LCD TECHNOLOGY ISSUE

Information DISPLAY

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The Magic Behind the LCD Blue Phase

POLYMER-STABILIZED BLUE PHASES

DISPLAYS KEY TO NETBOOK SUCCESS

INNOVATIVE DIMMING TECHNIQUES FOR LCDs

LCD-TV MAKERS GO THIN AND GREEN

EMERGING LCDs BASED ON THE KERR EFFECT

Plus
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December Contents

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The Photo Research SpectraScan product line is unique in that, unlike other instruments in their class, they are designed to address a wide range of measurement applications - the PR-730/735 is no exception. In addition to radiance / luminance measurements, the PR-730 / 735 can be equipped to measure irradiance / illuminance, radiant and luminous intensity and radiant and luminous flux.

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COVER: Blue-phase liquid crystals have been explored for several decades. However, their mesogenic temperature range was always too narrow for practical applications. But recently, this situation has changed when a small amount of polymer was embedded to stabilize the LC lattice structure. The research momentum for new blue-phase LCDs has been revitalized worldwide.

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editorial

A Plea for Clarity

by Stephen Atwood

It's hard to believe the year is almost over and soon the holidays will be upon us. Next month, all the analysts will be focusing on the early forecasts of retail sales and the display world will be buzzing with predictions about the 2010 business outlook. I love this season because it gives me an excuse to do "research" at all the local electronics stores and investigate all the latest gadgets. It remains fascinating to me how much innovation is ongoing and how many new ideas continue to flourish in the consumer-electronics space. However, with all the innovation and new technology also comes the potential for confusion. How do consumers compare competing products and how can they come to appreciate the benefits of each? I know this is not a new subject; in fact, I have written about it before, but it always seems to resurface around this time of year. I think we have all seen that manufacturers, in a never-ending effort to deliver the most appealing message to consumers, often resort to understandably simplistic but ultimately confusing branding or labeling.

This year the latest somewhat surprising product labeling is the trend of calling LCD HDTVs with LED backlights "LED TVs." No less than a half dozen of these types of TVs can be found on major electronic suppliers' Web sites and only when you read a more detailed description of the product will you appreciate that it is LC technology with LED backlighting. I doubt most consumers will investigate the fine print, so the effect is basically to create another virtual product category in their minds. Whether this is a serious problem probably depends on your perspective. Certainly, LCD TVs with LED backlights have numerous performance advantages but they also still have some of the same properties as conventional LCD TVs. Changing the name does not change the technology. Of course, when you look at the issue from the manufacturer's point of view, it's clearly a challenge to create a four-word description of the new TVs that is succinct but still technically accurate. More than four words in a product name, and it runs off the shelf label and maybe past the attention span of a non-technical consumer. Terms like "Plasma TV," "LCD HDTV," "Dynamic Contrast LCD TV," *etc*., are clear and concise. "LED-Backlit Wide-Color-Gamut LCD HDTV" is clearly over the limit. The issue gets more confusing when we look forward to the coming generation of organic LED (OLED) TV products entering the marketplace. When this happens, I fear significant confusion could prevail for consumers trying to understand the distinction between OLED and LED, which is, in fact, significantly greater than the one letter in the name.

A similar issue involves the various specifications manufacturers regularly quote as headline differentiating features. Some of these claims are difficult to appreciate in context and often have value only for grasping headlines. Contrast ratio is one of these cases. The "contrast ratio" stated on data sheets and store TV displays is almost universally the dark ambient contrast; *i.e.*, it does not include any of the effects of ambient room lighting on the image. Clearly, a display with higher intrinsic contrast will produce a wider range of luminance levels, but that may have little bearing on how good the picture looks in the user's actual home environment. Only a fair and balanced specification on ambient reflectivity can indicate this. Unfortunately, and once again in fairness to the manufacturers, in the absence of an accepted standard, trying to educate consumers on the interaction between reflectivity, ambient, and effective contrast would be a challenge. So, therefore, the question is: what does the

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OPTIS Introduces New Color LCD Modeler and 3-D Textures Application

OPTIS, a lighting simulation software developer with headquarters in France, has introduced two new products created specifically for the display-design market. SPEOS Color LCD Modeler is a simulation program designed for the prototyping of color LCDs. The 3-D Textures application allows for more accurate simulation of light from LEDs or other sources as it is redirected from a display backplane.

"A challenge for display manufacturers," says OPTIS Sales and Marketing VP Pete Moorhouse, "is to optimize the brightness and legibility of display panels as seen by the human eye, while also reducing the energy required for illumination, and in some cases reducing the number of light sources and therefore the weight of the product." Digital prototyping programs can help display manufacturers optimize designs while also reducing the number of physical prototypes they have to build. Since such prototypes take time to make and can end up costing thousands of dollars each, simulation programs also have the potential to greatly reduce R&D cycles and costs. "Some designers have been able to reduce the number of physical prototypes to one from six or seven," says Moorhouse. In addition, he notes, designers using OPTIS products have been able to reduce the number of LEDs in a product – from six or eight to three in a cell-phone display, for example.

OPTIS works with manufacturers of displays of all sizes, from cell phones to large screens, says Moorhouse, "but especially where optimization of backlighting is critical." The company's core light-simulation program, SPEOS, has been on the market for many years and has been used by manufacturers both in and out of the display business as a standalone or CAD-integrated program. The new product, the SPEOS Color LCD Modeler, is specifically made to model color LCD screens.

The SPEOS Color LCD Modeler can model displays with up to 16 million colors (256) gray levels. It allows for the modeling of nematic and chiral-nematic LC phases, as well as ferroelectric properties and TN and STN effects. It also handles retardation or compensation optical films, such as for touch-screen applications.

The 3-D Textures application is available as part of SPEOS integrated with the SolidWorks CAD programs CATIA and Pro/ENGINEER. 3-D Textures allows designers to create tens of millions of modeled points on optical surfaces, enabling a more accurate simulation of a backlight unit for a display, which is typically textured with up to millions of microscopic polymer "pyramids" that are placed on the backplane to redirect or diffuse light.

The combination of the new color-LCD-panel modeler and the backlight simulation tool will allow designers to deliver a "100% physically true representation of any LCD display," claims Moorhouse.

Both products were introduced in mid-October. Among the customers already employing OPTIS display simulation software are LG Display, Samsung, and Hyundai.

