LARGE-AREA-DISPLAYS ISSUE

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Large LCDs Roll Out

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This Samsung LCD TV incorporates an advanced 46-in. 1920 × 1080-pixel module. Six 46-in. panels can be fabricated on a single glass substrate at Samsung's new Gen 7 line in Tangjung, Korea. With the help of new plants that can process large substrates, the cost of LCD panels, especially large ones, is coming down rapidly.

Samsung

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Next Month in
Information Display

Display-Manufacturing Issue
- Higher-Generation Fabs
- Benefits of In-Cell Polarizers
- Resurgence of LCoS Displays
- Making Rollable Displays
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editorial

Adjusting to Maturity

In his report in this issue on the SID 2004 Business Conference, Joe Hallett notes that the conference's presentations made clear that parts of the flat-panel-display industry "are finally settling down to become a maturing big business." Joe's reaction to that was that "For someone who has been around this industry for a while, that requires a mental readjustment."

Like most of us, I spend most of my time thinking about the present and future, not the past. But Joe's comment triggered a backward glance.

We in the display industry have worked hard to construct a coherent story of our own past, a story that helps us understand where we are and where we have come from. We are not alone in this, of course. It is what historians do all the time. A modern insight – which has been traced back to John Adams, second president of the United States – is that the history we construct of our past does not look much like the "unconstructed" history that people lived through at the time.

The histories we construct tend to be logical and narrative, while history as it is being created is often incoherent, multi-faceted, and confusing. From the welter of events, we tend to select those that favor and explain the historical path that led to where we are now.

But the technological path to our display present, which seems so inevitable now, did not seem inevitable then. The "path" to the future was more like a swamp. Many of those who thought they saw a path forward sank in that swamp. (Many in the industry today still have mud on their feet.)

Even today's most accepted truths – such as the happy marriage between LCDs and laptop computers that set high-information-content LCDs on their path to dominance – were not clear at the time. There is an *Information Display* cover from about 1990 that shows several Grid laptop computers: one with an LCD, one with a plasma display, and one with an electroluminescent display (all monochrome). Grid was letting its customers make the choice, and the LCDs of the time did not make a choice in favor of LCDs obvious. (The monochrome plasma choice – red-orange and black – was quite appealing, although battery life was unimpressive.)

Now, as then, it is easy to bet on the wrong horse. Candescent Technologies initially made a reasonable case for field-emission displays (FEDs) as competitors for LCDs for notebooks, but then ran into a variety of serious developmental and manufacturing problems and missed its window of opportunity. More recently, PFE, Ltd., had an interesting technology for printing field-emission cathodes but could not overcome luminance and uniformity problems in time, even with a last-minute assist from the Philips HOPFED technology – a creative approach to improving FED performance that is described in this issue of ID.

There are, of course, many smaller companies and research groups that are making their mark today in areas as varied as electrophoretic displays, OLEDs, 3-D, interferometric displays, PDLCs, flexible displays and backplanes, FEDs, bistable displays, and LCoS projection, among others. But the mental readjustment Joe Hallett is trying to make relates to the mainstream LCD and PDP segments of the industry, which are big businesses by any standard. There is not

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my turn

Will Users Accept Mobile Phones as TV Receivers?

by Jyrki Kimmel

The rapid advances in mobile telephony and cellular networks have led to a vast expansion in data-based services using an over-the-air interface. While the cellular phone was originally a platform for voice applications, today it can be viewed as a multi-functional data device with telephony as one of its many features.

The availability of visual content in mobile phones has also increased very rapidly as digital still cameras have been integrated into mobile terminals. Users are now sending multimedia messages (MMS) with pictures in addition to "texting" short messages (SMS). The so-called third-generation (3G) networks will, as they become more prevalent, allow fast data rates to and from mobile terminals. With this development, mobile video telephony is just a key-punch away.

Television broadcasts to mobile terminals are now receiving increased attention as industry players realize the possibilities of the new networks. Even using the General Packet Radio Service (GPRS) – the precursor to 3G networks – allows downloading video clips as well as streaming services. Trials are also under way that utilize the digital-video-broadcast handheld standard (DVB-H) as a dedicated broadcast-radio interface in mobile terminals.

Mobile-phone screens today are mostly transflective active- and passive-matrix color LCDs. Looking down the mobile-phone-display highway for visual applications, OLEDs are a dot on the horizon, and microdisplays have also been proposed. However, there are certain usability constraints associated with all these technologies, and achieving an enjoyable TV viewing experience on a tiny screen is not an easy task for telephone manufacturers.

Equally important, the data channel must be able to deliver packed data and the mobile phone must convert the data to live video that is shown on the screen without block errors, jerky-movement artifacts, or loss of signal. DVB-H lets us achieve this last part where a digital TV network exists. The screens will have to comply with the needs of mobility – acceptable power consumption, good image quality, and a size small enough for a pocketable device. Transflective displays can provide these benefits both indoors and outdoors today.

Even given the imminent technical advances that will make mobile TV consumption possible, consumers need to be won over. User studies in the last few years have shown that the preferred mode for consuming TV content in mobile terminals is watching short clips – such as single gags of a comedy show while waiting for a bus. With the proliferation of new services in the DVB-H network, additional content such as mobile TV news will be available, increasing the average consumption time.

Mobile TV will become an additional way for consumers to enjoy television, but it will probably never replace home TV as the main platform. TV is still in many cases a shared experience; single-user platforms and personalized services will fragment the mobile-terminal user base. Sharing a good show with your friends will always require a larger screen than pocket-sized mobile phones can provide. But for personal TV-content consumption on the go, both indoors and out, mobile phones will be the platform of choice. ■

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Tuning LCDs to Tune in TV

Moving LCDs from the desktop to the living room requires larger panels, but it also requires new electronic features for contrast enhancement, color management, and response-time improvement.

by Dick McCartney

ACTIVE-MATRIX liquid-crystal displays (AMLCDs) have been making quick strides toward establishing themselves as contenders for large-screen television (TV) for the living room. This is no easy feat, given the demands of the consumer-television market for high performance at an affordable price. In order for AMLCDs to expand their market share, panel manufacturers must find new ways to improve performance while reducing cost.

When LCDs are applied to TV, there are several performance challenges that their display electronics must meet. First, there are the issues of sheer size and format. The XGA format (1024 × 768 pixels) dominates the notebook-PC application, while the SXGA format (1280 × 1024 pixels) dominates the LCD desktop-monitor application. The entry point for large-screen LCD TVs is WXGA+ (1366 × 768 pixels); at the higher end of the market, true high-definition television (HDTV) (1920 × 1080 pixels) is required. The true HDTV format requires over 2.5 times more data per image frame than the XGA notebook format.

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Fig. 1: *The improved color performance that is possible with color-enhancement processing is an important feature for LCD TVs. The original image is on the top; the color-enhanced image is on the bottom.*

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When XGA and SXGA applications for LCDs became commonplace, the need to reduce power consumption and electromagnetic interference (EMI) was met largely through the use of differential signaling and data-transmission lines. Transmission-line theory treats the signal path as a waveguide rather than wire connections, which allows the signal shape to be preserved as it travels. These signaling technologies were introduced to move digital pixel data to each column line driver at the rates required to write all the pixels in a typical 1/60-sec frame time.

Better Signals for Big Screens

Television applications place even more demands on signal integrity than do notebook and monitor applications. Not only are there more pixels per image frame but other demands as well. The larger panel sizes associated with television require signals to travel over longer distances, which translates into a higher probability of impedance-mismatch artifacts and cross-coupling.

In addition, at a distance of about 30 in. the column board that normally runs the full width of the display must be built as two separate boards to accommodate the size limits of printed-circuit-board (PCB) manufacturing. This contributes more discontinuity to the signal path, further corrupts the signal, and also interferes with optimization of signal routing.

In addition to these strains on the signal integrity, high-performance TV requires more gray scale per pixel than do computer applications. LCD TV requires a 30-bit pixel (10 bits of gray scale per RGB color) rather than the 24-bit pixel used in computer applications. This is necessary to eliminate the contour boundaries that can develop in the shallow luminance gradients characteristic of images such as a sunset or an ocean scene. The quantization of luminance across a spatial gradient can produce an objectionable visible line. This effect is exaggerated in TV because of the generally higher-contrast design.

LCD Contrast Enhancement

In addition to the intrinsic reasons for increasing gray scale, color and contrast image-enhancement processing produce images with 30-bit precision as a consequence of the processing's luminance scaling. An LCD's dark-room contrast ratio is limited because the display can not fully shut off the light valves that form each pixel – in short, the light valves leak. The current state-of-the-art contrast ratio for a high-end LCD TV today is approaching 1000:1, but conventional LCD TVs are closer to half of that.

To make up for this limitation, image processing has been developed to examine an image frame by frame and expand the range of the dominant luminance component. This allows images that have a narrow dynamic range of luminance (low contrast) to be scaled so that a larger number of gray levels can be seen.

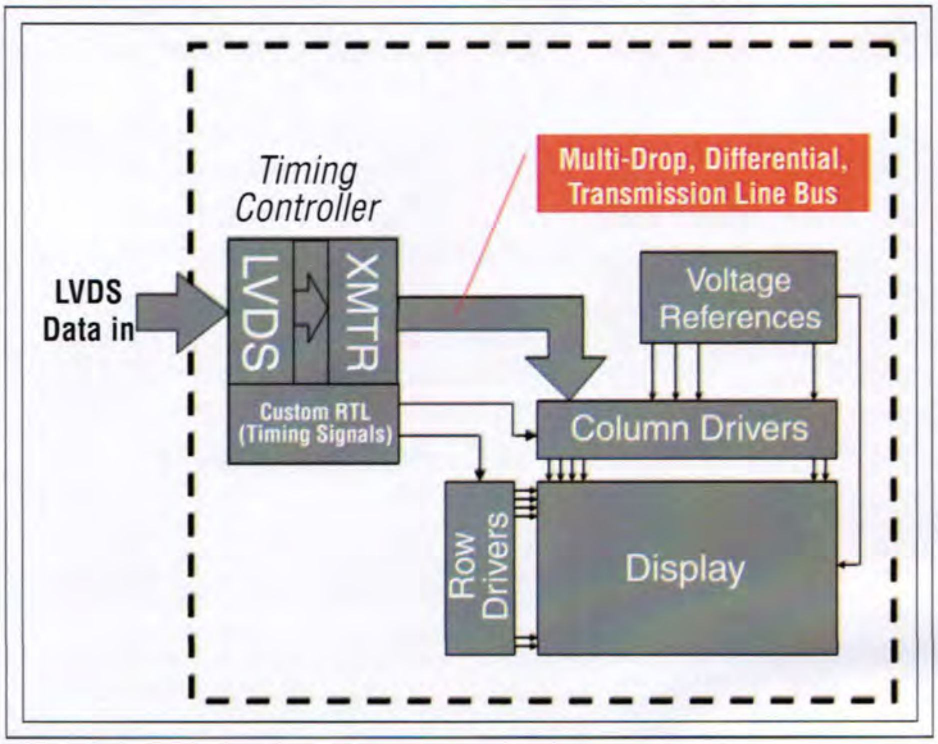

Fig. 2: The major functional blocks of a typical LCD module include a multidrop differential bus that operates across transmission lines to pour digital video data into the column drivers. Although effective in monitors and notebook PCs, this architecture is heavily taxed by LCD-TV applications.

Color HDTV

One of the most important qualities of a TV today is its color rendering. When different brands are placed side by side, consumers make their decisions, in large part, based on this feature. Consequently, much consideration is given to how best to map image colors into the color space produced by a given LCD panel. This remapping is done by transforming the image into an appropriate luma and chroma space and by processing the image to favor certain hues at the expense of others. This processing results in more RGB precision than is present in the original image; consequently, 10-bit gray scale (30-bit pixels) is required to properly render the image without truncation artifacts (Fig. 1).

The Need for Speed

Users of LCDs might find it surprising that LCDs are too slow for video applications. Computer applications are very forgiving of slow pixel-response times, but broadcast TV is another story. Each frame – or each half-frame in the case of interlacing – is captured in less than 1/60 or 1/50 sec. The moving component of the image is captured in sharper detail than in a film frame of a movie; in addition, it must be rendered on the display screen at faster rates than movie frames are presented in movie theaters.

This high presentation rate means that response time is much more of an issue for TVs than for most other video applications, and it is particularly important for HDTV.

