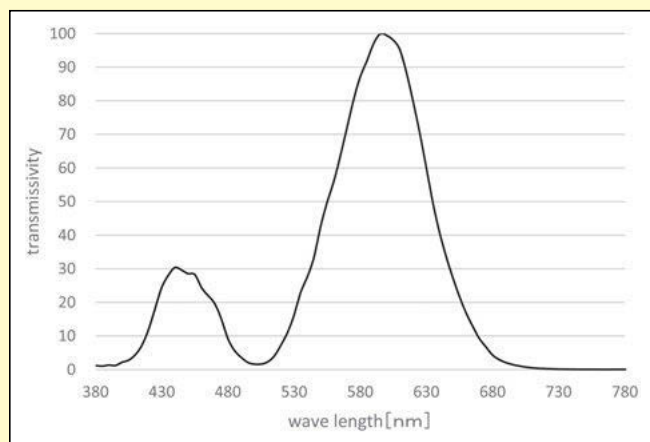


Figure 3-3: Spectral transmissivity with incident light of multiple angles.

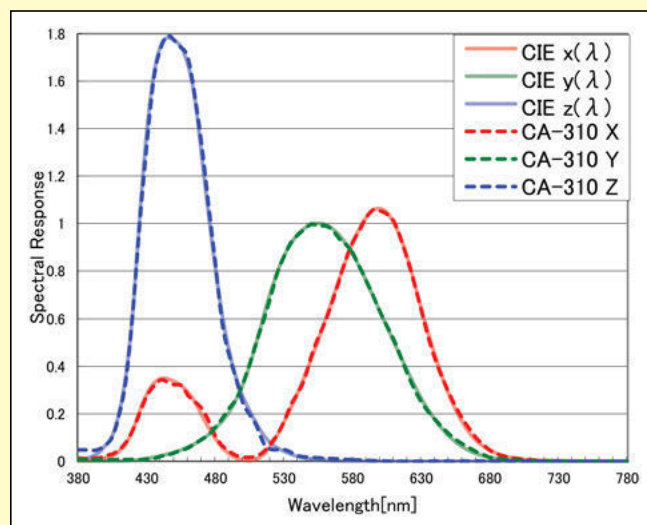


Figure 4: Spectral Response of CA-310.

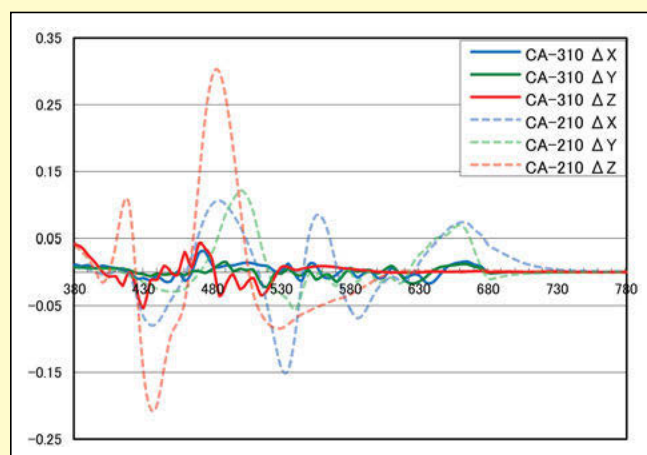


Figure 5: Amount of deviation from the color-matching functions.

### 5.2 Display Measurement Accuracy (in White Measurement)

Table 2 shows the measurement accuracy of CA-310 using user calibration. Those displays shown in Figure 2 were used for the test. The maximum difference shown in the table is 0.0006, which indicates that the accuracy level of the instrument is within 0.003. Therefore, even in the measurement of new types of displays, the CA-310 can measure in required accuracy.

### 5.3 Display Measurement Accuracy (in Single-Color Measurement)

For display inspection, RGB single-color measurement is an important item to secure high quality. Of course, the instru-

Table 2: Measurement accuracy after user calibration.

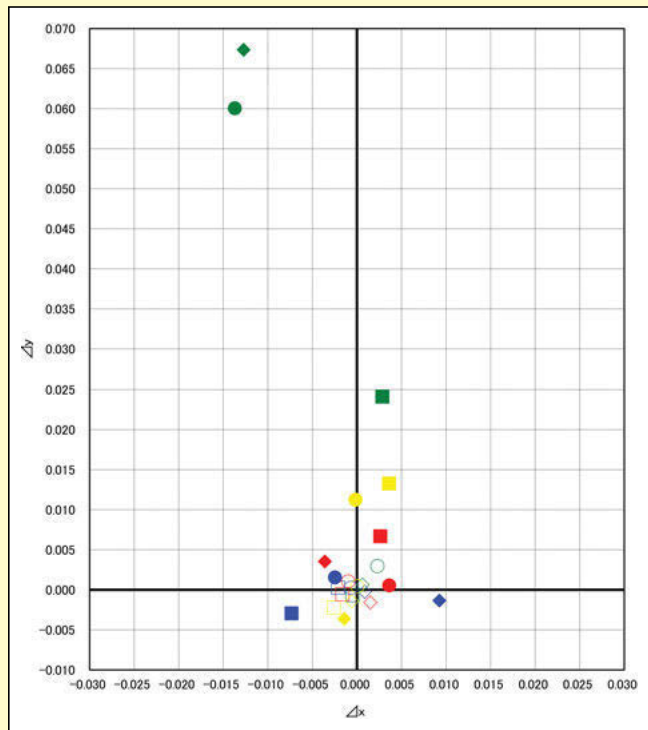
	$\Delta x$	$\Delta y$
LCD with LED backlight	-0.0001	0.0005
OLED	-0.0004	0.0006

ment's accuracy is the most important factor in inspection. *Figure 6* shows absolute data of CA-310 and CA-210, a conventional filter-type instrument for RGB single color, and white measurement of various displays. The target value is measurement data of CS-2000, Konica Minolta's spectral-type instrument. In RGB single-color measurement with an average of RGB absolute data, the CA-310 error is  $\pm 0.0012/\pm 0.0009$ , while the CA-210 error is  $\pm 0.0065/\pm 0.0187$ .

Therefore, the CA-310's error in absolute data is 1/5 in x and 1/20 in y of CA-210. This is a large improvement from that of a conventional filter-type instrument. This fact is also supported by improvement in the approximation of the sensor's spectral response to the color-matching functions.

## 6. Other Feature of CA-310 (Increased Sensitivity)

An instrument used in the manufacturing process is required to have a certain level of repeatability while achieving fast measurement speed. Improvement in repeatability can be achieved by increasing the utilization efficiency of the incident light. The higher transmissivity of the filter gets, the better utilization efficiency of the incident light becomes. In the forming of a conventional filter with a glass filter or gelatin filter, multiple sheets of filters are used by bonding them. Since the transmissivity is reduced with each additional number of filters, it has been common that the transmissivity at the wavelength of maximum



Painted dot is data of CA-210,  
a conventional filter-type instrument.  
Unpainted dot is data of CA-310.  
Color of dots represent color of display screen.  
Yellow dots represent white screen.  
■ □ LED Backlit LCD / ● ○ CCFL backlit LCD / ◆ ◇ OLED

**Figure 6:** White and RGB measurement of various types of displays.

transmissivity usually drops to 10%–50%.

On the contrary, the new interference filter was designed to maintain almost 100% at maximum transmissivity when its transmissivity is approximated to the color-matching function. Due to this technology capability, the sensitivity of CA-310 is improved by about 3 times compared with that of the conventional instrument.

## 7. Effects of Using CA-310 (User Benefits)

### 7.1 Effect of High-Accuracy Specification

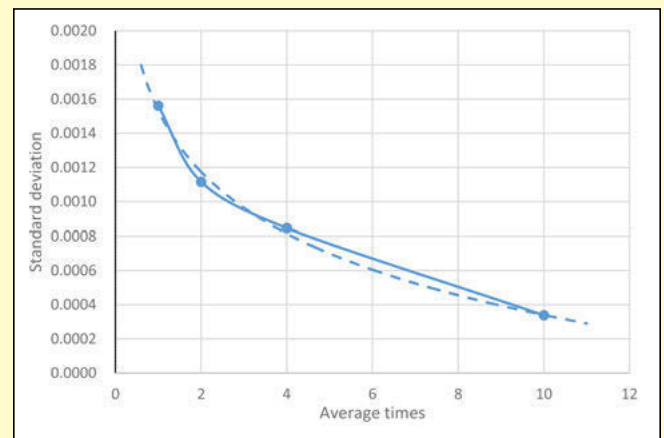
An instrument with high accuracy can contribute to the improvement in the quality of products. There are other user benefits as well.

Here is an example of a display manufacturer who guarantees a chromaticity tolerance within  $\pm 0.010$  from the target center value as a shipping condition of the product. Provided that the instrument has no measurement error, all products of which test results are within  $\pm 0.010$  can be shipped as good products. However, the actual instrument has measurement error and it should be taken into consideration to set tolerance. For example, if the error of the instrument is  $\pm 0.006$ , only the products with a measurement result within  $\pm 0.004$  can be judged as good products. Therefore, there may be a case where the product is judged defective due to the measurement accuracy of the instrument and should be judged good if inspected using the instrument with high accuracy.

In conclusion, the usage of a high-accuracy instrument could not only contribute to the improvement of product quality, but also contribute to overall productivity.

### 7.2 Effect of High-Sensitivity Specification

One of the issues a color luminance meter has is repeatability performance for low-luminance measurement. Repeatability can be improved by extending light receiving time. A similar effect can be obtained by averaging multiple measurements of fixed light receiving time, since it is equal to extend light receiving time. *Figure 7* shows repeatability of chromaticity x in relationship with the number of averaging when the CA-310 measures an LCD with an LED backlight at  $0.1 \text{ cd/m}^2$ . It is observed that repeatability is improving in proportion to the square root of the light receiving time. For instance, if the light-receiving time becomes nine times longer, repeatability improves by three times (the square root of 9). Conversely, a 3 times improvement



**Figure 7:** Average times and repeatability. Dashed line is the approximation line of the logarithmic function.

in sensitivity means that repeatability can be secured at the same level as that of the conventional instrument even if the light-receiving time becomes 1/9 the length. For the measurement of low luminance, repeatability becomes lower. The usual approach for correcting this problem is to increase the exposure or measurement time or to perform averaging both of which sacrifice measurement speed. Since the CA-310 can obtain the same level of repeatability as conventional instruments even at 1/9 of the light-receiving time, it is possible to secure high-speed measurement at low luminance.

Table 3 shows the measurement time in a display-evaluation test. The test was performed for 12 luminance points with the condition that the instrument should maintain a repeatability of  $\Delta xy (2\sigma) = 0.001$ .

It is remarkable that the measurement speed is shortened at low luminance range. The total measurement time of 12 points with CA-310 is 1.5 sec, which is a 4 times improvement from 6 sec for the CA-210, a conventional instrument.

## 8. Conclusion

In the course of technology advancements of various displays, expansion of the color gamut and pursuit of high contrast will continue. In order to meet the progression of technology, it is important for a color luminance meter to improve accuracy in order to accurately assess the brightness and chromaticity. In particular, the high performance in the spectral response is the most important. In this regard, it can be said that the CA-310 which is equipped with an optical filter of the new method described in this paper is the instrument which can meet evaluation demands of displays using the latest technologies.

