3-D DISPLAYS ISSUE

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SID

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Diving into 3-D Displays

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- Conflicting Focus Cues in Stereoscopic Displays
- Holographic 3-D Displays Get Refreshed
- A Bright Future for Projected Capacitive Touch Screens
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COVER: *Display makers are diving into the development of 3-D displays in unprecedented numbers. Sparked by recent technology advancements, true 3-D displays that once seemed like a science-fiction fantasy have never been so close to becoming reality.*

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Information DISPLAY

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Summertime, and the Living Is … 3-D!

It's now the midpoint of the year and for most of us that means summer and some much needed break time. Display Week 2008 is a fresh memory, and the schools and universities are on break as well. We got our own break by skipping the month of June, as we do every year, so we could put our full efforts into covering Display Week for you, which we will re-cap next month with extensive coverage.

Meanwhile, we focus on 3-D display technology this month. There has been significant news – as well as significant hype – this year over the promised second (or third) coming of 3-D projection to theaters around the world. The reality is that this time around, the 3-D experience is really here to stay, and the major motion-picture artists, directors, and producers are embracing the medium with enthusiasm. If you were at the special session on 3-D projection in at Display Week in Los Angeles in May, or if you have been lucky enough to already see a 3-D film using the RealD or Dolby technologies, you know the experience feels very natural, looks real, and is immersive enough to satisfy you for long periods of viewing. Of course, the artists need to use the medium wisely, but I have no doubt this will lead to a whole new period of innovation. Maybe by the next generation our children will laugh when we tell them movies used to be 2-D, let alone black and white.

Meanwhile, in this issue we switch gears from the entertainment to the more serious scientific aspects of how human vision accommodates 3-D images (pardon the pun) and the challenges of producing intuitive artificial 3-D images with display technology. I'm very grateful for the efforts of our Guest Editor Brian Schowengerdt (who also, incidentally, co-organized the SID 3-D Projection special session this year along with Brian Berkeley) and the four articles on the physics and related aspects of 3-D display technology.

I have watched the efforts to develop various 3-D technologies for a long time and, like many, have maintained some skepticism of all of the early demonstrations. In fact, I frequently tell the story of meeting Greg Favalora (CTO and Founder of Actuality Systems) in the lobby of a dormitory building in Boston around 1997. Greg had built the first prototype of his volumetric 3-D display while still in graduate school and was very excited about showing it to me – in the basement of the building. That basement housed a room full of computers, power supplies, controllers, and countless other gears controlling a small spinning flat mirror and a single color modulated laser. The laser modulator was synchronized with the spinning mirror and projected a simple vector based image onto its surface, creating a true volumetric image that appeared to be floating in space. While I could not imagine the amount of work it would take to get all that hardware into a reasonably sized enclosure, I could tell right away this was true innovation in progress. Still, when I considered the amount of processing power involved, and the necessary frame rates (related to how fast the mirror spun) that would be needed to produce flicker-free full-color 3-D images, I honestly had my doubts it could ever come together. Of course, over the next few years, Greg successfully launched his company and with his team has developed a number of very compelling 3-D display products showing how much can be accomplished through hard work and clever technological innovation. His hard work culminated with Actuality Systems winning the SID/*Information Display* 2007 Display Application of the Year Gold Award. This and many other early innovations are leading now to some serious candidates for mainstream direct-view and head-mounted 3-D concepts that are not as

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industry news

DuPont and Dainippon Screen to Develop Printed OLED Technology for Growing Flat-Panel-Display Market

WILMINGTON, Del., and KYOTO, Japan — **DuPont** and **Dainippon Screen Manufacturing Co. Ltd.** announced in May their intention to form a strategic alliance to develop integrated manufacturing equipment for printed organic-light-emitting-diode (OLED) displays. The companies also have signed an agreement relating to their intention to bring together the elements needed – materials, technology and equipment – to mass-produce OLED displays, delivering higher performance at a lower cost.

Small-size active-matrix OLED displays have recently become available from several manufacturers, but the current high cost of manufacturing limits market adoption, and constrains OLED manufacturing of large-size displays, according to a DuPont press release.

"The flat-panel-display market is about $100 billion annually and growing. DuPont is applying its science to make possible more vivid displays that are lower cost than current LCDs," said **David B. Miller**, group vice president, DuPont Electronic & Communication Technologies. "We are excited to combine our strengths with Dainippon Screen's unique printing technology to bring to market the core technology that will enable improved high-definition televisions and other flat-panel displays."

The companies are developing integrated coating and printing equipment for the fabrication of OLED displays from solution, an approach which is unique in the industry and can significantly reduce manufacturing costs for OLED displays, according to DuPont. DuPont brings to the alliance its small-molecule-based OLED solution materials and proprietary process technology from which excellent performance has been obtained in testing, stated the press release.

Dainippon Screen has developed a unique printing technology, called nozzle printing, in which the OLED materials can be printed accurately at very high speed. The goal of the alliance is to develop integrated OLED printing and coating equipment that will significantly reduce the production costs of flat-panel displays, with the aim of extending OLED technology to large-size displays and making them cost-competitive with LCDs. The companies have been working together over the past three years to jointly develop nozzle printers as an efficient method for printing OLED displays from solution. The first production scale printer is currently being constructed.

"We were interested in extending our deep LCD equipment experience into the OLED marketplace, and we felt that DuPont had developed a much needed, viable approach to OLED materials and technology that could expedite the commercialization of cost-effective OLED manufacturing," said **Yoshinari Yaoi**, corporate senior executive officer and president, FPD Equipment Company, Dainippon Screen. "We believe that this alliance could be the key for manufacturers to be able to produce affordable, high-quality larger-sized OLEDs using our unique nozzle printer technology."

— *Staff Reports*

Mitsubishi, Samsung Among Several Electronics Companies to Sue Vizio Over Video Patents

NEW YORK — **Mitsubishi Electric Corp.**, **Samsung Electronics Co.** and other electronics companies sued television maker **Vizio Inc.** for refusing to license patents for video-compression technology used in high-definition TVs, various media outlets reported June 3. Vizio is accused of violating 15 patents in the lawsuit filed June 2 in federal court in Manhattan.

Among the other parties joining the suit against Vizio were **Sony Corp.**, **Royal Philips Electronics NV**, **Thomson**, **Victor Co. of Japan Ltd. (JVC)**, and **Columbia University** of New York. They seek a court order to stop use of their inventions, plus cash compensation.

"For many years, the defendant has had an opportunity to license the patents," from individual companies or industry group MPEG LA, according to the complaint as reported by *Bloomberg*. "Vizio refused."

The patents are "essential" to an industry standard known as MPEG-2, which compresses movies so they can be broadcast and stored on DVDs, according to the complaint. According to the *Bloomberg* report, the electronics companies made similar claims in an April lawsuit against Target Corp. over its Trutech-brand TVs.

Irvine, California-based Vizio makes high-definition TVs sold by Circuit City Stores Inc., Costco Wholesale Corp., Wal-Mart Stores Inc. and other retailers. **Jim Noyd**, an outside spokesman for Vizio, said the company doesn't comment on pending litigation, according to *Bloomberg*.

The case is Mitsubishi Electric v. Vizio, 08-cv-5055, U.S. District Court, Southern District of New York (Manhattan).

— *Staff Reports*

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Coming at You! 3-D Displays Finally Seem Headed for Commercial Success

by Brian T. Schowengerdt

3-D display technology is coming of age and appears to have reached the tipping point for widespread commercial adoption.

Nowhere was this more apparent than during SID's Display Week this May, where a "Special Session on 3-D in Cinema" organized and co-chaired by Brian Berkeley (Samsung Electronics) and myself, featured six speakers at the forefront of the growing 3-D movement. Phil McNally (Dreamworks Animation), Rob Engle (Sony Pictures Imageworks), John Modell (3ality Digital), and Norman Rouse (Quantel) focused on content creation and showed stunning 3-D clips from their bodies of work, projecting them in stereo on a 25-ft.-wide screen with equipment provided by RealD. Jeff McNall (Dolby Labs) and Rod Archer (RealD) described the technical advances that are enabling the widespread conversion of theaters to 3-D.

The recent successes of 3-D movies (*Hannah Montana & Miley Cyrus: Best of Both Worlds Concert Tour* set Hollywood records by averaging more than $45,000 per screen during the opening weekend) and the decision of prominent moviemakers such as Steven Spielberg, Peter Jackson, and James Cameron to make 3-D movies have provided an impetus for more movie theaters to convert to digital 3-D. The number of 3-D capable theaters in the U.S. is expected to increase from the current 1500 to more than 4000 by the end of 2009 – which in turn is encouraging moviemakers to make more 3-D movies.

The term "3-D displays" encompasses a wide range of technologies, including stereoscopic, volumetric, and holographic displays. The projection systems in theaters are stereoscopic displays – meaning they present different images to right and left eyes. Why is it useful to do this? Our eyes, being separated by about 2.5 in., have slightly different vantage points and thus receive different images when viewing the same real-world scene. You can demonstrate this to yourself by lining up your thumbs, one in front of the other, and alternating between closing your right and left eyes – one thumb will appear to shift side-to-side relative to the other thumb. These "binocular disparities" between retinal images help your visual system to better estimate the distance to each thumb. If you place one thumb at arm's length and the other a few inches in front of your face, you will see large side-to-side shifts as you alternate eyes. As you bring one thumb toward the other, the disparities will decrease – all but disappearing when the thumbs meet at the same distance. We refer to this relationship between the actual distance between objects and the magnitude of binocular disparities between eye images as stereo vision, and it is one of the strongest contributors to general depth perception.

If we take pictures with two side-by-side cameras, we can capture these binocular disparities. If we later use a stereoscopic display to present the left camera image to the left eye and the right camera image to the right eye, the disparities can stimulate depth perception and give the viewer the impression that objects are in front of or behind the screen. The stereo displays in movie theaters are projection systems that have been retrofit to project alternating left and right eye views on the movie screen. By wearing special glasses that selectively filter the light reflected from the screen (with polarized lenses in RealD and IMAX 3D theaters, and special color filters in

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It's a Wrap for Display Week 2008

I can't write a column on Display Week 2008 held in Los Angeles without throwing in at least one Hollywood metaphor: "It's a wrap!" This is the phrase Hollywood directors shout out at the end of a production, letting everyone know that filming is complete, the actors can go home, and the staff can tear down the set. Watching the workers packing up the booths from the Exhibition late Friday during Display Week, made me think of the production that was Display Week, and the many stories told by the cast of thousands.

While *Information Display* will provide a complete review of Display Week '08 in our August issue, in this space I'm going to delve into a few larger themes that impressed me during Display Week: *Innovation, Revolution, Ubiquity, Going Green,* and *Prosperity*.

That attendees would see things reflective of *Innovation* at a SID symposium almost goes without saying. Several times during the week, I was blown away by the progress made on nearly all fronts of display technology. Organic light-emitting-diode (OLED) displays got bigger, brighter, and longer-lived, but also are demonstrating compatibility with new types of backplane technologies. All this points to a time in the future in which OLED displays might displace liquid-crystal displays (LCDs) as the primary display technology, very much as LCDs have displaced cathode-ray tubes (CRTS) in the past decade.

Of course, the LCD proponents will say "not so fast," and point out that OLEDs are great compared to LCDs, as long as you ignore size, cost, and availability. In the meantime, the engineers behind the juggernaut that is LCD have developed displays that are faster, have a lower power consumption, and a wider viewing angle, and continued reductions in cost. Plasma, projection, and other display technologies also had a major presence, creating the churn of competition that keeps electronic-display technology so vibrant.

Revolution is a word that is often overused. Here, I mean it in context of new types of technology that can fundamentally alter how displays are used, where they are used, and what new applications are enabled by new technologies. Several technologies on display offer the possibility of rewriting usage models for displays, putting them in places where displays have rarely been, and changing how the content served on the display might need to adapt to keep pace with the display capability.

Display Week 2008 showed a heavy presence of revolutionary technologies. Touch interfaces for displays may fundamentally alter the way the people interact with their displays, making the display an even more critical aspect of the machine-person interface. 3-D displays provide a brand-new set of capabilities for movie makers to provide a more realistic (or in some cases, unrealistic!) world to the audience. At Display Week 2008, it was even possible to see interesting concepts such as changeable "skins" for objects that can change color over the entire surface of a device. Imagine a cell phone where the color of the handset changes each time the phone rings, depending on who's calling!

Ubiquity is the coming trend that is going to put an electronic, visual interface nearly everywhere. Flexible and low-power displays can be placed where they have never been before, increasing the ability for people to interact with networked devices anyplace they go. Displays on shelves, displays in fabrics, displays wrapped around corners, displays going weeks or months without requiring a recharge, and displays

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Flexible Displays' Growth into a Multi-Billion-Dollar Industry Begins in 2008

by Jennifer Colegrove

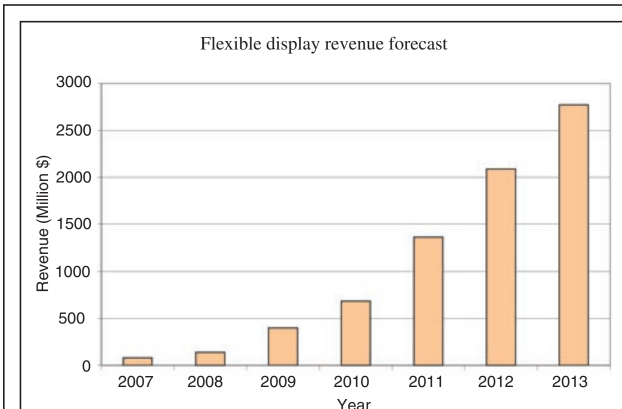
For years, many industry participants and consumers have dreamed of a display technology that would break through the limitations of glass-based displays. These limitations clearly can be seen in mobile devices, in which fragility, weight, and the shrinking size of the devices combine to place constraints on the display. What if displays could be rugged, lightweight, and foldable so that a large display area could fit into a small device?

New devices coming onto the marketplace, led by Polymer Vision's Readius – a truly rollable e-book and mobile phone that will be available to consumers by mid-2008 – may be the answer to many people's dreams. Additionally, and perhaps more importantly, the Readius and other active-matrix electrophoretic displays on plastic/metal foil substrates from companies such as E Ink may open up a host of new business and revenue opportunities not just for e-ink and e-paper producers, but also for consumer-electronics, industrial, and military device makers.

A host of new products taking advantage of this blossoming technology are slated to come to market, leading iSuppli Corp. to forecast that the total flexible-display market will reach $2.8 billion by 2013, a remarkable expansion of 35 times, from about $80 million in 2007. The establishment of several batch and roll-to-roll facilities is enabling rising shipments of flexible displays.

With a compound annual growth rate (CAGR) of 80.9% between 2007 and 2013, this represents an enormous financial opportunity for not only display vendors manufacturing the materials for this technology, but for those companies developing and manufacturing applications for end markets. And as flexible displays become more commonplace and more attention is paid to these displays, it is highly likely that the market will see many new entrants with new applications targeting new areas, similar to what has happened in the touch-screen display market thanks to Apple's iPod.

The bar graph below presents iSuppli's forecast for flexible-display revenues for the period of 2007 through 2013.



Market Drivers

Flexible displays are intuitively appealing to end users and product designers because of their ruggedness, thinness, light weight, and novelty. Such displays also offer manufacturers the potential for inexpensive fabrication because they can be made using new printing methods or roll-to-roll processing. Furthermore, flexible displays have the advantage of easy and relatively inexpensive shipping and safety handling compared to conventional rigid

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We are always interested in hearing from our readers. If you have an idea that would make for an interesting Business of Displays column or if you would like to submit your own column, please contact Aris Silzars at 425/898-9117 or email: silzars@attglobal.net.


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Consequences of Incorrect Focus Cues in Stereo Displays

Conventional stereo displays produce images in which focus cues – blur and accommodation – are inconsistent with the simulated depth. We have developed new display techniques that allow the presentation of nearly correct focus. Using these techniques, we find that stereo vision is faster and more accurate when focus cues are mostly consistent with simulated depth; furthermore, viewers experience less fatigue when focus cues are correct or nearly correct.

by Martin S. Banks, Kurt Akeley, David M. Hoffman, Ahna R. Girshick

VIEWING THE REAL WORLD stimulates many depth cues, all specifying the same 3-D layout. With modern graphics and display technology, most of these cues can be presented with high fidelity. But conventional displays always present the images on one surface [*e.g.*, the phosphor grid for cathode-ray displays (CRTs) or the focal plane associated with head-mounted displays (HMDs)]. Consequently, images presented on computer displays stimulate some cues that specify the depth intended by the graphics engineer (*simulated depth cues*) and others that specify properties of the display itself, such as its distance and the shape of its surface (*screen cues*). Screen cues include motion parallax due to the viewer's head movements relative to the screen and visible pixelization due to the discrete nature of the screen. Here, however, we consider only one class of screen cues: focus cues. Focus cues come in two forms.

Martin S. Banks *is a professor and* ***David Hoffman*** *is a graduate student in vision science at UC Berkeley; telephone 510/642-7679, e-mail: martybanks@berkeley.edu.* ***Kurt Akeley*** *is a principal researcher at Microsoft Research Silicon Valley.* ***Ahna R. Girshick*** *is a post-doctoral researcher at New York University's Center for Neural Science.*

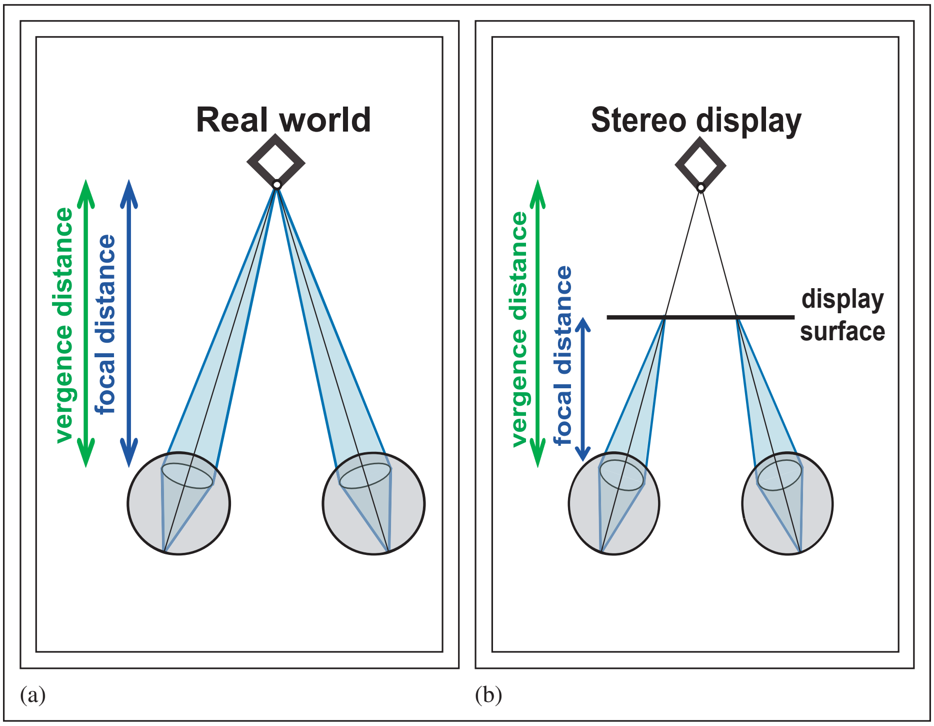

Fig. 1: *Vergence and focal distances with real stimuli and stimuli presented on conventional stereo displays. (a) Viewing an object in the real world. Vergence distance is the distance where the fixation axes of the two eyes converge. Focal distance is the distance to which the two eyes are focused. In the real world, vergence and focal distance are typically the same. (b) The same object viewed on a conventional stereo display. The display surface is nearer than the simulated object, so focal distance is shorter than vergence distance. Because focal distance is constant, vergence and focus distances match only for simulated objects at the focal distance.*

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Blur gradient in the retinal image. For real scenes, retinal blur varies consistently with changes in scene depth: the retinal image is sharpest for objects at the distance to which the eye is focused and blurred for objects at other distances. In conventional computer displays, focal distance is constant, so the scene appears sharp if the eye is focused on the display surface, and blurred if it is focused elsewhere. Consequently, the blur produced by viewing a conventional stereo display specifies flatness.

Accommodation. When viewing real scenes, the viewer accommodates (*i.e.*, changes the focal power of the lens in the eye) to minimize blur for the fixated part of the scene (the part of the scene to which the eyes are pointed, as opposed to objects in the visual periphery). As the eye looks around the simulated scene in a stereo display, the focal distance of the light does not vary, so accommodation signals flatness and a specific depth (Fig. 1).

Stereo displays present images separately to the two eyes. Objects within the images are displaced horizontally to create binocular disparity, which in turn creates the stimulus to vergence (the angle between the lines of sight when the two eyes fixate the same point in space). The binocular disparity creates a compelling 3-D sensation because it recreates the differences in the two eyes' images that occur in viewing real 3-D scenes. While the disparity signals are important, the incorrect focus cues in stereo displays are likely to cause perceptual distortions, viewer fatigue, and difficulty in achieving binocular fusion; they have also proven difficult to eliminate from conventional displays.[1] Here, we summarize some of the work in Hoffman, Girshick, Akeley, and Banks (2008)[2] on the influence of focus cues on depth perception and viewer fatigue during viewing of stereo displays.

For a stimulus to be sharply focused on the retina, the eye must be accommodated to a distance close to the object's focal distance. The acceptable range is the depth of focus, which is roughly ±0.3 diopters (D; diopters are viewing distance in inverse meters). For a stimulus to be seen as single (fused) rather than double, the eyes must be converged to a distance close to the object distance. Vergence errors must be less than Panum's fusion area (±15–30 arcmin, the maximum disparity for which the visual system can fuse the two eyes' images and thereby produce a single perceived image). Accommodation and vergence responses are normally coupled: accommodative changes evoke vergence changes (accommodative vergence), and vergence changes evoke accommodative changes (vergence accommodation).

In the real world, accommodation-vergence coupling is helpful because focal and vergence distances are almost always the same no matter where the viewer looks (diagonal line in Fig. 2). The *zone of clear single binocular vision* (green region in Fig. 2) is the set of vergence and focal distances for which a typical viewer can see a sharply focused single image; *i.e.*, it is the set of those distances for which vergence and accommodation can be adjusted sufficiently well. *Percival's zone of comfort* (yellow region) is an optometric rule of thumb for the viewing of stereo stimuli; it is the approximate range of vergence and accommodation responses for which the viewer can fuse images without discomfort. As shown in Fig. 2, vergence and focal distance must be close to one another to support clear, single vision without undue effort.

In conventional stereo displays, the normal correlation between vergence and focal distance is disrupted (horizontal line in Fig. 2): focal distance is now fixed at the display while vergence distance varies depending on the part of the simulated scene the viewer fixates. In natural viewing, focal distance would nearly always be identical to vergence distance (diagonal line). Given the conflict created in conventional displays, we expect that the ability to fuse a binocular stimulus will be reduced relative to the ability with real-world stimuli.

Prolonged use of conventional stereo displays is known to produce viewer fatigue and

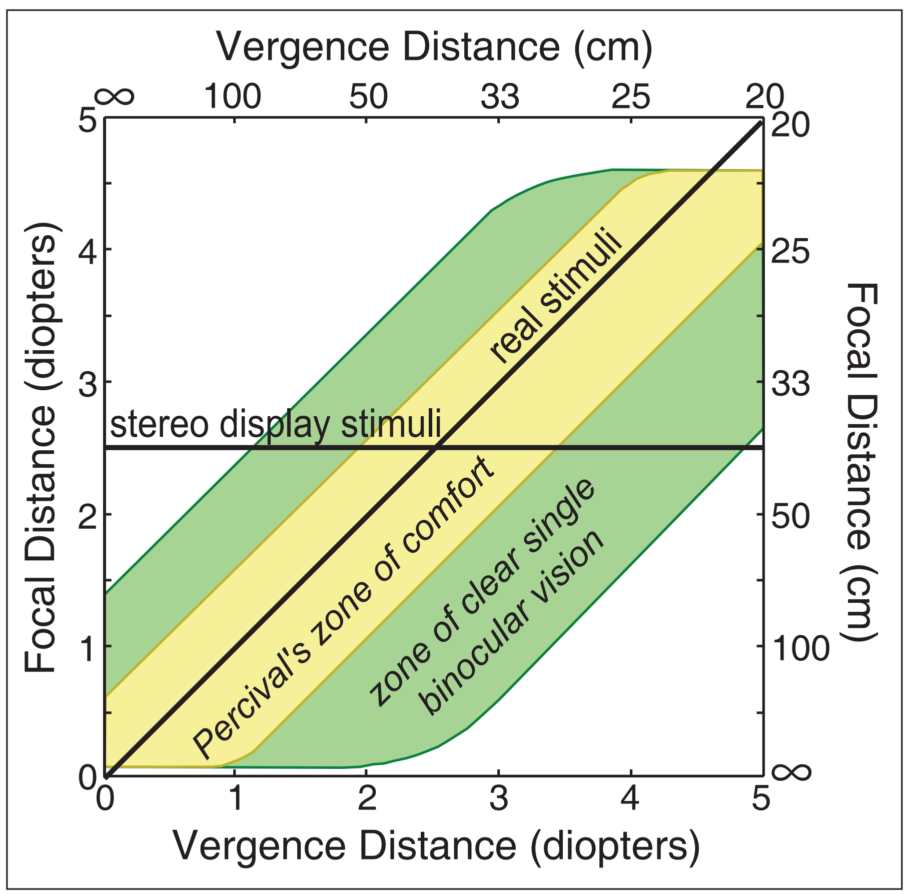

Fig. 2: *The range of vergence and accommodation responses possible and comfortable for a typical adult. The zone of clear single binocular vision and Percival's zone of comfort are represented by the green and yellow regions, respectively. The diagonal line represents most stimuli in the real world. The horizontal line represents stimuli in a conventional stereo display.*

discomfort; it has often been claimed that these symptoms are caused by the required dissociation between vergence and accommodation, but this has never been proven. Because stereo displays are being used in more and more applications, particularly medicine, it is important to determine if the dissociation really causes fatigue and discomfort. If we can find evidence that it does, it will help guide solutions to the problem.

There have been many efforts to construct displays that provide correct focus cues.[3] We developed a display (described in detail by Akeley *et al.*[1] and Hoffman *et al.*[2]) that provides nearly correct focus cues while using off-the-shelf graphics hardware and preserving view-dependent lighting effects such as occlusions, highlights, and reflections. The display is shown schematically in Fig. 3(a). Each eye views a light field created by optically summing three image planes with a mirror and two plate beamsplitters. This creates a volumetric stereoscopic display because the light for each eye comes from sources at different distances. We fix the viewer's position in front of the display, so that we can calculate each eye's view and display the correct disparities and viewpoint-specific lighting effects. We render all the images as sharp and allow the eye's optics to create the appropriate blur for each distance to which the eye accommodates. This eliminates the need to track fixation and accommodation. When we render points that fall between image planes, we use *depth-weighted blending*, a weighted sum of the two adjacent image planes along a line of sight. Depth-weighted blending simulates the focus cues that are appropriate for between-image-plane positions and thereby eliminates discontinuities in blur.