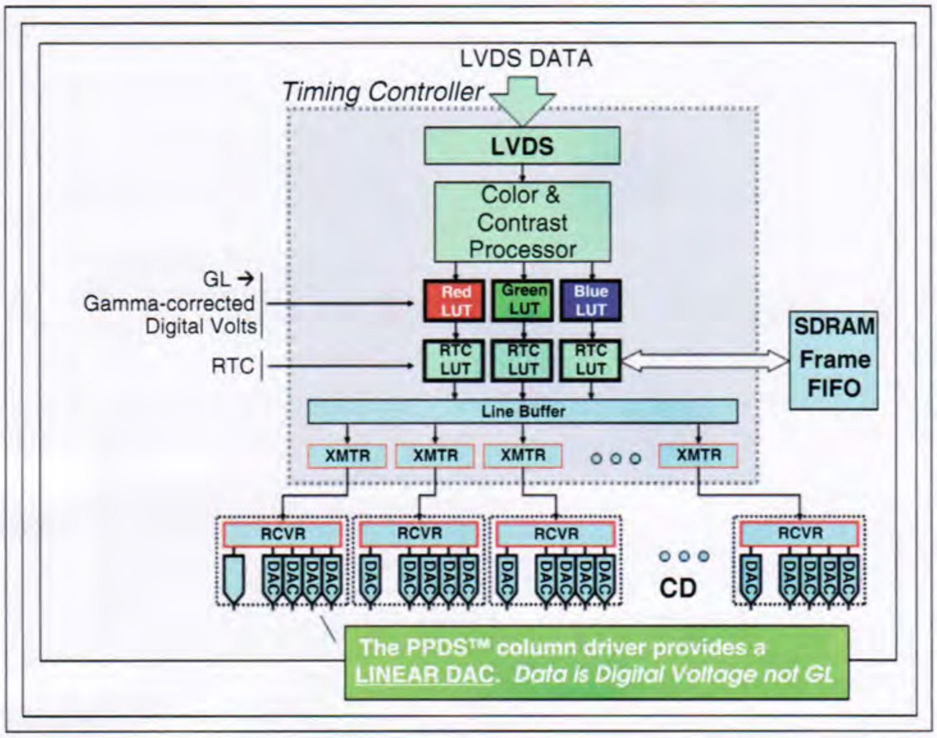

Fig. 3: The new Point-to-Point Differential Signaling™ (PPDS™) architecture involves a system of separate point-to-point links instead of the conventional multidrop bus. Each channel carries both column-driver control information and the digital voltage values that are converted to analog by the column driver.

LCD televisions require a response-time-compensation (RTC) overdrive block to compensate for the slow optical response of the LCD. The RTC block, resident in the timing controller (TCON), intercepts the digital video stream and compares the previous gray-level command to each pixel with the current gray-level command. It then chooses a predetermined alternative gray level from a look-up table (LUT). The alternative value programmed into the LUT is experimentally chosen to just bring the luminance to the target value at the end of one frame. If the new gray level is lighter than the preceding one, a command is sent for a gray level that is, initially, lighter still. If the new gray level is darker, an exaggeratedly darker (at first) command is sent.

Looking for Solutions

The electronic architectural solutions that worked well for LCD monitors and notebook PCs are inadequate when confronted by the additional demands posed by LCD-TV applications (Fig. 2). The multidrop differential bus architecture operating across transmission lines to pour digital video data into the column driver is heavily taxed by the LCD-TV application. The quality of the signal waveshape must be maintained to support the faster data rates required. Not only is this made difficult by the longer distances the signal must travel, but also by the added number of column-driver drops required for expanded TV formats.

To address these issues, some companies are exploring a cascade solution, in which the conventional bus enters one end of a column driver and is buffered and re-transmitted to the next column driver. This converts the conventional bus into a point-to-point solution that has much higher signal quality, but it does so at the expense of additional column-driver input/outputs and circuitry. This redesign of the bus architecture through cascading to improve signal integrity does not, however, address the broader requirement to provide more gray-scale precision, improved contrast, color management, and other advanced features.

Another Approach

First and foremost, delivering cost-effective 10-bit-per-color gray scale is a daunting challenge for the conventional resistive-string digital-to-analog-converter (RDAC) column-driver architecture. In the RDAC approach, which has been the exclusive solution for notebook and monitor applications to date, digital gray levels are sent to the column driver across a differential transmission-line bus.

The column driver maps these values to one of the voltage nodes on a series-resistance string. The voltage at each of these nodes is predetermined by the column-driver design to be just the voltage required to command the LCD to the brightness intended to be associated with the particular gray level. Thus, the RDAC not only performs the digital-to-analog-conversion function, but also the inverse gamma-conversion function that maps each gray level to the voltage required by the particular LCD to command the intended brightness.

This dual-purpose RDAC function is highly efficient in a 64-gray-level (6-bit) system. However, with the additional gray levels of a 256-level (8-bit) system, the column-driver dice necessary to bus both polarities of each of the 256 voltages from one end of the chip to the other, together with the circuitry required at each output to decode and select only one of these voltages, dominate the die area. At 1024 gray levels (10 bits), all things being equal, the die area is just too large for the RDAC to be an effective solution.

At National Semiconductor Corp., we made a significant departure from the conventional RDAC approach and created a column driver that uses a linear, cyclic digital-to-analog converter (DAC). This DAC is characterized by its small die area, which makes it possible to locate two copies of the DAC at each output – one for each polarity. A key feature of this DAC is its ability to scale to more bits of gray-level precision. Higher resolution simply requires more cycles of the same DAC circuit rather than more die area. With this architecture, we are able to provide a 10-bit gray-level capability with a cost-effective die size.

Another advantage of this approach is that the inverse gamma-conversion function is decoupled from the DAC conversion circuit. This means that each column-driver output converts digital voltage values into analog

***Fig. 4:** In the PPDS™ architecture, the gamma tables that reside in the timing controller allow picture-in-picture windows to have different gamma mappings, so colors can be optimized separately for each image.*

voltage values directly. The conversion from digital gray levels to digital voltages takes place upstream, in the TCON. In other words, the inverse gamma-conversion function is provided in a LUT resident in the TCON, which provides great flexibility in mapping each gray level to brightness on the LCD panel. In fact, a separate LUT for each color is possible, and real-time updates can be made to these tables to accommodate different image sources, contrast expansion, color management, and even temperature changes.

This column-driver architecture is part of the broader architecture we call Point-to-Point Differential Signaling™ (PPDS™) (Fig. 3). As the name implies, PPDS™ is not a multidrop bus, but rather a system of separate point-to-point links – a single channel per column driver. This channel carries both column-driver control information and the digital voltage values that are converted to analog by the column driver.

In the conventional bus architecture, data arrive at the column driver in burst mode because only one column driver receives data at a time, using the bus as a shared, global resource. In the PPDS™ system, all the column drivers receive their data simultaneously. So even though there is a single differential channel supplying each column driver with data, the channel is used during the entire line time. As a result, the clock frequency between the two systems is significantly different.

One of the important features of the PPDS™ system is that column drivers can be individually controlled through the data-packet header sent to each column driver, line by line. This type of embedded control is necessary because it eliminates the individual dedicated signals running between the column driver and TCON, saving space and reducing cost. Flexible control of the column driver makes it possible to implement special waveform control. Successful driving of large-format large-sized TVs must include control of the panel-driving waveforms to optimize signal propagation and the pixel-charging ratios.

Benefits of PPDS™ Architecture

The ability to provide independent RGB gamma tables allows the TCON to precisely correct the color temperature of each gray level. Independent RGB gamma LUTs allow each color to be gamma-corrected independently, providing constant color temperature across all gray levels and extending the acceptability of the technology into higher-performance applications.

Direct access to the gamma LUTs allows gamma characteristics to be dynamically or adaptively adjusted in real time, depending on the content, as determined by an image-processing unit in the TCON. Future configurations will be able to provide different gamma transfer functions in different windows of the display (Fig. 4). A computer operating system could provide window boundary coordinates to the TCON, and then have the TCON choose a different gamma LUT, depending on the region of the display being written.

Cinema-quality television is one of the goals of large-screen-TV manufacturers. One of the keys to cinema-quality images is gray-scale precision and color management. The PPDS™ architecture can support a full 30-bit color precision from input to display surface. This precision, coupled with the features deriving from the independent gamma LUTs, allows image processing that greatly enhances the viewer experience. Color and contrast enhancement of an image result in higher gray-level precision in the image. The independent gamma LUTs provide a means to directly control the image quality without the need for dithering or other methods of approximating the desired luminance in each pixel.

Consumer Approval: The Final Test

In monitor and notebook applications, LCD-module electronics stayed in the background, taking in gray-level commands and providing control signals to the panel to produce exactly those gray levels. Television requires the panel electronics to provide added front-of-screen performance with more color depth, improved color balance, dynamic contrast, response-time compensation, and controlled color temperature. This provides an opportunity – it actually creates the necessity – for the panel electronics to step out of the shadows and into the limelight. ■

LCoS Rear-Projection TVs Test the Market – Again

Each of the competitors of LCoS technology offers features that could attract customers – so what advantages can it offer?

by David E. Mentley

AFTER MANY FALSE STARTS at large and small companies over 10 years of development, rear-projection TVs (RPTVs) based on liquid-crystal–on–silicon (LCoS) light engines are ready to test the market in a big way. Interest in LCD RPTVs is very high in Japan, and in Taiwan LCoS excitement is rampant. Recent demonstration products have looked better than ever and may just be ready for prime time.

Previous attempts were plagued by problems that did not show up in the lab, but did give manufacturers headaches months after the products left the production line. Annoying defects like color shifting and image sticking now appear to be resolved. As the big consumer-electronics makers know very well, only when consumers buy tens of thousands of products and do not return them to the store will the product design and technology be certifiably ready for the market.

The list of LCoS companies (including developers and their partners) who did not make it to the party is quite long. Companies who have had development programs in LCoS projectors or TV in the past and are not now involved include IBM Corp., National Semiconductor Corp., Hughes, Digital Reflection, Display Research Labs, S-Vision,

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Brillian Corp.

***Fig. 1:** Brillian's 720-line LCoS rear-projection TV with a 65-in.-diagonal screen is now shipping, and the first products showed quality good enough to compete head to head with CRT- and DLP™-based RPTVs.*

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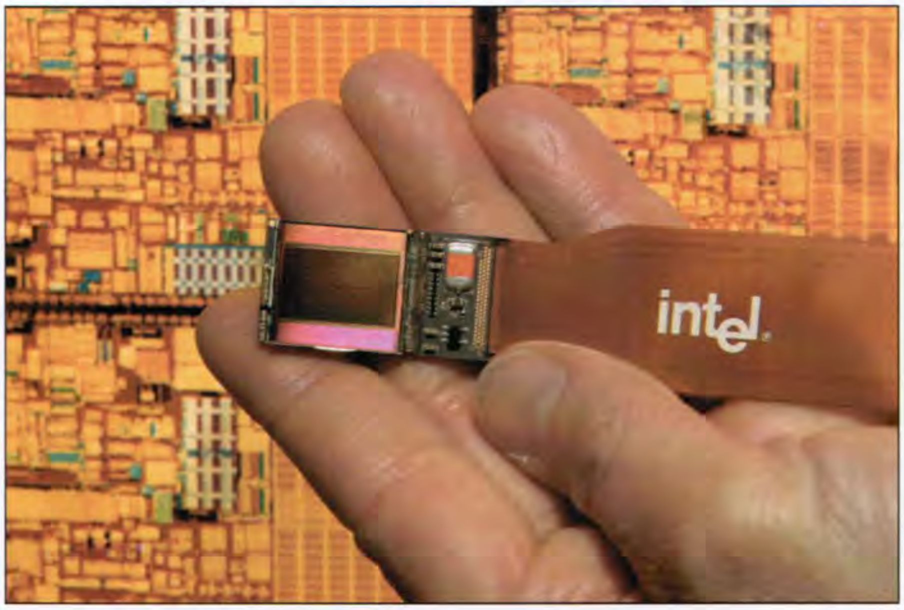
Displaytech, Raychem, Silicon Display, WAH III, and RAF Electronics. In simple terms, the original promise of combining the electronic benefits of Moore's Law with the demanding optics of projection systems proved too difficult from the standpoint of economics, manufacturing, and performance – until recently. Although not yet proved in the marketplace, LCoS technology now has all the indications of a technology that is ready to begin its ramp-up into the consumer market.

Despite the long list of departed LCoS developers, new entrants continue to arrive. This is yet another vote of confidence in the maturity of the technology. Current developers include Aurora Systems, Brillian Corp., CRL Opto, eLCOS, Himax, Hitachi, Integrated Microdisplays, Ltd., Intel Corp., JVC, MicroDisplay Corp., Philips, SpatiaLight, Sony, Taiwan Microdisplay Corp., and United Microdisplay Optronics.