**Table 3: Measurement time of 12 luminance points.**

cd/m <sup>2</sup>	Average times		Measurement time	
	CA-310	CA-210	CA-310	CA-210
204.8	1	1	0.05	0.05
102.4	1	1	0.05	0.05
51.2	1	1	0.05	0.05
25.6	1	1	0.05	0.05
12.8	1	1	0.05	0.05
6.4	1	1	0.05	0.05
3.2	1	1	0.05	0.05
1.6	1	1	0.05	0.05
0.8	1	2	0.05	0.1
0.4	2	8	0.1	0.4
0.2	5	22	0.25	1.1
0.1	14	80	0.7	4
<b>Total</b>		<b>Time (sec)</b>	<b>1.5</b>	<b>6.0</b>

For further information contact  
sensing-gc@konicaminolta.jp



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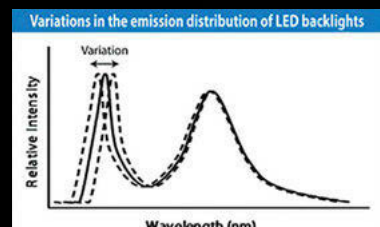
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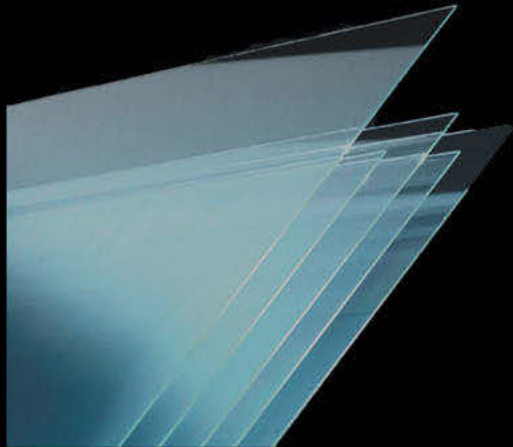
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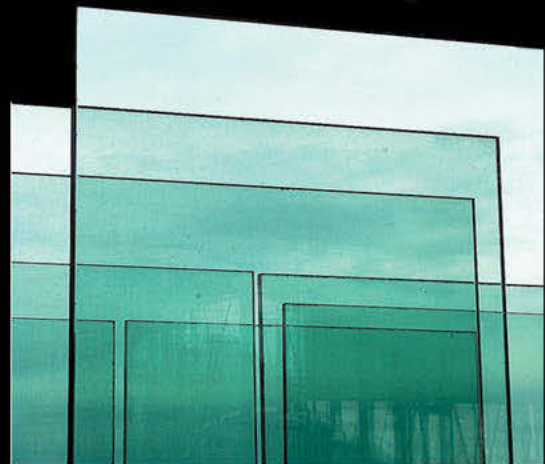
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IZO (Indium Zinc Oxide)  
FTO (Fluorine Tin Oxide)

Nanotubes, Nanoparticles  
AZO (Al Doped Zinc Oxide)  
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# From Idea to Enterprise – Technology Transfer Tips for Academics

*The earlier articles in this series by Helge Seetzen described the fundamental aspects of building a venture: people, funding, and monetization. While this information is useful for all aspiring entrepreneurial technologists, this fifth and final article in this series is devoted to the specific demographic of university researchers.*

by Helge Seetzen and Lorne Whitehead

UNIVERSITY RESEARCHERS are probably the largest potential source of commercially valuable inventions and yet they are generally not viewed as leaders in entrepreneurial value creation. We will therefore provide some commercialization tips for faculty members as well as some suggestions for investors and entrepreneurs working with faculty members. Joining me for this article is Dr. Lorne Whitehead, a previous CEO who has spent the last 20 years combining the roles of university professor and administrator with a high rate of patenting and spin-off company creation.

Before we begin, it is helpful to divide the path from idea to enterprise into stages. Words like invention, innovation, and commercialization are frequently used by politicians, theorists, and entrepreneurs alike to

describe the act of bringing a product to market, but, as you already saw in the first article (“Start-up Fundamentals,” July/August 2013), there are actually three distinct stages with unique requirements:

- Innovation is the process of turning an invention into a tangible product that allows people to benefit. This is not the responsibility of universities; generally they transfer inventions at this stage to existing companies or new start-ups.
- Commercialization is the engine that turns one dollar of investment into multiple dollars of return by leveraging the value of the innovative product. Larger companies are often best at this due to their inherent economy of scale and stability.

The role of university researchers is different in each stage, as you will see in the following sections.

## **Invention: Problems & Solutions**

“Invention is 1% inspiration and 99% perspiration.” – Thomas Alva Edison

One of us (Seetzen) runs a company that helps university inventors to commercialize their ideas, and as a result he speaks with hundreds of brilliant researchers every year. This has helped build an appreciation of the great potential for universities to contribute to economic growth and societal advancement,

but it can be challenging to unleash this potential.

On the positive side, universities are an ideal home for what might be called “deep invention,” which is (a) grounded in a sophisticated intellectual understanding and (b) inspired by significant societal need. One of the key challenges is to bring together these two different forms of understanding – a process that can often be accelerated through interdisciplinary collaborations and partnerships, but is seldom easy. Furthermore, almost by definition, the invention process can be difficult to predict and it is usually highly recursive – multiple trips back to the drawing board are the norm, not the exception. That is why such deep invention is intrinsically difficult, and, unfortunately, it is made even more so because it runs somewhat counter to the academic mainstream.

Despite these challenges, however, universities can be wonderful places to support deep invention. They offer a powerful combination of open exchange, multi-disciplinary thinking, and relatively large amounts of flexible funding.<sup>1</sup> Furthermore, they are welcoming places for people with challenges to visit. Often industrial researchers derive significant personal satisfaction through professional interaction with the university research system from which their careers began. Ultimately, successes grow from trust between people

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who have different perspectives and a shared goal.

From a commercialization perspective, a key during the invention stage is to focus on the big picture without losing sight of the details. It is important to avoid limiting performance comparisons only to alternatives in the same field (e.g. “our new electroluminescent display is twice as bright as other electroluminescent displays”). That’s academically convenient, but often misleading in the commercial context. Instead, the comparison should focus on all known avenues to solve the particular problem. Having the world’s fastest horse is largely useless if people drive cars.

Once you have an idea that stands the tests of comparison to alternatives, it is time to consider protecting it. Like companies, most universities lay claim to intellectual property created by their employees. The details vary, but a common model is university ownership with proceeds being shared with the inventors. Most universities operate so-called technology transfer offices to assist their faculty with the protection and commercialization of intellectual property. The sidebar “Technology Transfer Offices” provides more guidance on engaging with such an office, which is worth doing as early as possible in the invention process.

### Technology Transfer Offices

Technology Transfer Offices (TTOs) can be a powerful ally in the commercialization process if leveraged properly. To do so, faculty members need to understand three things about TTOs:

- **Ownership:** The university, in general, owns a significant portion of any proceeds derived from the inventions of faculty members. While this is often good value in terms of saved legal and IP expenses, inventors should keep in mind that this is ownership of proceeds related to the invention and not necessarily the commercialization. For example, if a venture is formed with the inventor as active executive and possibly investor, then the university should receive a share of the often relatively small amount of equity allocated to the intellectual property but not to the

stakes given for founding, investment, or future work incentive. Most of the value creation happens post-founding, so active inventors will often receive significantly more than the initial split with the university would suggest (conversely, passive inventors will often converge onto just their portion of the IP compensation).

- **Intellectual Property:** Managing IP is a key function of most TTOs. They already receive a portion of the commercial proceeds, so researchers might as well leverage these skills (and funding for patents). Inventions should be disclosed to the TTO as early as possible so that a proper intellectual property strategy can be formulated. The best researchers maintain a constant relationship with specific tech transfer officers for this purpose. In my experience, patents developed by TTOs are usually solid foundations for a start-up. Patents written by independent inventors are a bit like sticking your hand into a bee hive – there is honey in there somewhere but most of the time it just hurts a lot ...

- **Commercialization:** Contrary to what one might expect, most TTOs are not actually particularly good at transferring technology for money. While well intentioned, TTOs rarely have the budget or domain expertise to do effective business development, much less fund commercialization activities such as trade shows. The average Tech Transfer Officer has 20–30 files on her desk, at best organized into broad buckets like “physical sciences,” “life sciences,” and “IT.” The same officer will have no budget to travel or reach out to a particular industry. Unless somebody walks into her office with a check, this just is not going to be enough to commercialize the invention. That is why start-ups are needed.

Within the above limitations, the TTO can be of great help to researchers and especially those who are new to the commercialization process.

A special consideration for university researchers in this context is confidentiality. The very strength of universities – open collaboration and publication – can greatly undermine the value of inventions if not managed properly. The obvious step is to file a patent application before publishing your work,<sup>2</sup> but it is also worthwhile to think strategically about communication. Collaborations add tremendous value to most research initiatives as long as the partners have a good understanding of the terms of engagement. Patent offices usually treat universities as a single institution, but collaborations with external partners should be covered by confidentiality agreements. At minimum, those should specify intellectual-property ownership and likely future avenues for commercialization to make sure that all partners are on the same page.

Done right, the above steps should yield a protected solution to a meaningful problem. The next step is to turn that solution into value through innovation.

### Innovation: Start-Ups & Transfer

*“Business has only two functions — marketing and innovation.”* – Milan Kundera

If universities excel at invention, start-ups are the engine of innovation. The start-up environment is ideally suited to rapidly reducing risk by developing prototypes, assembling a multi-disciplinary team, and engaging with customers. This requires focus, speed, agility, and risk capital – none of which the university environment typically provides. University researchers often conceptually understand this barrier, but that does not necessarily make the transition easy.

The principal challenges in the transition are often funding and leadership. The former is a challenge because university grant funding is very different from raising venture investment. Obtaining university research grants is not easy, but imagine if grant applications happened like venture capital pitches: write a full proposal; fly to the funder’s office; realize that nobody read the proposal; explain, in 10 minutes why this research is relevant to a group of people who are at best only vaguely familiar with the field; hand over control of all material aspects of the research to the reviewers; and, finally, get rejected nine times out of ten because: “What if MIT were to start this research?” Throw in some general humiliation, and this is pretty much how venture fund raising works.<sup>3</sup>



If venture funding is already difficult, leadership is even more of a stumbling block for nascent start-ups. Unless they are willing to leave academia, it is very difficult for university professors to successfully lead start-up ventures. Even if their interpersonal leadership skills and business acumen are strong, faculty members simply do not have the required time, and, furthermore, they face multiple conflicting priorities that would inevitably make their start-up suffer. Publishing, teaching, grant writing, and many other academic duties may help fuel invention, but they cannot fuel a start-up. Accepting this is difficult for many inventors because it often means handing over control to others.

These factors conspire to make it extremely tempting for many faculty members to hold on to an emerging venture for longer than they should. Faculty-run ventures operating in university facilities with grant funding, and the unwillingness to change any of these aspects, are the dominant reason why venture investors stay away from many university opportunities – because such “research ventures” seldom generate wealth.<sup>4</sup> In contrast, spin-off companies often do.

A better solution is to make the transition gradual but deliberate. For example, Seetzen’s first venture operated in parallel to ongoing research in the originating lab for quite some time. This took the form of a modestly financed company working closely with the university lab. Critically, the former was an independent entity with its own leadership and venture financing, while the latter leveraged a large research grant to advance the fundamental science. A collaboration agreement between the company and university ensured that all university output was funnelled into the venture in exchange for equity.

The initial investment in a non-university executive for the company was small relative to the larger grant funding and workforce in the university lab, but even a small amount of professional investment made a big difference by establishing market valuation, solidifying the independence of the company from the university, and introducing commercial forces that prevented sliding back into the “research phase.” University-savvy angel investors and entrepreneurs are a great asset for this process. Earlier articles in this series that address team building provide some insight into the types of skills needed in a start-up and how to recruit the right person for the job.

Often there is an opportunity for one of the students in the project to take the day-to-day leadership role of the venture. This only works if the professor and student can truly shift their relationship to that of partners. To achieve this, the ex-student needs to step up to become a genuine leader through a mix of internal abilities and, generally, insane work hours (see the “Student Entrepreneurs” sidebar for more tips for students on this path). The faculty members need to accept that instead of a supervisory relationship, the ex-student now receives guidance from a wide range of sources of which the professor is only one. Savvy professors will actively encourage such ownership expansion of their students – this being the only way that their venture grows successfully!

### Student Entrepreneurs

Students can be a powerful technology transfer driver, but being a full-time entrepreneur while studying can be very challenging (and there is no such thing as a part-time entrepreneur). Here are a few tips for aspiring student entrepreneurs:

- **Synergy:** Try to find work/study activities that “count twice.” For example, combine your entrepreneurial research with your graduate thesis work, or turn your company’s market research into MBA papers. This requires a bit of forethought, but the impact can be tremendous. A good supervisor, someone who understands technology transfer, can help you identify synergy opportunities and structure your program accordingly.
- **Goal-Optimized Schedule:** The big risk for student entrepreneurs is the lack of focus: achieving half of two goals is usually worth nothing. So you need to be disciplined with schedules and goals, and ideally declare quarterly goals in a public manner – at least to your supervisor – for that added bit of reinforcement. Keep in mind that, unlike school work, entrepreneurship leaves no room for do-overs. All exams are final, so you need to focus on delivering all the time and create an environment that supports this.
- **Entrepreneur-Friendly Courses:** Look for courses that are light on

regular homework (weekly small stuff) and heavy on end-of-year papers (synergy!). Compact single-session courses are great because they reduce the “overhead” of course work (travel to campus, etc.). If you are doing a business on the side, you will really appreciate the blocks of uninterrupted time this will afford you.

- **Publishing Is Your Friend:** This applies to technical entrepreneurs and might seem counterintuitive at first glance. But a tech start-up really offers a lot of opportunity to publish papers: core principles, implementation ideas, application studies, etc. Try to attach a paper to every internal activity of your start-up. Not only it this good marketing for your venture, it also ensures that your parallel academic track does not fall behind.