— Jenny Donelan

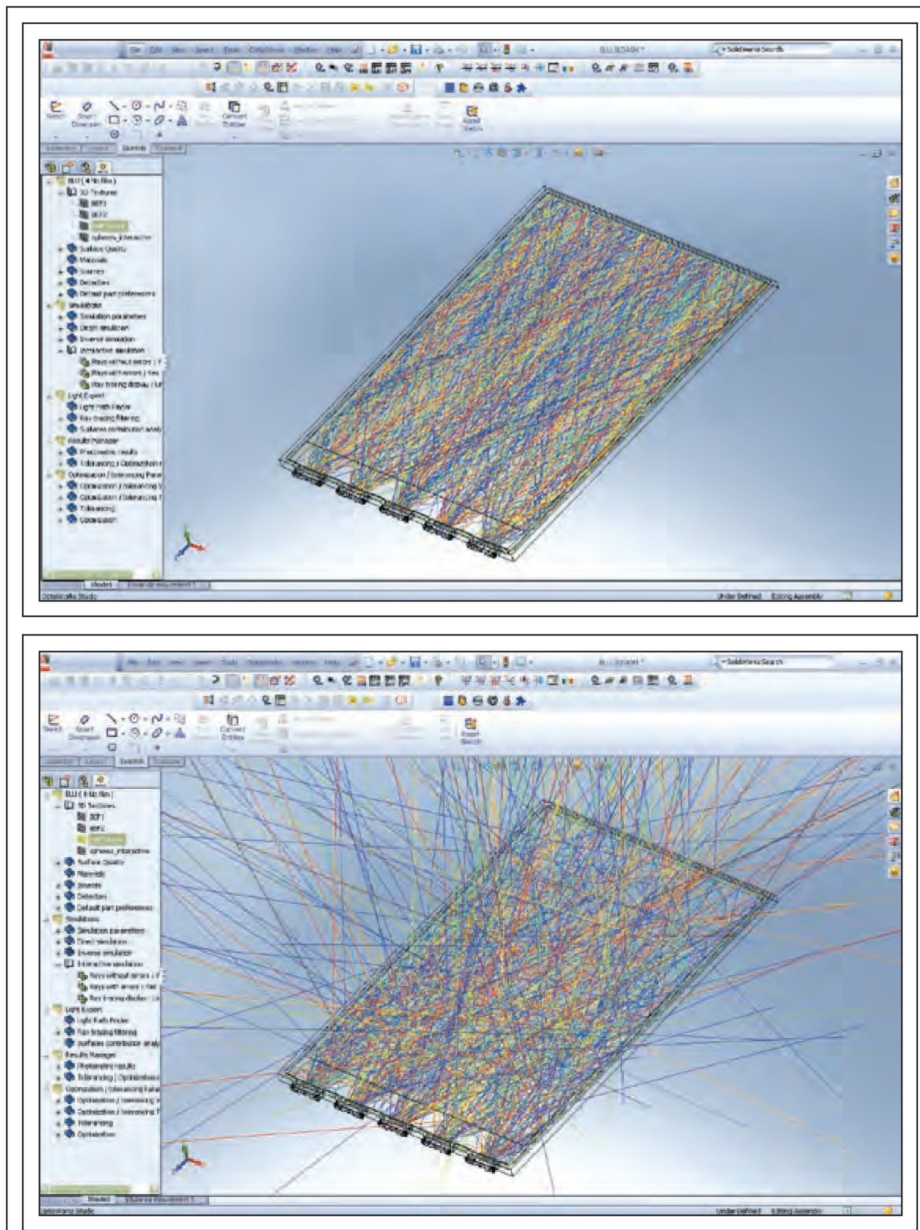

***Fig 1**: The panel not optimized by 3-D Textures (top) transmits much less light than the optimized version (bottom).*

Next-Wave LCD Technology

by Shin-Tson Wu

After more than three decades spent proving concepts through active research and device development, followed by massive investment in manufacturing technology, the thin-film-transistor liquid-crystal-display (TFT-LCD) industry finally took off and is now dominating the flat-panel-display business. Nowadays, LCDs have become indispensable in our daily lives, their uses range from cell phones, video games, and navigational devices to notebook computers, desktop monitors, large-screen TVs, and data projectors.

It seems as though LCD technology is fairly mature. The most critical issue – viewing angle – has been solved to an acceptable level using multidomain structures and optical-film compensation. The next most frequently mentioned shortcoming – response time – has been improved to 2–5 msec or less through low-viscosity LC material development, overdrive and undershoot voltage methodology, and the thin-cell-gap approach. Motion-image blur has been significantly reduced by using impulse driving, frame insertion, and fast-response liquid crystals. The color shift at oblique viewing angles has been dramatically reduced by using an eight-domain approach *via* two transistors. The contrast ratio has exceeded 1,000,000:1 through LED-backlight local dimming. The color gamut would exceed 100% NTSC if RGB LEDs were used. Even with all these technological advances, the cost has also been reduced dramatically through investment in advanced cost-effective manufacturing lines. So what is next? That's a very good question.

One promising advancement involves blue phase, a type of liquid-crystal phase that appears in a very narrow temperature range (1–2°C) between the chiral-nematic and isotropic phases; its molecular structure is made up of double-twist cylinders arranged in a cubic lattice with periods of ~100 nm. For this special LCD issue of *Information Display*, I invited Prof. H. Kikuchi of the Institute for Materials Chemistry and Engineering, Kyushu University, to write a review paper for general readers so they can have a glimpse of the microscopic blue-phase structures, polymer-stabilized blue phases, and their basic electro-optic properties. A second paper from my research group delves into device physics and macroscopic behavior of the electric Kerr effect from a display-device viewpoint.

Blue-phase liquid crystals have been explored for several decades. However, their mesogenic temperature range was always too narrow for practical applications. But recently this situation changed when a small amount of polymer was embedded to stabilize the LC lattice structure. The polymer-stabilized blue phase showed a reasonably wide mesogenic temperature range, covering room temperature. The research momentum for new blue-phase LCDs has been revitalized worldwide.

At the voltage-off state, the blue-phase liquid crystal appears optically isotropic. As the voltage increases, the induced birefringence increases based on the Kerr effect and the LC refractive-index distribution becomes anisotropic. When the device is sandwiched between two crossed polarizers, the transmittance gradually increases as the voltage increases.

In comparison to conventional nematic LCDs, polymer-stabilized blue phase exhibits four revolutionary features:

(1) It does not require any alignment layer, such as polyimide or inorganic SiO_2, which not only simplifies the manufacturing processes but also reduces the cost.

(2) Its response time is in the submillisecond range, which helps to minimize the

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California Is at It Again!

Paul Drzaic
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One of the unintended consequences of the rise of flat-panel televisions has been a sharp jump in the amount of electricity used to watch television. The biggest factor is the size: larger flat-panel screens have more area to light up compared to smaller CRT screens. Efficiency also plays a part. According to the California Energy Commission (CEC), on average, LCD televisions currently use about 17% more energy than CRTs on a unit-area basis, and plasma displays use over 50% more energy per unit area. The growth in sizes and in consumer demand has led California to estimate that about 10% of its residential electricity consumption (almost 9 GWh/year!) is tied to televisions or their peripherals.

The CEC is poised to adopt rules that would require new televisions sold within the state to dramatically reduce their energy consumption. Beginning January 1, 2011, new televisions sold in California can consume no more than 1 W in standby modes and must consume less than 32 W + 0.20 W × square inches of screen area. On January 1, 2013, the limits tighten to 32 W + 0.12 W × square inches of screen area. Screens 58 in. and larger will be exempt for a few more years, a temporary exemption designed to avoid negatively impacting the home-theater providers within the state, which typically deal with very large screens.

As you might expect, there has been much hue and cry about these standards. The Consumer Electronics Association, in particular, strongly condemns the rules, claiming that they will increase prices, cost jobs within the state, generate a black market for older technology, and constrain choices for consumers. On the other hand, several companies have come out strongly in favor of the new standards: PG&E (which has to provide energy for California), 3M (which manufactures energy-saving display films), and Vizio (a major flat-panel television retailer), all endorse them.

The CEC notes that numerous LCDs and a few televisions on the market already meet these standards (although currently the majority do not). Anyone paying attention to technology discussed in recent SID Symposia and publications knows that reduced power usage is an ongoing trend for LCDs and for plasma displays. Moreover, spokespeople for plasma displays promise that technology is being readied that will dramatically increase plasma-display efficiencies quite soon. So, it is not impossible for the industry to meet these goals, but a matter of choice.