Many of these companies call themselves manufacturers, but most are really fabless developers of LCoS intellectual property. Some do have silicon-backplane-manufacturing capacity, and most have sophisticated cell and packaging technology. The interface and control electronics are also critical to success. Many firms rely on light-engine assemblers to integrate the key optical components. JDS Uniphase Corp. is now ramping up its engine-building capacity with a new generation of optical components that guarantee accurate color and efficient design. (The companies mentioned in this article deal with LCoS projection; the list does not include companies dedicated to the near-to-eye or head-mounted-display forms of LCoS technology.)

Systems built by Brillian and Philips are now shipping, and the first products showed quality good enough to compete head to head with CRT- and DLP™-based RPTVs. Brillian's unit is a 720*p* LCoS RPTV with a 65-in.-diagonal screen (Fig. 1). The company has also shown a 1080*p* RPTV built around three of its 1920 × 1200-pixel chips. The prototypes provide color, contrast, and black-level qualities that are excellent. A very close spacing of the 8.1-μm pixels in the 0.72-in. chip produces no discernable gap on a 65-in. screen.

Television makers JVC and Sony, as well as LCoS developers Intel, SpatiaLight, and MicroDisplay Corp., also have prototype systems in various stages of refinement as of July 2004 (Fig. 2). All of this market activity comes at a time when digital-TV, high-definition-TV, and large-screen-TV products are pulling consumers around the world into electronics shops to upgrade or replace old products – products that can no longer deliver an image that is up to the quality available from DVDs or set-top boxes.



Intel

Fig. 2: *Intel has been showing prototype LCoS imagers, which the company says will reduce the costs of LCoS RPTV sets, as well as demonstration TVs using the prototypes.*

It is somewhat ironic that HDTV is the service that attracts the customer for advanced TVs, but DVDs, satellite, and digital cable with "enhanced definition" are the sources that are now being used for content delivery. Many buyers are simply getting ready for the day when HDTV content will be widely available through all delivery services.

The technological advantages of LCoS technology as a light modulator for projection systems began as hypothetical features well over 10 years ago. Most developers were split between the near-to-eye applications, which seemed to offer quick market entry – despite the fact that there was no demonstrated consumer demand – and projection systems, which already made use of several strong competing alternative technologies.

The mainstay of the RPTV market, the three-tube CRT design, still works fine for 480-line input signals. But to achieve both high resolution and a bright image with a CRT-based RPTV, the tube size and magnetics must be improved. Even with enhancements, achieving a full resolvable 1920 × 1080-pixel video image is not possible in a consumer CRT-based RPTV. Marketing materials promote "1080*i*" as the input signal without explaining that the resolvable image will be somewhere around 500–600 horizontal lines. Polysilicon LCD-based RPTVs have come a long way and are now quite appealing. They are generally limited to 1280 × 720 pixels.

As is well known, DLP™ RPTVs have exploded onto the market, ramping from 215,000 units last year to an estimated 750,000 in 2004. Although limited to 1280 × 720 pixels, DLP™ RPTVs have dropped in price along with this market expansion. The DLP™ engine has set the bar very high in terms of video performance, so all newcomers must meet the same price/performance standards in order to succeed. In short, all of the LCoS competitors offer some features that may attract different customers, whether it be color gamut or saturation, the soft edges of a scanned spot, crispness, or price. So what advantages can LCoS technology offer?

LCoS displays have long held out the promise of very-high-definition images along with low cost. Initial hopes were that imagers of 2, 3, 4, or 5 Mpixels would be possible with LCoS technology at little or no cost premium. While the latest semiconductor fabs can process 65-nm (or 0.065-μm) design rules, LCoS backplanes can be made with 0.25- or 0.35-μm processes. A single 200-mm wafer can hold 60–170 unyielded devices, depending upon the chip dimensions.

Chips can range from 0.7 to 1.2 in. on the diagonal, and all are in the widescreen format. At a wafer price of $1000 and a moderate yield of 100 dice per wafer, the silicon cost would be $10. This could be the basis for either a 1280 × 720- or a 1920 × 1080-pixel imager. Testing costs aside, the manufacturing cost should not be much different for either resolution.

Although this was the original motivation behind the LCoS push, the conversion of the backplane into a working active-matrix liquid-crystal light valve is where the difficulties and cost additions came in. It was the optical part of this electro-optical device that proved hard to master.

As for unlimited screen resolution, the minimum physical pixel size is now limited to about 8 μm, and this determines the die size and information content. Below 8 μm, performance suffers because of liquid-crystal effects at the boundaries. The current thinking is that a packaged LCoS device can, or soon will be, sold for about $100.

How Many Panels?

This leads to the next important issue: one, two, or three panels? The tradeoff is mainly that of cost against performance. Three-panel designs – in which light is separated into red, green, and blue paths, then modulated and recombined into a full-color image – now provide saturated colors, video performance, and the most appealing image. The penalty for a three-panel design is the cost of the engine, which must include three cells and extra lenses, prisms, and filters. Light throughput is generally better in three-panel engines; for filling a 60-in.-or-larger screen, there are few other options. Most developers are pursuing three-panel designs and are either targeting the high-performance market – as is the case of Brillian Corp. – or are betting that prices and costs will fall rapidly enough to face CRT, poly-Si, and DMD™ RPTVs head on.

A single-panel design works by separating the red, green, and blue fields by a function of time (in the case of a color wheel), space (in the case of a color-filter array), or both (in the case of a scrolling prism as in the Philips product). Single-panel LCoS engines for RPTVs are now being designed for smaller screen sizes of 45 in. or less and for low-cost products. The technical challenges are severe, but there are benefits to a single-panel design. Besides lower cost, the color elements are always in alignment.

MicroDisplay Corp. (MDC) now has prototypes of a 43- and a 52-in. RPTV that use a single 1280 × 720-pixel LCoS chip with a color wheel. The liquid crystal must be capable of very fast switching. MDC's display switches at 1 msec, allowing a field-sequential-color rate of 540 Hz. Philips's Cineos line of LCoS RPTVs ranges from 44 to 62 in., with all models based on a single LCoS panel. With a chip diagonal of 1.15 in., the Philips panel is on the large side; a new design with a chip diagonal of 0.9 in. is in the planning stage. Full color is generated by timing the data for each color subfield to the illumination of each subfield as it scrolls down the panel and is reflected through a lens to the screen.

The two-panel architecture is a compromise in which red light is given its own path and modulator, and blue/green data and light are managed in a second cell. The performance and bill-of-materials costs will be in between those of the single- and three-panel designs.

Over the past 5 years or so, many developers have suggested using the high information content of an LCoS imager to build a desktop monitor in the 20–30-in. range. Some clever designs with a depth of only a few inches were drawn up. But the market for desktop monitors of this size, either CRT- or LCD-based, has always been small, so this market segment never materialized. The performance of direct-view LCDs in this size range now makes desktop rear-projection monitors all but irrelevant.

This is probably not the case for a scaled-down LCoS RPTV. Rear-projection TVs measuring about 40 in. have been promoted in the past as "tabletop" units, and were based on three CRT light boxes. For a 1280 × 720-pixel imager using new compact optics and a singe-chip design, a very competitive tabletop LCoS RPTV is now possible. Such a product may be able to fill in where direct-view CRTs leave off at 36 in., and might even be viable down to 30 in. A bill of materials of $500 for such a product is highly likely within the next few years, and this will lead to retail prices of $1000–1200. Such products will compete not only with rear-projection CRTs, but with direct-view LCD and plasma TVs.

Interesting Times

If the diversity of opinion about liquid-crystal modes and single-chip *versus* three-chip panels were not interesting enough, there is a major debate raging as to whether digital or analog addressing is better. Digital-TV makers are just now receiving decoders capable of handling 10-bit color. These will be compatible with the 10-bit controllers and image processors that are now available. Full analog control of a video image has always been the gold standard, but 10-bit color will be nearly as good for the majority of viewers. So, as long as the digital LCoS imagers and drive electronics are capable of at least 10-bit control per color, they should be as good as analog.

LCoS technology is now capable of carving out its share of the 6-million-unit projection-TV market, but work still needs to be done to make it happen. Most importantly, prices will have to be driven downward over the next few years to align with competitive products, first with DLP™ RPTVs and eventually with CRT-based RPTVs. ■

Hopping-Electron Transport in a Field-Emission Display

Spindt tips are too expensive and carbon nanotubes produce non-uniform luminance, but HOPFEDs could realize the promise of FED technology.

by Daniel den Engelsen and Kees Kortekaas

FIELD-EMISSION DISPLAYS (FEDs) have been discussed for almost 20 years, and substantial efforts have been made in the last decade to begin production of these displays. Those efforts have not yet led to successful market introductions. This lack of success has led some to conclude that the "failing" product is better suited to a museum of oddities than to serving actual market needs.

Actually, the opposite is true. We estimate that in 2003 $100 million was spent worldwide on FED research and development, and, at the SID International Symposium and other conferences, many FED-related R&D projects are presented and continue to attract a lot of attention. This continuing interest shows that despite the dominance of liquid-crystal displays (LCDs) and plasma-display panels (PDPs) in the world of flat-panel-display (FPD) technologies, many believe in the commercial viability of FEDs.

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The Promise of FEDs

Why are FEDs still under consideration as a likely prospect for commercialization? First, FEDs are FPDs; an FED module, including the driver electronics, has the same depth as that of a PDP or an LCD module.

Second, FEDs have an inherently high luminous efficacy. In an FED, as in a cathode-ray tube (CRT), a phosphor layer is bombarded by electrons emitted by a cathode, and the light emission from the phosphors is therefore called cathodoluminescence (CL), which is one of the most efficient processes yet discovered for generating light in solids (Table 1).

Third, the short decay time of the phosphors makes an FED suitable for TV applications without requiring the introduction of complicated electronics to reduce motion artifacts.

The fourth reason is that, as an emissive display consisting of many mini-CRTs, FEDs might also share the success of CRTs by benefiting from the consumer's preference for direct-view images with a wide dynamic range.

These advantages may explain why FEDs are judged to be worthy of development, especially in organizations that were exclusively devoted to CRT development some years ago.

Table 1: Luminous Efficiency of Different Technologies for Generating White Light

Light-Generating Mechanism/Display Technology	Luminous Efficiency (lm/W)
Theoretical limit	220
Photoluminescence: TL lamp	80
Cathodoluminescence at 30 kV	30
CRT with 50% GT* at 30 kV	3
FED with 50% GT at 8 kV	6–7
RPTV (CRT) at projection screen	2.3
PDP with 50% GT	0.8
LCD TV	~3
Inorganic LED	5–10
OLED/PLED	3–5
Thin-film electroluminescence	1–2

*GT: glass transmission.

Note. This comparison refers to the luminous efficiency of generating white light with present-day phosphor materials and displays. Only the screen efficiency has been tabulated; the power consumed in addressing or scanning has been omitted. In practical circumstances, an FED is more efficient than a CRT, PDP, or LCD.

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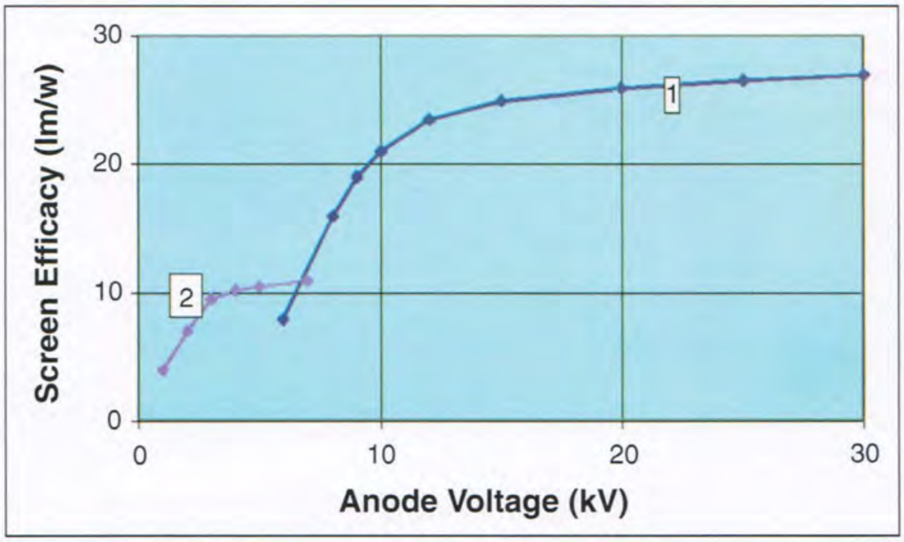

Fig. 1: The luminous efficiency of the white-light-emitting CL phosphors commonly used in CRTs and FEDs increases as the anode voltage is increased. Curve 1 describes the behavior of conventional CRT phosphors used with an aluminum backing layer. Curve 2 is for red and blue CRT phosphors and the green Y_2SiO_5:Tb phosphor without a backing layer.