We are interested in knowing how viewers perceive the images presented in various types of displays. Understanding this starts with the formation of the retinal images. The properties of those images are determined by the graphics rendering, the display of the rendering, and by the optics of the viewer's eyes. Human optics is linear and largely homogeneous, so we can use linear systems analysis to characterize retinal-image formation. We calculate the retinal images formed by luminance sine-wave gratings (patterns of light and dark stripes) presented on a given display. Specifically, we calculate the ratio of contrast in the retinal image divided by the contrast of the image presented on the display. It was important in these calculations to use the actual optics of human eyes because normal optical aberrations make the depth of focus larger than it is for idealized (*i.e.*, diffraction limited) optics.

The retinal images formed by viewing real-world stimuli, stimuli on conventional stereo displays, and stimuli in our multi-plane volumetric display are similar in some situations and quite different in others. The upper, middle, and lower rows of Fig. 4 show retinal-image contrasts for sinusoidal gratings presented in the real world, on a conventional display, and in our volumetric display. The left and right columns show those contrasts for spatial frequencies of 5 and 12 cycles/deg, respectively (the latter corresponds to fine detail and the former to less fine detail; a typical computer display viewed from 50 cm can display a maximum detail of ~18 cycles/deg). The x-axes represent the real or simulated focal distance of the stimulus. The y-axes represent the eye's focal distance, which is the distance to which the eye is focused. Colors represent the retinal-image contrast if the stimulus contrast is 1, red representing the highest contrast and blue the lowest. The optics in the modeling is those of author DMH's left eye. Austin Roorda (UC Berkeley) measured the optics and assisted with the modeling.

Consider a real stimulus at a distance of 2.5 diopters (D) at a spatial frequency of 5 cycles/deg (upper left panel in Fig. 4). As one would expect, focusing the eye at the actual object distance of 2.5D yields maximum retinal contrast. At a frequency of 12 cycles/deg (upper right panel), retinal-image contrast is reduced even when the eye is accurately focused and small errors in accommodation have a pronounced effect. The plots in the top row represent the normal relationship between object distance, accommodative response, and retinal-image contrast.

Next, consider a conventional display (middle row in Fig. 4). The distance to the display surface is fixed at 40 cm (2.5D), so retinal contrast is now maximized by accommodating to the distance of the display rather than to the simulated distance. To maintain a clear percept, the observer must hold accom-

(a) (b) (c)

Fig. 3: Fixed-viewpoint volumetric display. (a) Schematic of viewports in the display and optical paths to the eyes; the left side is a view from the top and the right side is a view from the right. (b) A viewer using the display. The head position is fixed with a bite bar. (c) Schematic of image-plane spacing.

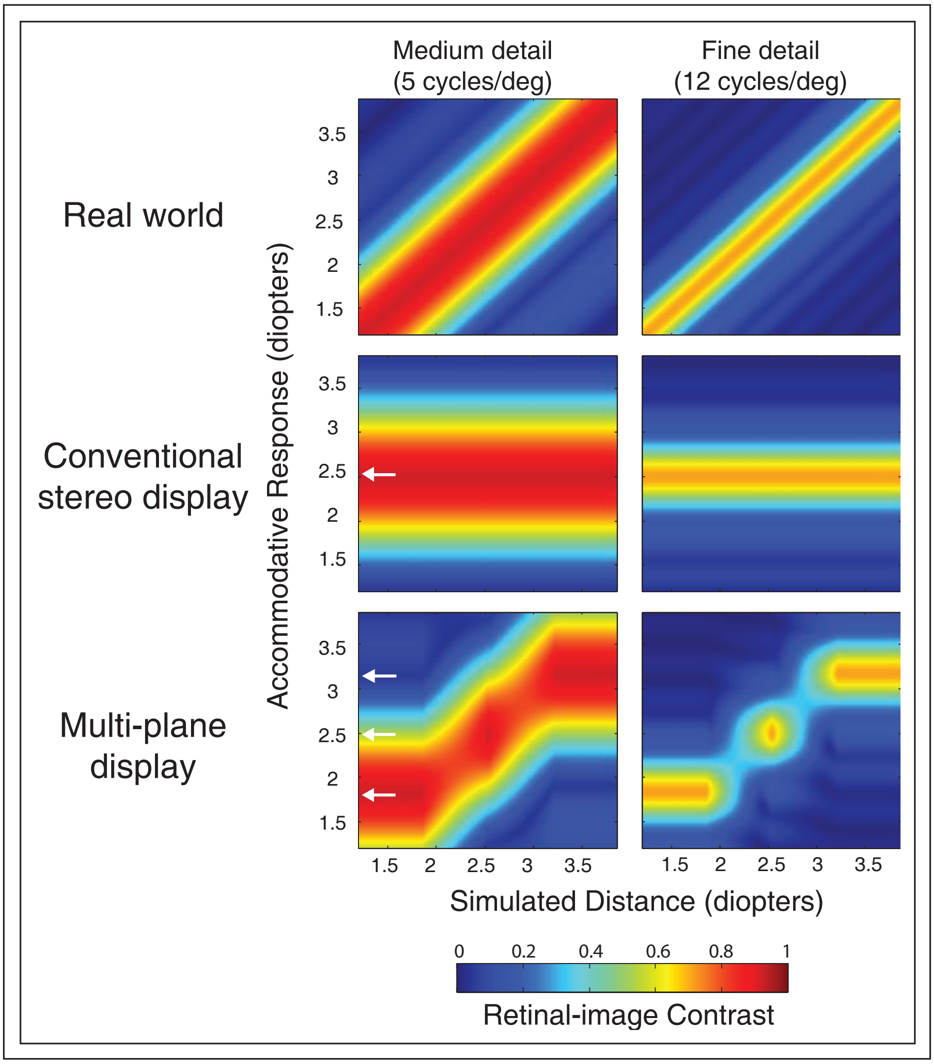

Fig. 4: Retinal-image contrasts for different display techniques. In each panel, simulated distance (in diopters) is plotted as a function of the distance to which the eye accommodates (in diopters). Retinal-image contrast for an object of contrast 1 is indicated by the colors. The white arrows in the middle and bottom rows represent the distances to the image planes.

modation fixed despite changes in simulated distance, and this requires the dissociation of accommodation and vergence.

Now consider our multi-plane volumetric display (bottom row). The three image planes are separated by 0.67D, so the workspace is a 1.33D volume. When the simulated distance is at the distance of an image plane, the retinal contrast produced by viewing our display is identical to the contrast produced by viewing a stimulus in the real world. When the simulated distance is between planes, the stimulus is formed by a depth-weighted blend of intensities from the two nearest planes. The retinal image created by blending is nearly identical to that produced by a real object at low spatial frequencies and a reasonable approximation at medium spatial frequencies. Importantly, retinal-image contrast is maximized by focusing at the simulated distance rather than at one of the image planes. At high frequencies, the blended image is a poorer approximation to the real world: the peak contrast occurs by accommodating to a distance near the image planes rather than at the simulated distance. Despite the relatively poor approximation at high spatial frequencies, the stimuli created in the multi-plane volumetric display appear quite realistic even for objects between image planes because low and mid spatial frequencies, where our approximation is good, are the most important for blur detection and control of accommodation.

We used the multi-plane volumetric display to examine the influence of appropriate and inappropriate focus cues on perception and fatigue. Vergence and accommodative distances differ in conventional stereo displays, but the differences are generally smaller than the spread of the zone of clear single binocular vision and also frequently smaller than Percival's zone of comfort. Nonetheless, many viewers find it difficult to fuse stimuli in stereo displays. We measured how focus cues affect the time needed to fuse a random-dot stereogram for different amounts of conflict between vergence and focal distance. The stimulus was a periodic corrugation in depth (like a corrugated tin sheet) in one of two orientations.

When properly fused and viewed binocularly, it was easy for the viewer to perceive the orientation correctly. But when it was viewed with one eye, or was not properly fused, it looked like noisy dots with no clear pattern in depth and the orientation could not be determined. The results are shown in

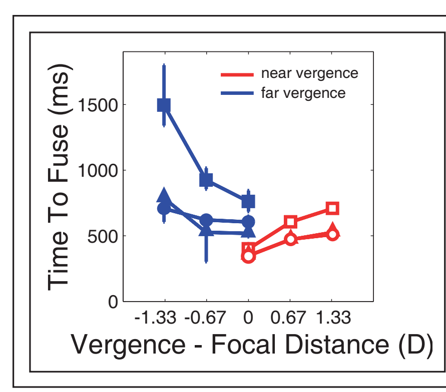

Fig. 5: Results of time-to-fusion experiment. Stimulus duration required to fuse and thereby perceive a corrugation in depth is plotted as a function of the difference between the vergence and focal distances in diopters. Red represents conditions in which the eyes had to converge (the eye movement required for viewing a near target) and blue represents conditions in which the eye had to diverge. Different symbol shapes are the data from different subjects. Error bars are 95% confidence intervals.

Fig. 5; all three subjects could fuse the stereogram (and thereby identify the corrugation orientation) at shorter durations when the vergence-focal conflict was small or zero. In the far-vergence condition (blue), the vergence stimulus appeared at a far distance (1.87D) and the focal distance was 1.87D (no conflict), 2.54D (medium conflict), or 3.21D (large conflict). In the near-vergence condition (red), the vergence stimulus appeared at 3.21D and the focal distance was 1.87D (large conflict), 2.54D (medium conflict), or 3.21D (no conflict). Thus, presenting focus cues that were appropriate or nearly appropriate for the depth in the stimulus led to consistently better perceptual performance.

We also examined whether the conflict between vergence and accommodation required in conventional stereo displays is the cause of visual fatigue and discomfort. The vergence-focal conflict in such displays is generally smaller than the zone of single clear binocular vision and Percival's zone of comfort (Fig. 2), so it is not a foregone conclusion that the conflict causes fatigue and discomfort. To examine this, we had 11 subjects fixate stereograms at various simulated distances in two sessions lasting 45 minutes each. In one session, vergence distance was randomized while focal distance was constant; this is the cues-inconsistent condition and is similar to the viewing conditions in conventional stereo displays. In the other session, we took advantage of the properties of the multi-plane display: vergence and focal distance were always the same, and they changed randomly from trial to trial; this is the cues-consistent condition. The two sessions were otherwise identical. Subjects answered questionnaires after each session. The results are shown in Fig. 6. Subjects reported significantly worse symptoms after the cues-inconsistent session. They also preferred the cues-consistent session over the cues-inconsistent one. This study offers the most compelling evidence to date that the visual fatigue associated with viewing stereo displays can be attributed to the unnatural relationship between vergence and focal distance.[2]

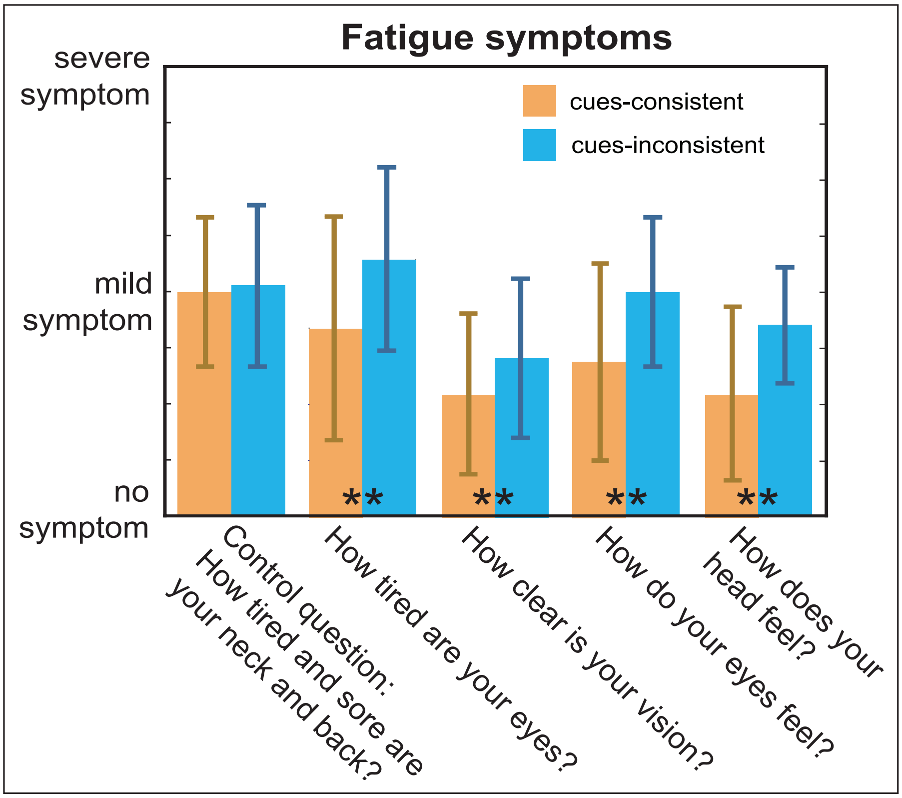

*Fig. 6: Results from the visual-fatigue experiment. The average symptom severity is plotted for each of the five questions. Orange and blue bars represent the data from the cues-consistent and cues-inconsistent sessions, respectively. Error bars are the standard deviation of reported symptoms from the 17 sets of observations (11 subjects, 6 tested twice). ** indicates p<0.025.*

Conclusions

Conventional stereo displays create conflicts among various signals the visual system relies on to estimate 3-D layout in natural scenes. Many of these signals, *e.g.*, binocular disparity, shading, and perspective, can be presented with high fidelity in modern displays, but some – particularly focus cues – cannot. The incompatibility between signals that are consistent with the simulated scene and focus cues that are consistent with the distance to the display surface may cause distortions in depth perception,[4] difficulties in fusing binocular stimuli, and viewer fatigue and discomfort. We developed a multi-plane volumetric display that allows us to present nearly correct focus cues for a variety of simulated viewing situations. Using the display, we showed that rendering nearly correct focus cues improves the ability to fuse binocular stimuli, increases the ability to perceive small variations in disparity, and reduces viewer fatigue and discomfort. As stereo displays become more widely used, it will become increasingly important to understand and minimize adverse consequences of inappropriate focus cues. On-going research in display technology is aimed at developing techniques for displaying all signals, including focus cues, with high fidelity so that the viewer can experience the intended depth percepts without undue fatigue or discomfort.

References

[1]K. Akeley, S. J. Watt, A. R. Girshick, and M. S. Banks, "A stereo display prototype with multiple focal distances," *ACM Transactions on Graphics* **23**(3), 804-813 (2004).
[2]D. M. Hoffman, A. R. Girshick, K. Akeley, and M. S. Banks, "Vergence–accommodation conflicts hinder visual performance and cause visual fatigue," *Journal of Vision* **8**(3):33, 1-30 (2008).
[3]B. T. Schowengerdt and E. J. Seibel, "True 3-D scanned voxel displays using single or multiple sources," *J Soc Info Display* **14**(6), 135-143 (2006).
[4]S. J. Watt, K. Akeley, M. O. Ernst, and M. S. Banks, "Focus cues affect perceived depth," *Journal of Vision* **5**(10), 834-862 (2005). ■

Refreshable Holographic 3-D Displays

In order to achieve holographic displays that can be refreshed, several properties must be combined, including efficient recording, erasing capability, and persistent storage (memory) of holograms. Here, the authors describe the development of the first updatable holographic 3-D display with memory, based on photorefractive polymers.

by Savaş Tay and Nasser Peyghambarian

HOLOGRAPHY occupies a special place among the various approaches to three-dimensional (3-D) visualization, and since the day they were introduced, people have been fascinated by them. Holograms provide autostereoscopic images that are viewable directly without the need for special eyewear (Fig 1). They help reduce the unwanted side effects of using special goggles, such as motion sickness and eye fatigue.[1] They are capable of very high spatial resolutions, full color, and a high degree of realism. Such characteristics make them very valuable tools for a wide range of applications, including medical, industrial, military, and entertainment imaging.

Although mostly known throughout science-fiction and entertainment circles, holography is a powerful technique with a solid theoretical foundation, and early pioneers such as Gabor, Leith, Upatnieks, and Benton have come up with an amazing array of applications that use holographic optical recording and processing.[2,3] Established applications of holography include non-destructive testing and evaluation, holographic data storage, nano-fabrication (interference lithography), and fabrication of diffractive optical elements used in spectroscopy, beam combining, and telecommunications.

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Unfortunately, the lack of suitable recording materials has limited to date the realization of many other exciting applications, especially those that require the dynamic changing of recorded images. Most of the successful implementations of holography mentioned above involve static images, and the recording media used are write-once, read-many type of

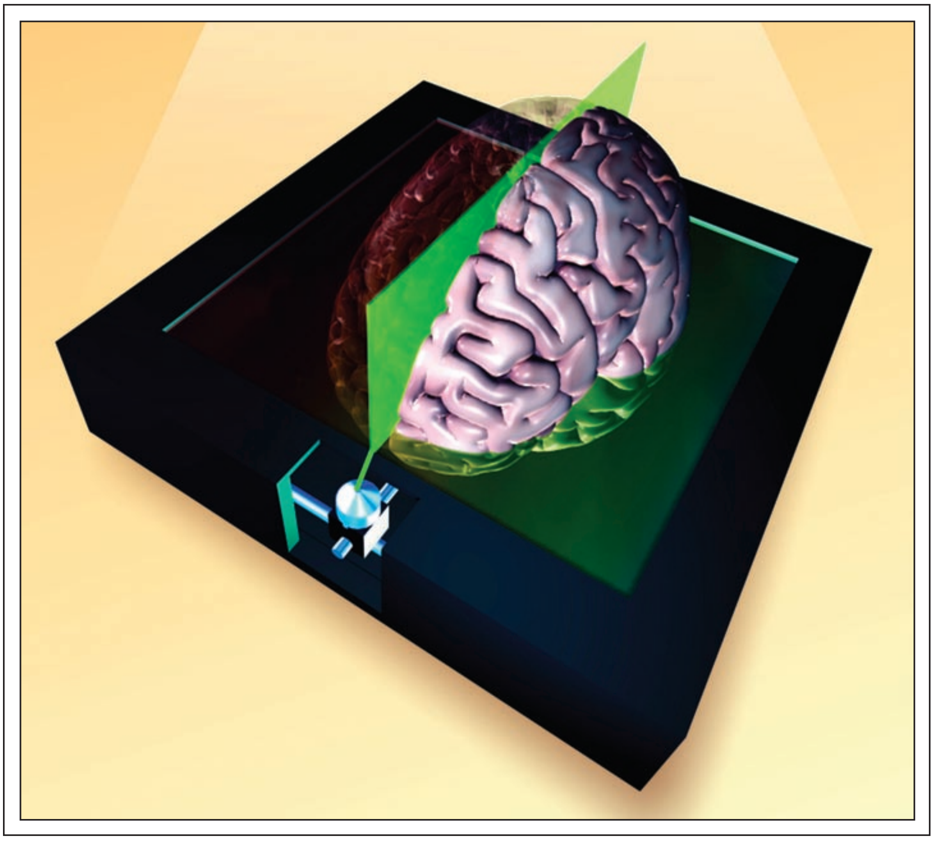

Fig. 1: *Illustration of the future holographic three-dimensional display.*

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materials. Dynamic or semi-dynamic (refreshable) recording materials could significantly improve the performance and extend the uses of holographic systems, and 3-D displays are one of the applications that could greatly benefit from such a capability.

To be suitable for refreshable 3-D displays, holographic recording material needs to have efficient writing and reconstruction (high sensitivity and diffraction efficiency), fast writing time, long image persistence (memory), capability of rapid erasure, and the potential for large display area – a combination of properties that has not been realized in a single material until recently. Previously, holographic recording materials included photopolymers, silver halide films, or dichromated gelatin. Images on these materials are permanently written and therefore cannot be erased or refreshed. Reversable recording media such as inorganic PR crystals are extremely difficult to grow to larger than a few square centimeters in size.

On the other hand, PR polymers – organic-based dynamic holographic recording materials – are capable of significantly larger sizes, very high diffraction efficiency, and sensitivity, which make them a good candidate for use in refreshable and dynamic holographic displays.

Here, we report the details of the development of the first updatable holographic 3-D display based on PR polymers.[4] With a 4×4-in. size, this is the largest holographic 3-D display to date and is capable of recording and displaying new images every few minutes. The main difference between our PR-polymer-based refreshable display and previously developed dynamic 3-D display systems based on opto-electronic systems is the memory capability of the PR polymers. The recording media employed in real-time dynamic systems such as acousto-optic or MEMS devices lack memory (storage of images) and require the continuous scanning of the image at video rate (30 Hz), which severely limits the achievable image size and resolution using these devices.

The holograms in our PR-polymer-based 3-D display can be viewed in a 45° viewing zone without the need for scanning. They achieved resolution comparable to that of NTSC TV, they persist for several hours without the need for refreshing, and can be completely erased and updated with new images whenever desired. With a few minutes of a turnaround rate, they occupy a special region between real-time and static displays that could be named semi-dynamic or near real time. Such near-real-time display of information has significant uses in applications where the data is not generated or processed instantaneously, yet still require the updating of images. Such applications include medical and military imaging, entertainment, and advertisement.

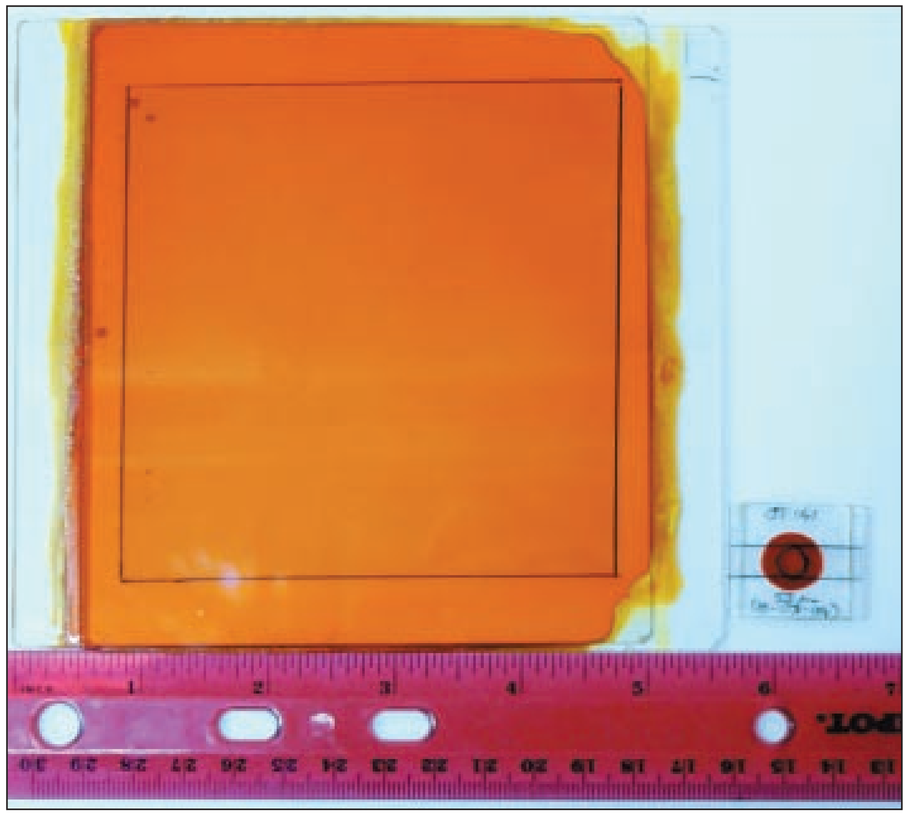

Fig. 2: 4-in. photorefractive polymer devices shown side by side with a smaller (5 mm) sample.

How It Works

In PR polymers, the interference light pattern created by two intersecting, coherent laser beams is recorded as a refractive-index modulation or a phase hologram.[5] This is achieved by electrical-charge generation in the illuminated areas through absorption of light, followed by transport and trapping in the dark regions. The spatial-charge distribution creates local electrical fields which in turn lead to a macroscopic refractive-index change through an electro-optic effect. The hologram can be erased via uniform illumination by a laser beam because the distribution of charges can be randomized by absorption of light. The record/erase cycle does not cause aging and degradation of the material, and new holograms can be recorded in the same location.

The holograms will gradually fade (decay) over time because the trapped charges are randomized by thermodynamic processes inherently present in materials. PR polymers that are designed to have fast recording time usually also have high hologram decay rates. However, for an updatable 3-D display application, a material with rapid recording and slow decay (long persistence) is required. Such a small ratio of persistence time to recording time, combined with other shortcomings such as small area, low diffraction efficiency, and susceptibility to electrical and optical damage has previously prevented the development of updateable holographic displays based on PR polymer composites.

Recently, we have developed new PR-polymer devices with favorable dynamic properties which make them suitable for use in updatable 3-D displays.[4] The new polymer system consists of a copolymer with a holetransporting moiety and a carbaldehyde aniline group (CAAN) attached through an alkoxy linker. A copolymer approach is used, which helped eliminate the phase separation between the functional components commonly seen in homopolymer PR composites while allowing larger non-linear chromophore doping. A copolymer with a polyacrylic backbone was used to attach pendant groups, tetraphenyldiaminobiphenyltype (TPD), and CAAN in the ratio 10:1 by the synthetic modification of the polyacrylate TPD (PATPD) polymer. The host PATPD-CAAN copolymer provides optical absorption and charge generation/transport at the writing wavelength (532 nm). A plasticizer, 9-ethyl carbazole (ECZ) was added to the composite to reduce the glass-transition temperature. A large refractive-index change was achieved by adding 30-wt.% fluorinated dicyanostyrene (FDCST) chromophore.

Device Fabrication

A composite of PATPD-CAAN:FDCST:ECZ (50:30:20 wt.%) was formed into thin-film devices by melting the composite between two transparent indium-tin-oxide-coated glass electrodes. The active layer thickness was set to 100 µm by using glass spacer beads. Figure 2 shows a 4 × 4-in. active-area thin-film device made from this composite next to a typical laboratory test sample. The device showed no dielectric breakdown for extended periods of use (several months) in our display setup, with hundreds of write/erase cycles experienced at high applied voltages (9 kV) and writing optical intensities around 100 mW/cm^2.

The PR thin-film devices show a diffraction efficiency of nearly 100% at an applied voltage of 5 kV in steady-state four-wave mixing measurements. We have developed a new recording technique to modify both rise and decay times by changing the applied voltage. Starting at a higher than usual applied voltage (9 kV), we have achieved a fast recording time of less than a second. We have then reduced the voltage to its optimal value of 5 kV, which ensured a long persistence time with high diffraction efficiency. The temporarily increased voltage during writing facilitates efficient separation of electron-hole pairs and improves the drift characteristics, forcing the charges to travel faster, while also increasing the orientational order parameter and rotational speed of the chromophores.