My view is that as a whole the flat-panel industry can and should embrace these rules. Regulations like these do work – California electricity consumption per capita is half the U.S. national average, due to the past introduction of energy-efficiency standards in multiple other areas. All industry segments, including displays, need to be focusing on efficiency for sustainability. This kind of conservation is necessary to significantly reduce greenhouse gas emissions in the near future. Finally, let's be a little self-serving. Energy efficiency can provide good justification for the early replacement of inefficient televisions in a saturating market, and this is the direction that flat-panel R&D is taking us anyway. California, leading the way, could benefit us all. ■

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Blue Phases for LCDs Based on Isotropic-to-Anisotropic Transitions

Novel LCD materials with fast response times and no requirement for alignment by rubbing have recently been developed. The polymer-stabilized blue phases, which exhibit electric-field-induced transitions from an optically isotropic state to an anisotropic one, boost the response speed of electro-optic switching without surface treatment.

by Hirotsugu Kikuchi

LIQUID-CRYSTAL DISPLAYS (LCDs) are very popular and are considered mainstream for flat-panel displays (FPDs). Behind the recent prominence of LCDs lies a significant improvement in moving-image display technology, which has long been considered a significant disadvantage of LCDs as opposed to self-luminous displays such as plasma displays. However, although improvements have been realized through the use of liquid crystals with improved response times and with driving techniques such as overdrive and black-frame insertion, a complete solution has not been achieved. Because these complex driving schemes increase cost, there is a strong thrust toward improving the fundamental response times of liquid crystals.

An innovative liquid-crystal material whose speed is more than an order of magnitude greater than that of conventional LCD materials has successfully been developed; furthermore, alignment processes such as rubbing are not necessary with this material. In this article, the basic characteristics of innovative liquid-crystal materials, their display mechanisms, the present state of the art, and the challenges that remain will be discussed.

Hirotsugu Kikuchi is with the Institute for Materials Chemistry and Engineering, Kyushu University, in Fukuoka, Japan. He can be reached at kikuchi@cm.kyushu-u.ac.jp.

The Blue Phase

There are many liquid-crystal phases: among them, the nematic, smectic, and chiral-nematic phases are well-known. Essentially, nematic materials are the most widely adopted (we must use the word "essentially" because chiral-nematic liquid crystals are used in the TN mode to be exact). Promising materials for higher-speed applications include ferroelectric, anti-ferroelectric, and banana-shaped liquid crystals; all of them are smectic. The blue phase is another liquid-crystal phase, different from both the nematic and smectic phases. It is seen only in a very narrow temperature range between the chiral-nematic phase, which is characterized by a relatively

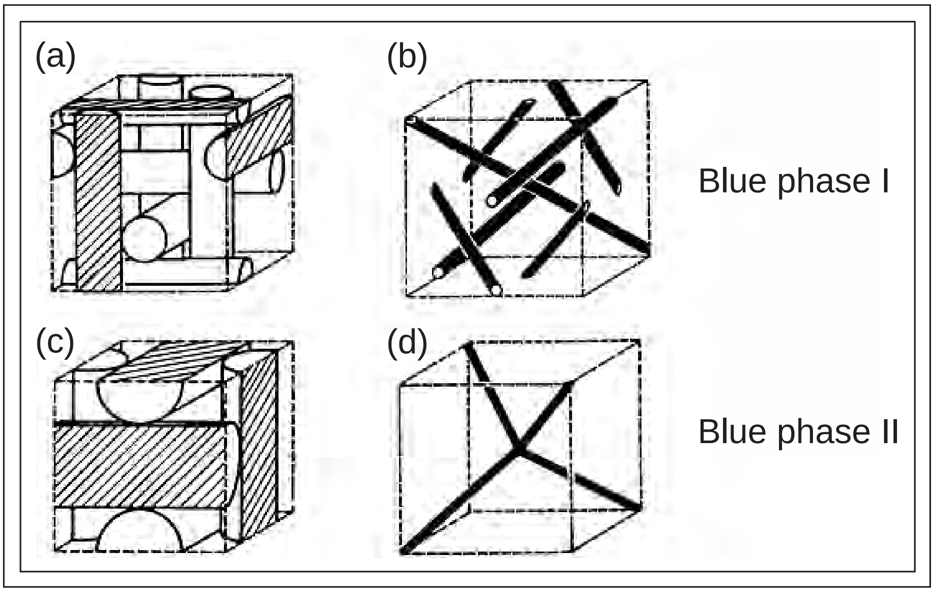

Fig. 1: This schematic illustration of the blue-phase structure shows blue-phase 1 [(a) and(b)] and blue-phase 2 [(c) and (d)].

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short helix pitch, and the isotropic phase. The blue phase has very singular characteristics [1-3]:

- It exists in a narrow temperature range (typically about 1°C).
- It is optically isotropic in the voltage-off state.
- It is optically active because it has Bragg reflections.
- There are three types, refered to as blue phase 1, blue phase 2, and blue phase 3 in order from the low-temperature side.
- Blue phases 1, 2, and 3 have body-centered cubic, simple cubic, and isotropic symmetries, respectively.
- The lattice constants of the unit cells of blue phases 1 and 2 are typically a few hundred nanometers, and the phases show Bragg diffraction in the UV–visible range. The term "blue phase" originates from the color of diffracted light; many actually appear bluish, but some do not.

The blue phase has a long history, beginning from when liquid crystals were first discovered in 1888, but the inner nature of this specific phase became clear only in the 1980s. The blue phase had long been left unnoticed, probably because of the very narrow temperature range in which it exists and its optically isotropic nature, which is unique in liquid crystals. In the 1980s, it became known that the phenomenon of frustration, a very new concept in liquid-crystal science, serves to bring forth the blue phase. Researchers then began to show more interest in and seek a better understanding of this phase. An important and basic characteristic of the blue phase is its complex 3-D hierarchical structure, which will be discussed in the following section.

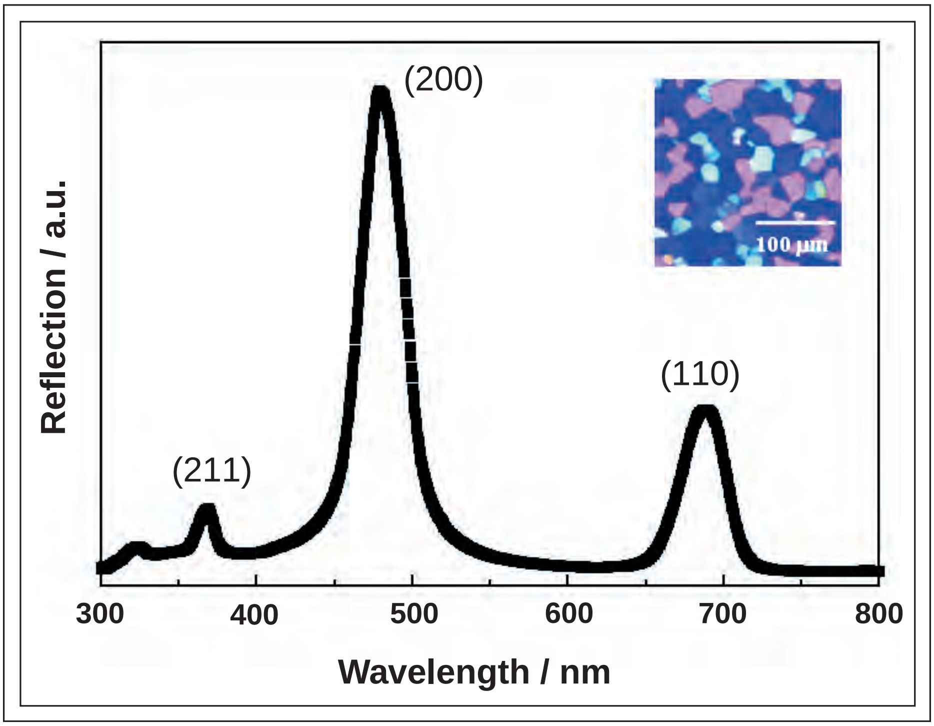

***Fig. 2:** The reflection spectra of blue-phase 1.*

Blue-Phase Structure

Both experimentally and theoretically, it is known that a blue phase forms a giant cubic crystal whose lattice constant is on the order of optical wavelengths (several hundred nanometers). A simple calculation indicates that there are 10^7 molecules in a giant, cubic unit lattice. The biggest problem encountered in the study of the blue phase in the 1980s was to determine how such a great number of molecules are aligned in the lattice. Figure 1 shows the currently accepted model of the blue-phase structure.