Obstacles to Commercialization

Despite their advantages, FEDs have experienced substantial difficulties when attempts have been made to introduce them to the market. In order to become a successful product, FEDs must deliver the same picture quality as that of LCDs and PDPs at a similar or lower cost. And high cost is a disadvantage for FEDs built with Spindt cathodes. The sub-micron technology required to fabricate Spindt tips is expensive to implement industrially and faces insurmountable yield problems.

For these reasons, most FED-development programs are now focused on relatively inexpensive carbon-nanotube (CNT) emitters. CNT-emitter technology is receiving a great deal of attention, but it has not yet brought a viable product to market. One of the reasons for this is that CNT FEDs have failed to meet the display requirement of good luminance uniformity [C. G. Lee *et al.*, *SID Intl. Symp. Digest Tech. Papers*, 1125 (2002)].

The luminance of a display can be characterized in terms of long- and short-range luminance uniformity. Long-range luminance uniformity refers to a range of viewing angles from about 30 to 60°, while short-range luminance uniformity refers to the range of viewing angles from about 0.05 to 2°.

The human eye is not sensitive to a smooth luminance variation in the long-range regime. For example, the luminance at the center of a CRT screen can be 1.5–2 times greater than in the corners without being noticed by viewers. However, the eye is very sensitive to short-range luminance non-uniformity, in which luminance variations of 0.5% are visible and variations greater than 1.5% are disturbing to most viewers.

The poor short-range luminance uniformity of FEDs employing CNT emitters – sometimes greater than 10% – is one of the main obstacles to commercialization.

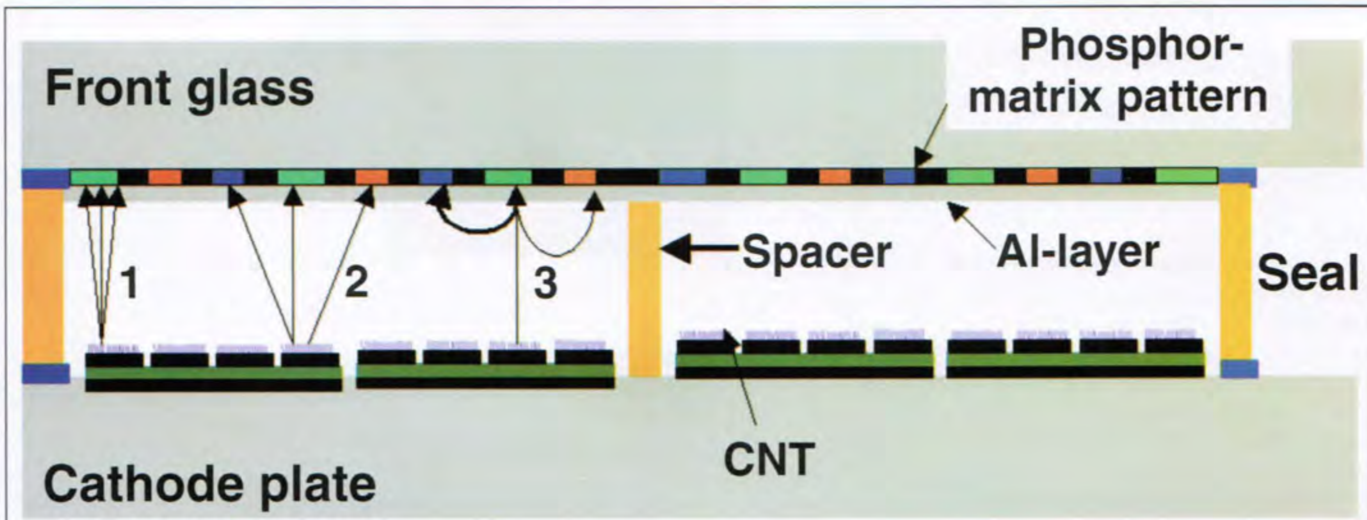

Fig. 2: In a conventional FED with CNT emitters and an under-gate architecture, a narrow beam-divergence angle can produce high color purity because no primary electrons land on the wrong phosphor (Area 1); the opposite can be true for a wide beam-divergence angle (Area 2). At higher anode voltages, even electrons that land on the correct phosphor can produce backscatter which may land on a neighboring phosphor dot (Area 3).

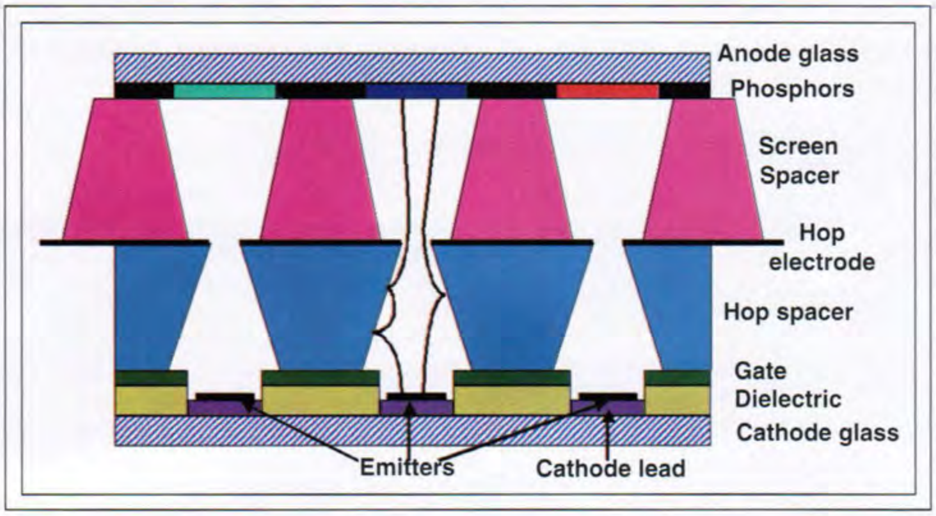

Fig. 3: The double-spacer architecture of a HOPFED allows each phosphor dot to receive a uniform electron distribution. (The aluminum backing layer on the phosphors is not shown.)

Another disadvantage is sensitivity to high-voltage breakdown. Electron bombardment and charging of the spacers that support the front and back plates of conventional FEDs can initiate a flashover, which, if repeated, can eventually lead to the destructive breakdown of the display. To avoid breakdown, FEDs are sometimes operated at a rather low anode voltage of 2–3 kV, which makes it impossible for the technology to realize its potential for high efficacy (Fig. 1). Even at a lower efficacy it is possible to achieve high luminance, but a serious penalty must be paid. If the anode voltage is decreased from 9 to 3 kV, the current density must be increased by a factor of roughly 7 to maintain the same luminance. This causes the phosphor to deteriorate at a much higher rate through the coulomb aging mechanism.

Another problem is that some field emitters have a rather wide beam-divergence angle and therefore need additional focusing to prevent the outer beam electrons from landing on the wrong phosphor dot (Fig. 2, Area 2). A small divergence angle can result in color purity (Fig. 2, Area 1) but it does not guarantee it. At anode voltages over 7 kV, backscatter can become a serious problem. At these voltages, backscattered electrons can have sufficient energy to pass through an aluminum backing layer and then energize a subpixel of the wrong color (Fig. 2, Area 3).

HOPFEDs

The remarkable potential in the physics and materials of Spindt-tip and CNT FEDs is offset by formidable practical difficulties. However, the hopping field-emission-display (HOPFED) architecture proposed by Philips and LG.Philips Displays reduces most of the difficulties to a decidedly manageable level [H. M. Visser *et al.*, *SID Intl. Symp. Digest Tech. Papers*, 806 (2003)].

In a HOPFED, a conventional pattern of field emitters – including cathode leads, dielectric insulator, and gate electrodes – is fabricated on a glass cathode. A conventional anode is coated with a pattern of phosphors and a black matrix which are covered with an aluminum backing layer.

The new elements that make this structure a HOPFED are the extra glass plates (the hop and screen spacers) that span the area between the anode glass and the cathode glass (Fig. 3). Both the hop-spacer (lower) and the screen-spacer (upper) glass plates contain lower (hop) and upper (screen) funnels which have been created by powder-blasting the glass. The funnel's interior walls are then coated with a layer of insulating material, MgO (magnesium oxide) in the lower funnel and Cr_2O_3 (chromic oxide) in the high-voltage upper funnel.

This unique architecture is designed to control electron transport through the insulating structure by collecting electrons from the

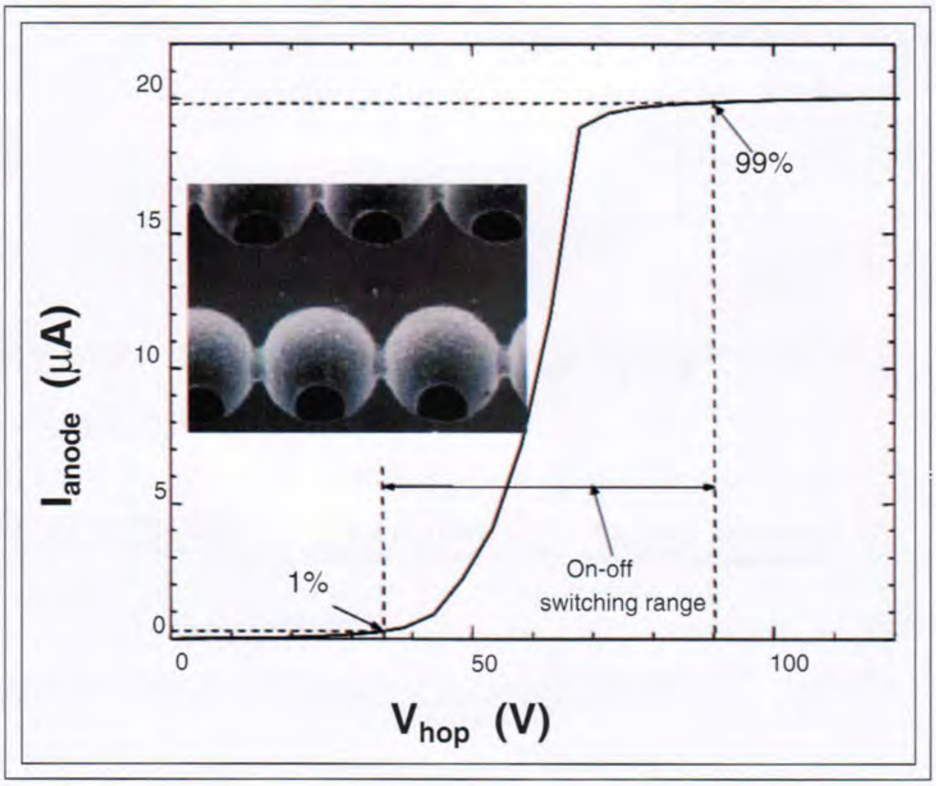

Fig. 4: It is possible to obtain a transmission of 99% through a HOPFED funnel with a hop voltage of only 75 V (inset shows funnels powder-blasted in glass).

CNT field-emitter plate and compressing them as they "hop" over the insulator and accelerate towards the exit of the funnel structure, where they are delivered to the correct phosphor dot.

In conventional FEDs, spacer charging by electron bombardment should be prevented as much as possible. However, in the HOPFED we encourage electron bombardment of the hop funnel's insulated surface, which is responsible for the unique properties of this architecture. This collection mechanism makes the requirements for the electron-beam quality at the emitters much less stringent because the electrons are mixed, homogenized, and compressed as they hop over the interior of the funnel wall. Another benefit is that the compression of the electron beams permits the use of large emitting areas, which automatically leads to lower drive voltages.

The electrons in the screen-spacer funnels are accelerated to anode potential, preferably between 7 and 9 kV, to permit a high luminous efficacy without over-exciting the phosphors. The hop and screen spacers block secondary and backscattered electrons from hitting the wrong phosphor dots, enabling high contrast and color purity. An additional advantage of a spacer for every pixel is that it is not noticeable to the viewer, a well-known disadvantage of conventional pillar or rib spacers.

Hopping

The electron transport in the hop funnels is a self-regulating secondary-electron-emission process. When the primary electrons, generated by the CNT field emitters, bombard the wall of the hop funnel, they initiate the emission of secondary electrons. These secondary electrons hop over the surface under the influence of a "hop potential" which is applied to the hop electrode, as indicated in Fig. 3.