The display hologram is generated by holographic stereography. This technique is based on optical multiplexing of a limited number of viewpoints of the same object (2-D perspectives at different angles) onto different parts of a recording medium to recreate 3-D perception along with parallax. This powerful technique does not require the actual object to be present for recording. It can use data from any device capable of providing 2-D perspectives of an object of interest. Imaging methods such as magnetic resonance imaging, computer-assisted tomography, aerial and satellite 3-D imaging, synthetic aperture radar, integral photography, or computer-assisted modeling can be integrated with this technique. For an actual object, the simplest way to generate the perspective data would be to capture video of the object from different

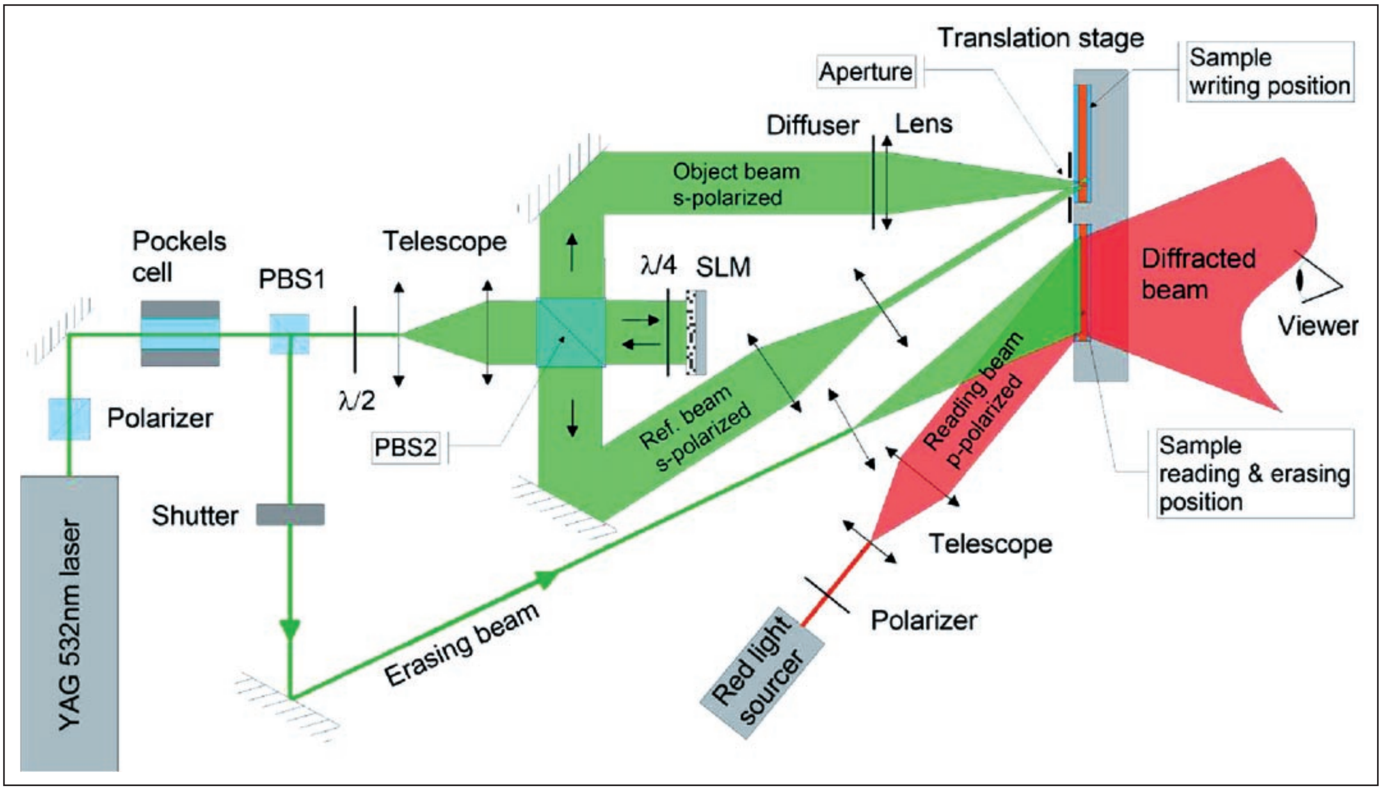

Fig. 3: Optical layout of the 3-D display.

angles using a camera moving on circular tracks. Once the 3-D perspective views are created, they are sliced into multiple view zones, and the view zone for each perspective is combined into a single image. This composite image, called a hogel, is what is actually recorded in a single slice or pixel in the holographic recording material.

A sketch of the 3-D display system we developed is presented in Fig. 3. The writing light source is a doubled YAG laser at 532 nm, a wavelength that is located within the absorption band of the PR material. The hogel information is loaded to the object beam using a spatial light modulator (SLM) controlled by a computer. The object beam interferes at the sample position with a reference beam to create a holographic representation of the hogel.

Writing is performed sequentially: the first hogel is recorded in the sample at the first location; next, the writing beams are turned off and the sample is moved to the second location where the second hogel is recorded. Once all the hogels have been recorded, the sample is moved to the reading position where the hologram can be viewed.

We have used red (633 nm) light from a low-power He-Ne laser in an LED to illuminate the holographic display. LEDs possess the advantage of negligible speckle, owing to their low coherence, but using a rotating diffuser in conjunction with the laser can also be used to reduce coherence-related speckle. Hologram erasure is accomplished by illuminating the sample with a homogeneous beam at a wavelength that is within the absorption band of the material.

The current system (Fig. 4) supports horizontal-parallax-only (HPO) holograms. In many applications, HPO imaging is an effective approximation of 3-D representation because humans perceive depth using the horizontally offset eyes. HPO reduces the number of hogels required to write the full hologram, thereby reducing the overall recording time. We note that our technique is compatible with full parallax imaging as well. We have recorded HPO holograms 4 × 4 in. in size with complex and high-quality images (see Fig. 5) using the system described above within 2 minutes. These images can be viewed for up to 3 hours without significant decay in image brightness and contrast, and can be erased anytime within a few minutes, thus comprising the first updateable holographic 3-D display with memory.

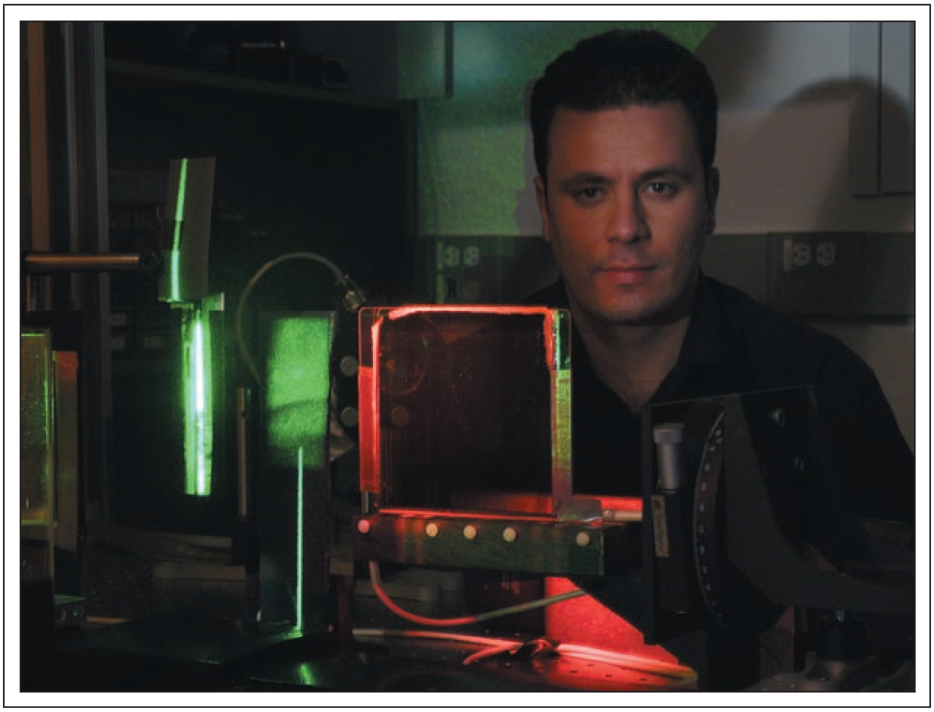

Fig. 4: Shown is the author and the 3-D display setup. The 3-D display can be viewed directly on the PR thin-film device.

Our 3-D display features a total horizontal viewing angle of ±45° with uniform brightness. The images are viewable directly on the PR thin-film device without the need for intermediate projection tools or magnification between the recorded image and the viewer. New images can be recorded when desired. The snapshots of the holograms presented in Fig. 5, which were captured using a CCD camera, are only a modest reproduction of the effect actually experienced upon direct viewing. This is principally due to the astigmatism introduced by the HPO recording technique and electronic artifacts such as saturation, to which the human visual system is relatively insensitive.

Conclusion

We do not anticipate any practical limit on the achievable display size using PR poymers: large devices can be fabricated and/or tiled together and the plastics industry has already shown the ability to laminate extremely large multi-layered thin films. Moreover, the persistence and diffraction efficiency of the material make it a leading candidate for future full-parallax displays, which typically require two orders of magnitude more information content than HPO displays. For larger full-parallax displays, a combination of short-pulse recording and thermal fixing can be used, which are future areas of research for holographic 3-D display development. Full-color imaging can also be implemented by fine tuning the absorption characteristics of the polymer composite.

In summary, we have developed PR polymer devices that combine exceptional properties such as large size, high efficiency, fast recording, image persistence, long lifetime, and resistance to optical and electrical damage, satisfying many of the major requirements for use in holographic 3-D displays. These advances have allowed us to demonstrate the largest PR holographic 3-D display to date. Holographic image-updating capability can significantly extend the applications of 3-D displays in the fields of entertainment, education, medical, and technical imaging.

References

[1]N. A. Dodgson, "Autostereoscopic 3-D Displays," *Computer* **38**, 31-36 (2005).

[2]M. R. Chatterjee and S. Chen, "Digital Holography and Three-Dimensional Display: Principles and Applications," T. Poon, *ed.*

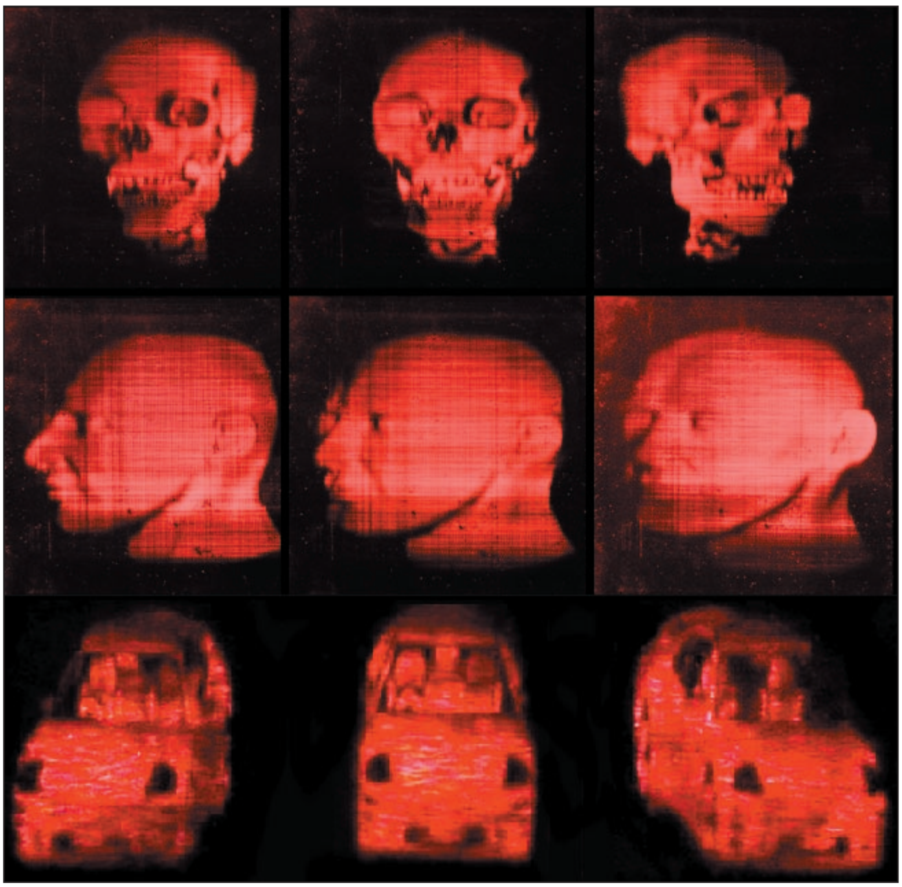

Fig. 5: Images from the photorefractive-based 3-D updateable display.

(Springer, New York, NY, 2006), Chapter 13, pp. 379-425.
[3]S. A. Benton and V. M. Bove, Jr., *Holographic Imaging* (Wiley Inter-Science, (2008).
[4]S. Tay *et al.,* "An updateable holographic three-dimensional display," *Nature* **451**, 694 (2008).
[5]O. Ostroverkhova and W. E. Moerner, "Organic photorefractives: Mechanism, materials and applications," *Chem. Rev.* **104**, 3267-3314 (2004). ■.

A New Approach to Electro-Holography: Can This Move Holography into the Mainstream?

Holography holds great promise for use as 3-D displays, but to date several challenges have prevented the technology from becoming commercialized. But those obstacles are now starting to be overcome. Here, SeeReal Technologies describes its new approach to electro-holography.

by Hagen Stolle and Ralf Häussler

THE THEORY OF HOLOGRAPHY was discovered in 1947 when scientist Dennis Gabor was seeking ways to improve the resolution of an electron microscope. A hologram of an object was generated by interference of the electron wave reflected from the object. The object was reconstructed via subsequent illumination of the hologram with the reference wave. The same principle applies when using visible light instead of electron waves.

Holography quickly captured the imagination of scientists and, over time, society developed a thirst for high-quality holography to transform limited 2-D representations into much more tangible, life-like images. Holographic displays are superior to stereoscopic displays with respect to 3-D depth perception because holographic displays reconstruct an accurate light field with pixels placed at correct optical viewing distance. However, two inherent historical barriers have prevented real-time holographic displays for computer-generated holograms from becoming reality.

- ***Insufficient Display Resolution.*** In order to achieve a viewing angle of 60°, which is necessary to serve several users, a pixel pitch of about 1 wavelength is required. This means that for a 47-in. holographic display, for example, a resolution of 250,000 times that of HDTV is required.
- ***Inadequate Data Volume and Processing Requirements.*** The computation of each display frame requires significantly more steps for a holographic display compared to a 2-D display. Hologram computation involves calculations of Fourier transformations. This factor, coupled with the greatly increased number of pixels required, places a demand for enormous amounts of computational power. Thus, real-time video-quality holograms would typically require processing power up to several hundred Peta-FLOPS, *i.e.*, approximately 10^{17} floating-point operations per second. This is far more than the current computation power of super computers.

The conventional approach to holographic displays reconstructs an object around the Fourier plane of a spatial light modulator (SLM). The size of the object reconstruction is limited to one diffraction order of the SLM because otherwise an overlap of multiple diffraction orders would be visible. The size h of one diffraction order is given by $h = \lambda d/p$, where λ is the wavelength, d is the distance between the SLM and object, and p is the pixel pitch.

As an example, with $\lambda = 633$ nm, $d = 500$ mm, and $p = 10$ µm, we get $h = 32$ mm. A small pixel pitch of 10 µm is needed for such a small object reconstruction with a lateral size of 32 mm. The absolute number of pixels depends on the viewing angle, *i.e.*, the angle from which the object can be seen. Prototype systems use 15 or 100 million pixels[1,2] or a high-frequency acousto-optic modulator.[3] Estimations result in a pixel count of 10^{12} pixels for a full-parallax display with a 0.5-m lateral object size and ±30° viewing angle.[2]

The fundamental difference between conventional holographic displays and our approach is in the primary goal of the holographic reconstruction. In conventional displays, the primary goal is to reconstruct the object. This object can be seen from a viewing region that is larger than the eye separation.

In contrast, the primary goal of our approach is to reconstruct the light wavefront generated by a real existing object for the location in space of each eye.[4] The reconstructed object can be seen if the observer's eyes are positioned in or close to at least one virtual viewing window (VW). A VW contains the Fourier transform of the hologram and is located in the Fourier plane of the hologram. The size of the VW is limited to one diffraction order of the Fourier transform of the hologram.

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Figure 1 illustrates our approach and shows a Fourier transforming lens, a spatial light modulator (SLM), and an eye of an observer. Sufficiently coherent light transmitted by the lens illuminates the SLM. The SLM is encoded with a hologram that reconstructs an object point of a 3-D scene. A scene with only one object point and its associated spherical wavefront is shown. It is evident that more complex scenes with many object points are possible by superposing the individual holograms.

The conventional approach to holographic displays generates the wavefront that is drawn in red. The wavefront information of the object point is encoded on the whole SLM. The modulated light reconstructs the object point that is visible from a region that is much larger than the eye pupil. Because the eye perceives only the wavefront information that is transmitted by the eye pupil, most of the information is wasted.

In contrast, our approach limits the wavefront information to the essential information. The correct wavefront is provided only at the positions where it is actually needed, *i.e.*, at the eye pupils.

Figure 1 shows a virtual VW that is positioned close to an eye pupil. The wavefront information is encoded only in a limited area on the SLM, which we refer to as the sub-hologram (SH). The position and size of the SH is determined geometrically by projecting the VW through the object point onto the SLM. This is indicated by the green lines from the edges of the VW through the object point to the edges of the SH. Only the light emitted in the SH will reach the VW and is therefore relevant for the eye. Light emitted outside the SH and encoded with the wavefront information of the object point would not reach the VW and would therefore be wasted. This is indicated in Fig. 1 by the green spherical wavefronts for the essential information and the red spherical wavefronts for the wasted information.

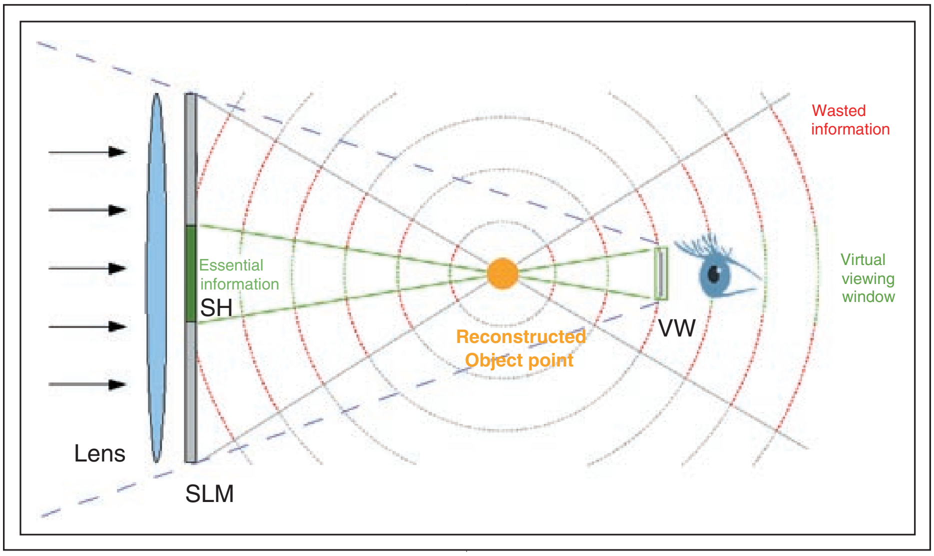

Fig. 1: *Side view of a holographic display with lens, SLM, one object point, and observer eye.*

Managing Pixel Size via a Tracked Viewing Window

The requirements on the pitch of the SLM are significantly lessened by our approach. Our holographic displays are equipped with an eye-position sensor and a tracking system that always positions two VWs at the observer's eyes, *i.e.*, one VW for the left eye and one VW for the right eye. This allows reducing the size of a VW to the size of an eye pupil. As noted above, the VW is the Fourier transform of the hologram. The pixel pitch of the SLM determines the diffraction angle, which in turn determines the size of the VW. A moderate pixel pitch $p = 50$ μm generates a VW with lateral size $h = 20$ mm at a distance $d = 2$ m, using $h = \lambda d/p$ with $\lambda = 500$ nm. These are typical values for a holographic display for TV applications.

These VWs, which may be generated by temporal or spatial multiplexing, can be increased in number to allow for multiple simultaneous viewers.

The size of the reconstructed scene is not limited by the pixel pitch but by the size of the SLM. The 3-D scene can be located anywhere in a frustum defined by the VW and the SLM. This frustum is indicated by the dashed blue lines in Fig. 1. The 3-D scene can be located in front of and behind the SLM. This contrasts with the conventional approach, in which the pixel pitch limits the size of the reconstructed scene.

Encoding Sub-Holograms in Real Time

The second major hurdle addressed was data volumes and computation speeds. Figure 2 illustrates how encoding the wavefront information of an object point in a small sub-hologram (SH) significantly reduces the computation effort.

Projecting the VW through an object point determines the size and position of its associated SH. This is indicated by the lines from the edges of the VW through each object point onto the SLM/hologram display. The hologram in each SH is a spherical phase factor that reconstructs its associated object point at the defined distance from the SLM. Superimposing all the individual SHs yields the final hologram of the complete 3-D scene.

The SH size depends on the VW size and the object point position and is typically on the order of 10 mm (about 0.4 in.). This is much less than the total hologram size of at least 20 in. and more. Therefore, the computation effort is significantly reduced, as each spherical phase factor has to be calculated for the small SH only. In contrast, the conventional approach to holographic displays requires calculation of the wavefront information of each object point on the whole hologram.

In actual computational terms, this only takes single-digit TFLOPS to create full-HDTV 3-D images in real time. This will be well within the GPU domain in the very near future and already allows adaptation to existing ASIC architectures.

Reducing Speckle and Higher-Order Effects

The reduction of speckle is carried out by conventional approaches as well as proprietary encoding techniques, again enabled by the VW concept. Because sub-hologram encoding requires only local coherence across the area of a SH, spatial and temporal coherence of the

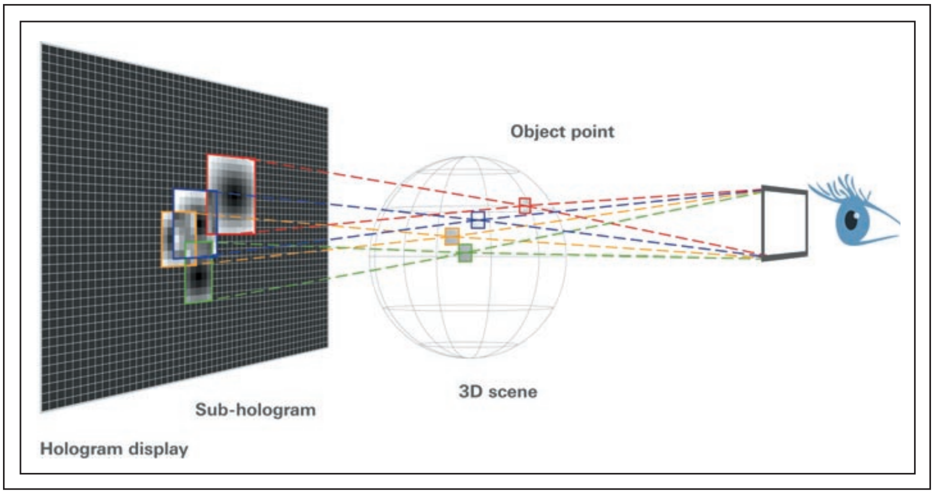

***Fig. 2:** An illustration of how sub-holograms are encoded in real time.*

light source can be reduced without affecting the object resolution visible from the VW. Further speckle reduction is achieved by spatial and temporal averaging of the 3-D scene. These methods reduce speckle by more than 95%.

Because a holographic display is based on the diffraction of light at the SLM, higher diffraction orders of diffracted light occur. The use of sub-holograms already eliminates higher-order effects within the VWs because the VW size is limited to one diffraction order of the SLM. To assure noise-free views for all users, additional solutions have been developed based on simple modifications of hardware components that sufficiently reduce higher diffraction orders outside the VW.

***Fig. 3:** SeeReal's prototype of a holographic display.*

Conclusion

The essential idea of our approach is that for a holographic display the highest priority is to reconstruct the wavefront at the eye position that would be generated by a real existing object and not to reconstruct the object itself. The tracked VW technology limits pixel size to levels already known for commercially available displays. Sub-hologram encoding brings computation into graphics card or ASIC range. SeeReal's new concept is applicable to desktop, TV, and mobile imaging.

While there have been impressive developments in 3-D display technology in the past decade, the remaining visual conflicts between natural viewing and 3-D stereo visualization have prevented 3-D displays from becoming a universal consumer product. In principle, the only 3-D display capable of completely matching natural viewing is an electro-holographic display.

SeeReal's new approach to electro-holography not only proves that it is possible, but that it is also closer to adoption than many experts imagined. The principles and concepts are in place. The checks and verifications are completed. Prototypes are in full use (Fig. 3). The technology already exists – it is just a question of time for all the pieces of the puzzle to come together and for the first commercial real-time 3-D holographic displays to hit the market.

References

[1]K. Maeno, N. Fukaya, O. Nishikawa, K. Sato, and T. Honda, "Electro-Holographic Display Using 15-Mpixels LCD," *Proc. SPIE* **2652**, Practical Holography X, 15–23 (1996).

[2]C. Slinger, C. Cameron, S. Coomber, R. Miller, D. Payne, A. Smith, M. Smith, M. Stanley, and P. Watson, "Recent developments in computer-generated holography: toward a practical electroholography system for interactive 3D visualization," *Proc. SPIE* **5290**, Practical Holography XVIII, 27–41 (2004).

[3]P. St.-Hilaire, S. A. Benton, M. Lucente, J. D. Sutter, and W. J. Plesniak, "Advances in Holographic Video," *Proc. SPIE* **1914**, Practical Holography VII, 188–196 (1993).