Figures 1(a) – 1(d) show the structures of blue phases 1 and 2, respectively.[1,2] Blue phase 1 has a body-centered cubic lattice structure and blue-phase 2 has a simple cubic lattice structure. The cylinders in Figs. 1(a) and 1(c) show double-twist cylinders, and the bold black lines in Figs. 1(b) and 1(d) show disclinations (defect lines). In each double-twist cylinder, molecules are radially twisted through 90°. The molecule is parallel to the cylinder axis at the cylinder center and is tilted by 45° against the cylinder axis at the outer radial periphery. In other words, the molecule is twisted from –45° to +45° from end to end. This corresponds to a quarter pitch (a 360° twist is one pitch). The diameter of a double-twist cylinder is typically about 100 nm, and a simple calculation shows that approximately 200 molecules with the molecular diameter of 0.5 nm are mildly twisted. The lattice constant for blue-phase 1 corresponds to one pitch of helix, and the lattice constant for blue-phase 2 corresponds to a half-pitch of helix. We generally see a very small mismatch in pitch length with that of the lower-temperature chiral-nematic phase. Peculiar to soft matter, a complex hierarchical structure is formed in a self-organized manner as a result of repetitively twisted molecular alignment. It is interesting to see that behind this structure is frustration between space topologies that smoothly connects the doubly twisted geometry and 3-D space. (Articles in referenced textbooks explain more about frustration.[1-3]) A disclination (a type of defect line), which stems from frustration, is formed as if it runs through the corner where the three double-twist cylinders orthogonally come close to one another. The symmetry in the disclination geometry is body-centered cubic in blue-phase 1 and simple cubic in blue-phase 2. It is estimated that the diameter of a disclination core is about 10 nm, and the inner molecular alignment is as disorderly as it is in the isotropic phase. Although details are not yet available, blue-phase 3 has also been identified; it is presumed that its structure is amorphous and that there is only doubly twisted short-range order.

Due to the very large periodic structure as discussed above, the blue phase exhibits Bragg diffraction in the UV–visible range. Blue-phase 1 exhibits diffraction from the planes (110), (200), (211), *etc.*, from the long-wavelength side, and blue-phase 2 shows diffraction from the planes (100), (110), *etc.* The following equation holds:

$$\lambda = \frac{2na}{\sqrt{h^2 + k^2 + l^2}}$$

Here, λ, n, and a are the incident wavelength, refractive index, and lattice constant, respectively, and h, k, and l are Miller's indices. For blue-phase 1, h, k, and l are even numbers. Figure 2 shows an example of the reflection spectrum of blue-phase 1; there are several reflection peaks, which is not the case for the chiral-nematic phase. Typically, the diffraction from the (110) and (200) planes in blue-phase 1 and from the (100) plane of blue-phase 2 are in the blue region, which is the origin of the term "blue phase."

For display applications, all diffraction wavelengths should be shifted out of the visible range. There are two methods to do so: changing the lattice constant and controlling the alignment. Here, an example is presented where the chiral-dopant concentration is controlled to decrease the lattice constant. Figure 3 shows the chiral-dopant concentration dependence of the diffraction peak from the (110) plane for blue-phase 1.

As the chiral-dopant concentration increases, the lattice constant decreases, and the diffraction peak shifts to the low-wavelength side. Because the diffracted light from the (110) plane has the longest wavelength, shifting it to the UV range eliminates the colored background in the visible range; the color is black under crossed polarizers.

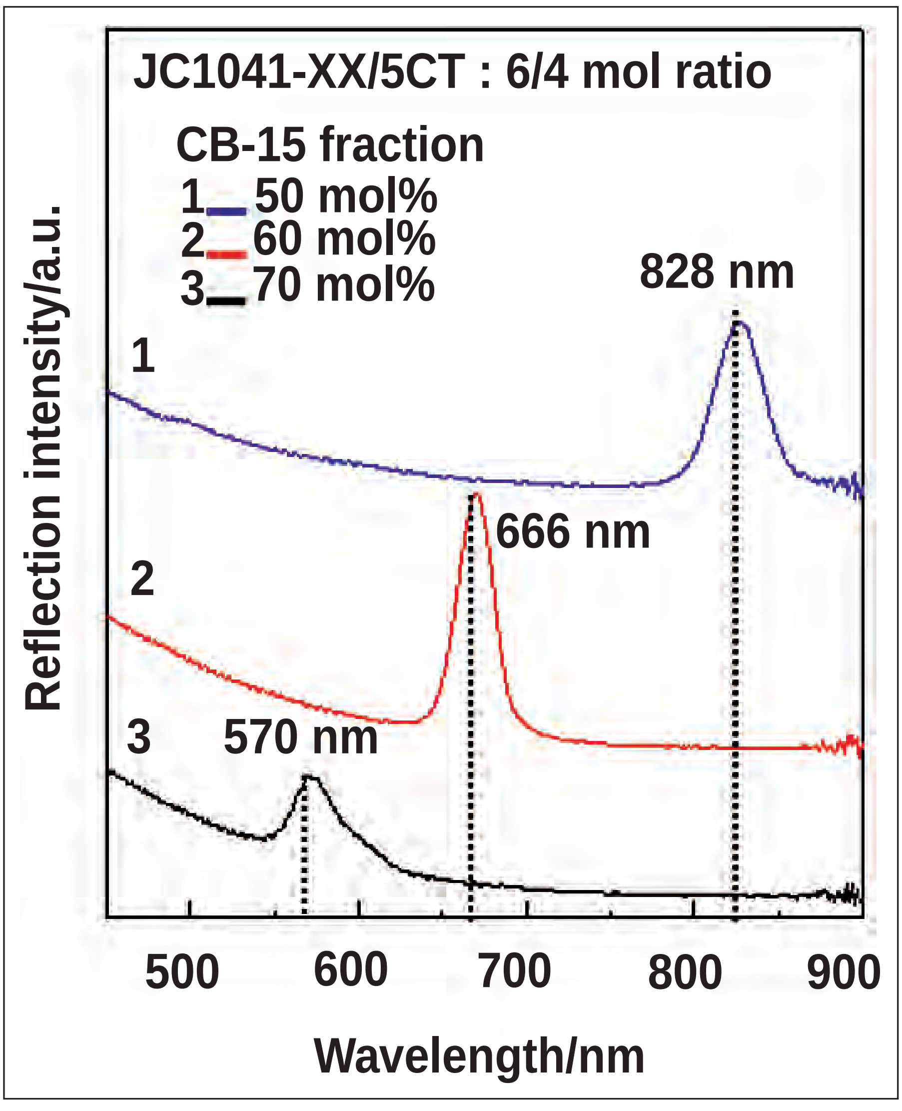

Fig. 3: *Shown is the dependence of chiral-dopant concentration in blue-phase 1 on the (110) reflection peak.*

Polymer-Stabilized Blue Phase

It has long been believed that the temperature range of the blue phase is too narrow. Today, however, many attempts have been made to solve this problem.