During the stabilization of this process, the wall is charged until the average electron landing energy is such that one primary electron generates one secondary electron and no net charge is deposited on the surface. Another way of saying this is that the secondary-electron-emission coefficient $\delta = 1$. If $\delta = 1$ occurs at a low electron energy, it generally means that the maximum value of δ (δ_{max}) will be high. So, we want to lower the potential required to drive the hopping process, and we can do this by covering the funnel walls with a material having a high secondary-electron-emission coefficient. MgO is an example of an insulator with a high δ_{max} of 12 and a low energy of 20 eV for $\delta = 1$.

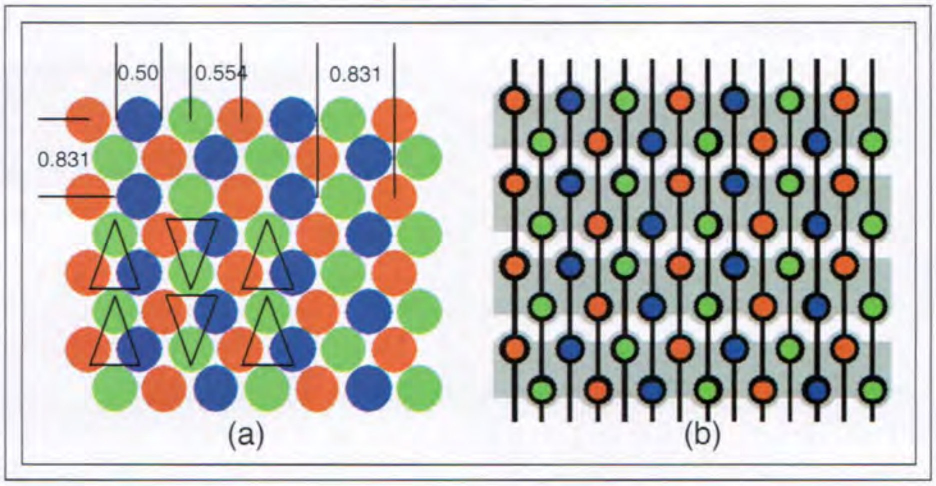

Fig. 5: High-density structure of a HOPFED, dimensions are in mm (a). This structure allows the representation of HDTV and XGA images on a 32-in. wide-format screen. Because of the staggered quincunx addressing mode, a horizontal line refers to two funnel rows (b).

With good design, only 75 V is required to obtain a transmission of 99% through a funnel. These numbers can be obtained with hop funnels having an entrance diameter of 0.35 mm and an exit diameter of 0.13 mm (Fig. 4).

The hop-spacer glass plate can be made with a high density of hop funnels (Fig. 5). We have fabricated both spacer plates from glass having a thickness of 0.4 mm, the funnels being made with a powder-blasting technology. In this technology, the minimum diameter of the funnel's entrance cannot be smaller than about 0.75 times the glass thickness. The high-density hop-spacer plate shown in Fig. 6, in which the funnels are arranged in a hexagonal symmetry, is about the maximum obtainable with a spacer thickness of 0.4 mm.

This high-density spacer enables a distance of 0.83 mm between the rows. The hexagonal arrangement permits XGA resolution on a 32-in. wide-format screen.

Smoothing the Electron Spot

The hop-spacer plate smoothes the non-uniformity of the electron emission from the field emitters. As a result, the intra-pixel uniformity improves significantly when non-uniformly emitting cathodes having wide beam divergence are used (Fig. 6). The marked improvement in luminance uniformity in the figure was obtained by applying a hop spacer coated with an MgO layer on top of a line of printed CNT emitters. The anode was coated with a layer of green phosphor only.

Although we expect the hop spacer to improve intra-pixel uniformity, it is clear that the inter-pixel uniformity also improves substantially. Interestingly, the electron spots are hollow. This is caused by the properties of the electron beam, the length of the screen spacer, and the strength of the electron-optic lens at the exit of the hop funnel.

The screen-spacer funnels are coated with a chromic oxide (Cr_2O_3) layer. Cr_2O_3 has a rather low δ_{max} compared to that of MgO, so the potential at the wall of the screen-spacer funnel is more evenly distributed.

The profiles shown in Figs. 6(c) and 6(d) are calculated electron-density plots. The distance between the two peaks matches the measured diameters of the luminance rings on the phosphor. Figure 6(d) shows the spot produced by a cathode only half of which is emitting. This indicates that hopping is highly effective in smoothing the non-uniform emission of field emitters.

Electron Bombardment

The sensitivity of field emitters, especially Spindt-type emitters, to ion bombardment has been described in the literature (see, for example, R. H. Reuss and B. R. Chalamala, *SID Intl. Symp. Digest Tech. Papers*, 81 (2001)]. It has been argued that CNTs are less sensitive, but under massive ion bombardment, CNTs will be damaged, too. The HOPFED architecture has the added benefit of protect-

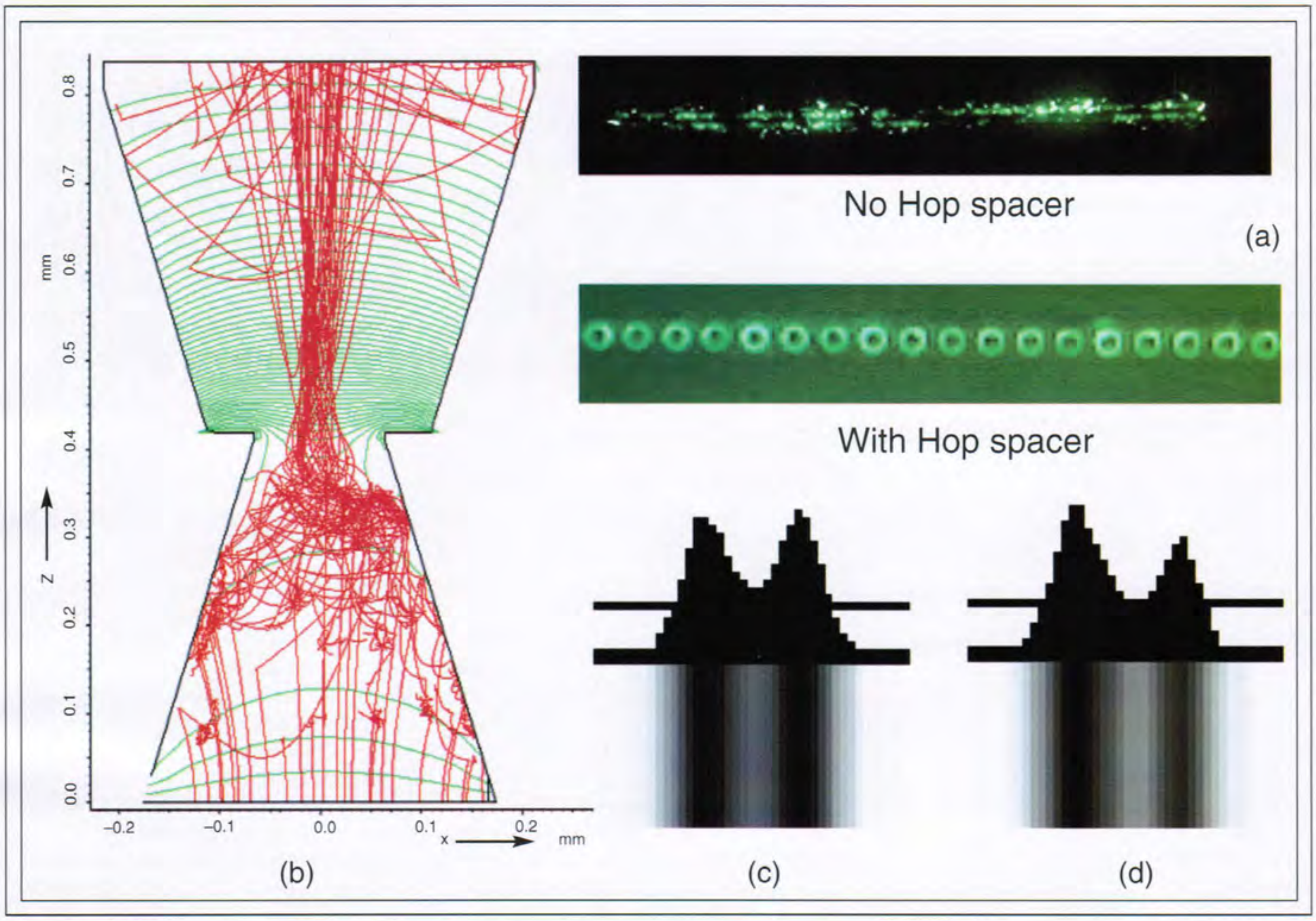

Fig. 6: When a hop-spacer plate is used, the uniformity of a line emission from printed CNTs is markedly improved. The pixel pitch is 1.2 mm and the exit hole of the hop funnel is 0.4 mm. The electron spots on the green phosphor have a ring-like shape (a). A computer simulation of the electric fields and electron trajectories in the hop and screen spacers shows how the technology produces its effect (b). A normal pixel spot profile is presented here as electron density, which corresponds to a ring-shaped spot (c). The spot profile of (d) comes from an emitter whose right half is not emitting, but the hop and screen spacers have made the pixel much more uniform.

ing the emitters from ion bombardment; the ledge formed at the exit of the hop funnel as shown in Fig. 3 blocks many of the ions formed in the screen funnel.

Computer simulations show that in a HOPFED only the center part of the cathode is bombarded by ions, so a ring-shaped cathode in the area below the ledge of the hop funnel is largely protected from ion bombardment.

Low-Capacitance Addressing

In a conventional FED, addressing is done line by line by applying appropriate potentials to the rows and columns. The capacitance between the gate and the cathode leads is usually quite high because of the small distance of 3–10 μm between the gate and cathode, so the capacitive losses associated with addressing the panel are rather large.

In a HOPFED, the distance between the gate or cathode and the hop electrode is about 0.4 mm, which is about two orders of magnitude greater than the distance between gate and cathode. This results in low-capacitance addressing, which facilitates pulse-width modulation at low gray levels because the short pulses necessary to render low luminance levels require a low capacitance.

Only about 40 V is required on the hop electrode to switch the beam from off to on. If the driving voltage is less than 60 V, relatively inexpensive drivers can be used.

The HOPFED Project

A project was started in 2001 at LG.Philips Displays to develop the design and process for manufacturing a HOPFED. This project had a lot of partners, notably Southeast University in Nanjing, China, but was halted in 2003 because LG.Philips Displays believed it would take too long to begin mass production and to climb the learning curve in view of the long lead enjoyed by LCDs and PDPs in the FPD-TV market. The development of the HOPFED technology will be continued at Southeast University. ■

Too Big for Roads

The SID 2004 Business Conference described an industry that is buying manufacturing equipment too big to be transported on roads, pursuing R&D of Gen 9 manufacturing systems, and developing cellular telephones that will receive television.

by Joe Hallett

THE second annual SID Business Conference was held on May 24, 2004, at the Washington State Convention and Trade Center in Seattle, Washington, preceding the 2004 SID International Symposium, Seminar, and Exhibition.

The conference repeated last year's success in Baltimore, having 705 attendees this year compared with 404 at last year's inaugural meeting. The conference was organized by its founder, Elliott Schlam (Elliott Schlam Associates).

Following greetings by SID President Shigeo Mikoshiba, the Business Conference followed last year's format, with industry experts expressing their opinions and presenting their data. The full-day non-stop program included panel discussions with the speakers. The program also featured a box-lunch panel discussion, consisting of panelists Matt Smith (Analyst, CIBC), Josh Epstein (Investment Banker, C. G. Cowen), and Alexander Wong (Partner, Apax Partners), in which the "investment climate and future prospects in the public and private markets" were discussed.

Bruce Berkoff (Executive Vice President, Marketing, LG.Philips LCD) presented the keynote address, "Flat, Digital, and Resolution That Will Knock Your Socks Off: The Future of Displays." Berkoff posed the question, "With the various FPD technology solutions that have emerged, which technologies will survive, and what new technologies and uses will be dominant in the future?"

He went on to observe that there are "three changes in the TV market: analog to digital, standard definition to high definition, fat to flat." In addition, from a product perspective, a TV "has to look as good off as on!" Television is presenting us, Berkoff said, with an incredible opportunity: the "largest market for FPDs is just beginning." But he carefully made the point that smaller screens will be part of the mix. "Big-screen TV isn't the only opportunity. There are more than 100 million headrests in 50 million cars this year."