With the right planning and dedication, this approach will not only provide you success as an entrepreneur but also serve as a great insurance policy in the form of strong academic credentials. We have all heard the stories of drop-outs who go on to create giant companies but that’s just survivor bias. Most start-ups fail. A good foundation of education, publications, and credentials ensures that you get significant value out of your student-entrepreneur years even if your venture does not become the next Facebook.

**Commercialization: Enterprise & Beyond**  
*“Spectacular achievement is always preceded by unspectacular preparation.”* – Robert H. Schuller

Once the foundation of the start-up is in place, it is time to turn on the commercialization engine. Previous articles in this series cover the key elements of product development, future financing, and exit avenues. The role of faculty members during this process is to continue to inject next-generation invention into the growing start-up. This requires a fine balance between pursuing promising research areas without neglecting the need to focus on product development. In our experience, the best way to achieve this balance is to formally separate the internal product engineering

group from the semi-external research team at the university. A good Chief Technology Officer (CTO) can form the bridge between these two teams without creating undue distraction for either.

Consider BrightSide Technologies, a venture co-founded by the authors, as a highly successful example of such a partnership. The scientific foundation of the venture was developed by a group of almost a dozen academic researchers at universities across the world. Leveraging about \$500,000 in corporate capital into over \$3,000,000 in research funding, this team developed the vast majority of the 30 patent families as well as producing dozens of high-impact papers (a wonderful source of marketing for a technology start-up). Meanwhile, the internal team of some 30 engineers developed prototypes for most of these concepts, built a high-quality product, and ultimately brought the technology into millions of televisions through licensing partners among the largest manufacturers. Neither achievement would have been possible without close collaboration and world-class expertise on both sides.

The last step of the voyage is to turn the start-up into a stable, large company, either through growth or an exit. When that happens, the relationship between university researchers and start-up developers changes yet again. Initially, the characteristics of start-up developers will appear quite attractive to large companies: dynamic, proactive, fast, goal-oriented, *etc.* Unfortunately, large-scale product engineering requires discipline, precision, and process – aspects that a start-up will often deliberately suppress in order to move faster. Thus, after a brief honeymoon, “dynamic” usually becomes “can’t focus,” “pro-active” becomes “disruptive,” “fast” becomes “sloppy,” and so forth. That is why most acquisitions ultimately fail, at least in the sense of talent retention.

Fortunately, many of the above requirements are a perfect fit for university researchers. The timelines, scope, and internal dynamics of universities are often quite well-matched with those of large companies. Combined with their mastery of the technical domain, this makes university researchers the ideal technology advisors for the large company – often more so than the developers in the start-up itself. This also allows the university researchers to form relationships with the acquirer that often endure far beyond the start-

up itself. Research chairs or permanent endowments provide a way for both parties to develop long-term collaborations that transfer much of the core scientific insight of the founding research group into the new large company owner. Completing the circle, university researchers can use those relationships to gain a deep understanding of new societal challenges, which they can fold back into the “deep invention engine” of the modern research university

Technology transfer offers a great opportunity for university researchers to bring their ideas to the next level. The role of the researcher changes during the three principal stages of entrepreneurship: idea generator during the invention stage, scientific leader during the innovation stage, and, ultimately, technology advisor. Done right, faculty members can be the driving force behind start-up creation, technical growth, and even the acquisition process as long as they partner with commercialization expertise to cover the natural limitations of the university environment. (Investors or corporate development executives interested in investing in University Ventures should see the sidebar, “Investing in University Ventures.”)

### Investing in University Ventures

Investing in university ventures is difficult but potentially very worthwhile. These tips might help investors or corporate development executives engaging with universities:

- **Know Thy Friends:** University Technology Transfer Officers are neither entrepreneurs nor lawyers, but rather a curious mix between incentive-less business developer and informal legal administrator. Most of them have a technical Ph.D. and very little off-campus work experience. Try to physically meet your counterpart early on to get a sense of their experience and listen carefully to their terminology. Universities have their own culture and vocabulary when it comes to commercialization. The more you normalize your language, the better your chances of closing a deal.
- **Accept Their Mission:** Ask yourself on the first day of any negotiation

whether you can accept the dual mission of the university: public research and student education. Technology transfer is a subordinate goal compared to these two, so you are never ever going to get a licensing or investment deal that limits the university’s ability to conduct research, publish the results, and allow students to write their theses. Instead of fighting these constraints, smart investors will tie these needs into their company, for example, by coordinating a publication calendar as a means to conduct technical marketing.

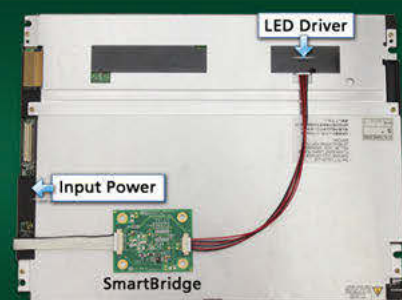
- **Licensee vs. Investor:** It is truly unfortunate that most university investment deals are considered a “license.” For a traditional license, the university is usually approached by companies that want to purchase something that the university owns. The inverse is true in the venture world, where it is the entrepreneur who wants the money and the investor who has it. Unfortunately, university researchers often genuinely believe that they are doing investors a favor by taking their money. Do not get offended when this happens. It is a consequence of their sheltered reality and not intended as a negotiation stance.
- **Charter vs. Folklore:** Universities have a lot of fundamental charter constraints. These are unavoidable and as an investor you just need to learn to live with them. But universities also have a lot of folklore that at first glance appear like charter issues. A classic example would be the often-quoted Bayh-Dole Act in the US: “We cannot sell the technology [Charter: Bayh-Dole prohibits assignment] so we need an ongoing royalty. [Folklore: Bayh-Dole makes no provision whatsoever about payment modality.] Understanding these differences can be critical for business decisions (*e.g.*, the inability to collect a lump sum payout would scuttle most venture investment deals for

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technologies with long times to market, whereas the inability to assign would not be a deal killer for the same investor). Beyond studying policy, your best bet is to ask your tech transfer officer to provide not just the “rules” but also the reasons behind them.

- **Risk Is Anathema:** Most university inventors are not just risk-averse. They do not just assess risk and then decide against taking it – they often genuinely do not understand the concept of risk. This usually pops up during the valuation process. Inventors, and to some degree universities, tend to over-value ideas. On the flip side, they tend to under-value human contributions. De-coupling past from future is your best bet for crossing this chasm. The past is sunk cost. The value of the invention has nothing whatsoever to do with the (government) money spent to get there and everything to do with the commercial opportunity going forward. You should therefore make a distinction between those inventors who will make substantial operational contributions post-founding and those that will not. The latter will be adequately provided for by the university portion of the deal. The former should be treated as founders with additional incentive grants.

During our five-article journey through the world of venture capital, we have covered a number of important topics, including start-up fundamentals, raising capital for technology ventures, key terms and potential pitfalls, exiting with grace and profit, and this last installment focusing on academic researchers. These articles can be found at [www.informationdisplay.org](http://www.informationdisplay.org), starting with the July/August 2013 issue. Together they form a useful guide to help would-be entrepreneurs through many of the important decisions and challenges they will meet on their journey.

<sup>1</sup>Individual academics will challenge this, but remember that U.S. universities spend four

<sup>2</sup>Publication, even on an informal basis, destroys patentability in most countries. The exceptions are the U.S. and Canada, where inventors receive a one-year grace period to file after publication. International rights are still lost, so it is still better to file before publishing, even in those countries.

4 “As you might remember from the second article in this series (“Raising Capital for Technology Ventures,” September/October 2013), seed stage valuations have little to do with objective value but rather with investment dynamics. Whether a university concept graduates after a year or a decade of research usually does not make any difference in valuation – thus ensuring that even those faculty-run “research ventures” that ultimately achieve escape velocity rarely get any economic credit for staying on campus longer than they should have. ■



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# Tablet PC and Smartphone Displays Converge

*The range between 5- and 9-in. screen sizes is emerging as the “sweet spot” for high-volume mobile devices. At the same time, display resolutions will continue to increase rapidly, with the mainstream pixel density for mobile phones moving above 300 ppi (pixels per inch) and above 200 ppi for tablet PCs. These trends provide significant opportunities for makers of small-to-medium high-resolution displays.*

by Paul Semenza

**T**HE SHIFT toward smartphones (mobile phones with processors capable of running operating systems and applications) has created significant demand for ever-larger screen sizes, which enhance the experience of games and other mobile applications, as well as usage of e-mail and the Internet. Starting with 5-in. displays in 2012, and followed by 6-in. displays in 2013, the mobile-phone market

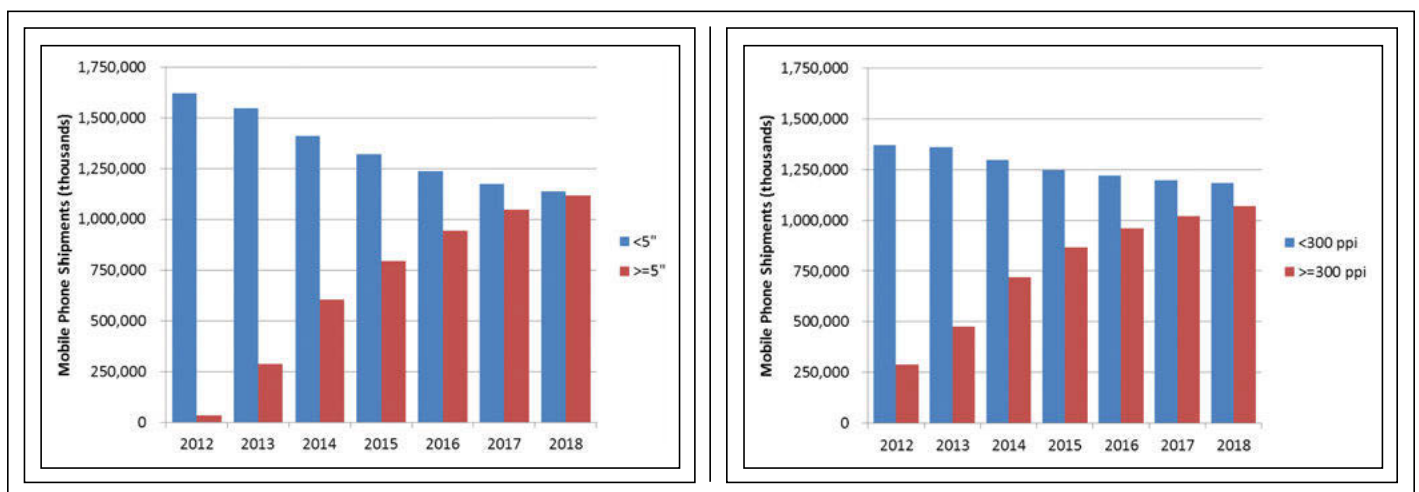
has shifted dramatically toward larger screen sizes. By 2018, 5-in. and larger displays will account for one-half of the mobile-phone market (Fig. 1).

Screen size is only part of the challenge of improving the mobile experience; for many tasks, information content and resolution are the key characteristics. The simplest measure in this regard is the number of pixels in the display. While there are many different pixel formats, the pixel counts on mobile-phone displays have increased dramatically. In 2012, three-quarters of mobile phones had

less than a half-million pixels (equivalent to SVGA format); in 2014, a third will have 1 million pixels (HD) or more; and in 2015, a quarter will have 2 million pixels (FHD) or more. We can expect 4-million-pixel displays (QHD, WQXGA) to start shipping in 2014, and potentially 8-million-pixel displays (4K) sometime in the future.