In 1993, Kitzerow *et al*. formed a blue phase with polymerizable liquid-crystal monomers; the monomers were polymerized in the blue phase, which immobilized the molecules, thus preserving the blue-phase structure in the solid resin.[4] In this type of material, although the characteristics of the blue-phase structure had been preserved, the dynamics of the liquid crystal had been lost because all of the molecules had been polymerized.

Then, in 2002, the authors reported that the temperature range of a blue phase could be increased to over 60°C by forming a small amount (7–8 wt.%) of polymers in the blue phase; the material was called the "polymer-stabilized blue phase" (Fig. 4).[5]

The molecular dynamics are not lost in the polymer-stabilized blue phase, and, moreover, the electro-optical response is very fast. It is believed that the polymers in the blue phase condense around disclinations, and the blue phase is stabilized when the disclinations are thermally stabilized.

In 2005, Yoshizawa *et al*. synthesized T-shaped liquid-crystal molecules and achieved a temperature range of 13°C for the blue phase.[6] These authors suggested that the biaxial nature played an important role.

In 2005, Coles *et al*. reported a temperature range as large as 44°C in the cooling process for a dimeric liquid crystal with strong flexoelectricity.[7] They suggested that flexoelectricity stabilizes disclinations. It is interesting, from an application standpoint, that in this system, the diffraction wavelength of the blue-phase lattice varies reversibly with the electric field.

As discussed above, technologies have recently been advanced in important ways to solve the problem of the narrow temperature range of the blue phase, and we now strongly believe in the prospective future of the blue phase.

Electro-Optical Effects and Driving Techniques

Because the blue phase is optically isotropic, a dark field under crossed polarizers occurs if the diffraction due to the lattice structure is shifted out of the visible range. The index ellipsoid is then an ideal sphere. Initially, therefore, there is no viewing-angle dependence originating from the liquid-crystal structure. However, when an electric field is applied, anisotropy or birefringence appears with the direction of the electric field as the optical axis. The index ellipsoid becomes an elongated ellipsoid stretched in the direction of the electric field if the dielectric anisotropy of the host crystal is positive. Conversely, we obtain a flattened ellipsoid contracted in the direction of the electric field if the dielectric anisotropy of the host crystal is negative. Therefore, the blue phase exhibits electric-field-induced birefringence of the type from which we can switch between optical isotropy and anisotropy, *i.e.*, from zero to finite birefringence with the application of an electric field. Induced birefringence is proportional to the square of the electric field at small fields. This type of electro-optical effect is significantly different from that in conventional liquid crystals, where the initial state is anisotropic and the optical axis changes with the electric field (see Fig. 5).

Electric-field-induced birefringence also exists in the polymer-stabilized blue phase and the polymer-stabilized isotropic liquid crystal, called the pseudo-isotropic phase. In the pure blue phase, *i.e.*, free from polymers, we see the local reorientation of molecules, lattice distortion, and phase transition as the electric field increases. But in the polymer-stabilized blue phase, the latter two effects are suppressed, and we only see the high-speed local reorientation of molecules.

To exploit electric-field-induced birefringence in display applications, we simply control the polarization of the incident light through the optical retardation produced by the induced birefringence, similar to the mode of retardation control used for IPS. As shown in Fig. 6, if a simple comb-shaped IPS electrode is used for the drive, the optical axis of the induced birefringence is parallel to the electric field, and the optical axes lie mainly in a plane perpendicular to the comb.

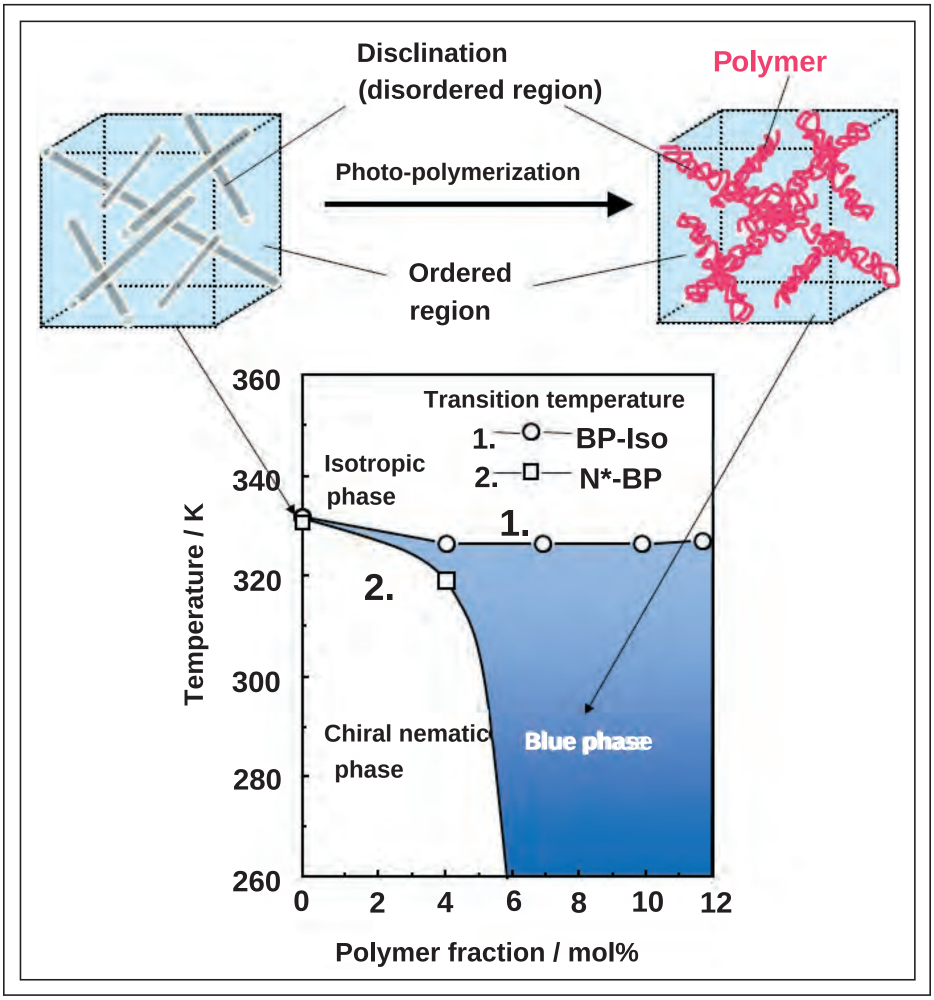

Fig. 4: *This schematic illustrates polymer-stabilized blue-phase 1 (PSBP1) and the aggregation state of polymers in PSBP1.*

Superiority to Competing Technologies

The optically compensated bend (OCB) and ferroelectric-liquid-crystal (FLC) modes are known modes used for fast-response LCDs. The OCB mode is characterized by bow-shaped liquid-crystal orientation, called the bend alignment, and can achieve switching times of less than 5 msec because of the small alignment change between the on- and off-states. The OCB-mode displays initially suffered from large transition times for switching from the initial splay mode to the bend-alignment mode, but the problem has been solved and the technology is now much closer to seeing practical use. The FLC mode is characterized by a switching speed of less than 1 msec and shows great potential. The key to its high speed lies in the tilt direction change caused by the inversion of spontaneous polarization in an FLC (such as chiral smectic C). But hurdles that remain include alignment handling and the stability of the alignment structure. Recently, a group led by Prof. Takezoe from the Tokyo Institute of Technology proposed a new high-speed LCD using the SmA-like phase of a banana-shaped liquid crystal, which achieves a fast switching time of about 100 μsec.