Hang-Ping D. Shieh (Director of the Display Institute and AU Optronics Professor,

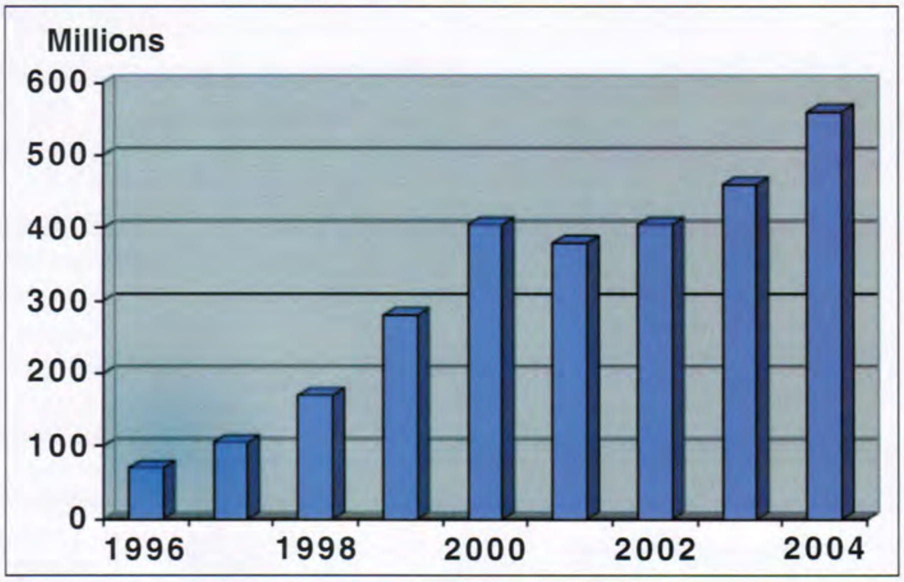

Fig. 1: In his SID Business Conference presentation, Nokia's Antti Lääperi noted that cellular-telephone sales are again growing at a healthy rate. (Data courtesy of Merrill Lynch, February 2004; figure from Nokia.)

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National Chiao Tung University and Co-Principal Investigator of Taiwan's Display Science and Technology Large-Scale National Project) opened the main part of the conference with "Flat Panel Display Roadmap in Taiwan." Shieh described the evolution of Taiwan's electronics and display businesses, and outlined the island's current need to recruit more technical, sales, and marketing personnel.

In the period from 1998 to 2003, when the focus was on developing TFT-LCD panels and components, Taiwan invested $12 billion. From 2001 to 2003, seven Gen 4 and 5 lines were built, and the manufacture of display components has become a major industry in Taiwan, where planning and government support have helped grow clustered businesses. In 2003, Taiwan's share of the worldwide market for large panels exceeded 35%, which was behind Korea's 45.2%, but substantially ahead of Japan's 19.1% (estimated data from IEK-IT IS, July 2003). Shieh expects Taiwan's share of worldwide TFT-LCD revenue to exceed 40% in 2004.

From 2003 to 2006, Taiwan plans to invest $15 billion for Gen 5.5 through Gen 7 TFT-LCD fabs, OLED and PDP capabilities, and local production of materials and components, Shieh said. The interest in domestic production of materials and components stems from the fact that these items account for about 70% of panel cost. In response to a question from the audience, Shieh said that the use of "local components will be about 80% in 2004."

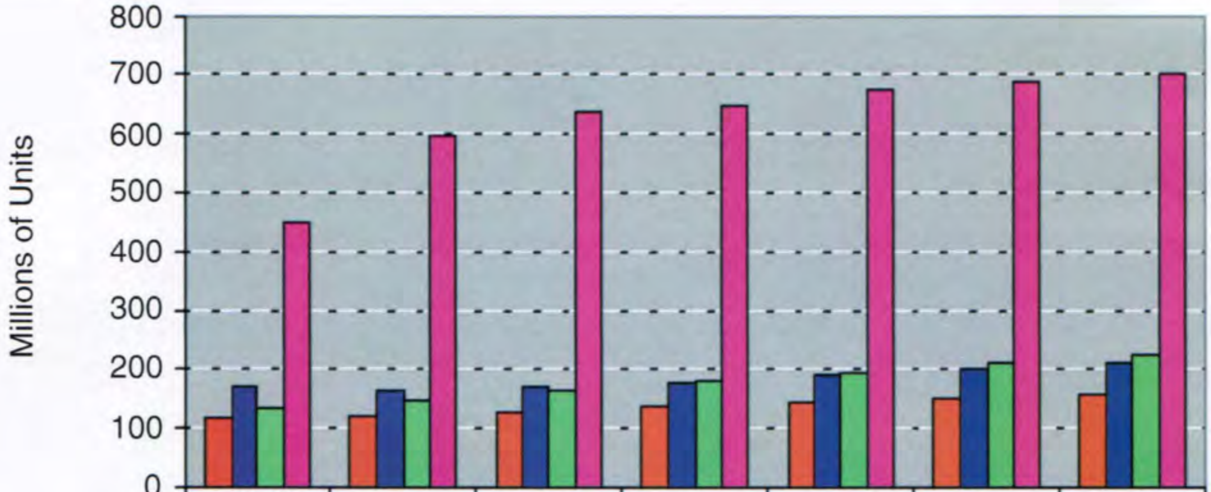
Peter L. Bocko (Division V.P. and Director of Technology Strategy for Corning Incorporated's Display Group) discussed Corning's major investments to expand its production of AMLCD glass, and described Corning's fusion-forming process. In response to a question about plastic substrates, Bocko predicted that glass would be the primary material for at least ten years. "Plastics are inevitable but way out [in time] ... and Corning technology will be available," he said.

Paul A. Breddels (Executive V.P., Liquid Crystals Division, Merck KGaA) said, "With the spectacular growth of the LCD industry over the last two decades, the business unit of Liquid Crystals within Merck has rapidly grown from a small R&D unit to an important industrial division."

He observed that Merck first offered liquid-crystal materials for sale 100 years ago. They were withdrawn for a while because of lack of market interest! Now, Breddels announced, Merck KGaA will make a €250 million investment in a new LC-production facility at Darmstadt to support industry needs for LC television. "It is Merck's largest-ever single investment," he said.

Small Is Beautiful ...

Although the Business Conference was dominated by coverage of large flat panels, Antti Lääperi (V.P., Audio-Visual Product Technologies, Nokia) reminded the audience that small displays also are undergoing explosive growth (Fig. 1). Personal handheld communications devices, such as cellular telephones and PDAs, have changed our culture and its



	2002	2003	2004	2005	2006	2007	2008
Desktop Monitors	117	119	128	135	143	151	158
TVs	169	164	170	177	191	201	210
PCs	131	147	165	180	196	209	227
Mobile Phones	451	596	635	650	676	690	702

*Excludes sub-displays. All segments shown represent panels, on the panel timeline.

Fig. 2: *The four leading flat-panel-display applications – monitors, TVs, laptop PCs, and mobile telephones – together account for one billion units, and they are expected to reach 1.3 billion units by 2008. (Courtesy of DisplaySearch.)*

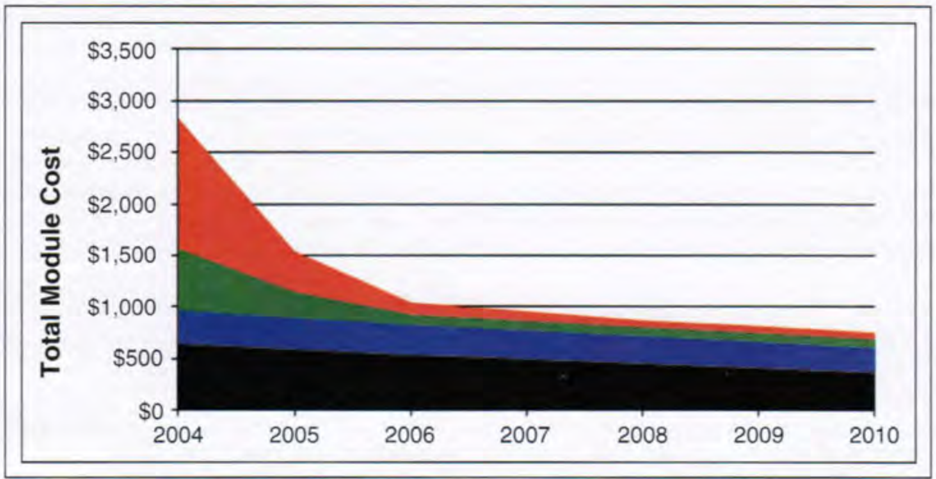


Fig. 3: The cost of a 50-in. 1365 × 768-pixel PDP module will drop dramatically between now and 2010, said iSuppli's David Mentley. The costs are for modules manufactured 2-up on a 1200 × 1400-mm glass substrate. Red indicates fixed costs; green, other variable costs; purple, electronics; and black, display materials. (Copyright 2004 iSuppli Corp.)

ways of doing business ... not a trivial result of display technology.

In "The Present and Future of Handheld Display Appliances," Lääperi said, "Mobile telecommunication is moving toward multimedia. Cameras, Internet browsers, and wideband communications channels, together with gaming applications, will play a key role in the future handheld-display marketplace."

The inclusion of cameras in cellular telephones increases display requirements. Images are likely to be saved in the telephone for later viewing, and image quality is important. As a result of this and other market pressures, the black-and-white display is "gone," he said. Lääperi went on to ask, "Will cellular telephones with cameras become so good that they will replace tiny pocketable still cameras?"

What about OLEDs for cellular telephones? "OLED image sticking has to be solved," said Lääperi. "AMLCDs will dominate for as long as I can see."

... And So Is Big

Thomas T. Edman (President and CEO, Applied Films Corp.) was more than bullish in "The FPD Capital Equipment Investment Environment." "Driven by growth in the LCD-monitor and LCD-TV end markets, the major (Korean and Japanese) TFT-LCD manufacturers are planning unprecedented levels of investment ... in new facilities processing ever-larger substrate sizes," Edman said. He said that "2004 will be a huge year for FPDs" and that "2005 business is projected to fall ... some 2004 business may be delayed because of smoothing."

The issues range from higher throughput and lower capital costs to pressure on delivery and 24-hour service. "Eighty percent of equipment is sold to the active-matrix business," Edman said, and "customers are looking to increase the size and throughput of substrates. Now, R&D is up to Gen 9."

"Gen 7 equipment is truly large equipment," he continued, "too big for roads. It will require manufacturing close to customers."

Ross Young (President, DisplaySearch) presented the case for TFT-LCDs to displace CRTs as the dominant technology in the overall display market. Over one billion units will be produced this year, he said, as the TV, monitor, PC, and mobile-telephone markets all converge to TFT-LCDs at the same time (Fig. 2). Young expects LCDs to dominate the display market through the end of the decade. TV should be the largest market segment in 2008, with roughly one-third of the total LCD business, as growth rates flatten for all segments except TV, he said. For rear-projection TV, Young expects microdisplays to overtake CRTs in 2006.

There are alternatives to LCDs, of course, at least in some market segments. In "Emissive Display Market and Technology Trends," David E. Mentley (Senior Vice President, iSuppli/Stanford Resources) said, "Although LCDs now dominate in terms of revenue, investment, and mindshare, other types of displays are still attracting attention."

Mentley noted differences in the cost structure of LCD modules – which typically include many refined (value-added) components – compared with that of emissive displays such as plasma-display panels (PDPs) that typically do not have such components. He also noted that PDP costs are expected to drop below one dollar per square inch (factory cost) in 2006 (Fig. 3).

In "Manufacturing Big Screen LCD TVs," Jun Souk (Executive V.P., Samsung Electronics) discussed manufacturing issues for LCD panels larger than 30 in.; presented Samsung's view of the TV market as "volatile, competitive, turbulent, and uncertain"; and described the competition between LCDs and PDPs.

Souk defined Gen 6 as 1500 × 1850 mm, with an emphasis on 26–27-in. displays, and Gen 7 as 1870 × 2200 mm, with an emphasis on 22–46-in. displays. He projected that the manufacturing-cost "gap" between LCDs and PDPs would continue to become narrower with the availability of larger Gen 7 glass substrates, and concluded, "LCDs will dominate the TV market!"

Larry F. Weber (former President and CEO of Plasmaco, a subsidiary of Matsushita) had an alternative point of view in his presentation, "Plasma Displays for the Digital Home Theater Market." Weber, well-known as a pioneering developer of plasma-display technology, noted that the PDP is celebrating its 40th anniversary. He sees the characteristics of plasma displays as uniquely suited to HDTV. "PDP technology should be the TV display technology of choice above 40 in. on the diagonal, sharing the market for 30–40-in. sizes, with the LCD dominating below 30 in.

"There is a synergy of HD and plasma," Weber said. "At a typical TV viewing distance of 10 ft. with a [minimum discernible] 1-mm pixel size, a 50–70-in. display is needed." Observing that a full 1920 × 1080 resolution is the ultimate goal for home theater, Weber cited Samsung's 80-in.-diagonal HDTV panel as evidence that PDP technology is ready to meet the challenge.