The rapid shift to higher resolutions has outpaced the increase in screen sizes, leading to increasing pixel densities. As shown in Fig. 2, a key distinction is at 300 ppi, roughly HD resolution on a 5-in. display, with all the

*Paul Semenza is the President of NPD DisplaySearch. He can be reached at [paul.semenza@displaysearch.com](mailto:paul.semenza@displaysearch.com).*



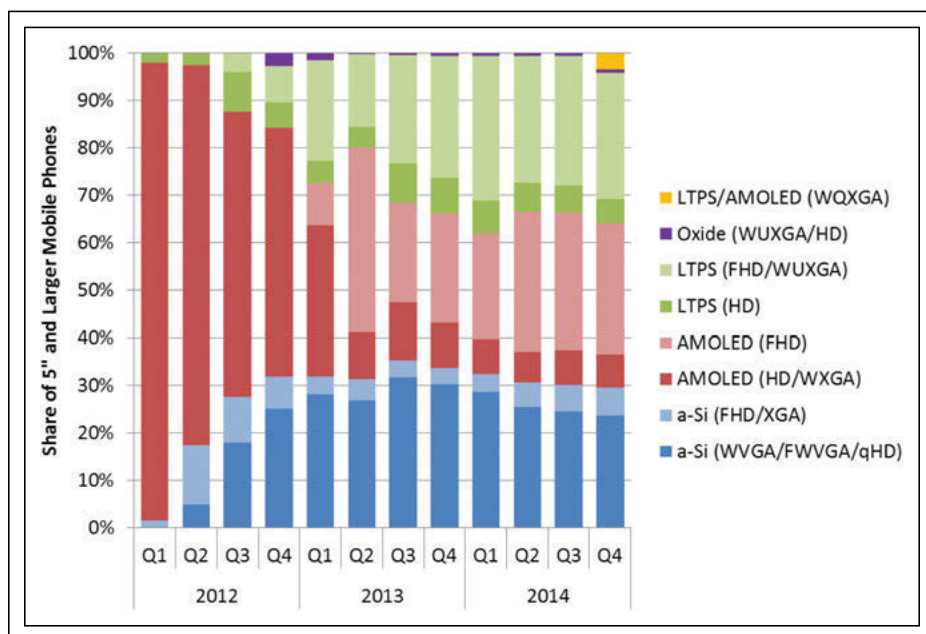
**Figs. 1 and 2:** At left, in Fig. 1, the mobile-phone market is in the midst of a significant transition to large screen sizes. At the same time, Fig. 2 (right) shows that as mobile-phone displays are getting larger, they are also rapidly shifting to higher pixel densities.

market growth taking place at or above this pixel density.

While Apple first drew attention to high resolution with its “Retina” display on the iPhone 4 at 330 ppi, it was quickly passed by higher pixel densities, including FHD displays on 5 in. (441 ppi) and then 4.5 in. (490 ppi), among others. The introduction of QHD and WQXGA displays this year is raising the bar to 500 ppi (QXGA on a 5-in. display) and above.

The shift to larger screen sizes and higher pixel densities has led to the possibility that smartphone displays could become available in the 4K format. Such a high pixel format requires new configurations of driver ICs (RAMless and ultimately compressed SDRAM), application processors, graphics processing units, and a high-bandwidth display interface (such as MIPI) in order to drive the display. Many of these components are in development, and, to some degree, content (such as 4K streaming from Netflix) and high-speed wireless networks (such as 4G LTE) are in development as well.

The question arises as to whether display technology is able to reach pixel densities in excess of 700 ppi at an affordable cost and level of power consumption. On a more practical level, such pixel densities are roughly twice the resolving power of the eye at typical viewing distances, leading some to wonder why manufacturers would suffer the cost and performance tradeoffs. While there have been some studies on the benefit of very high pixel



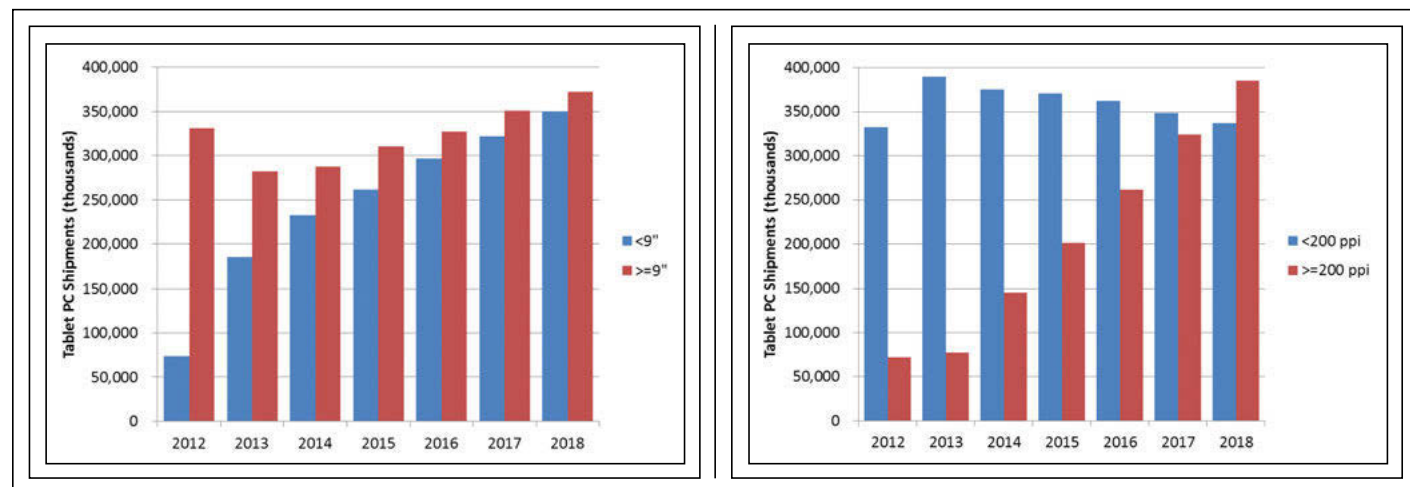
**Fig. 3:** Since the middle of 2013, the large-sized mobile-phone market has shifted toward higher-resolution technologies. As it has done so, LCD technologies have captured share from the AMOLED-display market.

densities on perceived image quality, there is relatively little basis for thinking that most viewers would perceive the difference between, for example, 600 and 700 ppi. One possibility is that the high pixel count could be utilized for other features, such as glasses-free 3-D.

The growth in high resolution has led to a shift in display technologies used for the

largest (5 in. and larger) and highest resolution (FHD and higher) phones (Fig. 3).

Samsung was the first to move into this space with AMOLED displays, using its PenTile architecture to increase the effective resolution beyond the accuracy limitations of the organic material deposition process. In the past year, AMOLED displays have faced



**Fig. 4 and 5:** Tablet PCs started out dominated by the original iPad 9.7-in. screen sizes, as shown in Fig. 4 at left, but, in the past few years, smaller screen sizes have grown much faster. At right, Fig. 5 shows tablet PCs are now at the beginning of a shift to higher pixel densities.



competition from LCDs in this space; from a-Si due to its low backplane cost and wide availability and from LTPS due to its ability to use smaller TFTs, enabling higher pixel densities with fewer LEDs, and thus lower back-light cost. While it is dominant in pixel densities up to 300 ppi, a-Si TFTs are limited in their ability to reach the highest resolutions, such as WUXGA and WQXGA, which are well above 300 ppi. At the same time, increased production of LTPS has enabled it to grow share. Leading LTPS suppliers LG Display, Japan Display, and Sharp have been increasing capacity, resulting in a doubling of input capacity between 2011 and 2013. Numerous suppliers are building LTPS capacity in China, including Tianma, Foxconn, BOE, and China Star, with the result that capacity is likely to again double between 2013 and 2016. Finally, oxide TFTs, in particular Sharp's IGZO technology, have entered at the high end of the market.

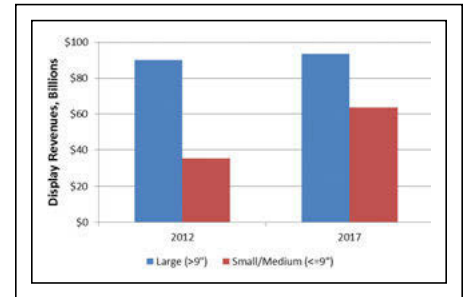
### Tablet PC Displays Get Smaller

While smartphones are driving the growth of mobile phones to larger than 5-in. screen sizes, the dynamics of the tablet PC market are driving growth to screen sizes below 9 in. As shown in Fig. 4, the tablet-PC market underwent a significant change in 2013, from one dominated by 9.7 in. to a bifurcated market with growth both above and below 9 in.

This has been due to a much higher rate of success for 7-in. devices, particularly those running the Android operating system. The success of these devices was one factor in Apple's decision to develop the iPad mini, with a 7.9-in. screen. A particular area of growth has been the so-called "white box" market centered in China, in which companies with little brand or technology presence integrate "open cell" or unfinished TFT-LCDs with standard components into low-end devices running open-source operating systems. These and other smaller screen sizes are expected to grow faster than screen sizes above 9 in. and will approach one-half of the market within a few years.

While the pixel densities are not as high as in smartphones, tablet-PC resolutions are also increasing, with the key break point at 200 ppi, with displays above that expected to provide all of the unit growth starting this year (Fig. 5).

As stated above, a-Si TFT-LCDs can easily handle pixel densities to 300 ppi, so they have dominated the tablet-PC market. However, Sharp began producing IGZO tablet-PC panels in 2013, and with FHD and higher pixel formats moving from less than one-fifth of tablet PCs shipped in 2013 to one-half in 2016, there will be increased demand for LTPS TFTs as well as oxide TFTs. Finally, with continued development of PenTile technology as well as organic material deposition, AMOLED



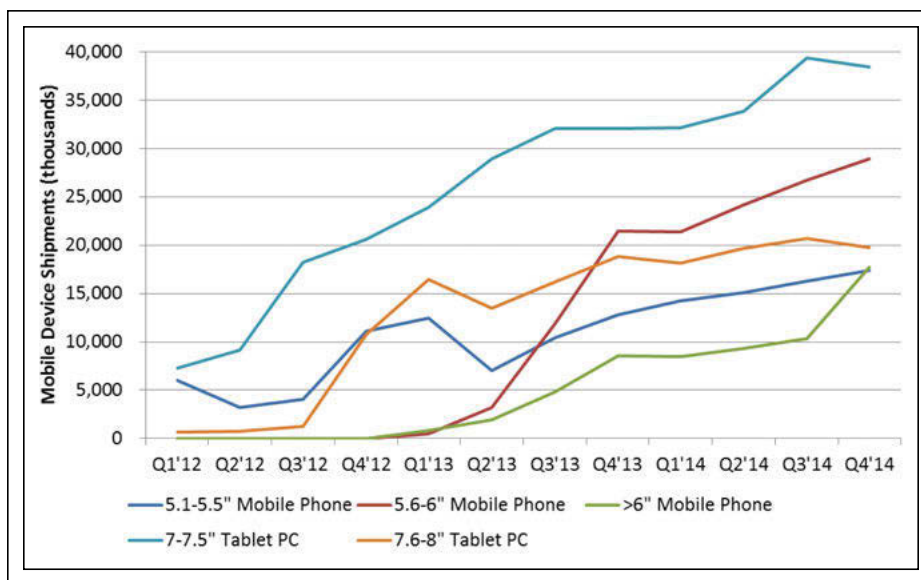
**Fig. 7:** The rapid growth in smartphones and small tablet PCs, particularly in high-resolution formats, is driving growth in revenues for small-to-medium flat-panel displays.

displays are also expected to play in the greater than 200 ppi tablet-PC panel market.

### Is There Room in the Middle?

With the rapid growth of smartphones above 5 in. and tablet PCs below 9 in., one could reasonably expect overlap of these two device categories, something that can be seen in the "phablet" products, as well as cannibalization. But as shown in Fig. 6, for the next several years, there appears to be room for both types of device to grow, as many consumers are adopting multiple devices.

While key distinctions will remain – such as whether the primary connectivity technology is cellular or WiFi and whether the device is purchased with a contract from a telecommunications carrier – the design and characteristics of smartphones and smaller tablet PCs are likely to continue to converge. This is a very positive development for the companies that can provide displays from 5 to 9 in., particularly at high resolutions, and is driving rapid growth in the category overall (Fig. 7).



**Fig. 6:** Over the past few years, larger mobile phones and smaller tablet PCs have each been able to grow rapidly.

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# Products on Display at Display Week 2014

*Some of the products on display at North America's largest electronic information-display exhibition are previewed.*

by The Editorial Staff

**T**HE SID 2014 International Symposium, Seminar, and Exhibition (Display Week 2014) will be held at the San Diego Convention Center in San Diego, California, the week of June 1. For 3 days, June 3–5, leading manufacturers will present the latest displays, display components, and display systems. To present a preview of the show, we invited the exhibitors to highlight their offerings. The following is based on their responses.