The polymer-stabilized blue phase and the polymer-stabilized isotropic phase also show unprecedented promise because of their overall merits: fast switching times (<1 msec), no need for alignment processing, and a wide temperature range.

Current State of the Art and Remaining Challenges

The most significant possible problem with

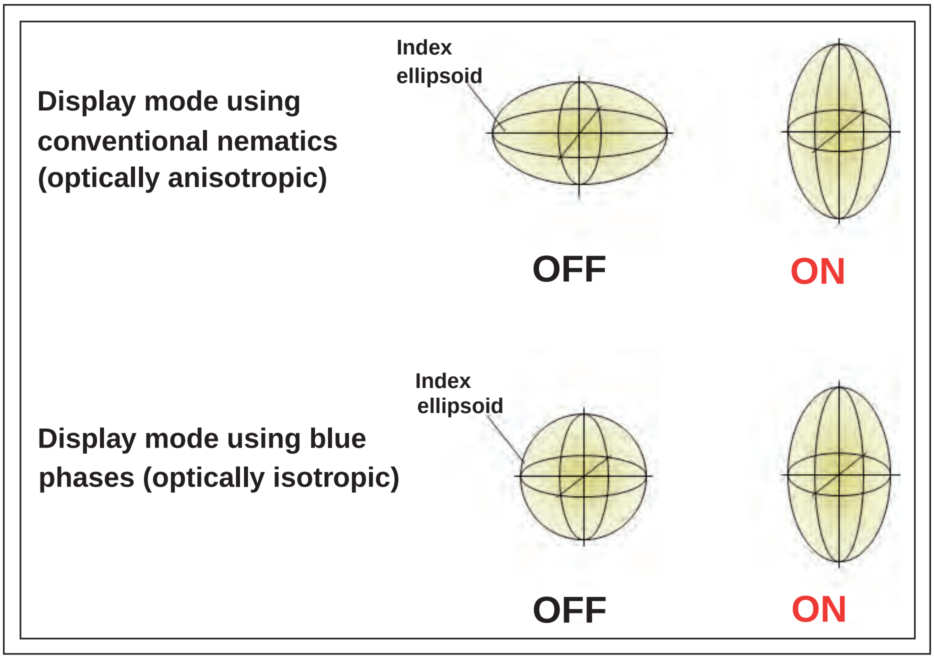

Fig. 5: Comparison of the electro-optic modes of conventional nematic LC and the blue phase.

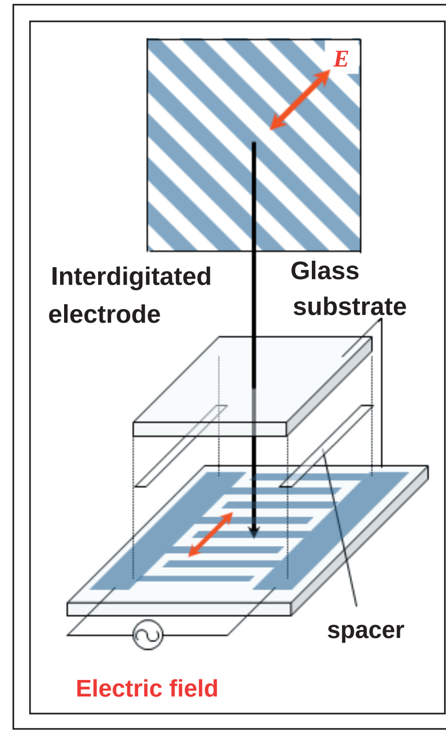

***Fig. 6:** Shown is a simple IPS electrode structure. Switching between the dark and bright states can be accomplished by switching the electric field on and off; the usual configuration is that the polarizing axes of the two (before and after) polarizers are orthogonal and the two axes are set 45° off the direction of the comb.*[8,9]

the polymer-stabilized blue and isotropic phases is the need for large driving voltages. The short correlation length in orientational order is the source of both the fast switching speed and the large driving voltage. In fact, several tens of volts are required across an electrode distance of 10 µm. Although by decreasing the electrode distance the driving voltage could be reduced, there would be a limit to the fabrication of small electrodes. The driving voltage of the polymer-stabilized blue phase depends on the dielectric anisotropy, birefringence, and elastic modulus of the host liquid crystal,[10] the fraction and structure of polymers, and the helical pitch (chiral-dopant concentration). Although there could be some other parameters, it is not easy to reduce the driving voltage to levels on the order of those used by conventional nematic liquid crystals merely through improvements in the material. It is very likely that improved electrode structures will be required for practical applications.

Residual birefringence will become a serious problem if the dielectric anisotropy and the birefringence of the host liquid crystal become greater. This is a phenomenon in which birefringence does not disappear after the electric field is applied and then removed. By improving the uniformity of the polymer network in the cell, the problem is partly, but not wholly, solved.

The light shield is an important factor in controlling display contrast. In the polymer-stabilized blue and isotropic phases, short-wavelength light is apt to leak through because, while diffraction and scattering occur mainly in the UV range, the longer wavelength tail is still in the visible range. This problem would not occur if the lattice constant and the correlation length of short-distance ordering are sufficiently small, but there is a trade-off with driving voltage.

Target Applications

Successful use of high-speed liquid crystals such as polymer-stabilized blue and isotropic phases in practice would lead to major improvements in LCDs. High-frequency driving would greatly improve the moving-image performance and reduce the effects of residual images.

Furthermore, higher speeds can lead to much lower power consumption. The field-sequential LCD, which is considered a promising future display system, drives the optical sources for the three primary colors in synchronism with the switching of the liquid crystals, thus realizing a full-color display without color filters. As a result, power consumption is considerably reduced simply because color filters, which absorb 70% of the backlight, are eliminated. No less important is the fact that higher-resolution images will be obtained because, by eliminating the color filters for RGB colors, the number of pixels per unit area could be increased threefold, and, further, the wiring could be simplified. A prerequisite for field-sequential LCDs is a more than threefold increase in speed, which cannot be realized easily with nematic crystals. Polymer-stabilized blue and isotropic phases allow for improvements of more than one order of magnitude over nematic crystals and are best suited to field-sequential-LCD systems.

Summary

Although both polymer-stabilized blue and isotropic phases have truly excellent characteristics, they have innate problems stemming from their structures and driving mechanisms, not to mention many as-yet unidentified factors. In the FPD industry, with excellent products and heated competition, the barrier for introducing an entirely new display mode could be considerably high. Under the circumstances, we greatly applaud the achievement of Samsung in demonstrating a blue-phase prototype panel. Although there is room for improvement in image quality, realizing a blue-phase TFT-LCD of significant size is an impressive step. In order to put the technology to practical use, an essential requirement will be cooperation among the various organizations in terms of the responsibility for materials, fabrication processes, device design, drive circuits, *etc.*

Acknowledgments

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Emerging LCDs Based on the Kerr Effect

Liquid-crystal displays based on the Kerr effect have recently been drawing attention due to their fast response time and simple fabrication process. Understanding the device physics through numerical modeling of this emerging LCD technology will play an important role in improving display performance as well as optimizing configurations.

by Linghui Rao, Zhibing Ge, Sebastian Gauza, Shin-Tson Wu, and Seung Hee Lee

THE Kerr effect, first discovered in 1875, is a type of quadratic electro-optic effect caused by an electrical-field-induced ordering of polar molecules in an optically transparent and isotropic medium. Liquid-crystal displays (LCDs) based on the Kerr effect are now emerging because they exhibit the following three distinct advantages: (1) the fabrication process is simple and cost-effective because it does not require any alignment layers, (2) the voltage off-state is optically isotropic, which means that the viewing angle is wide and symmetric, and (3) the switching time is in the sub-millisecond range. Therefore, the technology can be used for color-sequential displays without the use of color filters, resulting in a 3X higher optical efficiency and resolution – provided that RGB light-emitting diodes (LEDs) are used for the backlight.