[4]A. Schwerdtner, N. Leister, and R. Häussler, "A New Approach to Electro-Holography for TV and Projection Displays," *SID Symposium Digest Tech Papers* **38**, 1224–1227 (2007). ■

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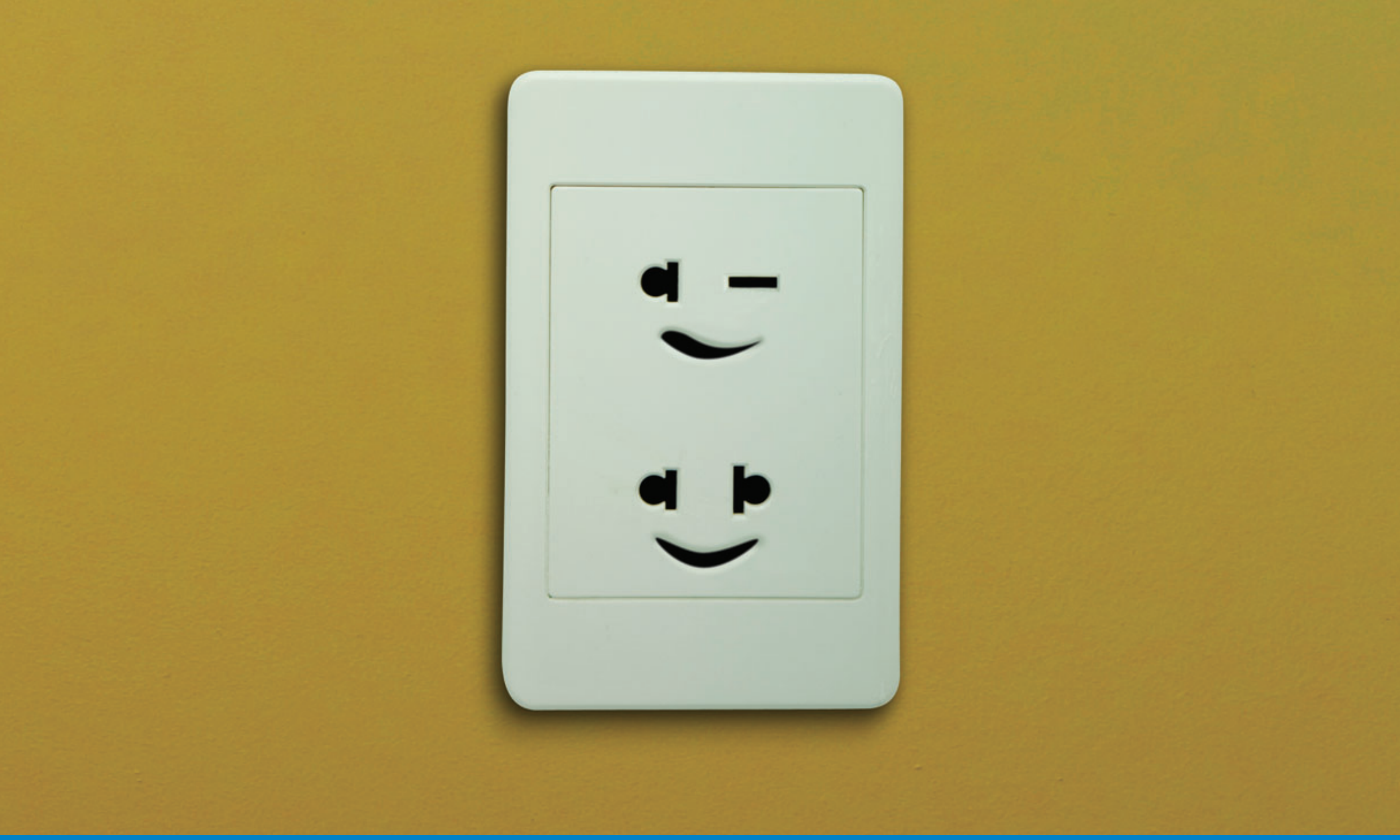

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Scanned Voxel Displays

Conventional stereoscopic displays can cause viewers to experience eye fatigue and discomfort, as well as compromise image quality, because these displays require the viewers to unnaturally keep the eye focal length fixed at one distance while dynamically changing the convergence point of the left and right eyes (vergence) to view objects at different distances. Volumetric displays can overcome this problem, but only for small objects placed within a limited range of viewing distances and accommodation levels; they also cannot render occlusion cues correctly. One possible solution – multi-planar scanned voxel displays – is described here.

by Brian T. Schowengerdt and Eric J. Seibel

THE HUMAN VISUAL SYSTEM is exquisitely specialized to perceive three-dimensional (3-D) relationships. A suite of interacting visual processes actively scan the environment, enabling the brain to accurately gauge the relative spatial locations of surrounding objects. When some depth cues are unavailable, the visual system uses the remaining cues to make best estimates. Think of how easy it is to walk across a room with one eye closed: the changing size and relative motion of objects, and the fact that nearby objects partially block the view of farther objects, provide sufficient depth cues to avoid running into obstacles. As tasks get more difficult – for example, shooting a basketball or excising tissue with a scalpel – the removal of some depth cues dramatically lowers performance.

Therefore, for difficult spatial tasks involving displays, such as laparoscopic surgery, it is helpful to provide as many accurate depth cues as possible, and the best way to do that it is to utilize a 3-D display. But it is not that simple. The simplest and most common devices for presenting 3-D data are stereoscopic displays; however, though they can create a compelling feeling of depth by including some cues that are not available in 2-D displays, they also generate inaccurate cues that provide conflicting depth information – a situation to which the human visual system reacts very poorly. This imperfect mimicry of 3-D viewing conditions creates sensory conflicts within the visual system, leading to eye fatigue and discomfort.

For 3-D displays to truly achieve their enormous potential, these issues must be overcome. This article presents approaches to building 3-D displays that better mimic reality and do not create conflicts within the visual system, including various volumetric displays that avoid accommodation/vergence decoupling for small objects over a limited range of distances and our scanned voxel displays that overcome the conflicts across an unlimited range of object sizes and distances.

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Hardwired Together: Focusing and Aiming the Eyes

When viewing objects in the real world, the information presented to and the demands placed upon the various processes in the visual system are matching and synchronous. One such process, *accommodation*, controls the focus of the eye's optics. Like a camera, the eye changes its focal power to bring an object at a given viewing distance into sharp focus on the retina (the imaging plane of the eye). Whereas a camera slides a lens forward or backward to shift focus from a distant to a nearby point, the eye stretches or relaxes an elastic lens positioned behind the iris and pupil, to change its convexity.[1] A second process, *vergence*, controls the distance at which the lines of sight of the eyes converge – *i.e.*, the distance at which a viewer is pointing his or her eyes.

When a viewer looks from an object in the distance to a closer object, two things must happen simultaneously in order to see the new object clearly: The viewer must converge both eyes to point at the new object and change the accommodation of the eyes' lenses to bring the object into focus (Fig. 1). These processes need to consistently act in concert when viewing real objects and, accordingly, a hardwired link connects their operation. A movement in one process automatically triggers a synchronous and matching movement in the other process.[2]

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Stereoscopic and autostereoscopic displays provide one image to the left eye and a different image to the right eye, but both of these images are generated by flat 2-D imaging elements such as liquid-crystal-display (LCD) panels. The light from every pixel originates from a flat surface (or, in some cases, two flat surfaces), so the optical viewing distance to each pixel is exactly the same; namely, the distance to the screen. This optical viewing distance acts as a cue to the visual system that all of the objects are flat and located at the same distance, even though the stereoscopic information provides cues that some objects are behind or in front of the screen – this places a demand on accommodation to focus the eye to the distance of the screen. Only when the viewed object is positioned at the actual distance of the screen (*i.e.*, the degenerate case of using the 3-D display as a 2-D display) can the eyes point and focus to matching distances and see a sharp image of the object (left side of Fig. 2). Objects that are positioned stereoscopically behind the screen require the eyes to point behind the screen while focusing at the distance of the screen, *i.e.*, viewers must attempt to decouple the linked processes of vergence and accommodation (right side of Fig. 2), or else the entire display with be blurry (middle of Fig. 2). This forced decoupling is thought to be the major source of eye fatigue in stereoscopic displays,[3-5] compromises image quality, and may lead to visual-system pathologies with long-term exposure (especially in the developing visual systems of children).[6]

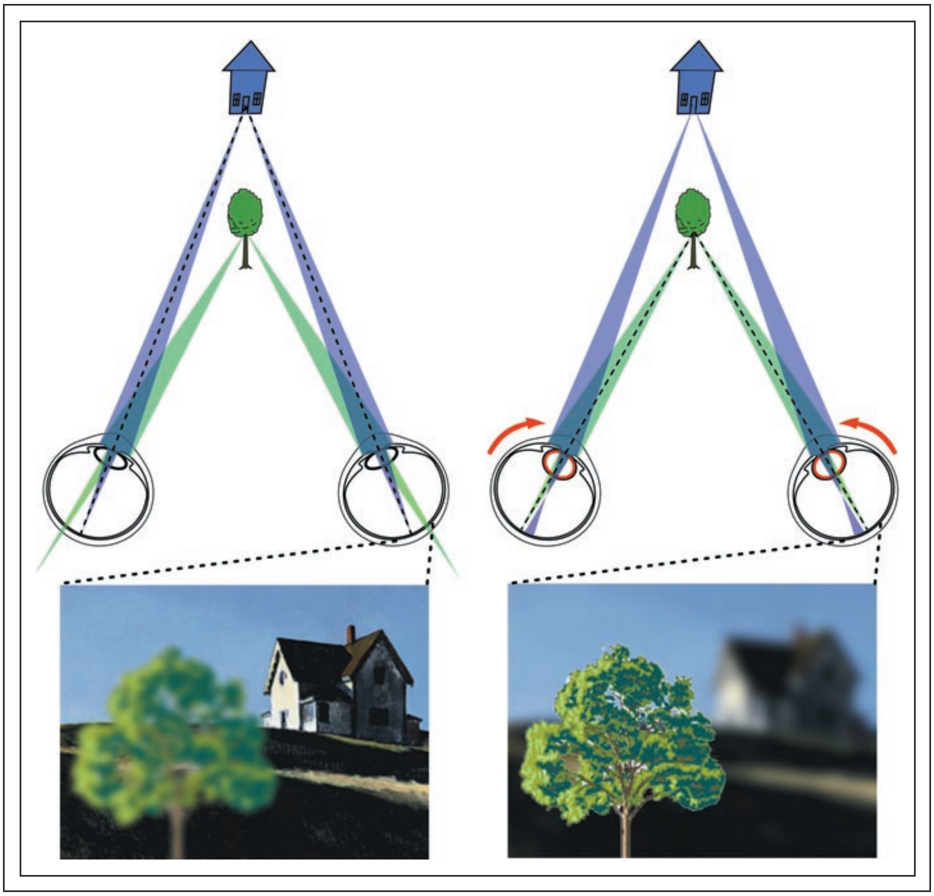

***Fig. 1:** The linked operation of accommodation and vergence when viewing real 3-D objects. **Left:** As a viewer looks at the house in the distance, the lines of sight (black dotted lines) of his/her eyes are converged to point at the house, while the eyes' lenses (ovals near the front of each eye) are accommodated to a matching distance to focus the light reflected from the house (blue solid lines) onto the retina to form a sharp image of the house. Because the tree is at a different viewing distance, the light reflected from the tree in the foreground (solid green lines) comes to focus behind the retina and is blurred in the retinal image. **Right:** As the viewer shifts gaze to the tree, the eyes simultaneously converge to the distance of the tree and increase the convexity of the lenses to accommodate to the matched distance. The increased optical power of the lens brings the light reflected from the tree into focus on the retina, while the light reflected from the house shifts out of focus.*

Volumetric Displays: Accurate Focus Cues, Limited in Size

Volumetric displays represent an alternative 3-D technology that can create matching accommodation and vergence cues and thereby avoid the conflict generated by stereoscopic displays. One such volumetric display, called the Perspecta display (Actuality Systems), is a swept-screen multiplanar display.[7] A circular projection screen (about 25 cm in diameter) spins around its center axis, sweeping the surface of the screen through a spherical 3-D volume. During each refresh cycle, a high-speed video projector projects 198 different 2-D slices of a virtual 3-D object onto 198 orientations of the spinning screen. Each point on the 3-D object is represented by a voxel (most simply defined as a three-dimensional pixel) within the 3-D volume, and light coming from that voxel reaches the viewer's eyes with the correct cues for both vergence and accommodation. Another volumetric display, the DepthCube (Lightspace Technologies), also uses a high-speed video projector to project multiple 2-D slices throughout a 3-D volume.[8] Rather than sweeping a screen through the volume, however, the DepthCube contains a stack of 20 liquid-crystal scattering shutters. At any given instant of time, 19 of the 20 shutters are almost transparent, while one active shutter acts as a scattering rear-projection screen. The active state "sweeps" through the shutter stack in a fashion functionally similar to the sweeping screen of the Perspecta display.

Though these volumetric displays create matching accommodation and vergence demands for the objects they display, they possess some disadvantages. A primary drawback is that the objects they depict are of limited size – they must physically fit within the scanned 3-D volume, such as within the

25-cm-diameter sphere of the Perspecta display. These displays cannot place two objects on opposite sides of a table, much less place objects on the distant horizon, and can only shift the focal level of objects through an accordingly small range of accommodation. A second disadvantage is that they do not represent occlusion correctly. Every voxel is visible to the viewer, even if that voxel represents a point on the opposite side of the object that should not be visible from that angle. Additional difficulties stem from the computational demand placed by the large number of voxels and the difficulty in leveraging conventional video-card technology to handle this load. For instance, each of the 198 slices of the Perspecta display has a resolution of 768 × 768 pixels, *i.e.*, the display must render over 116 million pixels per frame, making computation of moving video infeasible with current graphics processing units.

A fixed-viewpoint volumetric display has been developed by Akeley and colleagues that, unlike multi-view volumetric displays, correctly renders occlusion cues.[9] The approach used is somewhat similar to that of the DepthCube, in that image slices are placed at fixed distances with a volume. However, rather than sequentially turning those slices off and on, the slices are always on and optically superimposed using beamsplitters. A separate stack of slices is used to create the 3-D volume displayed to each eye, allowing accurate occlusion and viewpoint-dependent lighting effects to be presented. There are, however, only three slices in the current prototype, and accurate focus cues for an object are only produced when it is located at the distance of one of the three slices. The light loss associated with optical combining using beamsplitters makes a significant increase in the number of layers problematic. The prototype also is constrained to a maximum depth of 22.4 cm with focus cues, as the slices are placed 31.1, 39.4, and 53.5 cm from the viewer.

In order to recreate the full range of real-world depth perception, a 3-D display must be able to place pixels or voxels at optical distances ranging from the near point of accommodation (a focus distance of around

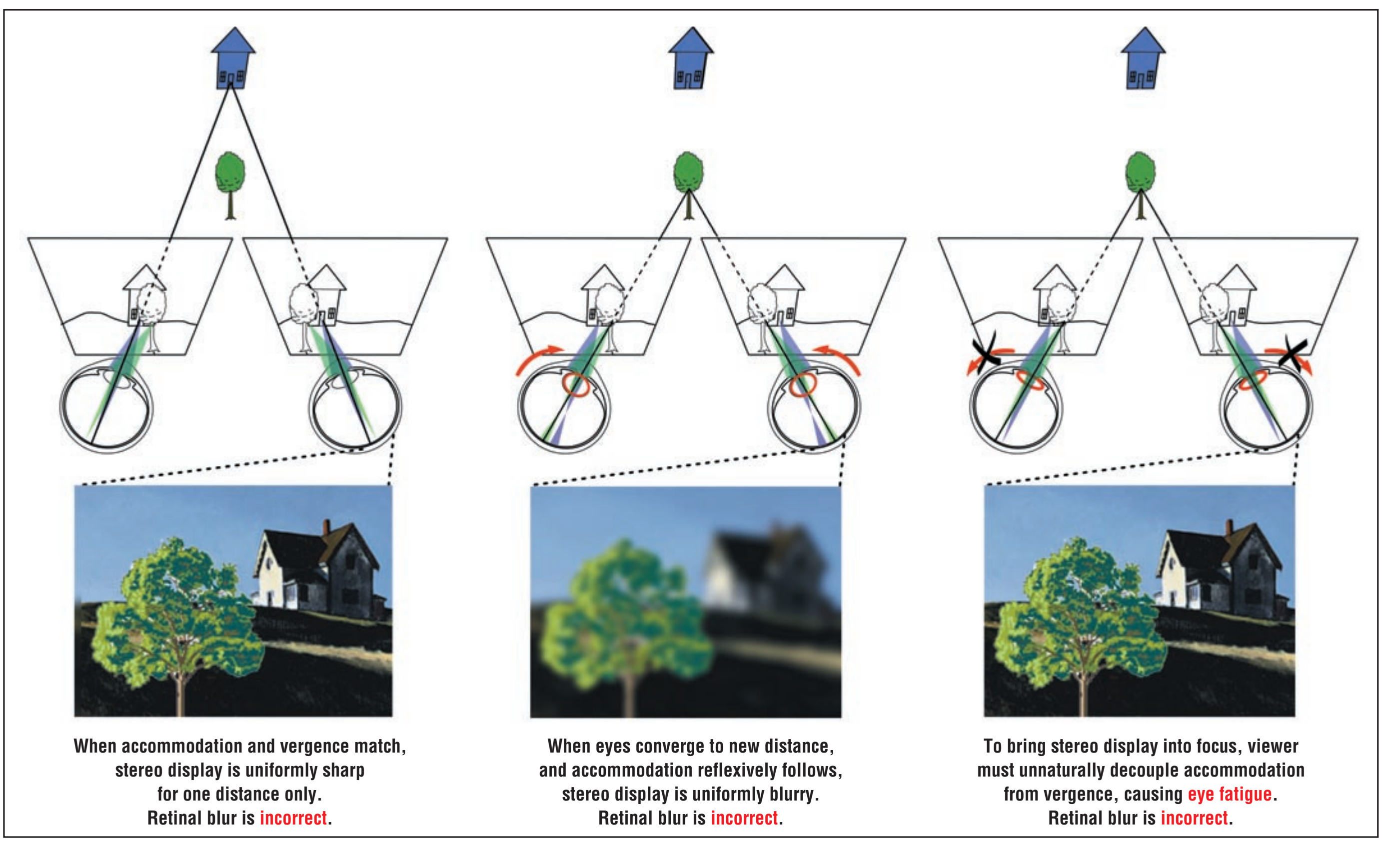

Fig. 2:* *Left: *There is only one correct position for accommodation when viewing conventional stereoscopic displays. Even though the house and tree are at different stereoscopic distances (there is greater binocular disparity between the trees than there is between the houses rendered in the left and right stereo-images), they will either both be in focus (if the viewer is accommodated to the one correct distance) or both be out of focus (if the viewer accommodates to any other distance).* ***Middle:*** *If the viewer shifts his/her gaze to the tree in the foreground, the change in vergence triggers a matching involuntary shift in accommodation, causing the entire display to become blurry.* ***Right:*** *To bring the display back into focus, the viewer is forced to decouple the linked processes and keep accommodation fixed at the distance of the house while converging to the distance of the tree.*

7 cm in a young viewer) to infinitely distant. We have developed a number of scanned voxel displays that overcome the accommodation/vergence conflict like volumetric displays but can also place objects anywhere from 6.25 cm from the viewer's eye to infinitely far away – surpassing the range required to match the full range of accommodation.

Approaches to Creating Scanned Voxel Displays

Scanned pixel displays such as the Virtual Retinal Display[10,11] biaxially scan a color- and luminance-modulated beam of light, serially moving a single pixel in 2-D across the retina to form an image (Fig. 3).

We have integrated a variable-focusing element into a scanned light display to enable a voxel to be triaxially scanned throughout a 3-D volume (Fig. 4). Unlike volumetric displays, the light is not projected onto a screen (moving or otherwise) but rather creates a 3-D volume of light that is viewed directly by the eye. By positioning the 3-D volume between the surface of a lens and its focal length, the 3-D volume can be magnified to occupy a virtual space stretching from the lens to the distant horizon. As when viewing real 3-D objects, the eyes can focus upon different points within the 3-D volume.

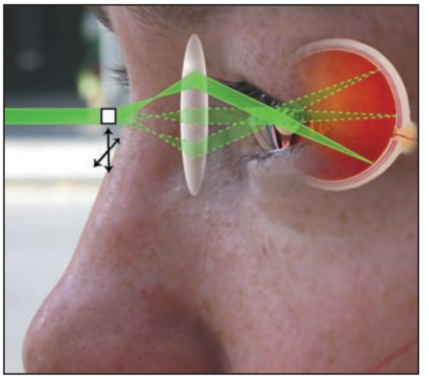

Fig. 3: A scanned pixel display projects a beam of color- and luminance-modulated light into the eye, and the lens of the eye (to the right of the pupil) focuses the beam to a point on the retina, creating a pixel. As the beam is scanned biaxially (scanner shown as the white box at the left), the pixel moves across the retina, forming a 2-D image. Only three pixels are shown, for simplicity of illustration.

We have designed and constructed a number of scanned-voxel-display prototypes using this approach, which are described in detail elsewhere,[12–14] but we will briefly describe a recent prototype that presents full-color stereoscopic multi-planar video directly to each eye, using a scanning beam of light. Before the beam is raster-scanned in the X- and Y-axes, it is first "scanned" in the Z-axis with a deformable membrane mirror (DMM) MOEMS device from OKO Technologies (Fig. 5). The DMM contains a thin silicon nitride membrane, coated with a reflective layer of aluminum, stretched in front of an electrode. The shape of the reflective membrane is controlled by applying bias and control voltages to the membrane and electrode. With no applied voltage (left side of Fig. 5), the membrane forms a flat mirror and a collimated beam reflected from its surface remains collimated. With an applied voltage, the reflective membrane is electrostatically deflected toward the electrode, forming a concave parabolic surface that will focus a beam of light to a near point (right side of Fig. 5). Intermediate voltage levels shift the focal point anywhere between the near point and optical infinity (*i.e.*, a collimated beam).

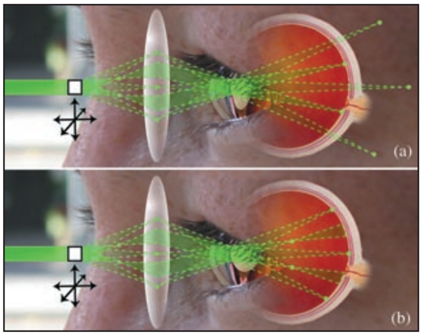

Fig. 4: In the scanned voxel display, a modulated beam is triaxially scanned throughout a 3-D volume that is viewed directly by the eye. For simplicity, only two image planes and five voxels are shown. In the top image, the viewer is accommodating to the distant horizon, with the far rear plane in the volume in focus on the retina (the foci are represented by two green circles). Graphics in that far plane (e.g., distant mountains and clouds) will be in focus for the viewer, while graphics in the other planes will be blurry proportionally to their distance from the viewer's point of focus (represented by the three foci behind the retina – notice how their light is diffusely spread when it reaches the retina). In the bottom image, the viewer has shifted accommodation to a near point, increasing the optical power of the eye's lens. Now, the front plane of the volume is in focus on the retina, bringing graphics in that plane (e.g., a branch from a nearby tree) into sharp focus for the viewer, while mountains and clouds in the far plane are shifted out of focus (the foci are in front of the retina, and the light is diffuse when it reaches the retina).

After being scanned in the Z-axis with the deformable membrane mirror, the beam is scanned in the X-axis with a spinning polygon mirror (Lincoln Laser Co.) and scanned in the Y-axis with a galvanometric mirror scanner (Cambridge Technologies), completing the tri-axial scan. This 3-D scanned voxel volume is optically divided with fold mirrors and relayed to the left and right eyes. The top of Fig. 6 presents a graphical overview of the complete optical system.

In this proof-of-concept prototype, two planes are scanned frame-sequentially into the eye. To provide the video content for the display, two images are presented in a "page-flipping" mode, in which even frames from the 60-Hz refresh rate are used to present one image, while the odd frames are used to present the second image. In synchronization with the page flipping of the images, the DMM shifts the focus of the scanning beam,

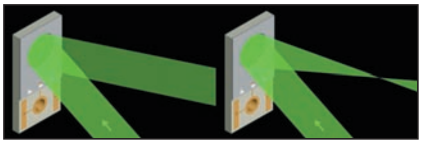

Fig. 5: The deformable membrane mirror (DMM) is used to dynamically change the focus of the beam before it is XY-scanned. The beam is shown entering from the bottom of the figure and being reflected to the right. If no voltage is applied across the membrane and electrode (left side of the figure), the membrane remains flat and doesn't change the focus of a beam reflected from its surface. If a voltage is applied (right side of the figure), the membrane electrostatically deflects toward the electrode, creating a concave parabolic mirror that shifts beam focus closer.

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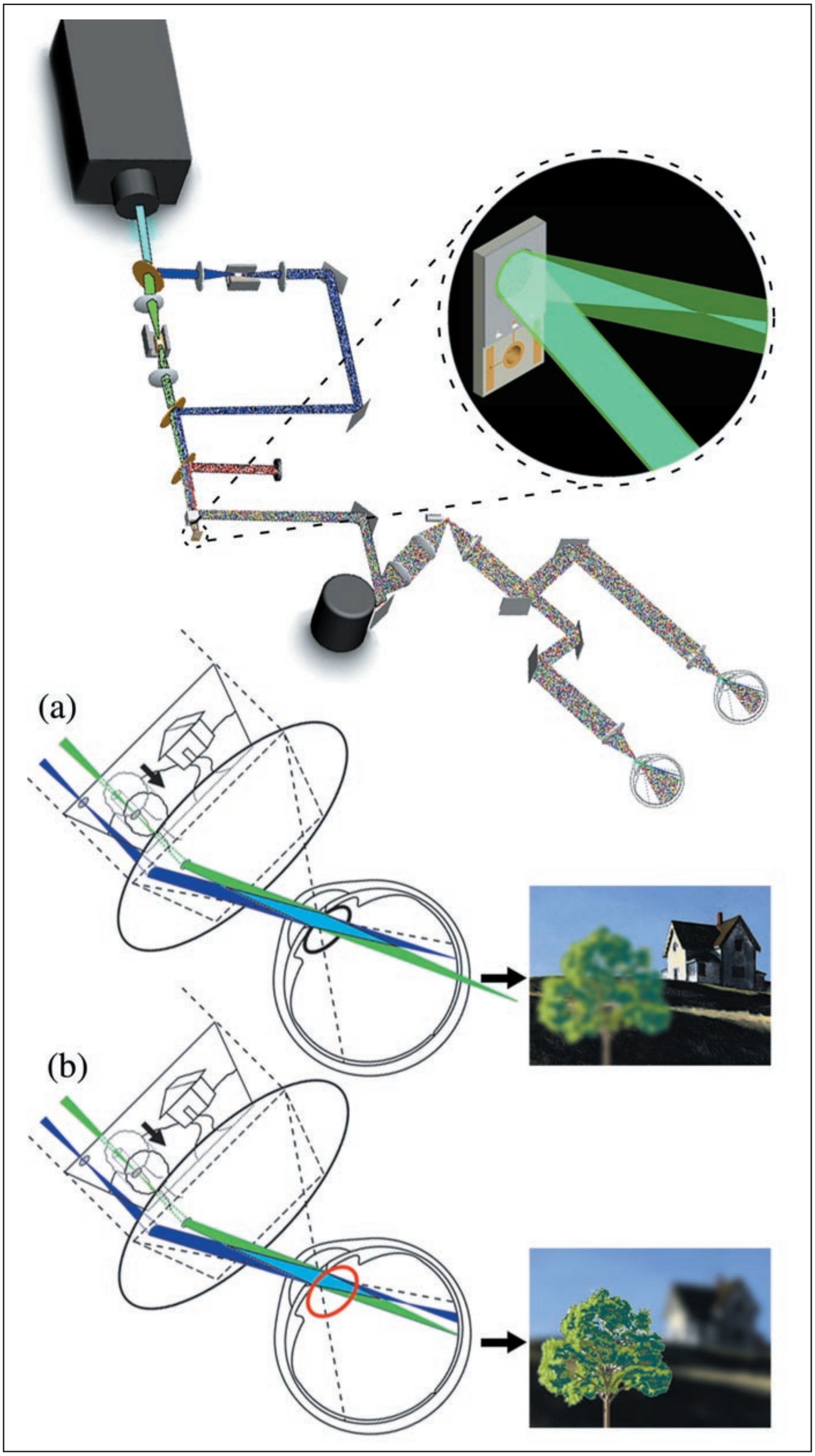

such that the two images are projected to different depth planes, creating a two-plane voxel volume. The viewer perceives the superposition of the two planes as one composite multi-layer image. By naturally accommodating the eyes, the viewer can bring objects in the background [Fig. 6(a)] or foreground [Fig. 6(b)] into focus on his/her retina. By rendering an object to a plane in the volume that matches its stereoscopic viewing distance, the cues to accommodation and vergence are brought into correspondence. Figure 7 shows sample photographs of multi-layer images displayed on the prototype.