"Booming of OLED Business" was the talk presented by Ding-Chang Wang (President & CEO, RiTdisplay Corp.), who addressed the outlook for OLEDs in handheld devices and mobile-display applications. Wang noted OLED applications in automotive audio systems, clamshell cellular telephones, and MP3 audio players, and suggested that new applications are evolving where fashion and style are important. "Overcoming the competition from LCDs is now the key issue for future business development." But the business is growing. The anticipated output of the major OLED manufacturers is greater than 60 million units in 2004 and greater than 100 million units in 2005, Wang said.

"Projection Television Market Overview" by Vincent F. Sollitto (President and CEO, Brillian Corp.) addressed "technologies, channel dynamics, issues, and innovations" for the growing HDTV marketplace. "HDTV is the hot market," said Sollitto. "Consumers are confused by too many good choices. They are buying what they see, and brand loyalty is less important."

Elliott Schlam (Elliott Schlam Associates) completed the formal presentations with "New Disruptive Display Technologies." Schlam suggested that despite the huge consumer markets controlled by mainstream display technologies, there are opportunities for lesser-known technologies to have a significant impact. These opportunities generally relate to display size, ambient viewing conditions, and cost, in both consumer and non-consumer markets.

Schlam described large LED displays as an under-recognized segment of the display industry. These displays are expensive arrays of tiled modules that are fully readable in sunlight. "The presence of large-screen displays is more extensive than most realize. Very-large-screen displays – well over one million billboards in the U.S. – represent a multi-billion-dollar potential market."

A concluding panel of speakers agreed that standardization of substrate sizes is difficult because display manufacturers use panel configuration to differentiate their products. The situation is further complicated by rapid evolution through new generations of panel sizes, now at Gens 7 and 7.5. As an aside, it was noted that panel-processing equipment has become so large that the height of local highway bridges can determine where a glass-processing factory should be built. The panelists also agreed that while "the applied part" of their business may be located close to customers, core technologies will remain close to home in technology centers.

Looking Forward

The first two SID Business Conferences have helped establish a broader awareness of the display industry as a significant part of the global electronics business. From this reporter's perspective, it would be beneficial to increase the focus on growth opportunities and trends within the industry that could have substantial commercial repercussions within a 5–10-year window. For example, it would have been interesting if the tremendous strides made by "electronic paper" and the increasing significance of electronic signage – both demonstrated on the SID 2004 exhibit floor – had received comparable emphasis in the business overview. Perhaps next year, when the Business Conference will be expanded to more than one day, these topics can receive coverage.

One strong impression from this conference is that things do not stay "new" very long. TV on the wall and the "Dick Tracy wristwatch" are now products instead of science-fiction staples. It is hard not to feel that parts of our industry – after decades of dynamic growth – are finally settling down to become a maturing big business. For someone who has been around this industry for a while, that requires a mental readjustment. ■

SID Recognizes Outstanding Achievers at 2004 Symposium

High-efficiency LEDs, liquid-crystal molecular alignment, and sublimation-transfer imaging media were among the scientific and technical advances recognized by this year's individual awards.

by Stephen P. Atwood

ALTHOUGH we often associate great technological achievements with the companies that market them, it is always leading individuals within those companies that create the technologies. That is why every year the Honors and Awards Committee of the Society for Information Display, with the approval of the Board of Directors, awards a few of those in our industry who have made truly outstanding contributions. The Committee selects the award winners from a list of nominees submitted by the SID membership. As observed by SID President Shigeo Mikoshiba, the achievements can take the form of research and discovery, entrepreneurial success, or outstanding service to the Society and the display industry as a whole. The 2004 awards were presented at a celebratory dinner on the evening of May 24 in Seattle.

This year, the **Karl Ferdinand Braun Prize**, along with a $2000 stipend provided by Thomson, was awarded to ***Shuji Nakamura*** "*For his pioneering inventions of high-efficiency blue, green, and white gallium nitride light-emitting diodes for full-color large-area outdoor displays and LCD back-lighting.*" Prof. Nakamura developed the first group-III nitride-based blue/green light-emit-

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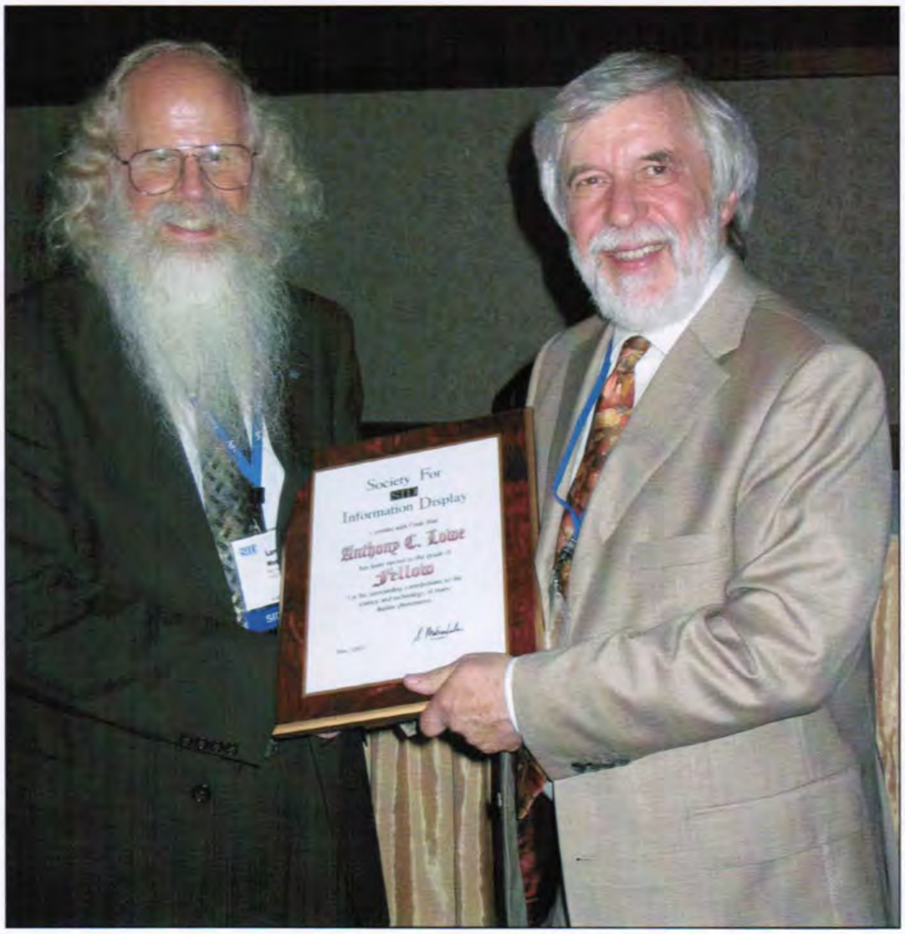

New SID Fellow Tony Lowe receives his plaque from Honors and Awards Committee Chair Larry F. Weber.

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Shuji Nakamura, winner of SID's 2004 Karl Ferdinand Braun Prize.

Tatsuo Uchida, winner of SID's 2004 Jan Rajchman Prize.

Masaki Kutsukake, winner of SID's 2004 Johann Gutenberg Prize.

ting diode (LED), as well as the first group-III nitride-based violet laser diodes (LDs), during his long tenure (more than 20 years) with Nichia Chemical Industries, Ltd. He is currently Professor of Materials and Director of the Center for Solid State Lighting and Displays at the University of California at Santa Barbara.

Prof. Nakamura thanked the awards committee and delighted the audience with an interesting talk on the many and varied uses of LEDs, including special lighting for growing plants whose requirements are limited to specific wavelengths of red and blue light. LEDs may be ideally suited to this and similar applications.

Prof. Nakamura also received a SID Special Recognition Award in 1996. He holds more than 100 patents and has published more than 200 papers in this field.

The **Jan Rajchman Prize**, along with a $2000 stipend provided by the Sharp Corporation, was awarded this year to ***Tatsuo Uchida*** *"For his outstanding contributions to the science of liquid-crystal molecular alignment and high-performance LCD technology."* Prof. Uchida's career has spanned almost 30 years of outstanding research at Tohoku University, where he holds the title of Professor in the Department of Electronics in the Graduate School of Engineering. His research areas have included the physical properties of liquid crystals, non-emissive displays, and optoelectronic devices.

When introduced, Prof. Uchida said there was "no greater honor than to receive this award today." He then described some of his many achievements, including a paper he published in 1981 describing an approach for additive color rendering. At the time, he said, the proposal was criticized for its power consumption and inefficiencies resulting from light absorption. Now, almost all color LCDs use this approach. Among his significant discoveries was a solution that improved the transmissive properties of reflective LCDs.

Prof. Uchida has received many honors, including the SID Special Recognition Award in 1988 and the SID Best Paper Award in 1990. He is a Fellow of the SID and a board member of the SID Japan Chapter.

The **Johann Gutenberg Prize**, along with a $2000 stipend provided by Hewlett-Packard, was awarded this year to ***Masaki Kutsukake*** *"For his development of high-quality sublimation-transfer imaging media and their commercialization."* Kutsukake-san joined Dai Nippon Printing Co., Ltd., in 1976 and began the development of the sublimation-transfer imaging media in 1983. Since that time, these

SID Honors and Awards Nominations

See page 54 of the August issue

Nominations Due October 8, 2004

e-mail: sidawards@sid.org

media have been adopted by several companies for video printer systems. As an ever-active researcher, he is now engaged in the development of new displays at the Dai Nippon Printing Research & Development Center.

This year, for the first time, the Johann Gutenberg Prize was sponsored by both the Society for Information Display and the Society for Imaging Science and Technology (IS&T).

The **Lewis and Beatrice Winner Award** for distinguished service was awarded this year to ***Jay Morreale*** *"For his outstanding service to the publications and conferences of SID."* He began working with SID in 1980 when he became involved in the management of the Society's annual symposium. In 1981, he became Managing Editor of the *Proceedings of the SID* – now the *Journal of the SID* – and of *Information Display* magazine in 1990. Jay is a well-recognized and much-appreciated face at many of SID's major events.

Jay is currently Director of Publications at Palisades Convention Management, Inc., and SID Symposium Coordinator, a position which he has proudly held for the past 20 years.

SID Fellows

Six members of the Society were awarded the grade of Fellow in recognition of their outstanding qualifications and experience as a scientist or engineer in the field of information display.

- ***Dr. Jean-Pierre Boeuf*** for his outstanding contributions to the research and development of plasma displays, especially by computer simulation of the gas discharge.
- ***Mr. Arlie Richard Conner*** for his inventive contributions in the field of liquid-crystal displays and for the development of low-cost lightweight liquid-crystal projectors.
- ***Dr. Katsumi Kondo*** for his pioneering contributions to in-plane-switching TFT-LCD technology, leading to the first commercialization of LCDs with intrinsically wide viewing angles.
- ***Dr. Anthony C. Lowe*** for his outstanding contributions to the science and technology of many display phenomena.
- ***Mr. Masataka Matsuura*** for his outstanding contribution to the research and development of active- and passive-matrix color liquid-crystal displays and for his leadership in the display community.
- ***Mr. Kouji Suzuki*** for his outstanding contributions to the research and development of thin-film-transistor liquid-crystal displays.

Special Recognition

The Society also gave several Special Recognition Awards to members of the technical and scientific community, not necessarily SID members, for distinguished and valued contributions to the field of information display.

- ***Mr. Hsuan Bin Chen*** for his outstanding entrepreneurial accomplishment in the management of a major TFT-LCD manufacturer.
- ***Dr. George W. Dick*** for his pioneering invention of the three-electrode plasma display which enabled commercial color plasma displays.
- ***Mr. Toshihiro Komaki*** for his outstanding contribution to the improvement of color-plasma-display performance by invention of the waffle rib structure.
- ***Mr. Robin Merrifield*** (shared with Louis D. Silverstein) for his outstanding efforts in the conversion of commercial airplane flight decks from mechanical instruments to color CRT displays, while maintaining safety of flight under all lighting conditions.
- ***Dr. Louis D. Silverstein*** (shared with Robin Merrifield) for his outstanding efforts in the conversion of commercial airplane flight decks from mechanical instruments to color CRT displays, while maintaining safety of flight under all lighting conditions.
- ***Dr. Haruhiko Okumura*** for his pioneering research and development of driving technology for liquid-crystal displays, especially the overdrive technique to reduce motion artifacts.
- ***Mr. Dan J. Schott*** for his sustained technical contributions to the development, design, and manufacture of liquid-crystal displays.