Background

Some isotropic transparent substances, such as liquids and glasses, can become birefringent when placed in an electric field ***E***.[1,2] The Kerr effect differs from the Pockels effect (which occurs only in crystals that lack inversion symmetry, such as lithium niobate or gallium arsenide) in that the induced birefringence (Δn) from the Kerr effect is proportional to the square of the electric field instead of varying linearly. Because Δn cannot increase unlimitedly with the electric field, it can be written as[1–3]

$$\Delta n = \lambda K E^2 = (\Delta n)_o (E/E_s)^2, \qquad (1)$$

where λ is the wavelength, K is the Kerr constant, E is the applied electric field, $(\Delta n)_o$ is the maximum induced birefringence, and the induced Δn saturates at $(\Delta n)_o$ when the electric field E exceeds a saturation field E_s.

Recently, this square-law-dependence phenomenon has also been observed in liquid crystals (LCs), such as polymer-stabilized blue-phase (BP) LCs. Moreover, amazingly, its Kerr constant is ~5–6 orders of magnitude higher than that of CS_2. (The Kerr effect constant is on the order of 1×10^{-14} m/V^2). BP is a type of LC phase that appears in a very nar-

Fig. 1: *Samsung's 15-in. blue-phase LCD prototypes were shown at Display Week 2008 (left) and 2009 (right).*

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row temperature range (1–2°C), between the chiral-nematic and isotropic phases, with a molecular structure comprising double-twisted cylinders arranged in a cubic lattice with periods of several hundred nano-meters.[4,5] However, polymer-stabilized BP exhibits a fairly wide temperature range, including room temperature. As a result, novel LCDs based on the Kerr effect are possible; *i.e.*, displays in which the birefringence is induced by the electric field rather than from the intrinsic Δn of the LC.

Samsung unveiled the world's first polymer-stabilized BPLCD prototype at the Display Week 2008 exhibition, arousing awareness in the display field that a technological revolution could be emerging. With its fast response time, this BPLCD can offer more-natural-appearing moving imagery with an unprecedented image-driving speed of 240 Hz (Fig. 1) or faster.

However, with this type of novel LCD based on the Kerr effect, the operating voltage is still too high (>50 V_{rms}) to be addressed effectively by conventional amorphous thin-film transistors (TFTs), due to a fairly small Kerr constant of the nano LC composite (K~1–10 nm/V^2).[6,7] Besides, the optical efficiency of the LC device is only ~65–75%. Therefore, there is an urgent need to develop material and device concepts to overcome these problems.

Approaches to Challenges

The authors have recently developed a model[3,8] to simulate the electro-optical properties of LCDs based on the Kerr effect in in-plane-switching (IPS)[9] and fringe-field-switching (FFS) cells.[10] To achieve a high contrast ratio, a LC cell is sandwiched between two crossed linear polarizers. Without an applied voltage, the LC unit is optically isotropic, having identical refractive indices in its principal coordinates, which leads to a very good dark state. When a voltage is present, a strong electric field (***E***) from the IPS electrodes induces birefringence of the BPLC which changes the phase retardation of the incident light. The refractive ellipsoid will have its major optic axis aligned along the direction of the ***E*** vector.

Therefore, it is possible to first compute the potential distribution ϕ from solving the Poisson equation $\nabla(\nabla\cdot\varepsilon\phi) = 0$ and then the distribution of electric field ***E*** in the media. Based on the electric field, we further calculate the induced birefringence distribution Δn from Eq. (1) and assign the local optic-axis direction of each unit along the ***E*** vector. We confine the calculated birefringence from Eq. (1) to be below the intrinsic birefringence $(\Delta n)_o$ of the LC composite, and then compute, using an extended Jones matrix, the related electro-optical properties,[11] such as voltage-dependent transmittance and viewing angle. Therefore, the dependence of LC electro-optics on different parameters such as wavelength, electrode configuration, and cell gap can be explored, as well as potential approaches for reducing the driving voltage.

The LC birefringence $(\Delta n)_o$ relates to the wavelength through the following single-band model[12,13]:

$$\lambda K \approx G\frac{\lambda^2\lambda^{*2}}{\lambda^2-\lambda^{*2}} \qquad (2)$$

Here, λ^* is the mean resonance wavelength and G is a proportionality constant. In an experiment with an LC cell based on the Kerr effect in the FFS structure by Ge *et al.*,[3] researchers derived G ~ 8.78 × 10^{-3} V^{-2} for K ~ 1.27 nm/V^2 at λ = 550 nm. Recently, H. Kikuchi's research group at Kyushu University in Fukuoka, Japan, reported a K ~ 10 nm/V^2 at λ = 633 nm.[7] Correspondingly, the authors have arrived at G ~ 8.78 × 10^{-2} V^{-2} and K ~ 12.7 nm/V^2 at λ = 550 nm. Together with λ^* ~ 250 nm for E-7 type LC mixtures (Δn ~ 0.22) due to elongated π-electron conjugation,[12] we can calculate, by using Eq. (2), the Kerr constants for λ = 450, 550, and 650 nm to be K ~ 17.6, ~ 12.7, and ~ 9.9 nm/V^2, respectively.

Figure 2 shows the simulated *V–T* curves of a 10-μm IPS cell with electrode width *W* = 5 μm and spacing *L* =10 μm. The electrode strips are placed at 45° with respect to the transmission axis of the top linear polarizer. The transmittance in the plot is normalized to the maximum value from two parallel polarizers at each wavelength. The color dispersion for red, green, and blue is comparatively larger than that of the nematic IPS or FFS cell. In a conventional nematic IPS or FFS cell, the on-state LC profile consists of two connected TN cells with a reversed twist

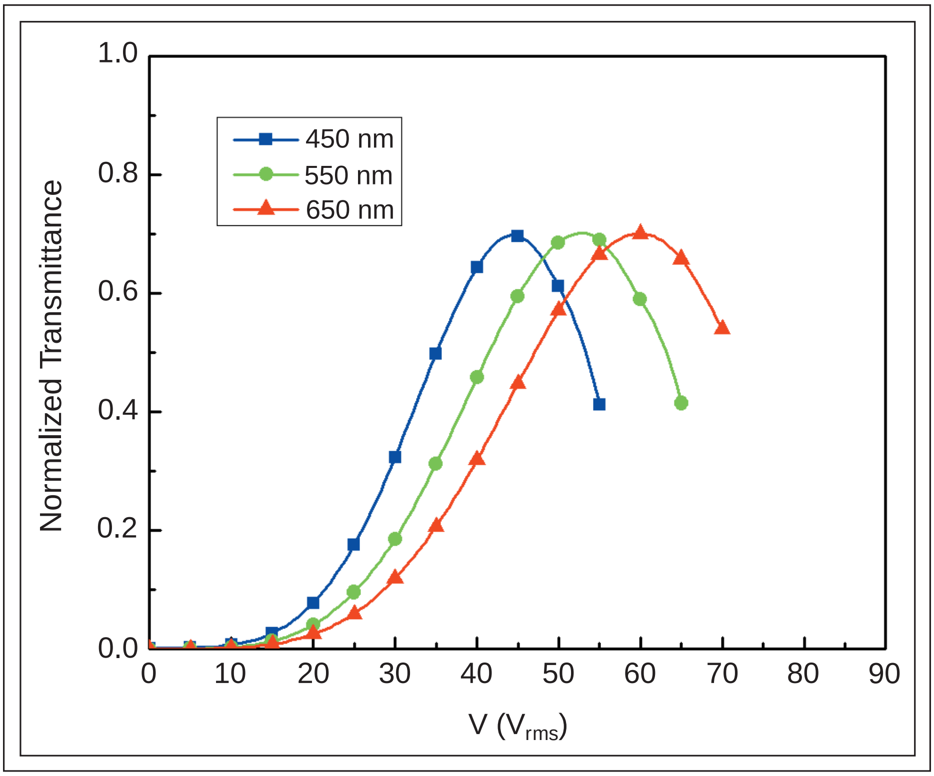


Fig. 2: *The graph shows the V–T curves of the BPLC in an IPS cell with cell gap d = 10 μm, electrode width W = 5 μm, and spacing L = 10 μm at R (650 nm), G (550 nm), and B (450 nm) wavelengths. Kerr constant K=12.7 nm/V^2 at 550 nm.*