Objectively Measuring Focal Range and Accommodation

In order to assess the full focal range of the prototype, we measured the diameter of the scanning beam at multiple locations with a beam profiler and used these measurements to calculate the degree of divergence of the beam across a range of DMM control voltages. The beam divergence data were, in turn, used to calculate the viewing distance of the virtual image and the amount of accommodation needed to bring the image into focus (Fig. 8). Virtual images displayed with the prototype can be shifted from 6.25 cm from the eye (closer than the near point of human accommodation) to optical infinity. Figure 9 shows objective measurements of the diopter power of accommodation (1/focal length) of human subjects to the display, taken with an infrared autorefractor (for more details, see Refs. 15 and 16). Subjects accurately shifted accommodation to match the image plane as it was optically shifted forward and backward with the DMM.

An interesting finding from our prior research is that the human accommodation response to the scanned voxel display is

Fig. 6: *The viewer brings different depth planes into focus by naturally shifting the accommodation of the eyes' lenses. By changing the voltage to the DMM rapidly, a frame-sequential multi-planar image is generated. (a) The viewer accommodates his/her eye to the distance and thus the house in the background plane is in focus while (b) the tree in the foreground plane is somewhat blurred. The viewer accommodates near, bringing the tree into focus on the retina while the house is shifted out of focus.*

dependent upon the diameter of the scanning beam. When the scanning beam is greater than 2 mm in diameter, subjects accommodate accurately and consistently. However, if the diameter of the beam is reduced to 0.7 mm, the display creates the virtual equivalent of a pinhole lens – the depth of focus of the display increases and accommodation begins to operate in an open feedback loop and become more variable, both within and between subjects.[17-20]

Current Challenges for the Single-Focus-Modulator Approach

We have described a proof-of-concept prototype that frame-sequentially projects two planes in a voxel volume, providing a limited degree of resolution in the Z-axis. One way to improve this resolution is to increase the number of frame-sequentially presented planes, mimicking the arrangement of volumetric displays, such as the swept-screen displays discussed in the introduction. However, unlike such volumetric displays, our scanned voxel displays are not limited to varying the Z-axis of voxels on a frame-by-frame basis. Indeed, it is not very computationally efficient to create a full 3-D voxel array since, for any given scene, the majority of voxels are not actively used to represent objects. A more elegant solution is to create a two-and-a-half dimensional (2.5-D) sculpted surface of voxels, in which there is one voxel per XY coordinate, and the Z-axis position of that voxel can be dynamically adjusted with a single focus modulator. This solution is more computationally efficient and better able to leverage conventional video-card architecture, as the display can be driven with a 2-D source image paired with a depth map of Z-axis values. For each refresh cycle of the display, the beam is moved in a 2-D XY raster, using the color and luminance data from the 2-D source image to control the intensities of the RGB light sources and the depth map to dynamically control the position of a single

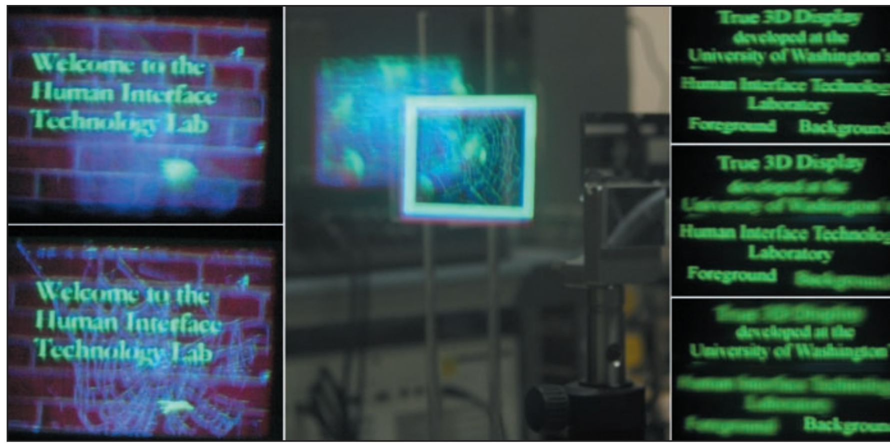

Fig. 7: Photographs taken of multi-layered images displayed on the prototype scanned voxel display. ***Left:*** *The camera is focused on the far voxel plane, which portrays a brick wall with green text. In the top photo, a voxel plane containing an image of a spider web is in front of the camera's plane of focus (analogous to a human viewer's point of accommodation). In the bottom photo, the voxel plane with the spider web is optically shifted with the DMM to align with the rear voxel plane.* ***Middle:*** *The display can also be used in an see-through augmented reality mode, in which the voxel image is presented to the eye with a beamsplitter, enabling virtual objects to be optically placed within the real world. The camera is focused near the front voxel plane, which portrays a spider web. The rear voxel plane, containing a stone wall and yellow airplanes, is behind the camera's plane of focus.* ***Right:*** *In the top photo, both voxel planes are aligned on the Z-axis, and the camera is focused at this point, yielding a uniformly focused image. In the middle and bottom photos, the voxel planes are separated and the camera's focus is shifted between the front and rear voxel plane.*

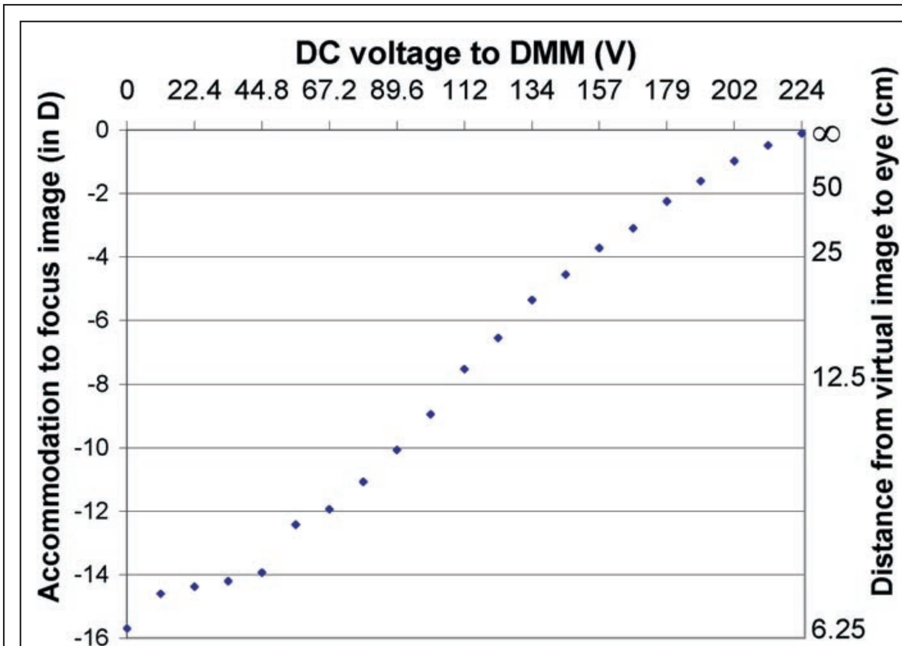

Fig. 8: *Optical distance to (right axis) and accommodation required to focus (left axis) a plane in the scanned voxel display, plotted as a function of the voltage used to drive the DMM. The diopter power of ocular accommodation required to bring the image into focus is equal to the negative inverse of the distance to the virtual image as measured in meters.*

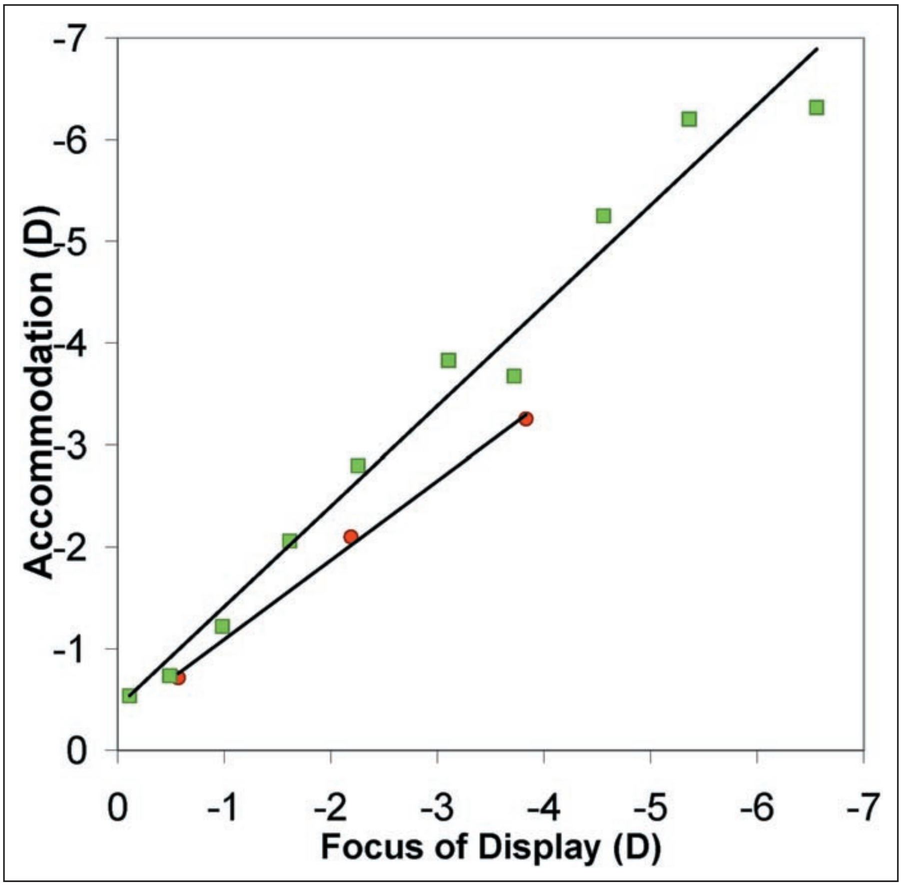

Fig. 9: The observed accommodation responses to two prototype scanned voxel displays plotted as a function of the objectively measured focus levels of the displays. Red circles represent accommodation responses of 10 subjects (averaged over time and subject) while viewing a display with a 3.5-mm-diameter exit pupil. Green squares represent the average (over time) accommodation response of a single subject viewing a display with an exit pupil between 2.9 and 1.6 mm. Least-squares linear regression lines have been fitted to each data set.

focus modulator on a "pixel-sequential" basis. Unfortunately, current DMMs are only capable of kHz focus modulation rates, rather than the MHz rates necessary to vary the focus of the beam on a pixel-sequential basis.

Solid-state electro-optical materials promise a faster alternative to deformable membrane mirrors. New electro-optical polymers are being developed at the University of Washington,[21] which will enable spatial light modulators that can operate at GHz rates – exceeding the speed requirements to perform pixel-sequential focus adjustment with a single modulator. As we await availability of these faster modulators, we are now developing scanned voxel displays that contain multiple focus channels in parallel, in order to overcome the speed limitations associated with a single modulator using currently available technology.

Scanned Voxel Displays Using Multiple Light Sources

In the prototype described above, a single RGB composite light beam is focus-modulated and scanned into the eye. We are nearing completion of a next-generation scanned voxel display that contains multiple RGB beams, each of which are placed at different focus levels before they are optically combined (see Fig. 10). The composite multi-focal RGB beam is then XY-scanned into the viewer's eyes with each component beam creating a different plane in a voxel volume, creating a layered multi-focal virtual image that appears to float in space. Unlike the prior prototype in which multiple planes are produced frame-sequentially, the new display generates the multiple planes simultaneously. The differences in focus between beams can be created by using fixed lenses (or mirrors) with different optical powers or by placing non-collimated light sources at different distances from a lens. As an alternative to using fixed-power lenses to create focus differences, each light source can be provided with a separate dedicated focus modulator (*e.g.*, DMM). Doing so provides the advantage that the Z-axis spacing between planes can be dynamically adjusted to be optimal for a given scene, a given viewer, or a given state of the observer (for instance, if an eye-tracker or accommodation tracker is available, then the planes can be shifted to most densely represent the viewer's region of interest). Each object in a virtual scene can also be assigned to a separate focus layer, and as that objects moves, the focus of the layer can be adjusted with the focus modulator to follow the object in depth.

One advantage to using multiple light sources to create different planes is that multiple focus distances can be presented along the same line of sight, enabling pixel-accurate depictions of transparency and reflections to be presented. For instance, a scene can be rendered in which a fish swimming under the surface of a lake and a reflection of a far away mountain from the lake surface can be seen overlapped, with the fish and mountain placed at different optical distances.

Conclusion

As we have discussed, conventional stereoscopic displays create fatiguing cue conflicts in the visual system between accommodation and vergence because viewers are forced to focus their eyes at one distance and point them at a different distance. Current multi-viewpoint volumetric displays can only overcome this conflict for small objects over a limited range of focus distances and cannot render occlusion cues correctly. We have presented two approaches to building 3-D scanned voxel displays that better mimic natural vision, projecting objects of any size at viewing distances from 6.25 cm to optical infinity and overcoming the cue conflict throughout the full range of human accommodation.

Commercial realizations of our prototype scanned voxel displays can include a lightweight head-mounted display (HMD), ideal for wearable computing and augmented reality applications, or a stand-alone desktop display, designed to be viewed from a distance. Using batch microfabrication techniques, the MOEMS scanners can be produced at low cost. Red laser diodes are inexpensive, allowing portable monochrome red scanned voxel displays to be manufactured affordably. A portable full-color system would currently require higher manufacturing costs. Blue laser diodes are expensive and have shorter lifetimes, but it is anticipated that both cost and lifetime will improve in the next few years. Small prototype green semiconductor lasers capable of MHz-rate luminance modulation have been demonstrated by Corning, Novalux, and OSRAM and will soon reach large-scale commercial production.

Non-fatiguing 3-D displays can be used for all 3-D viewing applications for which conventional stereoscopic systems are typically used. There are, however, some applications for which they are critical. Surgeons are increasingly using minimally invasive methods (*e.g.*, endoscopy and laproscopy) that require looking at displays for many continuous hours. 3-D displays enable surgeons to better guide endoscopes around obstructions within the narrow spaces of the body, but doctors must remain in top mental form throughout long surgeries, so it is crucial that these displays be non-fatiguing and comfortable. The guidance of minimally invasive surgery tools is a form of teleoperation, and other forms of teleoperation, such as the piloting of remote UAVs (Unmanned Autonomous Vehicles), also can greatly benefit from 3-D displays that can be comfortably viewed for extended durations. Finally, as 3-D displays are used for video games, we should not present young children with sensory conflicts that could lead to pathologies in their developing visual systems. While surgeons must spend hours concentrating on displays during surgery, children often voluntarily spend even longer periods concentrating on video-game displays.

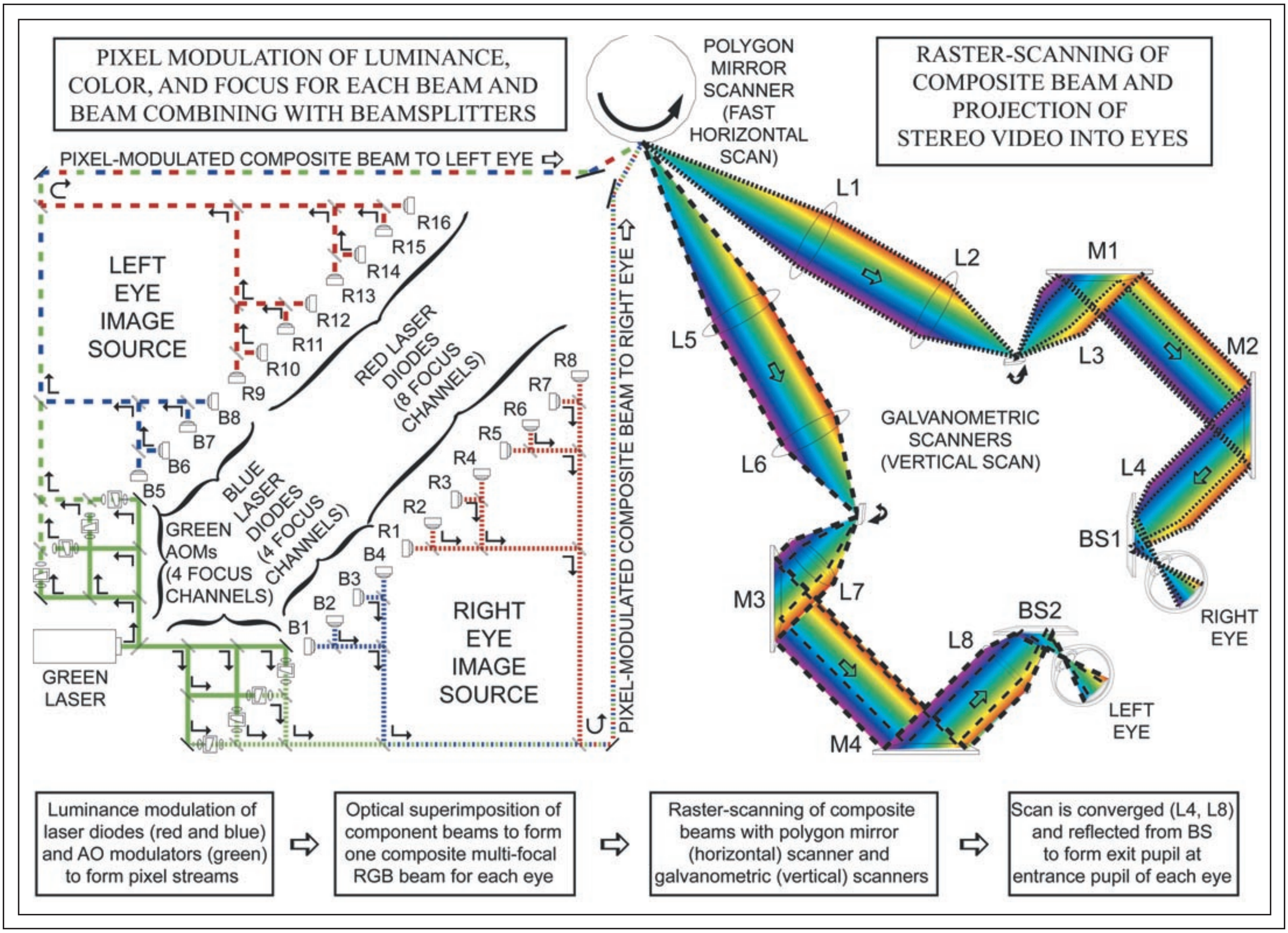

Fig. 10: *Overview of next-generation scanned voxel display. Multiple pixel streams are generated with separate RGB light sources. Each is placed at a different focus level before being optically combined and XY-scanned to form two 3-D volumes, one viewed by the left eye and one by the right.*

3-D improvements

Acknowledgments

This research was supported by a grant from the National Science Foundation Major Research Instrumentation program.

References

[1]H. L. F. v. Helmholtz and A. P. König, *Handbuch der physiologischen Optik*. (Leipzig, L. Voss., 1909).

[2]E. F. Fincham, "The accommodation reflex and its stimulus," *British Journal of Ophthalmology* **35**, 381-393 (1951).

[3]M. Mon-Williams, J. P. Wann, and S. Rushton, "Binocular vision in a virtual world: Visual deficits following the wearing of a head-mounted display," *Ophthalmic & Physiological Optics* **13**, 387-391 (1993).

[4]P. A. Howarth, "Empirical studies of accommodation, convergence and HMD use," *Proceedings of the Hoso-Bunka Foundation Symposium: The human factors in 3-D imaging* (1996).

[5]D. M. Hoffman, A. R. Girshick, and M. S. Bank, " 'Vergence' accomodation conflicts hinder visual performance and cause visual fatigue," *J. Vision* **8**(3):33, 1-30 (2008).

[6]S. K. Rushton and P. M. Riddell, "Developing Visual Systems and Exposure to Virtual Reality and Stereo Displays: Some Concerns and Speculations about the Demands on Accommodation and Vergence," *Applied Ergonomics* **30**, 69-78 (1999).

[7]G. E. Favalora, J. Napoli, D. M.Hall, R. K. Dorval, M. G. Giovinco, M. J. Richmond, and W. S.Chun, "A 100-Million-Voxel Volumetric Display," *Proc. SPIE* **4712**, 300–312 (2002).

[8]A. Sullivan, "A Solid-State Multi-Planar Volumetric Display," *SID Symposium Digest Tech Papers* **34**, 1531-1533 (2003).

[9]K. Akeley, S. J. Watt, A. R. Girshick, and M. S. Banks, "A Stereo Display Prototype with Multiple Focal Distances," *ACM Transactions on Graphics* **23**, 804-813 (2004).

[10]T. A. Furness and J. Kollin, *J. Virtual Retinal Display*, U.S. Patent #5467104 (1995).

[11]R. Johnston and S. Willey, "Development of a commercial Virtual Retinal Display," *Proc SPIE*, *Helmet- and Head-Mounted Displays and Symbology Design Requirements* **2464**, 2-13 (1995).

[12]N. L. Silverman, B. T. Schowengerdt, J. P. Kelly, and E. J. Seibel, "Engineering a retinal scanning laser display with integrated accommodation depth cues," *SID Symposium Digest Tech Papers* **34**, 1538-1541 (2003).

[13]B. T. Schowengerdt, E. J. Seibel, N. L. Silverman, and T. A. Furness, "Stereoscopic retinal scanning laser display with integrated focus cues for ocular accommodation," in A. J. Woods, J. O. Merritt, S. A. Benton, and M. T. Bolas (*eds.*), *Stereoscopic Displays and Virtual Reality Systems XI, Proc. SPIE-IS&T Electronic Imaging* **5291**, 366-376 (2004).

[14]B. T. Schowengerdt and E. J. Seibel, "True 3-D Scanned Voxel Displays Using Single or Multiple Light Sources," *J. Soc. Info. Display* **14**(2), 135–143 (2006).

[15]S. C. McQuaide, E. J. Seibel, J. P. Kelly, B. T. Schowengerdt, and T. A. Furness, "A retinal scanning display system that produces multiple focal planes with a deformable membrane mirror," *Displays* **24**, 65-72 (2003).

[16]B. T. Schowengerdt, E. J. Seibel, N. L. Silverman, and T.A. Furness, "Binocular retinal scanning laser display with integrated focus cues for ocular accommodation," in A. J. Woods, J. O. Merritt, S. A. Benton, M. T. Bolas (*eds.*), *Stereoscopic Displays and Virtual Reality Systems X, Proceedings of SPIE-IS&T Electronic Imaging* **5006**, 1-9 (2003).

[17]H. Ripps, N. B. Chin, I. M. Siegel, and G. M. Breinen, "The effect of pupil size on accommodation, convergence, and the AC/A ratio," *Investigative Ophthalmology* **1**, 127-135 (1962).

[18]R. T. Hennessy, T. Iida, K. Shina, and H. W. Leibowitz, "The effect of pupil size on accommodation," *Vision Research* **16**, 587-589 (1976).

[19]P. A. Ward and W. N. Charman, "Effect of pupil size on steady-state accommodation," *Vision Research* **25**, 1317-1326 (1985).

[20]P. A. Ward and W. N. Charman, "On the use of small artificial pupils to open-loop the accommodation system," *Ophthalmic & Physiological Optics* **7**, 191-193 (1987).

[21]L. R. Dalton, "Organic Electro-Optic Materials," *Pure and Applied Chemistry* **76**, 1421-33 (2004). ■

Touch the Future: Projected-Capacitive Touch Screens Reach for New Markets

Spurred by successful implementation in devices such as the Apple iPhone and the LG Prada phone, projective-capacitive touch screens seem poised for mass adoption in various applications. Here is an overview of the technology and how to decide which type of projective-capacitance touch screen to use in your product.

by John Feland

THE LAUNCH of the LG Prada phone in March 2007 [Fig. 1(a)], followed by the Apple iPhone in June 2007, iPod Touch in September 2007, and the Samsung Yepp YP-P2 in October 2007 [(Fig. 1(b)], signaled to the world that transparent projected-capacitive touch screens are ready for mass adoption. Prior to 2007, transparent projected-capacitive was a niche technology with little impact.

Total worldwide sales of projected-capacitive touch screens in 2006 were estimated to be less than $20 million; sales in 2008 could be five times that, as several varieties of this technology make their way into various platforms, and consumer-electronics companies use it to transform the end-user experience across multiple markets.

As companies seek to leverage this maturing technology in their products, several questions arise, such as which type of projected-capacitive sensor is right for my application? What is the trade-off between glass and PET substrates? These and other questions will be addressed below.

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Capacitive Touch Screens

Two main types of touch screens use capacitive sensing as the main input method: surface-capacitive and projected-capacitive. Surface-capacitive touch screens use a sheet of indium tin oxide (ITO) with at least four electrodes around the periphery. These electrodes sense the change in the surface capacitance when a grounded object, such as a finger, approaches. This method has been used for kiosk touch screens for quite a while, with 3M Micro-Touch being one of the major suppliers of such technology.

However, there are some limitations to surface-capacitive touch screens. They can only recognize one finger or touch at a time.

(a) (b)

***Fig. 1:** The LG Prada phone (a) and the Samsung Yepp YP-P2 media player (b) are two of the first consumer-electronics products to use projected-capacitive touch screens.*

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Also, given the electrode size, small screen sizes such as those used on handheld platforms are impractical.

Projected-capacitive touch screens are named for the electrostatic field lines these sensors project from their electrodes. There are two types of commonly used projective-capacitive sensing technology: self-capacitive and mutual-capacitive.

The most widely used method, self-capacitive (also called "absolute capacitive"), uses the object being sensed as the other plate in a capacitor. This object is sensed typically by driving a charge between the sensing electrode and the sensed object, and then measuring the charge stored in the resulting capacitive coupling. Figure 2 illustrates how this principle works.

Mutual-capacitive (also called "transcapacitive") sets up a capacitive coupling between neighboring electrodes. When the sensed object approaches the field lines projected from one electrode to another, the change in the mutual-capacitance is sensed and reported as position. Mutual-capacitance sensors have been used extensively as conductivity sensors for oil conditioning in automotive applications.