In closing, Dr. Weber thanked the hard-working members of his committee, and he also expressed gratitude and appreciation to Thomson for sponsoring the $2000 stipend included with the Braun Prize, to Sharp Corporation for sponsoring the $2000 stipend included with the Rajchman Prize, and to Hewlett-Packard for sponsoring the $2000 stipend for the Gutenburg Prize. ■

To the Editor

One of the best sources for the history of laptop computers, as well as the flat-panel-display industry, is *Electronic Display World* (*EDW*), a newsletter that was founded in 1981 and published by Stanford Resources in San Jose, California, until 2000. I served as Editor-in-Chief of the publication until 1996.

Recently, I persuaded iSuppli Corp. – the current owner of Stanford Resources – to donate the entire set of printed issues to the Smithsonian Institution's National Museum of American History in Washington, DC. We were able to create a complete set of Adobe print files so, at some point in the near future, all the issues will be available to the public on-line at the Smithsonian's Web site.

Unfortunately, we have been unable to locate the August and September issues from 1981. If any *ID* reader has one or both of these issues in his or her possession, or knows of a library that may have them, please contact me by e-mail at drjcast@aol.com. We can easily convert a printed copy to an electronic file and send it to Washington to complete the collection. Your help will be greatly appreciated.

Sincerely,
Joseph A. Castellano, Ph.D.
San Jose, California
drjcast@aol.com

To the Editor

In the February issue of *Information Display* magazine you wrote in your editorial about a visit that you made to Incotex in Moscow following the FLOWERS conference. It is unfortunate, but the story as told to you by Dr. Yuriy Sokolov had some serious omissions.

The plasma tile screens that Incotex is currently attempting to manufacture were actually developed by our company, MicS Ltd. (www.mics.msu.su). In 1999, we contacted Incotex to discuss a potential way for them to start the manufacturing of PDP tile screens based on our technology. Several months later we signed an agreement with Mr. Sokolov to found a new company, Polyscreen-S, to manufacture these PDP tiled screens based on our developments. As I write this letter, this history can still be found on the Incotex Web site (www.megholding.com/html/products/plasma.shtml) in the section entitled "Historical View."

Following the signing of this agreement, we transferred our technology to Incotex. Our key technologists then helped Incotex build the plant you visited, and they were instrumental in designing the production equipment.

Unfortunately, in 2002, Mr. Sokolov abruptly and unilaterally chose to terminate our participation and, we believe, to violate the contract that he had with us. Therefore, what you have written, based on [what] Mr. Sokolov [told you], does not, in our view, accurately reflect the origins and ownership of this technology.

The positive side of this is that since the termination of our participation in Incotex, we have developed a new generation of PDP tile screens that dramatically improve their performance. You can see the results of our work at "www.mics.msu.su" under the sign "New" in the "Products" menu.

Sincerely,
Alexandre Rakhimov, Professor,
Lomonosov Moscow State University
and Chairman of MicS, Ltd.
e-mail: arakhimov@mics.msu.su

Response

Incotex and Prof. Rakhimov have very different understandings of our past history.

At Incotex, we are very proud of our 32 patents in plasma-display technology, which provide independent confirmation of our contributions to the field. In 2005, we will be demonstrating dc plasma panels with a luminous efficiency several times higher than what we were able to show in the fall of 2003. We hope that you and other independent observers from Europe, the U.S., and Asia will be able to visit Moscow and see them for yourselves.

Best regards,
Dr. Y. Sokolov, Ph.D.
President of Incotex Holding

To the Editor

I would like to clarify some information in your March/April 2004 editorial.

I made MgO-coated PDPs while I was at IBM in 1970. When the first IBM PDP panels were introduced in 1973, they were MgO-coated, as were all subsequent IBM PDP products. This coating was implemented to protect the lead glass underlayer from excessive damage from sputtering in the ac discharge. Also, the high gamma of MgO reduced the panel firing voltages, which was an additional benefit.

In 1987, much of the IBM PDP manufacturing equipment and know-how was transferred to Plasmaco when IBM exited the PDP business. The MgO process and electron-beam deposition was also included in this transfer.

Regards,
Neil Poley
Lexington, Kentucky

Response

The editorial cited by Neil Poley reported on the Saga Forum held in December 2003, which celebrated the technical and educational contributions of Heiju Uchiike in the field of plasma-display panels. A speaker at the forum attributed the discovery that MgO is the most desirable dielectric layer for protecting the electrodes in an AC-PDP to Prof. Uchiike, which was repeated in the editorial.

– KIW

To the Editor

I read your recent editorial in the *Information Display* of March/April with some pleasant memories. I have met all of the personalities you mention.

With respect to efforts on the magnesium oxide coatings, I was disappointed that there was no mention of the extensive efforts at both Owens-Illinois and IBM. These efforts were nearly parallel and started in early 1970. I can attest to the effort at Owens-Illinois personally. O-I held the dominant patent in this area, which has long since expired. Of course, I do not wish to cast any shadow on the obvious effect and benefit that Prof. Uchiike has had on the field of plasma display.

I am retired from Electro Plasma, Inc., a continuation of the plasma business at Owens-Illinois.

Thanks for your continued fine reporting.

– Bernard Byrum

editorial

continued from page 2

much room in these segments for small-scale entrepreneurs anymore, except for the occasional clever IP developer who can sell his or her ideas to the major players.

That LCD and PDP manufacturing are big, maturing industries is no bad thing. It is essential if the benefits of flat-panel displays envisioned by the pioneers are to be incorporated in affordable and well-designed consumer products that reach a broad segment of the world's population. And the huge cash flow generated by these businesses permit the funding of display research at an unprecedented level. But if you grew up thinking of yourself as a revolutionary, it does take some adjustment to realize you are now king of the hill.

— KIW

We welcome your comments and suggestions. You can reach me by e-mail at kwerner@nutmegconsultants.com, fax at 203/855-9769, or phone at 203/853-7069. The contents of upcoming issues of ID *are available on the SID Web site (http:// www.sid. org).*

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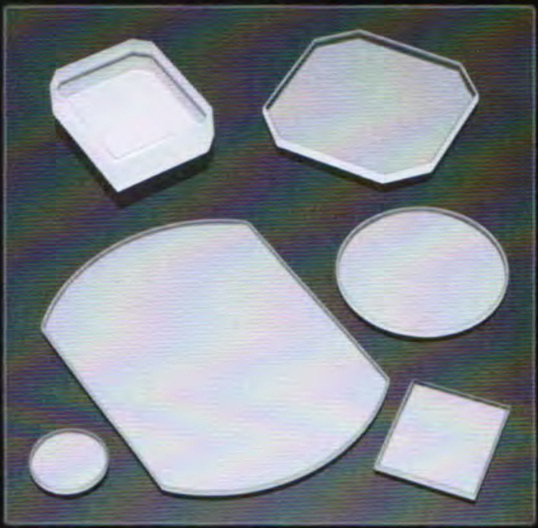

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which it said is "a major step towards the realization of reel-to-reel LCD manufacturing."

In addition, Philips reported, the changeover in the process has provided an extra benefit, one which is of great value for flexible-display applications. "Patterning the plastic foil with an adhesion promoter, applied by an offset-printing process prior to UV exposure, results in robust interconnects between the solid-plastic cover layer and the plastic foil, and hence a [more] robust display," according to the company. The change thus improves the paintable display's resistance to the stresses caused by bending, and these displays can endure a bending radius as small as 1 cm.

Philips's Paintable LCDs are just one approach among many in the worldwide quest to create flexible displays that can, at the very least, be bent once to conform to a nonplanar surface and, at the ultimate, be rolled up or folded and placed in our pockets. The quest includes participants in many companies, universities, and governments, and the approaches are quite varied, tapping into a range of flexible substrates, including plastic, thin metal foils, and superthin glass.

The goal of all these efforts is the same: to free designers of display-based products from the traditional constraints of rigidity. This, noted Philips, is often a severe disadvantage in product design. By allowing LCDs to be built from the bottom up on a single substrate, using sequential coating and UV-curing steps to create a functional LCD stack, Philips's revolutionary Paintable LCD technology opens up the possibility of creating LCDs that conform to curved and irregularly shaped surfaces.

Clearly, PES presents a most interesting possibility for passive-matrix LCDs on flexible substrates, but what about active-matrix variations? Philips also reported at SID 2004 that it has demonstrated active-matrix Paintable LCDs on glass substrates, noting that "it is anticipated that future implementation of plastic electronics will allow them to be produced on plastic substrates as well." ■

***David Lieberman**, a veteran display journalist living in Massachusetts, can be reached at davidlieberm@earthlink.net.*

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Painting Displays

by David Lieberman

There are not many research operations in the world that are responsible for as many display innovations as Philips Research Laboratories. And, historically, there are very few companies on the display scene that have been involved in so many types of display technologies as Royal Philips Electronics of The Netherlands.

Among the technologies demonstrated or discussed by the company at the latest SID International Symposium were a relatively large (13-in.-diagonal) OLED TV manufactured by ink-jet printing, an LCD capable of on-the-fly 2-D/3-D conversion, an active-matrix electronic-paper display from the company's strategic relation with E-Ink Corp., and impressive scrolling-color LCoS-based rear-projection TVs. Philips also demonstrated the latest version of its "Paintable LCD" devices, which appear to be almost ready for introduction.

In mid-2002, Philips Research first described its work on a new LCD-manufacturing technique it calls Photo Enforced Stratification (PES). This novel processing technique, the company claimed, "paves the way to cheaper, thinner, and lighter LCDs" with flexibility and a "free" form factor. According to Philips, the coating steps of the process are "comparable to painting," and can be performed on a variety of substrates, including plastic. The process enables "large paintable displays on walls or flexible displays integrated into clothing."

Where Philips's Paintable LCD technology differs from the norm is in the structure and manufacturing process. The liquid-crystal cells are encased by polymer walls and equipped with a polymer cap, resulting in FPDs that are not restricted to rectangular shapes and planar form factors. SiPix Imaging has achieved the same flexibility with its Microcup® electrophoretic displays. SiPix, however, forms its protective cells before the display material is applied, while Philips applies a mixture of materials at one time and then separates them by curing.

According to Philips, the "crucial" benefit of PES lies in its ability to fabricate LCDs without the cumbersome vacuum suction process. The PES coating and curing process, the company claimed, is "very suitable for manufacturing displays in a reel-to-reel process, the ultimate low-cost large-area manufacturing solution."

Philips's Paintable LCD is a single-substrate structure built with a series of coatings, and the LCD-cell-formation stage originally took three steps. In step one, a mixture of a polymer-forming material and liquid crystals was coated onto the substrate of choice; and then, in step two, the two materials were separated by the application of ultraviolet (UV) radiation. During the third step, "the complete layer is exposed, causing the formation of an LC layer on the bottom and a polymer layer on the top of the cells. By carrying out the irradiation in two steps, closed cells of liquid crystals are formed," Philips explained, with "rigid walls of polymer material making up the sides of the individual LC cells."

At SID 2004, the company explained that it had taken a new tack to the formation of the LCD cell in PES, representing a major improvement over its previous process. Philips has now replaced one of the previous two UV-exposure steps with "a much simpler and less-time-consuming offset-printing stage,"

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calendar

FPD International 2004. Contact: Nikkei Business Publications, URL: http://expo.nikkeibp.co.jp/fpd.
October 20–22, 2004 Pacifico Yokohama, Japan

11th Annual Symposium on Vehicle Displays. Contact: Mark Goldfarb, PCM, 212/460-8090 x202, fax -5460, e-mail: mgoldfarb@pcm411.com.
October 21–22, 2004 Canton, MI

First Americas Display Engineering and Applications Conference (ADEAC 2004). Contact: Mark Goldfarb, PCM, 212/460-8090 x202, fax -5460, e-mail: mgoldfarb@pcm411.com.
October 25–27, 2004 Ft. Worth, TX

The Fourth SIDMAC OLED Research & Technology Conference (OLEDs 2004). Contact: Mark Goldfarb, PCM, 212/460-8090 x202, fax -5460, e-mail: mgoldfarb@pcm411.com.
November 4, 2004 Park Ridge, NJ

12th Color Imaging Conference 2004. Contact: IS&T, 703/642-9090, fax-9094, e-mail: info@imaging.org.
November 9–12, 2004 Scotsdale, AZ

11th International Display Workshops (IDW '04). Contact: Niigata Visitors & Convention Bureau, e-mail: nvcb@nvcb.or.jp.
December 8–10, 2004 Niigata, Japan

International Display Manufacturing Conference & Exhibition (IDMC '05). Contact: www.di.nctu.edu.tw/IDMC05.
February 21–24, 2005 Taipei, Taiwan

SID International Symposium, Seminar & Exhibition (SID '05). Contact: SID HQ, 408/977-1013, fax -1531, e-mail: office@sid.org.
May 22–27, 2005 Boston, Massachusetts ■

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