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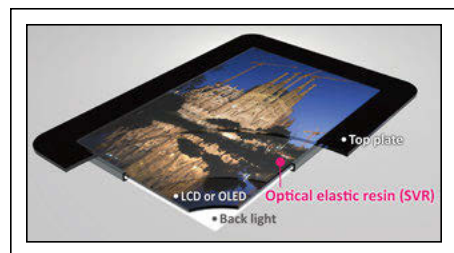
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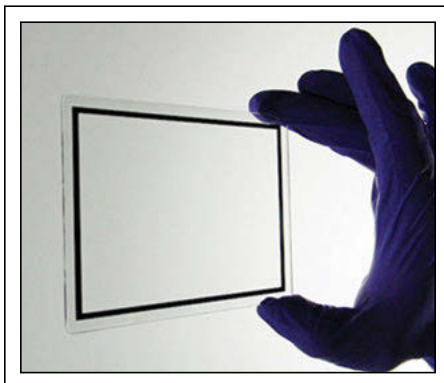
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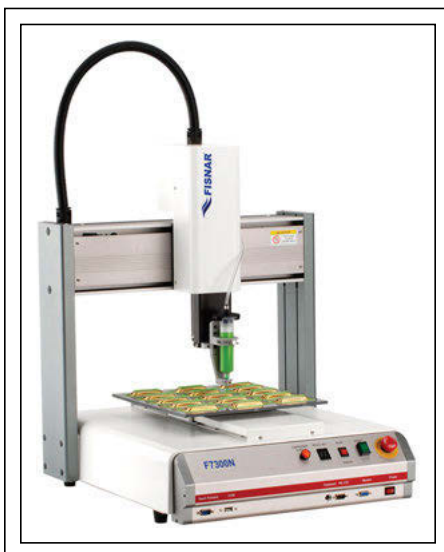


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The FLEEx Front Light Panel provides illumination for small-to-medium-sized reflective displays using the world's thinnest film-based light guide. FLEEx's front light incorporates only a single LED coupled to an optically engineered film to provide the most elegant and most efficient front light on the market. The FLEEx Front Light Panel can be bonded directly to reflective LCDs (including the Sharp™ line of memory LCDs), transreflective LCDs, and reflective e-Paper displays.



## FLUXIM

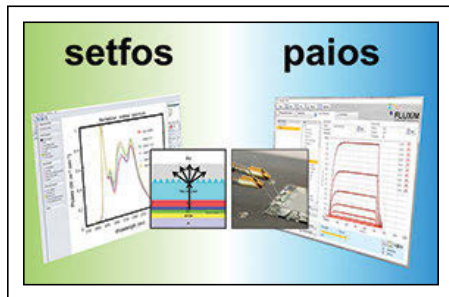
Winterthur, Switzerland +41-44-500-47-70  
www.fluxim.com  
Booth 1945

### OLED Design Tool

A new version of the OLED design tool SETFOS has been launched by Fluxim for studying light-scattering enhancement. The software calculates the radiation of oscillating dipoles embedded in OLEDs

## trade show preview

containing planarization layers, color filters, as well as scattering structures. The user easily assesses how light scattering in the OLED improves the overall out-coupling performance for lighting or display applications and can tune the scattering function. Moreover, Fluxim exhibits the all-in-one OLED measurement platform PAIOS for dynamic characterization, advanced parameter extraction, as well as stress testing. The powerful PAIOS software provides pre-defined experiments such as impedance spectroscopy, transient electroluminescence, and more.

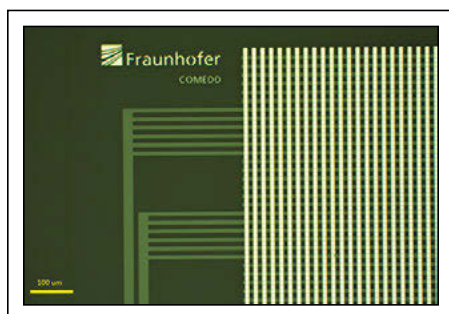


### FRAUNHOFER COMEDD

Dresden, Germany +49-3-51-88-23-0  
www.comedd.fraunhofer.de  
Booth 1608

#### Orthogonal Photolithography

Orthogonal Photolithography is a patented technology, pioneered by Fraunhofer COMEDD group leader Dr. Alex Zakhidov. It takes advantage of the fact that the vast majority of organic materials are either oleophilic or hydrophilic and are hence orthogonal to highly fluorinated chemicals. Therefore, appropriate fluorinated photoresists can be used to pattern organic layers without compromising the performance of organic devices. The availability of such orthogonal photoresists promises to enable the fabrication of complex device structures, expanding the range of possibilities for organic electronics. Fraunhofer COMEDD established Orthogonal Photolithography in its clean room and incorporated it into a 200-mm wafer microdisplay pilot fabrication line.

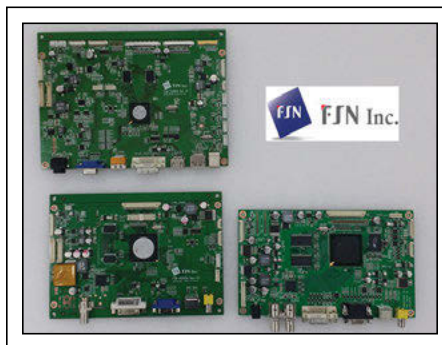


### FSN

Gyeonggi-do, Korea +82-31-817-6812  
www.fsndisplay.com  
Booth 431

#### 4K × 2K and HD-SDI Board (FPGA) Solution

FSN's FSB-800UHD and FSB-720WQX boards provide the best 4K × 2K solutions. The FSB-800UHD supports 3840 × 2160 @ 60-Hz panels, while the FSB-720WQX board drives 3840 × 2160 @ 30-Hz panels. Also, FSB105SDI, FSB-106SDI, FSB-510HD-SDI, and FSB-600SDI along with FSB-800STX are the best solutions for high-quality broadcasting HD LCD monitors. Also, FSB-800STX supports 90° and 180° rotation for the FPGA board.



### FUTABA CORPORATION OF AMERICA

Schaumburg, IL 847/884-1444  
www.futaba.com  
Booth 731

#### Flexible Displays

Futaba Corporation of America will feature its portfolio of OLED displays and touch products, highlighting its FLEXIBLE OLED displays. Futaba is responding to today's demanding display needs with a number of exciting technologies including flexible displays that can be applied to curved surfaces. These shatterproof displays conform to curves with a radius as small as 40 mm and are ultra-thin at less than 0.25 mm. Futaba's flexible display sizes vary from 3.5 to 1.4 in. and are available from 262k color (shown) to monochrome.

#### Submit Your News Releases

Please send all press releases and new product announcements to:

Jenny Donelan  
Information Display Magazine  
411 Lafayette Street, Suite 201  
New York, NY 10003  
Fax: 212.460.5460  
e-mail: [jdonelan@pcm411.com](mailto:jdonelan@pcm411.com)



### HENKEL CORP.

Rocky Hill, CT 860/571-5266  
www.henkelna.com  
Booth 1311

#### Optically Clear Adhesive

LOCTITE® 5193 is a single component Liquid Optical Clear Adhesive (LOCA) with improved moisture cure through depth. It is specifically designed for gap filling of display devices for improved optical performance and durability. It is a low-viscosity silicone that upon exposure to UV/visible light cures into a clear, transparent silicone rubber. The product contains a secondary moisture cure mechanism which fully cures any remaining material in potential shadowed areas. LOCTITE® 5193 is available in 50-mL syringes, 300-mL cartridges, and 18-kg pails.



## INCOM

Charlton, MA 508/909-2200  
www.incomusa.com  
Booth 1903

### Fused Fiber Optics

Incom produces glass and polymer fused fiber-optic faceplates, tapers, and microstructures. Incom is the leading supplier of fused fiber optics to the display industry, enabling displays to have any outer geometry imaginable. Incom's fiber optics transfers an image from one plane to another, allowing for tactile feedback in programmable digital displays. The optics not only enhances the user interface by blocking high-angle light and simplifying systems of multiple displays/buttons, but it can also create contoured displays. This technology has been used in high-end audio mixing, casino gaming, military tanks, and head-up displays for military aircraft.

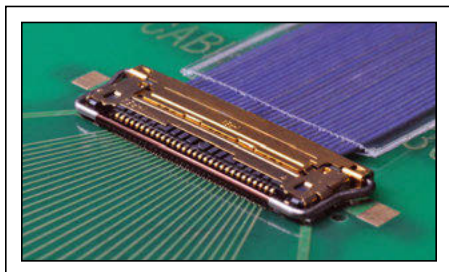


## I-PEX

Austin, TX 512/339-4739  
www.i-pex.com  
Booth 1427

### 4K-UHD Connector

Micro-coaxial cables made with the I-PEX Cabline-CA 0.4-mm-pitch connectors are being used to transfer 4 eDP signal lanes at a data rate of 5.4 Gbps to drive the 4K × 2K UHD panels. This data rate does not stress the capability of the 10+ Gbps connector design. Additional grounding contacts under the header connector provide the short return path required for the best high-data-rate transmissions. Performance results regarding impedance, eye pattern, and S-parameters — Insertion/Return loss, NEXT and FEXT — are available and will be discussed during the Exhibitors Forum on Wednesday, June 4th at 5 pm.

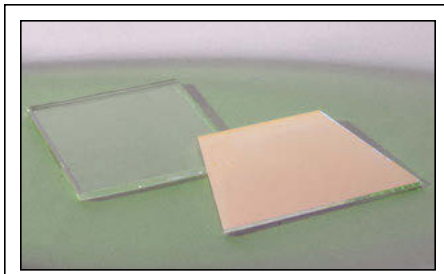


## IRIDIAN SPECTRAL TECHNOLOGIES

Ottawa, Ontario, Canada 613/7441-4513  
www.iridian.ca  
Booth 1926

### AR/AS Coatings

To address the many varied requirements in display applications (touch-screen displays, automotive instrument panels, etc), Iridian has developed durable and reliable AR/AS coatings with performance tailored to specific customer needs. Customizable features include tint and reflectance level, along with new techniques to minimize the appearance of fingerprints in different usage scenarios. Iridian's AR/AS coatings, available in sizes as large as 20 in. on the diagonal achieve contact angles in excess of 100°, pencil hardness of 6H, and survivability in excess of 8000 steel-wool rubs while maintaining high transmission in excess of 99%.

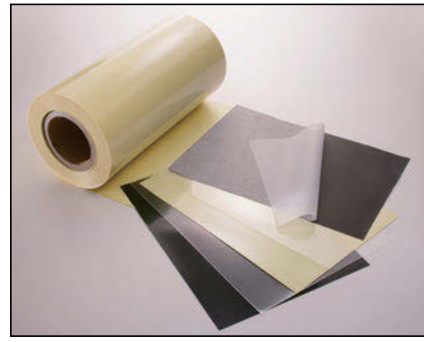


## IWATANI CORP.

Tokyo, Japan +81-3-5405-5797  
www.iwatani.co.jp  
Booth 1831

Iwatani Corp. provides high-performance film and industrial tape products specialized for electronic devices. The Acrylic Foam ISR-ACF series demonstrates a high-shock-absorbing performance suitable for LCD and OLED application. Not only for shock absorbing, but Acrylic Foam is also the best solution for the common display problem of the so-called "Ripple Effect" which can be improved by using the line-up of various foam densities. With its innovative technologies and superb analysis, the ISR-ACF series allows for different design concepts for customers. Because of its qualities, the ISR-ACF series is suitable for mobile devices.

**For Industry News, New Products,  
Current and Forthcoming Articles,  
see [www.informationdisplay.org](http://www.informationdisplay.org)**



## JDI DISPLAY AMERICA, INC.

San Jose, CA 408/501-3720  
www.j-display.com  
Booth 1332

### 12.1-in. 4K × 2K TFT-LCD Module

Japan Display, Inc. (JDI), a global leader in mobile display technologies, will feature a high-resolution (365-ppi) 12.1-in. 4K × 2K (3840 × 2160 pixels) TFT module designed for tablet use. The display allows users to enjoy precise and dynamic images with pixel density similar to that of full high-definition (full-HD) smartphones and provides an approximately 4 times larger screen size. Low-temperature polysilicon technology (LTPS) enables not only high-capacity information content and high resolution, but also low power consumption and a thin module with narrow borders, ideal for mobile-use devices such as tablets. The display also features wide viewing angle and high contrast.



## KOPIN CORP.

Westborough, MA 508/870-5959  
www.kopin.com  
Booth 1812  
Westborough, MA 01581-3341

### Ultra-Compact Display Module

Kopin Corp.'s ultra-compact Pupil™ WQVGA Display Module (428 × 240 resolution) is aimed at emerging smart eyewear. The Pupil module offers a



## trade show preview

sharp full-color image with a 10.5° field of view and simple diopter adjustment from -4D to +2D. The super-efficient Pupil module and Kopin's A230 ASIC together consume less than 100 mW at a display brightness of 2000 nits, sufficient for clear visibility even under bright sunlight. Kopin has implemented the world's first natural-looking smart eyewear (a concept demo) by embedding the Pupil display module inside the eyewear frame.



### LUMINEQ DISPLAYS

Espoo, Finland +358-9-7599-530  
www.lumineq.com  
Booth 321

#### Transparent Displays

Transparent displays are ideal for high-end applications, where a subtle look and first-class viewing experience create differentiation. What makes TASEL different from other transparent display technologies is the unparalleled optical quality and clarity. Content can be presented with a TASEL display that complements the user experience. This can be a see-through display on a glass elevator or a transparent gauge on a coffee pot. TASEL displays are customizable. The display glass can be drilled, bent, or cut to shape to fit demanding end-product specifications.