Millions of self-capacitive solutions are used by people every day for position sensing, namely, the touchpad that is ubiquitous on today's notebook computer. The typical notebook touchpad uses an array of X and Y sensing electrodes to form a sensing grid. When a finger approaches the touchpad, the electrodes push a small amount of charge between that finger and the sensor electrodes. Algorithms then process the signals from this row-column sensor to resolve the location of the sensed object, in this case a finger.

In both types of projected-capacitive sensing, the sensor electrodes can be designed in a fashion so as to be able to detect more than one finger on the sensor at any given time.

The basic theory of operation for opaque projected-capacitive sensing on devices such as touchpads and projected-capacitive touch screens is the same; the differences lie in the sensor electrode materials, sensor substrates, manufacturing methods, and many other items in the solution stack. Touchpads can be made of opaque materials and use metallic or carbon-based electrodes in the sensing area. Projected-capacitive touch screens must be transparent and therefore are often made with the same transparent conductor found on resistive touch screens, *i.e.*, ITO.

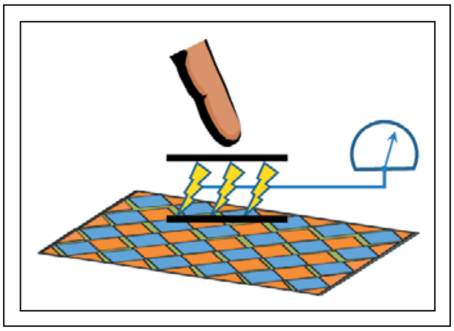

Fig. 2: *This illustrates how self-capacitive touch screens work.*

However, unlike resistive touch screens, projected-capacitive touch screens do not require an air gap between layers or the ability to deform any of the layers; hence, a sensor can use rigid glass or a PET substrate. Another key difference between the construction of projected-capacitive and resistive touch screens is the requirement for the ITO to be patterned on the former rather than deposited in a continuous film as in the latter. This extra complexity is well worth the trouble, given the benefits in using projected-capacitive touch screens.

Synaptics, for example, uses a patented diamond pattern on the multiple layers of its ClearPad sensor. The sensors in the X-axis form one layer, the sensors in the Y-axis another layer, then a ground or shield layer rounds off the stack-up, as shown in Fig. 3.

There is no clear choice between glass and PET substrates. Both can be laminated to a plastic or glass lens (screen cover), depending on the OEM's product design. Glass tends to be a bit thicker, heavier, and more expensive but offers greater overall stiffness, potentially reducing some costs elsewhere in the device. Glass has higher transmissivity than PET, though both are superior to resistive touch screens of the same size. PET sensors are thinner and easier to laminate to the product lens (because laminating a flexible material to a rigid material is easier than laminating two rigid surfaces). Both glass and PET substrates can be used to manufacture self-capacitive and mutual-capacitive touch screens, since the manufacturing methods are very similar.

Most sensor suppliers utilize a continuous batch sputtering process to etch the ITO pattern onto the substrate.

3M MicroTouch announced in 2007 the availability of a roll-to-roll method of manufacturing projected-capacitive sensors. In the past, etching such a pattern, though clear, caused a difference in the reflectance of the surface of the touch screen, causing the pattern to be visible as light played across the surface. Recent advances in reflectance matching have rendered the sensor pattern all but invisible.

While surface-capacitive touch screens have practical limitations on how small they can be produced, projected-capacitive touch screens have limitations on their maximum size.

The sensor electrodes have to be close enough so that the finger can affect the field lines of at least two electrodes to interpolate the position of the finger. As such, the number of sensor electrodes needed increases geometrically as the screen size increases. As projected-capacitive touch screens increase in size, the number of sensor electrodes that need to be routed back to the controller increases rapidly, forcing the inactive border of the sensor to increase as well. There are a few tricks to create larger projected-capacitive touch screens, but none of these schemes have been tested as a real product as of yet.

Controllers Are the Key

Without a controller, a sensor is just an inert piece of glass or PET. Compared to the broad proliferation and integration of resistive touch-screen controllers in everything from application processors to MP3-decoding chips, projected-capacitive touch screens still require specialized silicon to drive the sensors and decode the position of the finger or fingers on the screen.

The approach that Synaptics takes in the ClearPad modules on the market today uses the self-capacitance technique, borrowed from the millions of notebook touchpads already in service. The sensing scheme used by the Synaptics controller polls each sensor trace on the X-axis and then each sensor trace on the Y-axis, looking for the maximum capacitance point on each axis. This technique provides good rejection of unison noise such as changes in moisture, temperature, or even an external noise source such as 60-Hz line noise.

Apple uses the mutual-capacitance technique for the iPhone and iPod touch screens. The sensing scheme used by the Apple/Broadcom controller excites each line on the Y-axis one at a time. For each Y-axis line, the con-

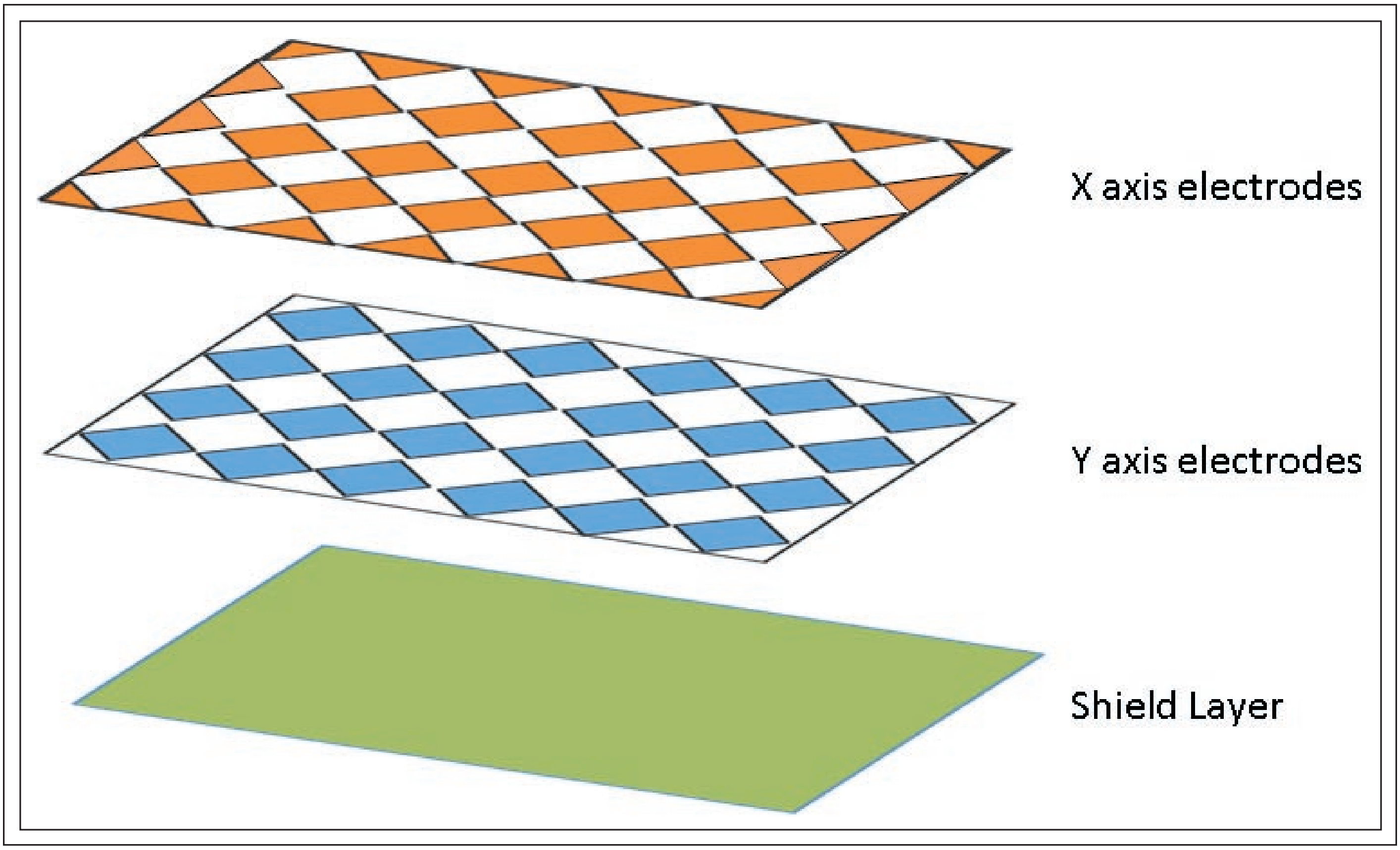

Fig. 3: *Synaptics's patented diamond pattern used on its ClearPad sensor.*

troller measures the capacitance at the intersection of that line with each X-axis line. The result is an "image" of whatever is touching the surface at each of ~700 X–Y intersections. However, this technique is very sensitive to environmental noise, much more so than the self-capacitive technique. Since none of the other controller suppliers listed above are in any shipping products yet, it's unknown what technique they use.

Rich Palette of Gestures

The feature that is driving the adoption of projected-capacitive touch screens in general is the rich palette of gestures now possible. The user-experience and user-interface designers on many OEMs' product-development teams are hungry for this new capability. The use of intuitive gestures holds tremendous promise in reducing the complexity of today's consumer devices.

One question that's often asked is where should the processing of gestures take place? Gestures can be processed and decoded in four places: in the touch-creen controller, in a separate CPU or DPS, within the touch-screen driver on the host CPU, or in the application that's running on the host CPU. As in the "glass *vs.* PET substrate" question, there is no single correct answer – each architecture has tradeoffs. In the Apple iPhone, the touch-screen silicon consists of two separate chips: a Broadcom analog controller that processes the raw analog signals from the sensor and converts them into a digital data stream of multiple X and Y points, and an NXP (Philips) ARM-7 CPU that decodes the digital data stream into gestures. In the Apple iPod Touch, these two pieces of silicon are combined into a single, second-generation Broadcom chip that includes both analog and digital cores. One reason that Apple chose to process the gestures on a separate CPU (rather than the host CPU) was to ensure the fastest possible response to gestures. The iPhone includes a total of five or six separate ARM cores; it's clear that the overall product architecture is that of distributed computing.

Synaptics used a different approach in the Samsung Yepp YP-P2 media player. With much simpler functionality than a smartphone, a media player generally only has one CPU, which limits the range of possible gesture-processing choices. The Samsung Yepp YP-P2 media player uses Synaptics ChiralMotion™ gesture as the main method of searching through the various applications. (ChiralMotion is an intelligent virtual-scrolling gesture that allows the user to control the direction and speed of scrolling by varying the speed and radius of arcs through which he moves his finger.) The touch-screen controller outputs a digital data stream of single X and Y points from the touch screen. The recognition of the ChiralGesture takes place in the touch-screen driver running on the host CPU. The driver notifies the UI application of the user's intent, so that the UI application can allow the user to "tunnel" through the other applications on the player for a nice blend of eye-candy and ease-of-use.

Conclusion

Projected-capacitive touch screens are one of the most promising interaction methods for tomorrow's handheld devices. Thinner, more robust, and optically clearer than resistive, supporting the use of multiple-finger gestures, and pushing the industrial design envelope, this next generation of touch screens is likely to see a broad adoption. Already the portfolio of available options (self-capacitive, mutual-capacitive, under glass, under flat or curved plastic, *etc.*) is giving OEMs tremendous flexibility in how they integrate this maturing technology.

Already we are seeing numerous experiments as to how handheld device manufacturers are using projected-capacitive solutions to differentiate not only their design, but also the user's experience. We expect to see more of these devices in the market soon with successful product launches. ■

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Edited by Aris Silzars

A novel driving method and device to reduce color breakup in color-sequential displays

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Abstract — Color-sequential displays offer a better luminous efficiency, a higher spatial resolution, and a lower cost than conventional displays. However, a common problem is that visual effects cause color edge-blurring of a moving picture, a phenomenon called color breakup or rainbow effects. Most driving methods, such as increasing the frame rate and inserting a black/white frame or another color sub-frame to reduce the color breakup in color-sequential displays, has been presented in many papers, but every method has some limitations and problems. An innovative driving method and device to reduce the color-breakup phenomenon will be demonstrated in this paper, designed without increasing the driving frequency. Instead, the brightness is increased by one third at the very least. This method divides the driving frequency into four sub-frames (WRGB), which is operated at 180 Hz compared to 240 Hz for conventional driving. Our result shows that the image quality is improved. The color-breakup simulation based on "eye trace integration" and compensated white light will also be presented in this paper.

The gray level of the white sub-frames was obtained from subtracting the minimum value of the three sub-frames, as was indicated in Fig. 13. The best driving method to reduce the color breakup was found to be WRGB. The color breakup has been reduced by decreasing the backlight ratio, increasing the driving frequency, and inserting a black frame and a white frame. The WRGB driving method shows the weakest color-breakup phenomenon in the white test pattern and offers higher brightness compared to RGBKKK.

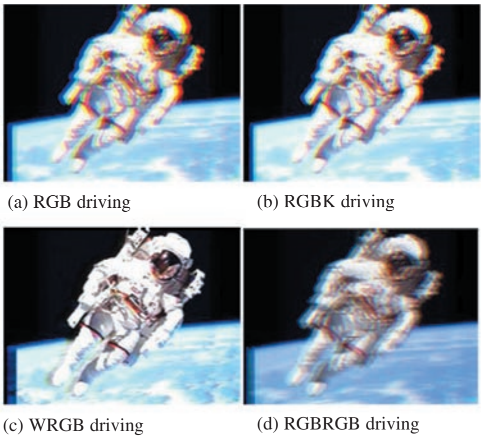

FIGURE 13 — Compared with different driving frequency and inserting color frame $v = 12$ ppf, BL ratio = 1. (a) RGB driving, (b) RGBK driving, (c) WRGB driving, and (d) RGBRGB driving.

Evaluation of thin-film photodevices and application to an artificial retina

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Abstract — First, conventional poly-Si thin-film photodevices, *p–i–n* thin-film photodiodes (TFPDs), and *p–n* TFPDs were evaluated. It was found that the photo-induced current (I_{photo}) is not simultaneously relatively high and independent of the applied voltage (V_{apply}). Next, a novel poly-Si thin-film photodevice, *p–i–n* thin-film phototransistor (TFPT), is proposed. It is found that the I_{photo} is simultaneously relatively high and independent of V_{apply} because the depletion layer is formed in the entire intrinsic region and the electric field is always high. These characteristics are preferable for photosensor applications. Finally, the *p–i–n* TFPT was applied to an artificial retina. The photo-illuminance profile is correctly detected and the output voltage profile is correspondingly outputted. This artificial retina is expected to be suitable for human beings because it can potentially be fabricated on a flexible, harmless, plastic, and organic substrate.

The circuit configurations, planar photographs, and characteristics of the artificial retina are shown in Fig. 5. The retina pixel is based on an elementary current mirror, but some improvements are added by considering the device characteristics of the *p–i–n* TFPT and the poly-Si TFT and operation of the artificial retina. The part for the current mirror consists of two *p*-type poly-Si TFTs, and the part for the load resistance consists of two *n*-type poly-Si TFTs.

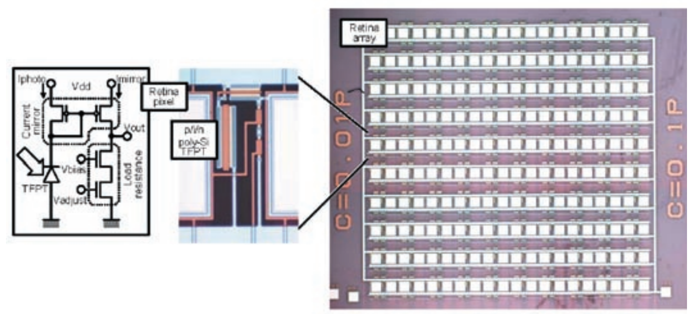

FIGURE 5 — Artificial retina.

Bistable SmA liquid-crystal display driven by a two-direction electric field

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Eva Korblova
David Walba
Noel A. Clark
Wei Lee

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Abstract — A new operation mode of a bistable smectic A (SmA) display using two sets of electrodes, one without specific features to induce homeotropic orientation of the director and the other with an in-plane pattern to induce planar orientation of the director, has been demonstrated. Both statements of the director orientation are the stable states of SmA liquid crystals. Compared with the electrical addressing mode of a conventional SmA display, the SmA display mode presented in this study exhibits a high contrast ratio, excellent bistability, and reasonably fast switching under the employment of two crossed polarizers. Moreover, gray level can be achieved by regulating the frequency, owing to the formation of the focal-conic defect. This operation mode of a bistable SmA device demonstrated great potential for further application in flexible displays.

To exemplify the bitsability of a SmA LC cell, a striped electrode pattern on the bottom substrate is adopted. In these cells, the alignment layer favors homeotropic orientation, so the dark state appears initially, as can be seen in Fig. 9(a). By applying a horizontal electric field on the striped electrodes, the LC molecules are then switched from the homeotropic to planar texture between two striped electrodes in the S2 cell, as shown in Fig. 9(b). The bright state remains stable after turning the voltage off [Fig. 9(c)].

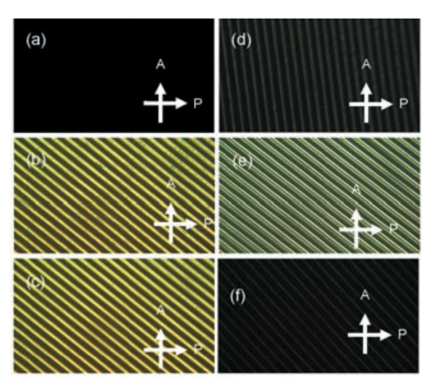

FIGURE 9 — Microscopic observation of an S2 striped cell with homeotropic alignment layers and a cell gap of 3.0 μm. (a) The dark state arises from the homeotropic alignment and crossed polarizers. (b) The bright state appears after applying an in-plane voltage of 100 V with a 1-kHz square waveform on the striped electrodes and (c) then turning the field off. The LC director now lies in the cell plane at 45° with respect to the transmission axis of either polarizer. (d) The planar texture is confirmed by rotating the cell to make the LC director parallel to the transmission axis. (e) The dark state appears after applying the normal-to-the-plane voltage of 100 V at 1 kHz and (f) then turning the field off.

Temperature instability of low-temperature deposited a-Si:H TFTs fabricated on plastic substrate

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Abstract — Low-temperature deposited a-Si:H TFTs have been successfully fabricated on colorless polyimide (CPI) substrate for flexible-display applications. A serious degradation in threshold voltage was observed after applying external thermal stress. The threshold-voltage shift saturates after applying several thermal stress cycles. In addition, the TFTs show instability under long periods of thermal stress with fixed temperature. This phenomenon was composed of thermally induced traps and substrate-expansion-induced mechanical stress. Finally, the a-Si:H TFT backplane fabricated on a PI substrate at low temperature has been successfully demonstrated for flexible AMLCDs.

Figure 12 shows the relationship between the bending direction and V_{th} shift. The V_{th} shift has great directional property under mechanical stress. A larger V_{th} shift is observed when the bending direction is perpendicular to the channel length. Thermal-induced substrate expansion will also induce mechanical stress on a-Si:H TFTs. This biaxial expansion will induce stress in both directions perpendicular and parallel to the channel direction. The expansion in the channel width, just like the bandwidth in the perpendicular direction, results in a very large V_{th} shift. This explains why V_{th} degrades more in larger channel widths under long periods of thermal stress.

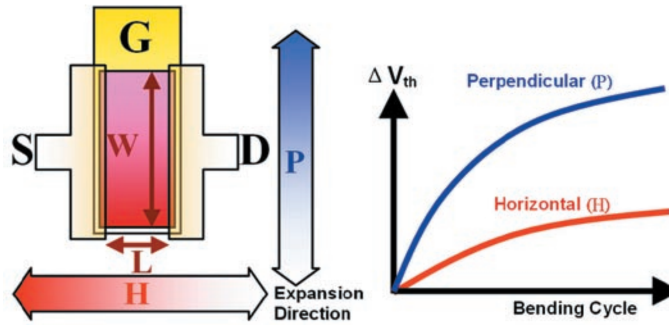

FIGURE 12 — Relationship between bending direction and threshold voltage shift.

Energy-transfer dynamics of blue-phosphorescent iridium and rhodium complexes doped in fluorescent molecules

Isao Tanaka
Kazuyuki Shibata
Eiji Tokunaga
Shizuo Tokito

NHK

Abstract — The temperature-dependent photoluminescence features of polycarbonate thin films doped with blue-phosphorescent molecules, either bis[(4,6-difluorophenyl)-pyridinato-N,$C^{2'}$] (picolinate) iridium (FIrpic) or bis(2-phenylpyridinato-N,$C^{2'}$) (acetylacetonate) rhodium [$(ppy)_2Rh(acac)$], which have an equivalent triplet energy of 2.64 eV, have been studied. The photoluminescence intensity of the FIrpic-doped polycarbonate thin film did not show any dependence on temperature. On the other hand, as for the $(ppy)_2Rh(acac)$-doped polycarbonate thin film, decreasing photoluminescence intensity with increasing temperature (especially above 100K) was clearly visible. These results reflect that the internal heavy-atom effect of $(ppy)_2Rh(acac)$ is weaker than that of FIrpic. Furthermore, the steady-state and time-resolved photoluminescence spectra of tris(8-hydroxyquinoline) aluminum (Alq_3) thin films heavily doped with FIrpic or $(ppy)_2Rh(acac)$ (50 wt.%) at 8K was studied. It was found that the enhanced phosphorescence from Alq_3 is mainly due not to the external heavy-atom effect by doping with the phosphorescent molecule but to the exothermic triplet energy transfer from the phosphorescent molecule to Alq_3.

The energy-transfer and light-emission mechanisms are discussed hereafter. Figure 6 shows the schematic energy-level alignment of the lowest singlet-excited (S_1) states, the T_1 states, and the singlet-ground (S_0) states in Alq_3, FIrpic, and $(ppy)_2Rh(acac)$. After photoexcitation, both the S_1 states in Alq_3 and the S_1 states in FIrpic or $(ppy)_2Rh(acac)$ are generated. The prompt fluorescence emission from Alq_3 consequently occurs. Moreover, delayed fluorescence with a longer lifetime should be considered. For FIrpic and $(ppy)_2Rh(acac)$, the rapid ISC from the S_1 states to the T_1 states might occur because of strong spin-or-bit coupling.

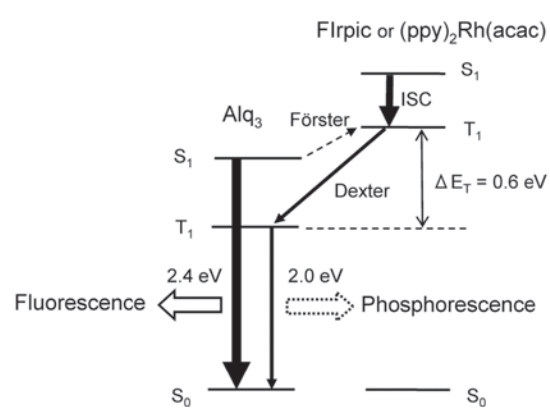

FIGURE 6 — Schematic energy-level alignment of singlet-excited state (S_1), triplet-excited states (T_1), and singlet-ground states (S_0) in Alq_3 and FIrpic, and $(ppy)_2Rh(acac)$. The energy-transfer and light-emission processes are is shown by the arrows.

Energy-recycling high-contrast organic light-emitting devices

Chih-Jen Yang
Ting-Yi Cho
Chun-Liang Lin
Chung-Chih Wu

National Taiwan University

Abstract — It is reported that by integrating OLEDs with solar cells, ambient-light reflection as low as 1.4% (even superior to that achieved with polarizers) can be achieved without compromising the EL efficiency for high-contrast display applications. Furthermore, in such a configuration, the photon energies of both the incident ambient light and the portion of OLED emission not getting outside of the device can be recycled into useful electrical power via the photovoltaic action, instead of being wasted as in other reported contrast-enhancement techniques. These features shall make this present technique attractive for high-contrast display applications and portable/mobile electronics that are highly power-aware.

Photos in Fig. 3 show the appearance of a low-reflection [OLED plus solar cell] stack (with one OLED on and others off) and a highly reflective bottom-emitting OLED under strong ambient illumination. For the present [OLED plus solar cell] stack, the high contrast between the off pixel (which is almost completely black) and the on pixel is clearly seen without using any contrast-enhancement films.

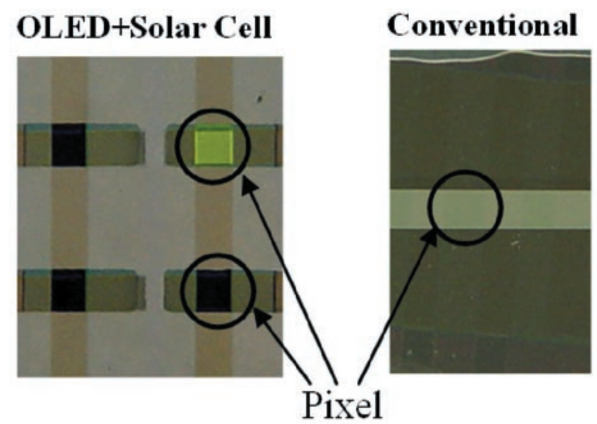

FIGURE 3 — Color photos of the [OLED plus solar cell] stack and the conventional bottom-emitting OLED.

Performance of liquid-crystal displays for fire-service thermal-imaging cameras

Joshua B. Dinaburg
Francine Amon
Anthony Hamins
Paul Boynton

Hughes Associates, Inc.

Abstract — As use of handheld thermal-imaging cameras (TICs) becomes more prevalent in the first-responder community, it is important that standard test metrics be available to characterize imaging performance. A key performance consideration is the quality of the image presented on the TIC display. This paper focuses on TICs that use liquid-crystal displays to render an image for the user. Current research on TIC performance for first-responder applications makes use of trained observers and/or composite-video-output-signal measurements. Trained observer tests are subjective and composite video output tests do not evaluate the performance of the complete imaging system. A non-destructive objective method was developed that tests the performance of the entire thermal-imaging system, from the infrared sensor to the display. A thermal target was used to correlate the measured thermal imager composite video output signal with the luminance of the display. A well-characterized charge-coupled-device (CCD) camera and digital recording device were used to measure the display luminance. An electro-optical transfer function was determined that directly relates the composite video output signal to the luminance of the display, providing a realistic characterization of system performance.

The measured display performance of three TICs are shown in Fig. 5. Th eerror bars represent the standard deviation from many identical experiments. It was clear that the three TICs subjected to this test do not exhibit similar display characteristics. Therefore, any test measuring only the NTSC output signal will not accurately describe the quality of the TICs relative to each other, highlighting the necessity of display testing. The vast differences in the character of the visual display of each TIC indicated that determining performance solely from data captured from the video output port may significantly mislead users about the actual TIC imaging quality.

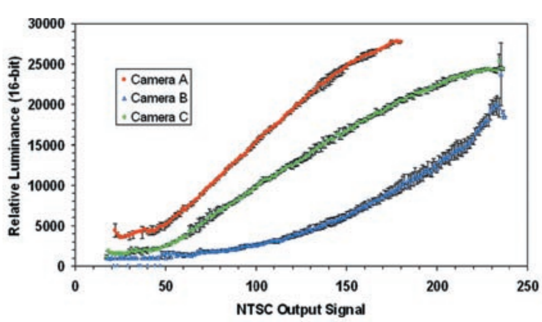

FIGURE 5 — Relative luminance as a function of 8-bit recorded NTSC output signal for three different TICs. The 16-bit relative luminance is measured in counts and the NTSC output signal is measured as an 8-bit pixel gray level.

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A preview of some of the most interesting papers appearing in the July 2008 issue of the *Journal of the SID.*

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Edited by Aris Silzars

Ga-doped zinc oxide: An attractive potential substitute for ITO, large-area coating, and control of electrical and optical properties on glass and polymer substrates

Tetsuya Yamamoto
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Aki Miyake
Hisao Makino
Naoki Yamamoto

Kochi University of Technology

Abstract — Ga-doped ZnO (GZO) films with thicknesses of 30–560 nm were prepared on glass substrates at 200°C by ion plating with direct-current arc discharge. The dependences of the characteristics of GZO films on thickness were investigated. All the polycrystalline GZO films, which showed high transmittance in the visible region, were ZnO crystallites with a wurtzite structure highly oriented along the (0002) plane. The resistivity, ρ, of GZO films decreases with increasing film thickness. The highest ρ achieved is 4.4×10^{-4} Ω-cm with a carrier concentration, n, of 7.6×10^{20} cm^{-3} and a Hall mobility, μ, of 18.5 cm^2/V-sec, determined by Hall effect measurement for the GZO films with a thickness of 30 nm, and the lowest ρ is 1.8×10^{-4} Ω-cm with $n = 1.1 \times 10^{21}$ cm^{-3} and $\mu = 31.7$ m^2/V-sec for the GZO film with a thickness of 560 nm. In addition, highly transparent GZO films with thicknesses of 12–300 nm were fabricated on unheated polymethyl methacrylate (PMMA). The ρ of these transparent GZO films decreased from 20 to 4×10^{-4} Ω-cm with film thickness.

Zinc oxide (ZnO) with a wurtzite structure is a versatile material with a wide band gap of 3.37 eV at room temperature. n-type ZnO thin films have, in recent years, been rediscovered as a subject of considerable research interest due to their unique physical properties [low resistivity of 2×10^{-4} Ω-cm, high visible transmittance (90%) and high infrared (IR) reflectance and absorbtance in the microwave region] and their wide range of possible electronic and optical applications. Special attention has been directed toward the blue-to-UV-wavelength LED because of the wide band gap of ZnO and the highly efficient ultraviolet photoluminescence.

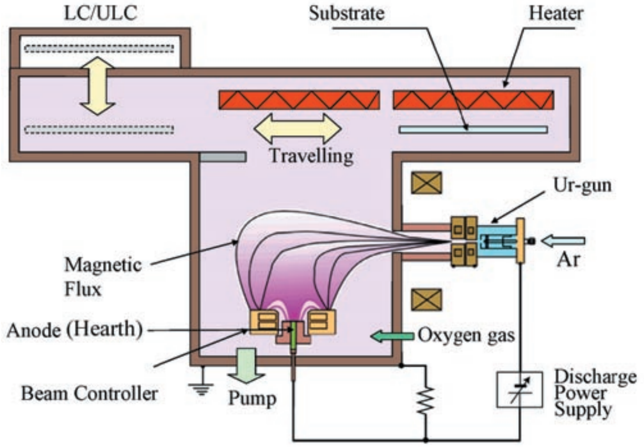

FIGURE 1 — Schematic diagram of ion plating by direct-current arc discharge with a traveling substrate.

Study on parasitic and channel resistance of poly-Si thin-film transistors by metal-induced crystallization

Saurabh Saxena
Jun Hyuk Cheon
G. P. Kennedy
Jung Ho Bae
Jin Jang

Kyung Hee University

Abstract — The channel-length-dependent transfer characteristics of TFTs using poly-Si by metal-induced crystallization through a cap (MICC) of a-Si to evaluate the parasitic and channel resistances have been studied. The MICC *p*-channel TFTs studied in the present work showed a maximum field-effect mobility, threshold voltage, and gate swing of 53 cm^2/V-sec, –4.4 V, and 0.8 V/dec for *W/L* = 12 μm/6 μm, 71 cm^2/V-sec, –5.3 V, and 0.9 V/dec for *W/L* = 12 μm/12 μm, and 113 cm^2/V-sec, –7 V, and 1 V/dec for *W/L* = 12 μm/24 μm, respectively. It is found that the parasitic resistance is higher than the channel resistance, and both decrease with increasing temperature.

304 stainless-steel foil, 150-μm-thick with a composition ratio of Fe/Cr/Ni: 72/18/10 wt.%, was used to fabricate the devices used here. The metal foil was polished by chemical mechanical polishing (CMP) before TFT fabrication. Then, a 1-μm-thick SiO_2 buffer layer was deposited on the front and back sides of the metal foil. A buffer layer improves the surface roughness of the metal foil and prevents the contamination from the metal foil during the heating and annealing processes. The poly-Si TFT was fabricated as a self-aligned coplanar structure on metal foil.

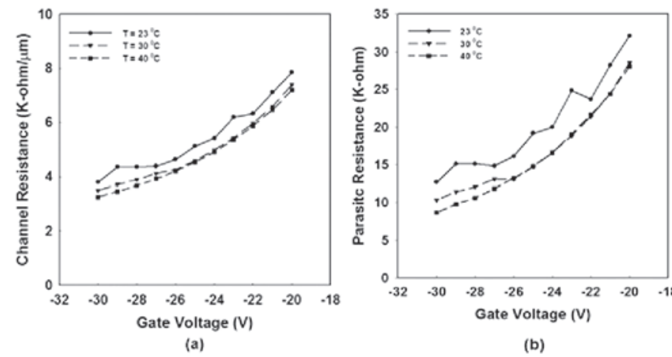

FIGURE 5 — (a) Channel and (b) parasitic resistance variation as a function of MICC TFT gate voltage and temperature.

A new a-Si:H TFT pixel circuit employing data-reflected negative-bias annealing for a stable and uniform AMOLED

Sang-Myeon Han
Hee-Sun Shin
Hyun-Sang Park
Min-Koo Han

Seoul National University

Abstract — A new a-Si:H pixel circuit to reduce the V_{TH} degradation of driving a-Si:H thin-film transistors (TFTs) by data-reflected negative-bias annealing (DRNBA) is presented. The new pixel circuit compensates V_{TH} variation induced by non-uniform degradation of each a-Si:H pixel due to various electrical stress. The proposed pixel circuit was verified by SPICE simulations. Although the V_{TH} of the driving a-Si:H TFT varies from 2.5 to 3.0 and 3.5 V, the organic light-emitting diode (OLED) current changes by only 1.5 and 2.8% in the emission period, respectively. During the negative-bias annealing period, the negative V_{GS} is applied to the driving TFT by using its own data signal. It is expected that the V_{TH} shift of the driving TFT can be effectively reduced and the V_{TH} shift can be compensated for in our new pixel circuit, which can contribute to a stable and uniform image from an a-Si:H TFT active-matrix OLED.

The proposed CDRNBA pixel circuit is composed of six a-Si:H TFTs and two capacitors as shown in Fig. 3. S1 is connected to the data line and the gate of the DTR and controlled by the S_n signal, which is the *n*th scan signal. S2, whose gate is connected to the S_{n-1} signal is the *n*–1-th scan signal and is connected to the V_{DD} line and the gate of the driving transistor (DTR). S3, controlled by the A signal, is connected to S1 and the source of DTR. S4 is connected to the gate of the DTR and V_{SS} and controlled by signal N. The OLED is connected to S5 and V_{SS}. The period of the OLED's emission is determined by S5 which is controlled by the emission signal and connected to the source of the DTR and OLED.

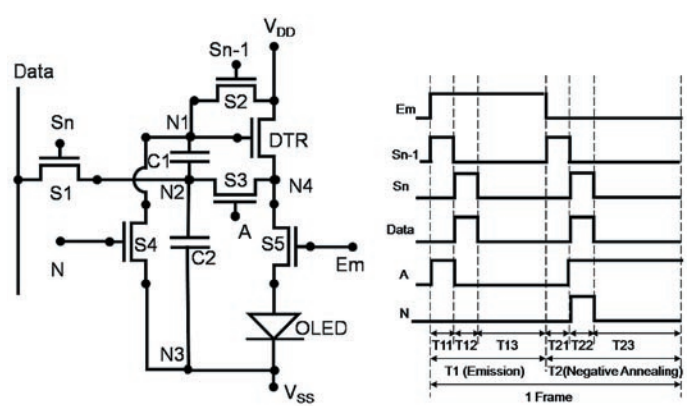

FIGURE 3 —The proposed CDRNBA a-Si:H pixel circuit for an AMOLED and the timing diagram. The DTR is a driving TFT.

Reduced dc offset and faster dynamic response in a carbon-nanotube-impregnated liquid-crystal display

Wei Lee
Hui-Yu Chen
Yu-Cheng Shih

Chung Yuan Christian University

Abstract — Liquid crystals have been extensively employed in photonic devices, especially in current flat-panel displays. Demands on high-quality electro-optical performance of liquid-crystal displays have continued to impel delicate molecular designs, chemical syntheses, as well as advanced cell-manufacturing processes, leading to a reduced dc offset and faster intrinsic response in the devices. Here, a novel approach toward the reduction of the residual dc and response time is reported based on carbon-nanotube doping. It is demonstrated that a minute amount of carbon nanotubes as a dopant can suppress the unwanted ion effect, invariably lower the rotational viscosity, and modify other physical properties of the liquid crystals, giving the approach an opportunity in display applications.

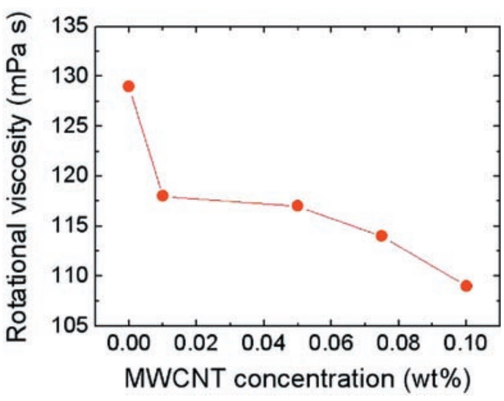

FIGURE 9 — Dopant-concentration dependence of E7's rotational viscosity at 35°C.

TABLE 2 — Optical decay times τ_d in planar-aligned E7 cells with various doping levels of CNTs at 30°C.

Concentration of MWCNTs (wt.%)	τ_d $(0 \rightarrow \pi)$ (msec)	τ_d $(0 \rightarrow 2\pi)$ (msec)	τ_d $(0 \rightarrow 3\pi)$ (msec)
0.00	5.7	19.6	53.0
0.01	5.7	19.6	48.5
0.05	5.7	19.6	43.2
0.10	10.5	66.9	120.8

Laser-based multi-user 3-D display

Phil Surman
Ian Sexton
Klaus Hopf
Wing Kai Lee
Frank Neumann
Edward Buckley
Graham Jones
Alex Corbett
Richard Bates
Sumanta Talukdar

De Monfort University

Abstract — The development of a multi-user stereoscopic display that does not require the use of special glasses (autostereoscopic), and enables a large degree of freedom of viewer movement and requires only the minimum amount of information (a stereo pair) for the displays described. The optics comprise an RGB holographic laser projector that is controlled by the output of a multi-target head-position head tracker, an optical assembly that converts the projector output into steerable exit pupils, and a screen assembly comprising a single liquid-crystal display (LCD) and image multiplexing screen. A stereo image pair is produced on the LCD by simultaneously displaying left and right images on alternate rows of pixels. Novel steering optics that replace the conventional backlight are used to direct viewing regions, referred to as exit pupils, to the appropriate viewers' eyes. The results obtained from the first version of the display, where the illumination source consists of several thousand white LEDs, are given and the current status of the latest prototype being constructed on the basis of these results is described. The work indicates that a laser-based head-tracking display can provide the basis for the next generation of 3-D display.

The prototype comprises a holographic projector, an array assembly, a screen assembly, and a multi-user head tracker. The array consists of two separate 49-element arrays, one for the left exit pupils and one for the right pupils. The prototype uses a large mirror that is constructed from surface-silvered acrylic sheet whose surface contour is formed by this being inserted into a pair of curved grooves. A mirror is used instead of a Fresnel lens in this application in order to prevent fringing effects between this lens and the Fresnel lenses located on the back surface of the array elements.

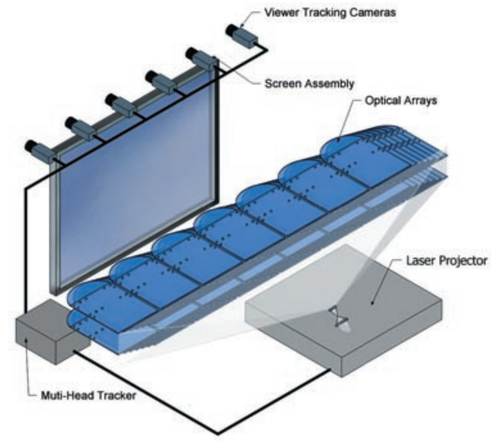

FIGURE 17 — MUTED prototype.

Development and application of less-mercury flat fluorescent lamps for backlights and general lighting

Horng-Show Koo
Chih-Hung James Chang
Nam-Kwon Cho
Jae-Hong Lee

Minghshin University of Science and Technology

Abstract — A novel flat discharge fluorescent lamp used as the light source of backlight modules for LCDs and general lighting systems has been researched and developed. This new type of lamp is a less-mercury flat fluorescent lamp with two-dimensional emission and superior to conventional one-dimensional cold-cathode fluorescent lamps in terms of optics, energy-savings, production efficiency, reliability, and chromatic performances. Physical characterization of the optics, temperature, mechanical design, thermal shocking, reliability, and corresponding environments have verified that flat fluorescent lamps will be the next-generation light sources for backlight modules and general lighting systems.

Test results show a more even distribution without the use of diffusers or enhancers for external electrode flat fluorescent lamps (EE-FFLs). Although new technologies may help to reduce the use of brightness enhancers and diffusers, EE-FFLs can provide similar results for brightness and distribution as shown in Fig. 4. The comparison of the lighting distribution shows that the EE-FFL (approx. 750 × 440 mm) provides a larger lighting area covered by the fluorescent lamps (approx. 1220 × 600 mm).

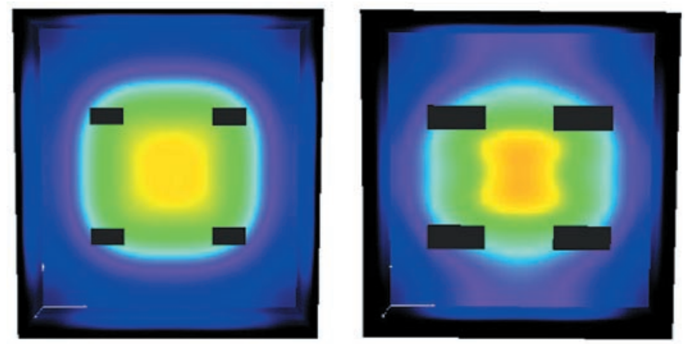

FIGURE 4 — Comparison of light distribution of flat fluorescent lamp (left) to standard fluorescent lamp (right).

Interconnecting drivers to flexible displays

Jonathan Govaerts
Bjorn Vandecasteele
Jan Vanfleteren

Ghent University

Abstract — Several options to interconnect driver chips to a flexible display are discussed and investigated. In the first option, bare test dies are flip-chip (FC) assembled onto polyethylene terephthalate (PET) display substrates. The second option involves test flexible polyimide (PI) substrates, imitating tape-carrier-packaged drivers (TCP), bonded onto the same PET substrates, whereas the third option uses actual TCPs on stainless-steel display substrates. Each option makes use of bonding technology with anisotropically conductive adhesive, supplied as film (ACF). The reason for using ACF is that drivers typically have high output counts, and therefore very fine pad features, 200-μm pitch and below. The technology has been adapted for each option, considering the requirements of the substrate. Every option includes an explanation of the bond test setup, the bonding process itself, and a discussion of the test results. The conclusion summarizes the achievements made in the research reported in this article.

The principle of assembly technology using ACF is shown in Fig. 1: the ACF is applied to the substrate, then the component is aligned and positioned and, finally, the assembly is cured under thermocompression. As the ACF, Hitachi AC8408Y was used. The conductive particles are gold-coated plastic spheres, approximately 5 μm in diameter. These are coated with a very thin insulation layer that has to be cracked open during the thermocompression step. The purpose of this insulator is to prevent lateral conduction due to clustering particles.

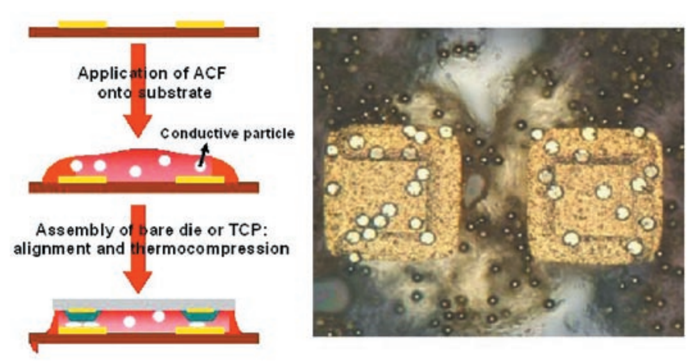

FIGURE 1 — Principle of assembly technology using ACF.

Silicon-nanocrystal-based photosensor integrated on low-temperature polysilicon panels

Wen-Jen Chiang
Chrong-Jung Lin
Ya-Chi n King
An-Thung Cho
Chia-Tien Peng
Chih-Wei Chao
Kun-Chih Lin
Feng-Yuan Gan

National Tsing Hua University

Abstract — A photodetector using a silicon-nanocrystal layer sandwiched between two electrodes is proposed and demonstrated on a glass substrate fabricated by low-temperature polysilicon (LTPS) technology. Through post excimer-laser annealing (ELA) of silicon-rich oxide films, silicon nanocrystals formed between the bottom metal and top indium thin oxide (ITO) layers exhibit good uniformity, reliable optical response, and tunable absorption spectrum. Due to the quantum confinement effect leading to enhanced phonon-assisted excitation, these silicon nanocrystals, less than 10 nm in diameter, promote electron–hole-pair generation in the photo-sensing region as a result resembling a direct-gap transition. The desired optical absorption spectrum can be obtained by determining the thickness and silicon concentration of the deposited silicon-rich oxide films as well as the power of post laser annealing. In addition to obtaining a photosensitivity comparable to that of the *p–i–n* photodiode currently used in LTPS technology, the silicon-nanocrystal-based photosensor provides an effective backlight shielding by the bottom electrode made of molybdenum (Mo). Having a higher temperature tolerance for both the dark current and optical responsibility and maximizing the photosensing area in a pixel circuit by adopting a stack structure, this novel photosensor can be a promising candidate for realizing an optical touch function on a LTPS panel.

The proposed silicon-nanocrystal-based photodetector is formed by post excimer-laser annealing (ELA) of silicon-rich oxide (SRO) layer deposited between the bottom metal and top ITO electrodes, as shown in Fig. 1. The transparent top ITO electrode available in the LTPS process allows for ambient light to penetrate and reach the photo-sensing region while the bottom metal layer made of molybdenum (Mo) is designed to shield the photo-sensing region from direct backlight illumination.

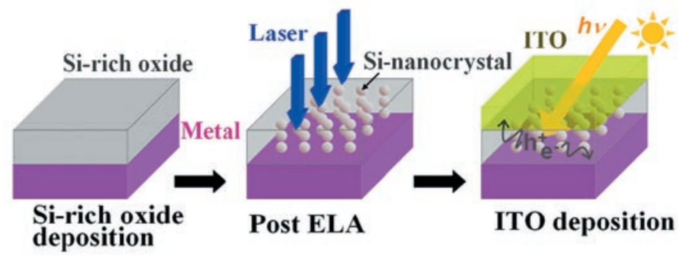

FIGURE 1 — Process step for forming a silicon nanocrystal layer on top of a metal electrode. The silicon-rich oxide film is first deposited by PECVD and then post annealed by ELA. Finally, the ITO electrode is deposited on the top of silicon-nanocrystal layer.

AMOLED panel driven by time-multiplexed clamped inverter circuit to reduce complex control signals

Chun-Ho Chen
Ke-Horng Chen
Che-Chin Chen
Yi-Fu Chen
Han-Ping D. Shieh

National Chiao Tung University

Abstract — A time-multiplexing technique employing a pulse-width-modulation (PWM) charge-pump scheme for driving active-matrix organic light-emitting-diodes (AMOLEDs) is described. This scheme greatly reduces the number of control lines. The two- or four-phase PWM driving technique not only reduces costs through the simplification of manufacture but also improves the uniformity and lifetime of OLED panels. Experimental results show that the proposed circuit effectively and precisely controls the timing of OLED data-writing and light emission.

In order to implement the time-multiplexing technique in the OLED-display system, we propose a novel pixel circuit shown in Fig. 4. In Fig. 4, transistors M_{P1} and M_{P2} are used to alternatively control the upper and lower OLED panels by the time-multiplexing technique. In other words, writing and illuminating periods are exchanged between the upper and lower parts to obtain the following advantages. First, the synchronization of two individual PWM control signals is controlled by one global PWM control signal. Second, when one block is in the writing mode, the other block is in the illuminating mode.

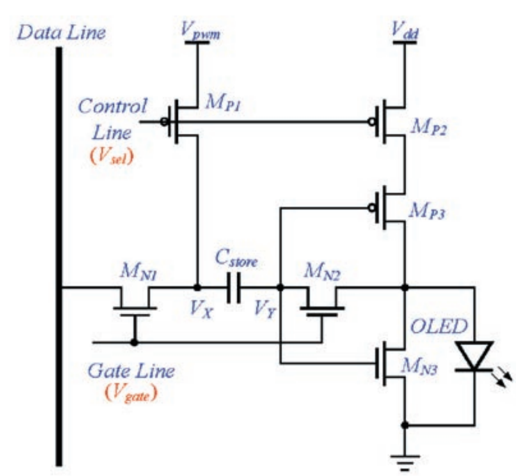

FIGURE 4 — The pixel-driving-circuit design using the charge-pump technique.

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on

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The *Journal of the SID* is planning a Special Section on 3-D Display Technologies to be published during the second quarter of 2008. **We are soliciting original contributed papers describing advances in a wide variety of designs, structures and components, for 3-D Display Technologies.** Suggested topical areas include:

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The **Guest Editor** for this Special Section dedicated to 3-D Display Technologies is **Adi Abileah** from Planar Systems, Inc., Beaverton, OR, USA.

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All inquiries should be addressed to **Adi Abileah at Adi.Abileah@planar.com.**

SID
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editorial

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far away from mass-market appeal as some might think.

I also want to tell you about another exciting mid-year development related to the website for *Information Display* magazine (www.informationdisplay.org). In May, we launched our Display Industry Forum, which I hope will grow into a valuable destination for our industry. The goal for this forum is to be the go-to space online for members of the display community to discuss the latest news, technology, and anything else affecting the industry – so bookmark the page, comment on existing posts, or start your own discussions! At the same time, we also launched our blog page, right before Display Week began. This became the destination for all our on-the-scene news from LA this year written by Michael Morgenthal and others. We hope to re-launch this feature in the next few months with several authors who will contribute regularly to the blog on important aspects of the industry. We welcome your feedback and suggestions for potential topics and authors.

There is no question today that many people get their news and contribute their views online, making major impacts on the industry at truly digital light speed. The display community is no different and we're working hard to fulfill that expectation at *ID* Online. At *ID*, we're committed to providing both the best in print information and the best in online content and features as well. Be sure to visit the site every day – after all, the site will only be as good as those who use it. And enjoy the rest of your summer. There's lots to do and it promises to be a busy second half of the year for the display world!

Stephen P. Atwood

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president's corner

continued from page 6

specially engineered for computers designed for emerging economies – all these capabilities offer new potential for designers to add even greater functionality, and impact more people, on a worldwide basis.

Given the vast size of the electronic-display industry, its products and practices leave a significant footprint on the world. Many companies now recognize that *Going Green* is both a good way to show responsibility, and that it's good for business. I plan on discussing green technologies in a future column, but suffice it to say that many companies now recognize that using green technologies, and making their products energy efficient, offers them a competitive advantage that can drive growth with good margins. People may look back and see that Display Week 2008 marked the beginning of the major trend of technologies developed and marketed specifically for their environmental friendliness; I expect green to be the color of choice for SID meetings for many years to come.

Finally, *Prosperity* is the lifeblood of the industry, and we're fortunate to be in an industry that is still growing at a healthy pace. I spoke to a number of people during the week from all areas of the electronic-display industry. Many business leaders told me that their companies are coming off of a very good year. Researchers and engineers are finding that their talents are in strong demand, as companies strive to differentiate themselves from the intense competition. Sales and business-development staff on the exhibit floor were generally quite pleased with the amount of traffic. Many companies were delighted by their ability to show both the display community and assembled media that their products are best in class. This type of publicity builds buzz around a company and brand.

Time and again, I heard about the connections being made on the exhibit floor, during the symposium sessions, and in the various networking events. The face-to-face contact you get when bringing industry leaders together is almost magical in driving the next round of innovation and is a major aspect of the attraction of Display Week for SID.

So, it's a wrap, but I can't wait to see the next installment next year. See you in San Antonio!

Paul Drzaic
President
Society for Information Display

We are always interested in hearing from our readers. If you have an idea that would make for an interesting Business of Displays column or if you would like to submit your own column, please contact Aris Silzars at 425/898-9117 or email: silzars@attglobal.net.