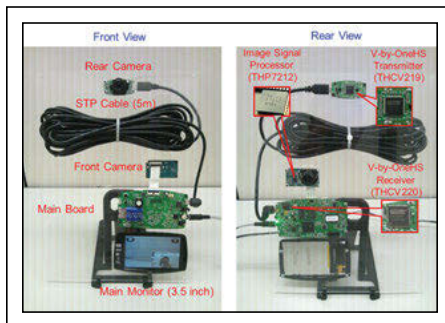


### MACNICA USA

San Jose, CA 408/325-8710  
www.macnica.com  
Booth 526

#### Drive Recorder

Macnica will demonstrate a Drive Recorder consisting of high-quality cameras, a 5-m-long cable, a 3.5-in monitor, and Thine Electronics V-by-One®HS transmitter and receiver.



### MOLECULAR IMPRINTS

Austin, TX 512/339-7760  
www.molecularimprints.com  
Booth 833

#### Roll-Based Lithography System

The LithoFlex™ 350 is a precision roll-based lithography system which uses Molecular Imprints' proprietary Jet and Flash™ Imprint Lithography (J-FILTM) technology. Leveraging success in the semiconductor market, this platform is capable of serving applications requiring nanoscale resolution, pilot-line productivity at an exceptionally low cost of ownership. This platform can be configured to accommodate flexible or rigid substrates for nanoscale (below 50 nm) lithography. Suitable applications include display wire-grid polarizers and plasmonic color filters, light-emitting-diode pattern substrates and emerging life-science devices such as DNA sequence flow cells on biosensors.

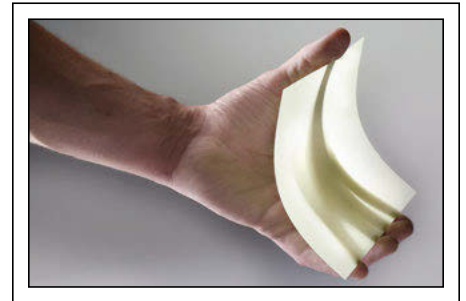


### NANOSYS

Milpitas, CA 408/240-6700  
www.nanosysinc.com  
Booth 1622

#### Quantum-Dot Enhanced Film

Each sheet of Quantum Dot Enhancement Film (QDEF) contains trillions of tiny quantum dots. The dots produced are tuned to create better color by changing their size during fabrication to emit light at just the right wavelengths. Conventional light-emitting materials such as crystal phosphors have a broad fixed spectrum. Quantum dots can actually convert light to nearly any color in the visible spectrum. For the first time, display designers have the ability to tune and match the spectrum more accurately to color filters. This leads to LCDs with perfectly accurate color and power-sipping energy efficiency.



### NEONODE

Santa Clara, CA 316/462-8258  
www.neonode.com  
Booth 730

#### Optical Multisensing Touch Solutions

Neonode's zForce® RADIUS is a MultiSensing® offering from Neonode® specifically developed for wearable devices with circular displays. zForce® RADIUS enables OEMs to add differentiated functionality to their wearable devices, such as standard touch, underwater operation (zForce® NEMO), and air gestures (zForce® AIR). Advantages include a true round display, high optical clarity due to no ITO layer, underwater operation, use with gloves, power management, very low BoM cost, and high manufacturing yield.



## NICOMATIC

Warminster, PA 215/444-9580 x217

[www.nicomatic.com](http://www.nicomatic.com)

Booth 427

### Gold-Plated Flat Flexible Cable

Nicomatic is now offering gold-plated flat flexible cable (FFC). Similar to tin-plated FFC, gold-plated FFC provides board-to-board interconnectivity. Additionally, it is also capable of mating with standard ZIF/LIF connectors. However, non-gold plating is more susceptible to corrosion from contaminants such as oils, chemicals, and water, whereas gold-plating prevents corrosion. In fact, gold-plated FFC mating to gold connectors will have no galvanic corrosion, even in harsh and demanding environments. Gold plating also prevents problems with whiskering and oxidation. Gold plating allows for a greater life cycle as well. While tin takes only 50 insertions/extractions, gold can do 10 times as many.



## nLIGHT

Vancouver, WA 360/566-4460

[www.nlight.net](http://www.nlight.net)

Booth 1810

### Laser Patterning

Laser patterning of metal traces and transparent conductors for markets such as touch-sensor modules, displays, flexible electronics, photovoltaics, and the internet-of-things sensors including medical, automotive, and wearable electronics. Innovating laser patterning, the TFP-500 achieves the lowest-cost patterning results through the use of high-peak-

power fiber lasers, very-high-speed scanners with the largest field-of-view available, and proprietary control software to achieve very high accuracy across the entire 500 mm × 500 mm field of view. Metal trace conductor patterning has been qualified to 20-μm line / 20-μm space dimensions.



## NORITAKE ITRON CORP.

Arlington Heights, IL 847/439-9020

[www.noritake-elec.com](http://www.noritake-elec.com)

### Advanced Custom Assemblies

Noritake has the ability to design and manufacture advanced custom assemblies using its knowledge gained though over 48 years of vacuum fluorescent display design and manufacturing. Core technologies include ceramics technology, thin-film technology, thick-film technology, mounting technology, vacuum technology, display circuit design, and firmware design.



## OCULAR

Dallas, TX 214/635-1920

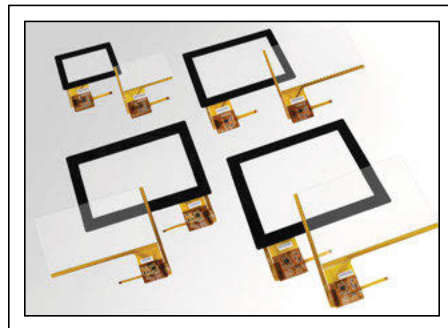
[www.ocularlcd.com](http://www.ocularlcd.com)

Booth 721

### Chip-on-Flex PCAP Touch Panels

Ocular's Crystal Touch TRUE Multi-Touch PCAP touch panels are now available with a Chip-on-Flex (COF) assembly. The Crystal Touch standard

product portfolio has expanded to include 3.5-, 4.3-, 5.7-, 7.0-, 10.1-, and 10.4-in. Chip-on-Flex designs. Standard COF versions have been added to increase design flexibility and eliminate the separate controller PCB to save space. The new standard COF versions are available with or without a pre-integrated cover glass and utilize an I2C interface.



## JOIN SID

We invite you to join SID to participate in shaping the future development of:

- Display technologies and display-related products
- Materials and components for displays and display applications
- Manufacturing processes and equipment
- New markets and applications

In every specialty you will find SID members as leading contributors to their profession.

<http://www.sid.org/Membership.aspx>

## ORIENT DISPLAY (USA) CORP.

Bellevue, WA 425/698-1938

[www.OrientDisplay.com](http://www.OrientDisplay.com)

Booth 1731

### Ultra-Thin HD TFT-LCD

Orient Display will feature model ODMD12100, an ultra-thin 5.0-in. HD TFT-LCD with an integrated projected-capacitance (P-CAP) touch panel. The IPS TFT-LCD features a resolution of 720 × 1280, MIPI-DSI interface, wide viewing angle, normal black mode, and a brightness of 440 nits at the CTP surface. P-CAP features OGS, optical bonding, integrated FT5336 controller, multi-touch, pen and writing function, glove operation, etc. Overall module is only 2.3 mm thick including TFT, backlight, and CTP. The operation temperature range is from -20 to +70°C.

## trade show preview

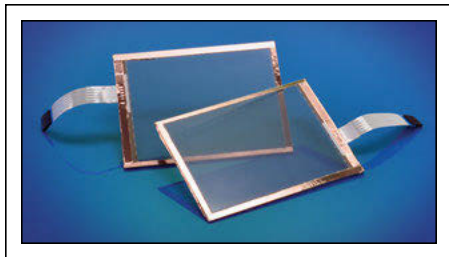


### PARKER CHOMERICS

Millville, NJ 856/293-2761  
www.parkerchomerics.com  
Booth 1521

#### EMI-Shielded Touch Screen

Parker Chomerics' EMI-shielded touch screens combine today's state-of-the-art touch-screen technologies with industry-leading EMI shielding expertise. Touch screens are available in a wide range of military and industrial products. They are being specified in more ruggedized applications such as military, homeland security, first response, and medical where EMI shielding is required. A touch screen fully integrated with an EMI shield simplifies the compliance with these tough EMI requirements.



### QUADRANGLE PRODUCTS

Englishtown, NJ 732/792-1234  
www.quadrangleproducts.com  
Booth 1830

#### Halogen-Free Wire and Cable

Many industries are on the verge of adopting new "Halogen Free" cable requirements. With various governing environmental and medical bodies beginning to require the use of "Halogen Free" components in products, Quadrangle Products has taken the initiative to implement and inventory "Halogen Free" wire and cable. We now offer "Halogen Free" wire and cable for custom cable assemblies. The halogen-free wire and cable is also available to those customers that fabricate their own assemblies. Quadrangle Products, Inc., is a Certified ISO 9001:2008 custom cable manufacturer. All cable assemblies are manufactured to IPC/WHMA-A-620 standards.



### RADIANT ZEMAX

Redmond, WA 425/844-0152  
www.radiantzemax.com  
Booth 621

#### Imaging Photometers

Radiant Zemax will feature the ProMetric® Y, the latest addition to their family of imaging systems. The new Y16 and Y29 Imaging Photometers deliver big performance in a small size, using cooled interline CCD sensors of 16 or 29 megapixel resolution and 12-bit dynamic range. ProMetric® Y is perfect for inspecting flat-panel displays, keyboards, surface defects, cosmetic blemishes, and much more. Optimized for high-volume production, ProMetric® Y offers USB/Ethernet communication, Smart Control™ electronically controlled lenses and Smart Calibration™ automatic flat-field correction. TrueTest™ Automated Visual Inspection Software and PM-KB™ Illuminated Keyboard Test Software provide full data analysis and pass/fail test capabilities.

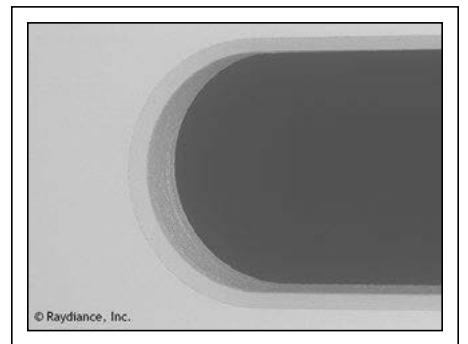


### RAYDIANCE

Petaluma, CA 707/559-2123  
www.raydiance.com  
Booth 1709

#### All-Laser Precision Manufacturing Solutions

The future of display glass has arrived. Pioneering ability to control cut-out shapes, chamfer and interior features, while processing thinner materials and new formulae in one-step, optimizes factory workflows with higher yields and zero post-processing steps. Ready to integrate into manufacturing lines, Raydiance all-laser precision manufacturing solutions combine Raydiance's ultra-fast femtosecond laser technology with the company's materials processing expertise and proprietary application-specific software. Game-changing, Raydiance's non-contact fabrication methods for glass and brittle materials enable rapid prototyping of new product designs and transfer to manufacturing within hours instead of weeks.



### SARTOMER AMERICAS

Exton, PA 610/363-4100  
www.sartomer.com  
Booth 420

#### Curable Resins

Sartomer's CN4000 series oleophobic exterior-grade ultraviolet and electron-beam energy curable resins provide excellent protection for polyester, polycarbonate, and acrylic films. Accelerated weathering testing proves the materials can take the abuse of a wide range of climates for top-coating highly transparent films and glass. The low refractive index provides anti-reflective properties for inter-layer coating or adhesive, reducing the loss of light transmission between layers and the top-coated surfaces while maintaining excellent physical and color stability.





## SAVE THE DATE

# Display Week 2015

SID International Symposium,  
Seminar & Exhibition  
May 31–June 5, 2015

### SEVASA

Barcelona, Spain +34-938-280-333  
www.sevasa.com  
Booth 315

#### Anti-Glare Glass for HD Displays

Sevasa® has expanded its line of anti-glare glass by adding HapticGlas HPT-TEC, an anti-glare non-sparking micro-etched glass for high-definition displays. It features exceptional tactile feedback, resistance to scratches and stains, very low maintenance, and high durability. A wide range of HPT-TEC is available with several finishes for different solutions and applications. For custom requirements or pre-set specs, HPT-TEC accepts all chemical processing and at sizes up to 2250 × 3210 mm (88 × 26 in.) and a diagonal of 154 in. HapticGlas is ideal for HD applications such as multitouch walls/ tables, HD displays, digital signage, ATMs, point-of-sale displays, and outdoor applications.