SID 2009 honors and awards nominations

On behalf of the SID Honors and Awards Committee (H&AC), I am appealing for your active participation in the nomination of deserving individuals for the various SID honors and awards. The SID Board of Directors, based on recommendations made by the H&AC, grants all the awards. These awards include five major prizes awarded to individuals, not necessarily members of SID, based upon their outstanding achievements. The **Karl Ferdinand Braun prize** is awarded for ***"Outstanding Technical Achievement in, or contribution to, Display Technology."*** The prize is named in honor of the German physicist and Nobel Laureate Karl Ferdinand Braun who, in 1897, invented the cathode-rat tube (CRT). Scientific and technical achievements that cover either a wide range of display technologies or the fundamental principles of a specific technology are the prime reasons for awarding this prize to a nominee. The **Jan Rajchman prize** is awarded for ***"Outstanding Scientific and Technical Achievement or Research in the Field of Flat-Panel Displays."*** This prize is specifically dedicated to those individuals who have made major contributions to one of the flat-panel-display technologies or, through their research activities, have advanced the state of understanding of one of those technologies. The **Otto Schade prize** is awarded for ***"Outstanding Scientific or Technical Achievement in the Advancement of Functional Performance and/or Image Quality of Information Displays."*** This prize is named in honor of the pioneering RCA engineer Otto Schade, who invented the concept of the Modulation Transfer Function (MTF) and who used it to characterize the entire display system, including the human observer. The advancement for this prize may be achieved in any display technology or display system or may be of a more general or theoretical nature. The scope of eligible advancement is broadly envisioned to encompass the areas of display systems, display electronics, applied vision and display human factors, image processing, and display metrology. The nature of eligible advancements is not limited and may be in the form of theoretical or mathematical models, algorithms, software, hardware, or innovative methods of display-performance measurement, and image-quality characterization. Each of these above-mentioned prizes carries a $2000

SID honors and awards nominations

Nominations are now being solicited from SID members for candidates who qualify for SID Honors and Awards.

- KARL FERDINAND BRAUN PRIZE. Awarded for an outstanding *technical* achievement in, or contribution to, display technology.
- JAN RAJCHMAN PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, research on flat-panel displays.
- OTTO SCHADE PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, the advancement of functional performance and/or image quality of information displays.
- SLOTTOW–OWAKI PRIZE. Awarded for outstanding contributions to the education and training of students and professionals in the field of information display.
- LEWIS & BEATRICE WINNER AWARD. Awarded for exceptional and sustained service to SID.
- FELLOW. The membership grade of Fellow is one of unusual professional distinction and is conferred annually upon a SID member of outstanding qualifications and experience as a scientist or engineer in the field of information display who has made widely recognized and significant contribution to the advancement of the display field.
- SPECIAL RECOGNITION AWARDS. Presented to members of the technical, scientific, and business community (not necessarily SID members) for distinguished and valued contributions to the information-display field. These awards may be made for contributions in one or more of the following categories: (a) outstanding technical accomplishments; (b) outstanding contributions to the literature; (c) outstanding service to the Society; (d) outstanding entrepreneurial accomplishments; and (e) outstanding achievements in education.

Nominations for SID Honors and Awards must include the following information, preferably in the order given below. Nomination Templates and Samples are provided at *www.sid.org/awards/nomination.html.*

1. Name, Present Occupation, Business and Home Address, Phone and Fax Numbers, and SID Grade (Member or Fellow) of Nominee.

2. Award being recommended:
   Jan Rajchman Prize
   Karl Ferdinand Braun Prize
   Otto Schade Prize
   Slottow–Owaki Prize
   Lewis & Beatrice Winner Award
   Fellow*
   Special Recognition Award

   *Nominations for election to the Grade of Fellow must be supported in writing by at least five SID members.

3. Proposed Citation. This should not exceed 30 words.

4. Name, Address, Telephone Number, and SID Membership Grade of Nominator.

5. Education and Professional History of Candidate. Include college and/or university degrees, positions and responsibilities of each professional employment.

6. Professional Awards and Other Professional Society Affiliations and Grades of Membership.

7. Specific statement by the nominator concerning the most significant achievement or achievements or outstanding technical leadership that qualifies the candidate for the award. This is the most important consideration for the Honors and Awards committee, and it should be specific (citing references when necessary) and concise.

8. Supportive material. Cite evidence of technical achievements and creativity, such as patents and publications, or other evidence of success and peer recognition. Cite material that specifically supports the citation and statement in (7) above. (Note: the nominee may be asked by the nominator to supply information for his candidacy where this may be useful to establish or complete the list of qualifications).

9. Endorsements. Fellow nominations must be supported by the endorsements indicated in (2) above. Supportive letters of endorser will strengthen the nominations for any award.

E-mail the complete nomination – including all the above material by **October 10, 2008** – to cnelsonk@comcast.net or sidawards@sid.org or by regular mail to:
Christopher N. King, Honors and Awards Chairman, Society for Information Display,
1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008, U.S.A.

stipend sponsored by Thompson, Inc., Sharp Corporation, and Philips Consumer Electronics, respectively.

The **Slottow–Owaki prize** is awarded for ***"Outstanding Contributions to the Education and Training of Students and Professionals in the Field of Information Display."*** This prize is named in honor of Professor H. Gene Slottow, University of Illinois, an inventor of the plasma display and Professor Kenichi Owaki from the Hiroshima Institute of Technology and an early leader of the pioneering Fujitsu Plasma Display program. The oustanding education and training contributions recognized by this prize is not limited to those of a professor in a formal university, but may also include training given by researchers, engineers, and managers in industry who have done an outstanding job developing information-display professionals. The Slottow–Owaki prize carries a $2000 stipend made possible by a generous gift from Fujitsu, Ltd., and Professor Tsutae Shinoda.

The fifth major SID award, the **Lewis and Beatrice Winner Award,** is awarded for ***"Exceptional and Sustained Service to the Society."*** This award is granted exclusively to those who have worked hard over many years to further the goals of the Society.

The membership grade of **SID Fellow Award** is one of unusual professional distinction. Each year the SID Board of Directors elects a limited number (up to 0.1% of the membership in that year) of **SID members** in good standing to the grade of **Fellow.** To be eligible, candidates must have been members at the time of nomination for at least 5 years, with the last 3 years consecutive. A candidate for election to Fellow is a member with ***"Outstanding Qualifications and Experience as a Scientist or Engineer in the Field of Information Display who has made Widely Recognized and Significant Contributions to the Advancement of the Display Field"*** over a sustained period of time. SID members practicing in the field recognize the nominee's work as providing significant technical contributors to knowledge in their area(s) of expertise. For this reason, five endorsements from SID members are required to accompany each Fellow nomination. Each Fellow nomination is evaluated by the H&AC, based on a weighted set of five criteria. These criteria and their assigned weights are creativity and patents, 30%; technical accomplishments and publications, 30%; technical leadership, 20%; service to SID, 15%; and other accomplishments, 5%. When submitting a Fellow award nomination, please keep these criteria with their weights in mind.

The **Special Recognition Award** is given annually to a number of individuals (membership in the SID is not required) of the scientific and business community for distinguished and valued contribution in the information-display field. These awards are given for contributions in one or more of the following categories: (a) ***Outstanding Technical Accomplishments,*** (b) ***Outstanding Contributions to the Literature,*** (c) ***Outstanding Service to the Society,*** (d) ***Outstanding Entrepreneurial Accomplishments,*** and (e) ***Outstanding Achievements in Education.*** When evaluating the Special Recognition Award nominations, the H&AC uses a five-level rating scale in each of the above-listed five categories, and these categories have equal weight. Nominators should indicate the category in which a Special Recognition Award nomination is to be considered by the H&AC. More than one category may be indicated. The nomination should, of course, stress accomplishments in the category or categories selected by the nominator.

While an individual nominated for an award or election to Fellow may not submit his/her own nomination, nominators may, if necessary, ask a nominee for information that will be useful in preparing the nomination. The nomination process is relatively simple, but requires that the nominator and perhaps some colleagues devote a little time to preparation of the supporting material that the H&AC needs in order to evaluate each nomination for its merit. It is not necessary to submit a complete publication record with a nomination. Just list the titles of the most significant half a dozen or less papers and patents authored by the nominee, and list the total number of papers and patents he/she has authored.

Determination of the winners for SID honors and awards is a highly selective process. Last year less than 30% of the nominations were selected to receive awards. Some of the major prizes are not awarded every year due to the lack of sufficiently qualified nominees or, in some cases, because no nominations were submitted. On the other hand, once a nomination is submitted, it will stay active for three consecutive years and will be considered three times by the H&AC. The nominator of such a nomination may improve the chances of the nomination by submitting additional material for the second or third year that it is considered, but such changes are not required.

Descriptions of each award and the lists of previous award winners can be found at *www.sid.org/awards/indawards.html*. Nomination forms are available at *www.sid.org/awards/nomination.html* where you will find Nomination Templates in both MS Word (preferred) and Text formats. Please use the links to find the Sample Nominations, which are useful for composing your nomination since these are the actual successful nominations for some previous SID awards. Nominations should preferably be submitted by e-mail. However, you can also submit nominations by ordinary mail if necessary.

Please note that with each Fellow nomination, only five written endorsements by five SID members are required. These brief endorsements – *a minimum of 2–3 sentences* to a maximum of one-half page in length – *must state why clearly and succinctly, in the opinion of the endorser, the nominee deserves to be elected to a Fellow of the Society. Identical endorsements by two or more endorsers will be automatically rejected* (no form letters, please). Please send these endorsements to me either by e-mail (preferred) or by hardcopy to the address stated in the accompanying text box. Only the Fellow nominations are required to have these endorsements. However, I encourage you to submit at least a few endorsements for all nominations since they will frequently add further support to your nomination.

All 2009 award nominations are to be submitted by October 10, 2008. E-mail your nominations directly to cnelsonk@comcast.net or sidawards@sid.org. If that is not possible, then please send your hardcopy nomination by regular mail.

As I state each year: "In our professional lives, there are few greater rewards than recognition by our peers. For an individual in the field of displays, an award or prize from the SID, which represents her or his peers worldwide, is a most significant, happy, and satisfying experience. In addition, the overall reputation of the society depends on the individuals who are in its 'Hall of Fame.'

When you nominate someone for an award or prize, you are bringing happiness to an individual and his or her family and friends, and you are also benefiting the society as a whole."

Thank you for your nomination in advance.

– Christopher N. King
SID Honors & Awards Committee

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screens. When flexible displays break, they do not have any sharp edges that can cause injuries or further damage.

Mobile handsets were the leading application for flexible displays in terms of unit shipments in 2007. This application will remain a significant source of demand, but will not grow very fast, falling behind smart labels, electronic display cards, and other applications.

Flexible displays have been and will continue to be used for many applications such as e-readers/e-paper, electronic display cards, electronic shelf-labels, automotive applications, clothing/wearable, point-of-purchase/public signage and advertisements, removable storage devices, and other products. And as this technology becomes pervasive in society, expect to see numerous other products and innovations coming from current players and new players looking to cash in on the buzz from the technology.

2008: "Year One" for Flexible Active-Matrix Displays

Flexible displays entered consumers' daily lives long before Readius, with products such as Motorola, Inc.'s Motofone handset, electronic-card displays, and T-shirt displays. However, all of these were direct-drive or passive-matrix types of flexible displays. Until now, active-matrix flexible displays did not exist to provide the image quality that users expect from their LCD TVs and PC monitors.

But in 2008, this has changed. Prime View International (PVI), LG Displays (formerly LG.Philips LCD), and Plastic Logic all have announced that they will offer high-resolution flexible active-matrix displays in production by the second half of 2008. Therefore, 2008 represents "Year One" for flexible active-matrix displays, a major turning point for the industry.

Value-Chain Complexity

The value chain for flexible displays is more complex than glass-based displays. More than a dozen display technologies can be made into flexible screens, ranging from conventional LCDs and bistable LCDs to organic light-emitting-diode (OLED), electrophoretic, electrochromic, and electroluminescent (EL) displays. In addition, flexible displays can utilize several substrate materials, transparent conductors, and TFT material types.

In terms of unit shipments, electrophoretic displays will continue to be the leading type of flexible display for the next 5 years, after which they likely will be surpassed by electrochromic flexible-display shipments due to smart labels and other high-volume applications. However, electrophoretic flexible displays will lead in revenue for the foreseeable future, driven increasingly by high-value applications such as e-books. Flexible EL displays had the second highest revenues in 2007; applications include clothes and wearable, point-of-purchase/signage/advertisement, and mobile handsets. Flexible conventional LCDs and EL displays will follow electrophoretic displays in revenues over the next 5 years.

Plastic was the dominant substrate material for flexible displays in 2007, serving nearly all of the total substrate area. iSuppli forecasts that plastic substrates will continue to be the dominant material for flexible displays, with more than 94% of the market in 2013. Stainless-steel substrates will enter the market in 2008 with applications in active-matrix electrophoretic displays and later in active-matrix OLED displays and LCDs.

As mentioned earlier, the introduction of active-matrix flexible displays is a major turning point for the industry, and iSuppli forecasts that the revenue from active-matrix flexible displays will increase dramatically, reaching 74% of the total market value by 2013. An investment of several-hundred-million dollars has been made in flexible displays in the past couple of years and capacity is currently expanding. For example:

- Polymer Vision received $27 million in funding, a spin-off from Philips, in January 2007. "Readius" will be available to consumers in mid-2008.
- PVI has announced the mass production of flexible active-matrix electrophoretic displays in the second half of 2008.
- LG Displays has announced the mass production of flexible active-matrix electrophoretic displays in the second half of 2008.
- Plastic Logic received $100 million funding in January 2007 to build a manufacturing plant in Dresden, Germany (plus the support of the German government in terms of land) and will start production in the second half of 2008. The initial capacity will be more than 1 million display modules (equivalent of 10-in. on the diagonal) per year.
- Several roll-to-roll facilities have been or are being established.

In terms of form factor, iSuppli forecasts that truly bendable/flexible display unit shipments will increase to 26% of the total shipments in 2013, starting from 13% in 2007; the majority of "flexible" displays are expected to be used in a flat or formed configuration.

Conclusion

After years of R&D as well as a fair amount of dreaming, active-matrix flexible displays will finally be entering the commercial marketplace in 2008, sparking a huge growth in this segment as display manufacturers, OEMs, and consumers get more familiar with these types of devices during the next few years. Myriad technologies can be used to make flexible displays, meaning that there is likely to be some market shakeout to go along with the explosive growth.

Jennifer Colegrove *is the senior analyst for emerging display technologies at iSuppli Corp. and author of iSuppli's* Flexible Displays Report, Touch Screen Report, Low Power and Zero Power Display Report*, etc. She can be reached at iSuppli Corp., 2901 Tasman Dr., Suite 201, Santa Clara, CA 95054; telephone 408/654-1700, fax -1750, e-mail: jcolgrove@isuppli.com.*

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Dolby theaters) the left eye sees only the left image and the right eye only the right image.

Stereoscopic displays are the most ubiquitous "3-D" displays because they are the simplest to design, manufacture, and drive. In essence, they are two standard 2-D displays – one for the right eye and one for the left. However, this approach is limited in its ability to correctly re-create all of the depth cues present when viewing the real world.

In this special issue of *Information Display*, we feature four articles that discuss the limitations of stereoscopic displays, provide empirical data suggesting that they compromise performance at 3-D tasks and contribute to eye fatigue, and explore a number of holographic and volumetric display technologies that overcome these limitations.

In "Consequences of Incorrect Focus Cues in Stereo Displays," vision scientists Marty Banks and David Hoffman of UC Berkeley, engineer Kurt Akeley of Microsoft Research, and NYU neuroscientist Ahna R. Girshick discuss the physiology of the human visual system and the sensory conflicts arising from the incorrect focus cues present when viewing stereoscopic displays. They report empirical data gathered in studies of human subjects using a multi-planar volumetric display testbed that strongly support the contention that these sensory conflicts hinder performance of 3-D tasks and contribute to eye fatigue.

Holographic display technology offers the potential to reconstruct an accurate light field with accurate focus cues, but dynamic holography has been limited by the computational power and storage necessary to drive the displays. In "Refreshable Holographic 3-D Displays," Sava Tay of Stanford University and Nasser Peyghambarian of the University of Arizona describe an updateable holographic medium with memory, based on photorefractive polymers, that helps to overcome the storage challenge. In "A New Approach to Electro-Holography: Can This Move Holography into the Mainstream?" Hagen Stolle and Ralf Häussler of SeeReal Technologies describe a viewpoint-specific approach to digital holography which dramatically lowers the computational requirements to display high-resolution dynamic imagery.

Volumetric displays also can provide an accurate light field to viewers and can leverage existing 3-D graphics cards. In "Scanned Voxel Displays," co-authored by myself and colleague Eric Seibel at the University of Washington, we describe a viewpoint-specific volumetric display that can render correct focus cues for objects ranging from inches in front of the eyes to the distant horizon.

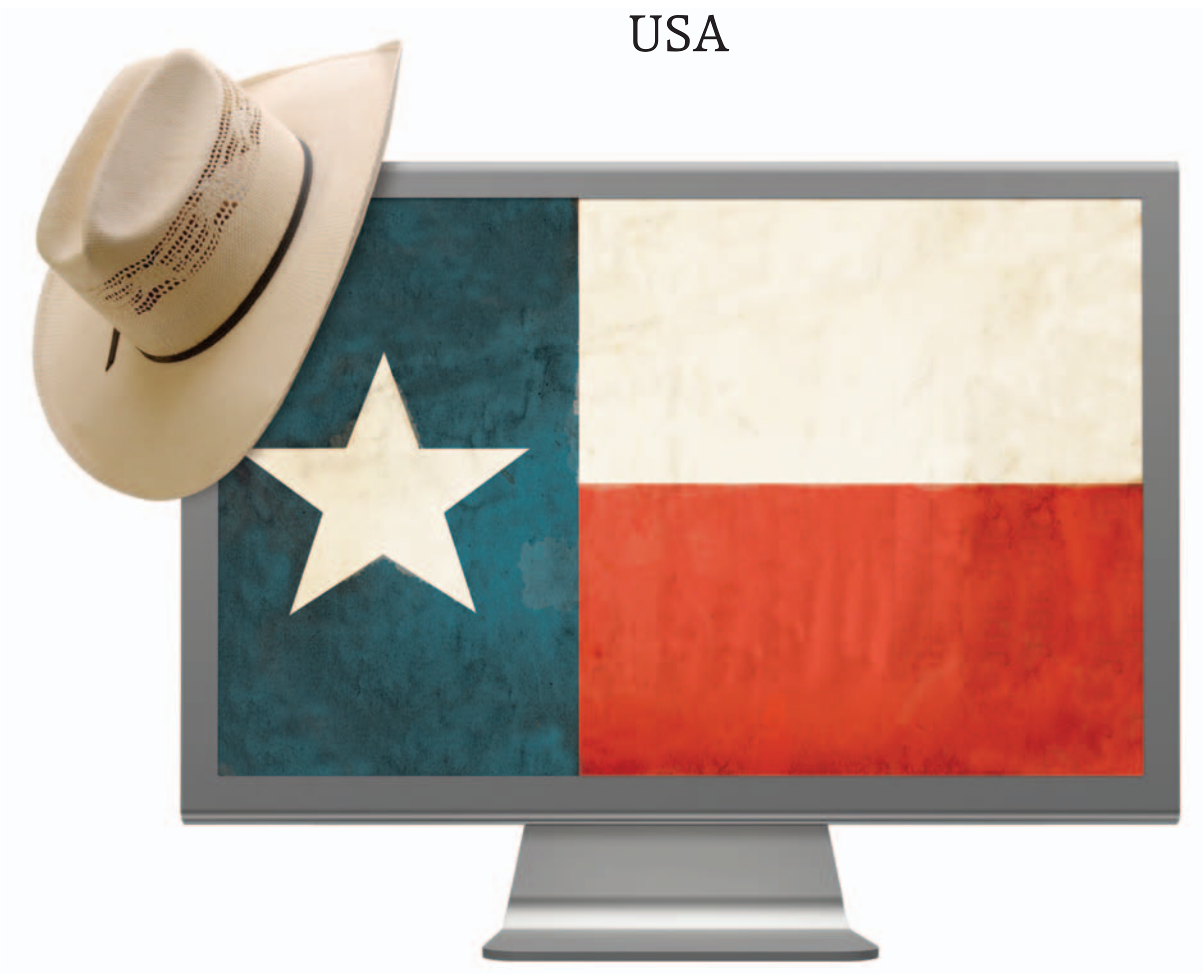
This is an exciting time to be working in 3-D. The broad adoption of today's stereo displays, coupled with the advances in holographic and volumetric displays, promises to herald a new age of 3-D display. As DreamWorks Animation CEO Jeffrey Katzenberg has proclaimed, 3-D is "the single most revolutionary change since color pictures."

Brian T. Schowengerdt *is with the Department of Mechanical Engineering and the Human Interface Technology Laboratory at the University of Washington, Box 352600, Seattle, WA 98195-2142; telephone 206/422-1927, e-mail: bschowen@u.washington.edu.*

Display Week 2009:

The SID International Symposium, Seminar & Exhibition

San Antonio Convention Center
San Antonio, Texas
USA



SID

DISPLAY WEEK

San Antonio, Texas · May 31-June 5, 2009 · www.sid2009.org

In addition to the International Conferences and Meetings to the right, SID is also sponsoring the following Regional and Topical Meetings:

13 MARCH 08

SID-ME Mid-Europe Chapter Spring Meeting 2008

MARCH 13–14, 2008
Jena, Germany

Topical sessions include:

- Microdisplay Applications
- Light Sources
- Optics: Design & Fabrication
- OLED Microdisplays

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23 SEPTEMBER 08

SID Mobile Displays 2008

SEPTEMBER 23–24, 2008
San Diego, California, USA

Topics include:

- Mobile-phone product design
- Other handheld mobile system designers
- Small display makers
- Driver chips for mobile displays
- Display component makers including backlights, optical enhancement films, polarizers, and drivers
- Wireless service providers
- Power management
- Graphics and display system architecture
- Materials and components for mobile displays

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16 OCTOBER 08

Vehicles and Photons 2008

OCTOBER 16–17, 2008
Dearborn, Michigan, USA

Topical sessions include:

- FPD technologies for vehicle applications
- Optical components
- Human factors and metrology

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For information on SID Conferences, contact:

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SOCIETY FOR INFORMATION DISPLAY

Since 1962, an international technical society devoted to advancing

18 MAY 08

SID 2008 International Symposium, Seminar & Exhibition

MAY 18–23, 2008
Los Angeles, California, USA

SID's Premier Annual Event featuring:

- Special Session on 3-D Cinema (new)
- Display Applications Session (new)
- Technical Sessions
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- Author Interviews
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- Investors Conference
- Short Courses
- Technical Seminars
- Applications Tutorials
- Product and Technology Exhibition
- Exhibitor Forum
- Evening Panel

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13 OCTOBER 08

Asia Display 2008 (AD 2008)

International Display Manufacturing Conference (IDMC 2008)

International Meeting on Information Display (IMDC 2008)

OCTOBER 13–17, 2008
Ilsan, Korea

Topical Sessions Include:

- Active-Matrix Devices
- LC Technologies and Other Non-Emissive Displays
- Plasma Displays
- OLED Displays
- EL Displays, LEDs, and Phosphors
- Flexible Displays/Plastic Electronics
- FEDs and Ultra-Slim CRTs
- Projection Displays
- Display Electronics, Systems, and Applications
- Applied Vision/Human Factors/3-D Displays
- Display Materials and Components
- Display Manufacturing and Measurement Equipment
- Novel and Future Displays

Co-sponsored by SID, KIDS, USDC, and Display Search

SID KIΔΣ

3 NOVEMBER 08

International Display Research Conference (IDRC)

NOVEMBER 3–6, 2008
Orlando, Florida, U.S.A.

Topical sessions include:

- LCDs and other non-emissive displays
- CRTs/FEDs/PDPs
- LEDs/OLEDs/ELDs
- E-Paper/Flexible Displays
- Microdisplays
- Projection Displays
- Electronics and Applied Vision
- Systems, Applications
- Markets

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10 NOVEMBER 08

Color Imaging Conference (CIC '08)

NOVEMBER 10–14, 2008
Portland, Oregon, U.S.A.

An international multi-disciplinary forum for dialogue on:

- Scientific disciplines
- Color image synthesis/analysis/processing
- Engineering disciplines
- Applications

Co-sponsored with IS&T

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3 DECEMBER 08

International Display Workshops (IDW '08)

DECEMBER 3–5, 2008
Niigata, Japan

Workshops and topical sessions include:

- LC science, technologies & displays
- CRTs, PDPs, FEDs, OLEDs, 3Ds
- Large-area displays
- Display materials, components & manufacturing equipment
- Applied vision & human factors
- EL displays, LEDs & phosphors
- Electronic paper
- MEMS for future displays and electron devices

Exhibition of products and services

Co-sponsored by the Institute of Image Information and Television Engineers (ITE)

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SOCIETY FOR INFORMATION DISPLAY

International Conferences and Meetings

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membership/subscription request

Use this card to request a SID membership application, or to order a complimentary subscription to *Information Display.*

PROFESSIONAL INFORMATION

1. Are you professionally involved with information displays, display manufacturing equipment/materials, or display applications?

110 ☐ Yes   111 ☐ No

2. What is your principal job function? (check one)

210 ☐ General /Corporate /Financial
211 ☐ Design, Development Engineering
212 ☐ Engineering Systems (Evaluation, OC, Stds.)
213 ☐ Basic Research
214 ☐ Manufacturing /Production
215 ☐ Purchasing /Procurement
216 ☐ Marketing /Sales
217 ☐ Advertising /Public Relations
218 ☐ Consulting
219 ☐ College or University Education
220 ☐ Other *(please be specific)*

____

3. What is the organization's primary end product or service? (check one)

310 ☐ Cathode-ray Tubes
311 ☐ Electroluminescent Displays
312 ☐ Field-emission Displays
313 ☐ Liquid-crystal Displays & Modules
314 ☐ Plasma Display Panels
315 ☐ Displays (Other)
316 ☐ Display Components, Hardware, Subassemblies
317 ☐ Display Manufacturing Equipment, Materials, Services
318 ☐ Printing/Reproduction/Facsimile Equipment
319 ☐ Color Services/Systems
320 ☐ Communications Systems/Equipment
321 ☐ Computer Monitors/Peripherals
322 ☐ Computers
323 ☐ Consulting Services, Technical
324 ☐ Consulting Services, Management/Marketing
325 ☐ Education
326 ☐ Industrial Controls, Systems, Equipment, Robotics
327 ☐ Medical Imaging/Electronic Equipment
328 ☐ Military/Air, Space, Ground Support/Avionics
329 ☐ Navigation & Guidance Equipment/Systems
330 ☐ Oceanography & Support Equipment
331 ☐ Office & Business Machines
332 ☐ Television Systems/Broadcast Equipment
333 ☐ Television Receivers, Consumer Electronics, Appliances
334 ☐ Test, Measurement, & Instrumentation Equipment
335 ☐ Transportation, Commercial Signage
336 ☐ Other *(please be specific)*

____

4. What is your purchasing influence?

410 ☐ I make the final decision.
411 ☐ I strongly influence the final decision.
412 ☐ I specify products/services that we need.
413 ☐ I do not make purchasing decisions.

5. What is your highest degree?

510 ☐ A.A., A.S., or equivalent
511 ☐ B.A., B.S., or equivalent
512 ☐ M.A., M.S., or equivalent
513 ☐ Ph.D. or equivalent

6. What is the subject area of your highest degree?

610 ☐ Electrical/Electronics Engineering
611 ☐ Engineering, other
612 ☐ Computer/Information Science
613 ☐ Chemistry
614 ☐ Materials Science
615 ☐ Physics
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