### SLENCIL COMPANY

Orange, MA 978/544-2171  
www.slencil.com  
Booth 1706

#### Tethered Touch-Screen Stylus

The ST series tethered stylus for “resistive” touch screens is manufactured in a full range of light to “rugged” duty applications. The elastomeric tethers have a 10:1 extension ratio, packaging 40 in. of unencumbered extension back into 4 in. of helical coil; this material has a 5000-psi tensile strength making it virtually unbreakable. Models are offered in slim D-series (0.075) tethers, medium H-series (0.088) and commercial duty R-series (0.103) – also offering plastic jacked wire to meet extreme strength applications. Consider the marketing features of color-matched plastics as well as corporate imprinted logos – all done in-house and made in the USA.



### SOLOMON SYSTECH

Shatin, Hong Kong +852-2207-1672  
www.solomon-systech.com  
Booth 1130

#### High-Performance PMOLED Driver ICs for Wearables

Wearable technology has become a hot trend, in particular for applications such as smart watches

and health and fitness devices. Solomon Systech offers an array of display solutions for wearable applications, including PMOLED driver ICs, LCD drivers ICs, MIPI bridge chips, etc. These PMOLED driver ICs support displays in icon, dot matrix, and character; mono, gray-scale and color mode; and also in curved/bendable screens. The driver ICs operate at a low input voltage level with low power consumption and are highly integratable with excellent display quality. They are available in portrait and landscape orientation to fit different form factors and also support a display brightness high enough for outdoor use.



### TANNAS ELECTRONIC DISPLAYS

Orange, CA 714/633-7874  
www.Tannas.com  
Booth 1620

#### Resized LCD Assemblies

A liquid-crystal-display (LCD) is mounted on the front surface of a panel where the LCD may cover the instrument mounting screws and access hole. The LCD would normally be an integral part of the instrument and be mounted to the panel as a single instrument assembly. This LCD embodiment is a standalone, separate assembly mounted on the front surface by means of a flange. The resized LCD assembly with LED backlight mounting is low profile and can include the bezel and switches. It is ideally suited for avionics.



## trade show preview

### **TIANMA MICROELECTRONICS (USA)**

Chino, CA 909/590-5833

[www.tianma-usa.com](http://www.tianma-usa.com)

Booth 1320

#### **LTPS-TFT Display**

Tianma will be highlighting one of its hottest products, the new 5.0-in. LTPS TFT display with full HD (1080 × 1920) resolution, IPS panel, LED backlight, narrow bezel, and slim design. This high-quality display is suitable for smartphone application and other similar products.



### **UICO**

Elmhurst, IL 630/815-8589

[www.uico.com](http://www.uico.com)

Booth 1134

#### **Durable P-CAP Touch Solutions**

UICO's duraTOUCH® Surface brings a unique intelligent human-machine UX to end users. UICO's proprietary capacitive sensing circuit wraps and conforms to an array of surfaces. High-resolution controlling and solid-state sensing plus gloveSENSE® and waterSENSE® make it ideal for everything from joysticks to steering wheels to robot "skin." duraTOUCH® Surface monitors intangible impressions and connects users to information to provide greater control, safety, and improved performance.



### **UNIVERSAL DISPLAY CORP.**

Ewing, NY 609/671-0980 x321

[www.udcoled.com](http://www.udcoled.com)

Booth 1214

#### **OLED Lighting**

Universal Display Corporation (UDC) will be showcasing the Moon Window which demonstrates some unique features of OLED lighting. It has the ability to not only create a transparent lighting panel, but to also hide an image within the transparent panel. When off, the Moon Window appears to be nothing other than a normal glass-paned window, but when turned on, a glowing image of the moon appears. We created this prototype as a scale model of an architectural feature.



### **WESTAR DISPLAY TECHNOLOGIES**

Saint Charles, MO 636/300-5112

[www.westardisplaytechnologies.com](http://www.westardisplaytechnologies.com)

Booth 1431

#### **Automated Display Measurement System**

Westar Display Technologies will be demonstrating PanelTest™, an automated test system for fast electro-optical characterization of mobile displays

from cell-phone size up to 17 in. The standard PanelTest provides three sensors: a camera, spectrometer, and real-time photodetector to provide measurements of uniformity, color, contrast, luminance, cross-talk, response time, flicker, and more. The system is light-safe and includes a video-test-pattern generator and industrial computer. PanelTest allows the user to easily create custom test scripts. PanelTest options include a viewing-angle imager and custom display fixtures.



**VISIT  
INFORMATION  
DISPLAY ON-LINE**

[www.informationdisplay.org](http://www.informationdisplay.org)

### **WESTBORO PHOTONICS**

Ottawa, Ontario, Canada 613/729-0614 x527

[www.wphotonics.com](http://www.wphotonics.com)

Booth 1624

#### **Imaging Spectral Colorimeter**

Westboro Photonics will feature the WP214 Imaging Spectral Colorimeter which references every measurement to an integrated spot spectroradiometer. Lens options allow 2-D uniformity as well as viewing-angle measurements of flat-panel displays. At 9 Mpixels, the new WP690 imaging colorimeter is ideal for 2-D characterization and defect detection. For characterization and calibration in production, Westboro Photonics will introduce a 2-Mpixel imaging colorimeter at Display Week. This new instrument measures luminance and chromaticity in under 5 sec.





## ZEON

Louisville, KY 502/775-2000  
www.zeonex.com

### Enhanced Optical and Retardation Film

ZEON will be highlighting applications of its latest generation ZeonorFilm® optical and retardation films. ZeonorFilm has excellent optical and dimensional stability under heat and humidity, critical criteria for LCD panels. For projected-capacitance touch sensors, ZeonorFilm allows premium optical viewing with and without sunglasses – in both portrait and landscape orientation. New versions optimized for OLED displays will be featured for reducing reflection. ■



See for yourself display technology that looks better from every angle.

## ENHANCED DISPLAY SOLUTIONS from DONTech

**EMI/RFI Shielding Optical Filters**

- ITO coatings <1  $\Omega$ /sq to 300  $\Omega$ /sq, index-matched to air or lamination
- Conductive optical grids – Plated/woven or etched meshes

**High Performance AR Coatings and Contrast Enhancement Filters**

- MIL-C-14806, SAE AMS-2521
- Photopic reflectances <0.75%, <0.5%, <0.25% and <0.1%
- Color filters
- Glass and plastic polarizers

**Night Vision Compatibility Filters – SWP Hot Mirrors**

- MIL-STD-3009/MIL-L-85762A - NVC filters
- Secure lighting filters

**Transparent Heaters**

- Power densities of 0.1 to 5 watts/sq in
- Index-matched to air or lamination

Since 1971, Dontech, Inc. has been designing and manufacturing optical filters for displays and precision optical assemblies, servicing the needs of the military, medical, avionic, and industrial electronics markets.

**DONTech**  
Innovating Optical Solutions  
215-348-5010 • WWW.DONTech.COM

See Us at Display Week 2014 Booth 921



*continued from page 2*

rare opportunity to hear from and meet some of the individuals whose groundbreaking work made plasma displays possible. Through various presentations, you will get not only a look back at the history of plasma technology but an exciting look forward at some tantalizing new possibilities for the future. This comes, of course, at a time when we've heard about the closing of some plasma TV facilities (Panasonic specifically), but this cannot diminish the richness of this event and all that has been accomplished by those who conceived of this technology, developed it to practical levels, and nurtured it into commercial success.

Display Week 2014 is also home to the "Innovation Zone" or "I-Zone," as we call it. Here you can see live demonstrations of emerging information-display technologies by small companies, startups, universities, government labs, and independent research labs in space provided and paid for by SID. Exhibitors are selected by the I-Zone committee from a pool of applicants, so you know these will be some of the most exciting and creative things at the show. The I-Zone is located inside the main Exhibit Hall.

Our cover story this month is the annual Display Industry Awards, which recognize the most innovative display products and technology from all of 2013. The list of choices for these awards was overflowing with worthy recipients and I can honestly tell you as a member of the DIA committee that the final selections were really the best of the best. It is exciting that this year's awards recognize a wide range of flat, curved, and flexible display technology embodiments, which have been widely anticipated for years and finally are among us in numerous exciting forms. As you read the synopsis of each award winner compiled by Jenny Donelan, I suspect you will also be able to see just how far this industry has come, especially in just the last several years, during which these types of products were widely anticipated but still seemed so far away from reality.

Wearable computing technology is a hot topic these days, with lots of new gadgets and personal devices hitting the market. Virtually all of these devices include a display with a user interface, and many need innovative display solutions to realize the vision of truly wearable technology vs. something portable you can carry around but is not part of your clothing or person. With that in mind, we

offer a editorial introduction on this topic by our guest editor Xiao-Yang Huang, titled "What's Up with Wearables," which helps explain the nature and make-up of this technology area as well as outline all the technical papers being presented this year on wearable displays. Xiao-Yang also introduces two feature articles covering specific topics in this field: augmented vision and electronic shoes.

The first, "Augmented Edge Enhancement on Google Glass for Vision-Impaired Users," by Alex Hwang and Eli Peli, is an easy to appreciate practical application of head-worn displays to overcome vision deficiencies in people with conditions such as macular degeneration. It is an important topic and one that almost all of us will face some day to some degree and using commercial display glasses to help in this area is an exciting opportunity to explore.

The second article has the potential to be more whimsical: "New Shoes? No Problem. Creating Dynamic Fashion with Wearable Displays" by Wallen Mphepo *et. al.* The researchers on this project wanted to create an article of clothing (in this case shoes) that could change their appearance as needed to match the rest of a person's outfit and circumstances. They achieved this through the use of electrophoretic display material over the surface of the shoe to provide different colors and patterns as desired. I admit when I first reviewed this article I was not sure how serious this was or how practical it could be. But, as I read their work, talked it over with colleagues, and thought about the rapidly growing infrastructure around self-expression enabled by our new portable devices (phones, tablets, etc.), I realized this really is another potential serious application of display technology. The shoes may look simple, but they are the prototype for all kinds of clothing, accessories, and even jewelry that can become a canvas of free expression for the wearer.

There has been a lot of buzz lately around the topic of quantum-dot-enhanced LCDs and whether they will pose a challenge to the potential color-gamut advantages of OLED TVs. The discussion got started at the SID Los Angeles Chapter One-Day Symposium earlier this year, which we reviewed last month in *ID*. Seth Coe-Sullivan, co-founder and Chief Technology Officer with QD Vision, made a bold prediction that the new LCD TVs (with quantum-dot enhancement, of course) will have all the performance advan-

tages needed, including those we have been expecting from OLED TVs, to be the technology leader for the next generation. Needless to say, there are many different opinions on this subject and we thought it would be best to let Seth explain his view in more detail, which led to this month's Enabling Technology article, aptly titled "The Virtues of Quantum Dots." Here Seth compares and contrasts the various strengths and weaknesses of OLED and LCD TVs and suggests how the addition of quantum-dot technology gives the edge to LCD going forward. So, is Seth right? You decide after reading his article.

This month we present the fifth and last installment of Helge Seetzen's terrific series on the venture capital world, entitled "From Idea to Enterprise – Technology Transfer Tips for Academics." Helge and co-author Lorne Whitehead discuss the opportunities for commercially valuable inventions that come from university researchers as well as the ins and outs of working with faculty and students on potential spin-outs. This has been a great series that I know many have found very valuable. Here, at *ID*, we are all grateful to Helge for putting in the extensive time and effort to compile it all for us over the last year or so.

In case by now you were wondering if we forgot the regular Display Marketplace series, fear not, for this month we welcome back regular contributor and well-respected analyst Paul Semenza for his discussion of the convergence of tablet PC and smartphone displays. This is another one of those topics that sort of snuck up on us – the reality that smartphones are getting bigger and bigger while the market push for displays with more than 300 ppi continues to grow. It turns out that the same dynamics are at work on both tablet and phone platforms and the convergence is a natural evolution of the trend first started by companies such as Apple and Samsung around 2012. Is it a tablet? Is it a phone? Is it a phablet? Will it matter in a few years? Read what Paul has to say.

And this concludes this month's issue of *Information Display*. I hope you all have a safe and prosperous trip to San Diego and I'll see you all there. ■

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## Wearable Display Presentations at Display Week 2014

### Wearable Displays I: Imaging Devices

*A 0.23-in. High-Resolution OLED Microdisplay for Wearable Displays*

Reo Asaki, Sony Corp., Kanagawa, Japan

*Color-Filter LCOS with Double-Mirror Structure*

Yuet-Wing Li, Himax Display, Inc., Tainan, Taiwan, ROC

*Fully Integrated CMOS Microdisplays for Wearable Sports and HMD Applications*

Petrus Venter, University of Pretoria, Pretoria, South Africa

*Invited Paper: Development of Eyewear Display Systems: A Long Journey*

Mark Spitzer, Google, Mountain View, CA, USA

*Late-News Paper: Front-Lit LCOS for Wearable Applications*

Yuet-Wing Li, Himax Display, Inc., Tainan, Taiwan, ROC

### Wearable Displays II: Optics Design

*Optical Design of a Compact See-Through Head-Mounted Display with a Light-Guide Plate*

Jui-Wen Pan, National Chiao Tung University, Tainan, Taiwan, ROC

*Binocular Holographic Waveguide Visor Display*

William Bleha, Holoeye Systems, Inc., San Diego, CA, USA

*Quality of Augmented Information for Different Distances on See-Through Near-to-Eye Displays*

Toni Järvenpää, Nokia Research Center, Tampere, Finland

*Augmented Edge Enhancement for Vision Impairment Using Google Glass*

Alex Hwang, Schepens Eye Research Institute, Harvard Medical School, Boston, MA, USA

### Wearable Displays III: Direct View

*OLEDs on Textile Substrates with Planarization and Encapsulation Using Multilayers for Wearable Displays*

Kyung Cheol Choi, KAIST, Daejeon, South Korea

*Genuinely Wearable Display with a Flexible Battery, a Flexible Display Panel, and a Flexible Printed Circuit*

Ryota Tajima, Semiconductor Energy Laboratory Co., Ltd., Kanagawa, Japan

*Flexible Substrate with Low Reflection, Low Haze, Self-Cleaning, and High Hardness by Nano-Structured Hard Coating and Surface Treatment*

Jiun-Haw Lee, National Taiwan University, Taipei, Taiwan, ROC

*Wearable Display for Dynamic Spatial and Temporal Fashion Trends*

Wallen Mphepo, University of Sunderland, Sunderland, UK

*Late-News Paper: Wearable-Display Expectations: Enabling Mobile-Display Experiences of the Future*

Brian Gally, Qualcomm MEMS Technologies, Inc., San Jose, CA, USA

ment on Google Glass for Vision-Impaired Users,” by Alex Hwang and Eli Peli of the Schepens Eye Research Institute at Harvard Medical School, is an example of the fixed category. It describes a method for outlining the edges of objects viewed through a Google Glass display in order to make it easier for vision-impaired users to recognize faces and other objects at appropriate distances. Not being able to recognize a face in time to say hello at what it considered a socially appropriate distance can be a real detriment to an individual’s personal happiness. Not being able to recognize certain objects in time could be life threatening. This is a category of wearable display that has real potential to improve the quality of life for vast numbers of people, particularly the elderly.

The second article in our wearables introduction is “New Shoes? No Problem. Creating Dynamic Fashion with Wearable Displays” by Wallen Mphepo from the University of Sunderland in the UK and Jiaqi Gao, Miao Li,

Justin Wang, Mega Mengmeng, Tian Dan, Hanson Zhao, and YinLei Liu from iShuu Technologies, UAB, Vilnius in Lithuania. While the topic is fun – a high-fashion shoe with an e-Paper display that can change colors and patterns based on commands from a smartphone – the paper’s authors are very serious in their efforts to create a wearable display that serves fashion – not just a novelty item. It’s this kind of focus that will separate wearable displays with lasting impact from those that are merely fads.

The authors of both of these papers represent the best of the wearable research – real applications that will help users in their daily lives in ways both profound and pragmatic. We hope you enjoy their work. If you are reading this article at Display Week 2014, make sure to catch some of these wearable sessions, which take place Wednesday, June 4.



## Display Week 2014

### Innovation Zone (I-Zone)

June 3–4, 2014

At Display Week 2014, the Society for Information Display will provide a forum for live demonstrations of emerging information display technologies in an exhibit called the “Innovation Zone” (I-Zone) in the main Exhibit Hall. The I-Zone will showcase cutting-edge demos and prototypes that will lead to the products of tomorrow.

The I-Zone offers researchers space to demonstrate their prototypes or other hardware demo units for 2 days free of charge at the premier display exhibition in North America and gives attendees a chance to view best-in-class emerging information display technologies in a dedicated area on the show floor. Access to free exhibition space encourages participation by small companies, startups, universities, government labs, and independent research labs.

The I-Zone Selection Committee will evaluate submissions and select the strongest proposals to receive free space within the I-Zone. If their proposal is accepted, applicants must cover their own expenses, including travel, lodging, and the creation of a tabletop exhibit demonstrating their prototypes. In addition, a knowledgeable person must be on hand on Tuesday and Wednesday, June 3–4, while the I-Zone is open to the public to run the demonstration and answer questions.

At Display Week 2014, the I-Zone Committee will select a winner of the “Best Prototype at Display Week” award, to be announced in *Information Display* magazine.

## Winning *JSID* Outstanding Student Paper Describes Novel Multi-Color Reflective Display

Compiled by Jenny Donelan

Electrochromic (EC) displays – those with reversible color changes caused by electrochemical redox reactions – have various advantages as reflective-type displays over comparable conventional displays, including high visibility under sunlight, a memory effect (they retain an image without a charge), and color-changing picture elements. (EC displays are expected to achieve better color variation without color filters than conventional reflective displays.) To improve on the current generation of electrochromic devices, it is necessary to develop multifunctional EC materials that enable control of multiple colors, various color densities, and specular reflection.

Ayako Tsuboi, a graduate student at Chiba University in Japan, and Dr. Kazuki Nakamura and Professor Norihisa Kobayashi of the Graduate School of Advanced Integrated Science at Chiba, recently undertook the task of developing next-generation electrochromic materials based on electrochemically sized controlled silver nanoparticles. They eventually developed a localized surface plasmon resonance (LSPR) based display device that they believe is suitable for use in information displays and light-modulating devices such as electronic paper, digital signage, and smart windows. In the device, the size of the electrochemically deposited silver nanoparticles is finely controlled by applying two consecutive different voltages. The device shows a wide variety of colors depending on the size of the silver nanoparticles. The researchers' report on this work, "Chromatic characterization of novel multicolor reflective display with electrochemically size-controlled silver nanoparticles," as described in the August 2013 issue of the *Journal of the SID*, recently received SID's prize for Outstanding Student Paper of 2013.

According to *JSID* Editor-in-Chief John Kymissis, the team's paper was chosen for both content and execution. "The committee was enthusiastic about both the novelty and of the work and quality of the paper," he says. "Several of the reviewers noted the particularly comprehensive treatment of the problem and detail in explaining the technique used and work performed."

### The Possibilities of Silver Nanoparticles

There have been many attempts to create color reflective displays, including those based on E ink and color filters, microfluidics, tunable photonic crystals, and more. While some of these efforts have been successful – E Ink has a working three-color display, Spectra – the goal of realizing a full-color reflective display that is commercially viable has remained elusive. Two years ago, the team at Chiba University reported (in *Advanced Materials Journal*) on an Ag deposition-based device that showed three subtractive primary colors – transparent, silver mirror, and black.

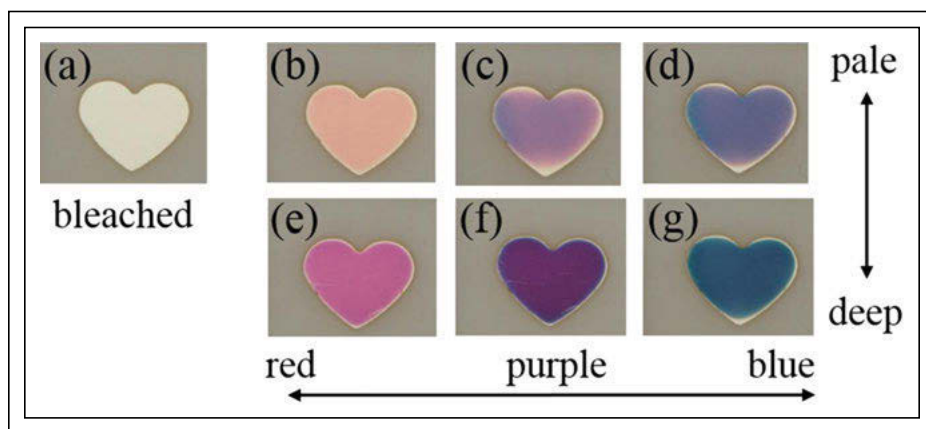
"In the course of this silver deposition research," says Kobayashi, "we found that the optical state of silver deposition was affected by the size and coalescence of silver particles deposited on an electrode. We therefore tried to control the structure of the silver particles to represent various optical states with only silver deposition." Applying DC voltage to the particles induced non-uniform growth, but the team discovered they could control the nucleation of the structures, and, hence, the color through a voltage-step method.

The challenge here, notes Kobayashi, was in determining suitable first and second voltage values to control the size of the silver nanoparticles uniformly on an electrode. Eventually they were able to determine the values necessary to represent red, magenta, purple, cyan, and blue using only silver deposition, with no dyes, pigments, or filters.

Reversible color changes between the transparent and vivid colored states were achieved (Fig. 1).

### Fabricating the Device

The team combined two colors (red and blue) with its previously realized three colored states (transparent, silver mirror, and black), using a device composed of a flat ITO electrode and an ITO particle-modified electrode. When a constant voltage was applied, the device entered a silver-mirror state as Ag was deposited on the flat ITO electrode. When Ag was deposited on the rough ITO particle-modified electrode, the device turned black. And when Ag nanoparticles were electrodeposited uniformly on the flat ITO electrode using the voltage-step method described earlier, the device turned red or blue depending on the  $V_2$  application time. These changes in the optical states were all reversible. By applying an oxidation voltage to the deposited silver (+0.6 V), all colored states returned to the transparent state. The length of time required for reversing differed for each colored state (silver mirror, black, red, and blue states required 20, 25, 0.1, and 1 sec, respectively). In previously reported Ag deposition-based devices, such reversibility was hardly observed because the Ag deposit could not be fully dissolved by electrochemical oxidation. The bleaching properties of the team's latest device were superior to previous ones because the  $\text{Cu}^{2+}$  ions in the electrolyte



**Fig. 1:** Above are photographs of the device with heart-shaped spacers: (a) before an application of the voltage and after an application of various step voltages; (b)  $-4.2$  V for 10 msec and  $-1.5$  V for 4 sec; (c)  $-3.8$  V for 50 msec and  $-1.7$  V for 17 sec; (d)  $-3.8$  V for 50 msec and  $-1.7$  V for 25 sec; (e)  $-4.2$  V for 10 msec and  $-1.5$  V for 10 sec; (f)  $-4.2$  V for 10 msec and  $-1.5$  V for 25 sec; and (g)  $-3.8$  V for 50 msec and  $-1.7$  V for 40 sec.



effectively promoted the dissolving of the Ag nanoparticles by electrochemical mediation. After the coloration voltages were shut off, the device held its colored states for certain periods (silver mirror, black, red, and blue states for 325, 300, 5, and 25 sec, respectively).

As a result of these efforts, the team successfully fabricated an LSPR-based EC device with transparent, silver mirror, red, blue, and black states in a single device. Various color densities and specular reflection were also demonstrated. Future research will involve investigating the color variations to realize full-color electronic displays.

Graduate student Tsuboi said, "I am really honored to receive such a great award. It could not have been achieved without the support of my seniors and my colleagues. I hope that this EC device can be used to achieve colorful electronic paper or smart windows and help us lead a more vibrantly colored life."

*continued from page 3*

### **i-sft and Lumineq Form Ruggedized Display Agreement**

i-sft, a flat-panel manufacturer, has entered into a cooperative agreement with Lumineq Displays, a business unit of the Finland-based Beneq group. Both companies specialize in developing and manufacturing displays used in extreme environments. i-sft is the inventor and sole manufacturer of displays based on energy-efficient excitation ( $e^3$ ) plasma light technology, used to make high-brightness long-life displays for extreme environmental conditions and temperature ranges. Lumineq Displays is a premier manufacturer and developer of thin-film electroluminescent (TFEL) displays. Lumineq also manufactures and develops transparent electroluminescent (TASEL) thin-film displays. The agreement is designed to enable both companies to offer specialized solutions to industrial customers from fields such as mining, marine and off-shore, public safety, medical devices, and avionics.

— Jenny Donelan

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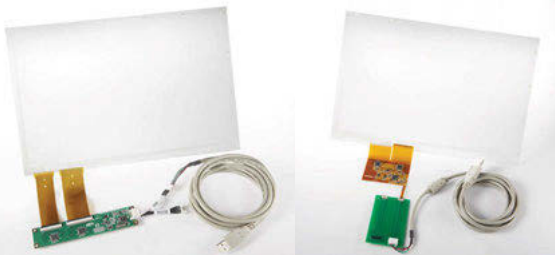
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