sense; thus, this special two-TN-cell profile generates a self-compensation effect for wavelength dispersion.[14] But in the IPS BPLC cell, the transmittance originates from the pure phase retardation of the Kerr effect, similar to a vertical-alignment (VA) cell. A shorter wavelength has a larger K constant and then a larger $\Delta n/\lambda$ value; thus, the on-state voltage is lower. However, as opposed to the nematic VA cell, the induced birefringence (bright state) has a multi-domain structure originating from the electrical-field profiles. In an IPS cell, horizontal fields dominate between electrode gaps, while vertical components flourish above the electrode surfaces.[14] Because each locally induced birefringence also aligns with the electric field, the induced refractive ellipsoids in the whole cell will gradually align from a vertical to a horizontal direction starting from the electrode center to the electrode gap. This multi-domain profile leads to a more symmetric and wider viewing angle, as will be shown later.

As for the electrode effect, the induced birefringence Δn from Eq. (1) is proportional to E^2 and the optic axis of the ellipsoid is along the electrical-field vector $\boldsymbol{E}$. In an IPS structure, the electric field is horizontal between the pixel and common electrode and vertical above the electrodes. For the LC cell at 45° away from the polarizer's transmission axis, only the induced Δn from the horizontal electric fields contribute to the overall transmittance; *i.e.*, the high transmittance occurs between the electrodes. The incident light on top of the electrodes does not have any phase change because the optic axis of the refractive ellipsoid there is vertically aligned by the electric field. In a conventional nematic IPS cell, because the LC is a continuum material, the horizontal rotation of LC directors in the spacing area of the pixel and common electrodes will also produce a weak in-plane LC rotation on top of the electrodes and thus contribute to a weak light transmission, which eventually enhances the overall transmittance. However, in the IPS cell based on the Kerr effect, the viewing angle is more symmetric because the induced Δn above the electrode surfaces will act on the oblique incident light.

When it comes to the cell configurations in the electro-optics of the LCDs based on the Kerr effect, Fig. 3 shows the simulated *V–T* curves for cells in different *W/L* ratios (electrode width *W* to spacing width *L*), cell gaps, and Kerr constants (K_1 = 12.7 nm/V^2 and K_2 = 10K_1). Generally speaking, the cell gap affects the transmittance and response time in a conventional IPS cell. However, the transmittance does not significantly change with cell-gap variance, as we can see from the *V–T* curves for the electrode dimensions (W = 5 µm, L = 10 µm) and (W = 5 µm, L = 5 µm) with cell gap d = 5 and 10 µm. This is because the penetration layer thickness for the induced $\Delta n > 0.05$ at the spacing area is only ~0.1–0.2 µm.[8] As we know, the transmittance mainly comes from the contribution of the induced birefringence from the Kerr effect in the spacing area in between the electrodes. As long as the cell gap is larger than the fairly small penetrating depth in the vertical direction, the transmittance would not critically depend on the cell gap. The tiny shift may come from a passivation layer with a much smaller dielectric constant than the LC composite, which makes the electric energy more concentrated in the LC layer in a 5-µm cell rather than a 10-µm cell. For the electrode dimensions, a smaller electrode spacing usually leads to a stronger electrical-field intensity, which in turn results in a lower driving voltage. For example, in Fig. 3, the operating voltages of electrode configuration (W = 5 µm, L = 5 µm) are always lower than that of the dimension (W = 5 µm, L = 10 µm). Considering that only the regions between electrodes contribute to the transmittance, a larger L/W ratio favors the dimensions of (W = 5 µm, L = 10 µm) and (W = 2 µm, L = 4 µm) with L/W = 2 having higher transmittance than the dimension (W = 5 µm, L = 5 µm) with L/W = 1. However, the IPS cell with W = 2 µm and L = 4 µm exhibits a slightly higher operating voltage as compared to the cell with W = 5 µm and L = 5 µm. In an IPS cell, the electric fields generated from the bottom in-plane electrodes penetrate into the LC layer with a depth proportional to $W + L$, which is typical for a Poisson problem in the form of $\nabla^2\Phi = 0$. As a result, for two IPS cells with a similar electrode spacing width L, the one with a larger dimension ($W + L$) will have a thicker LC penetrating depth contributing to the induced Δn and thus a lower voltage is needed for the peak transmittance. If we compare the *V–T* curves of (W = 2 µm, L = 4 µm) at K_1 = 12.7 nm/V^2 and K_2 = 10K_1, the

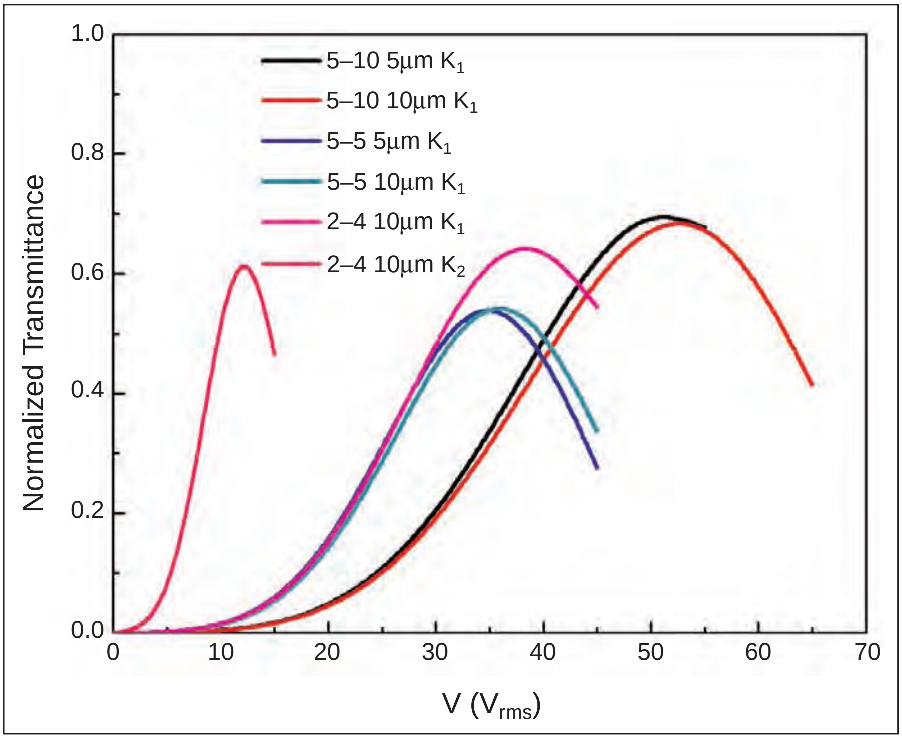


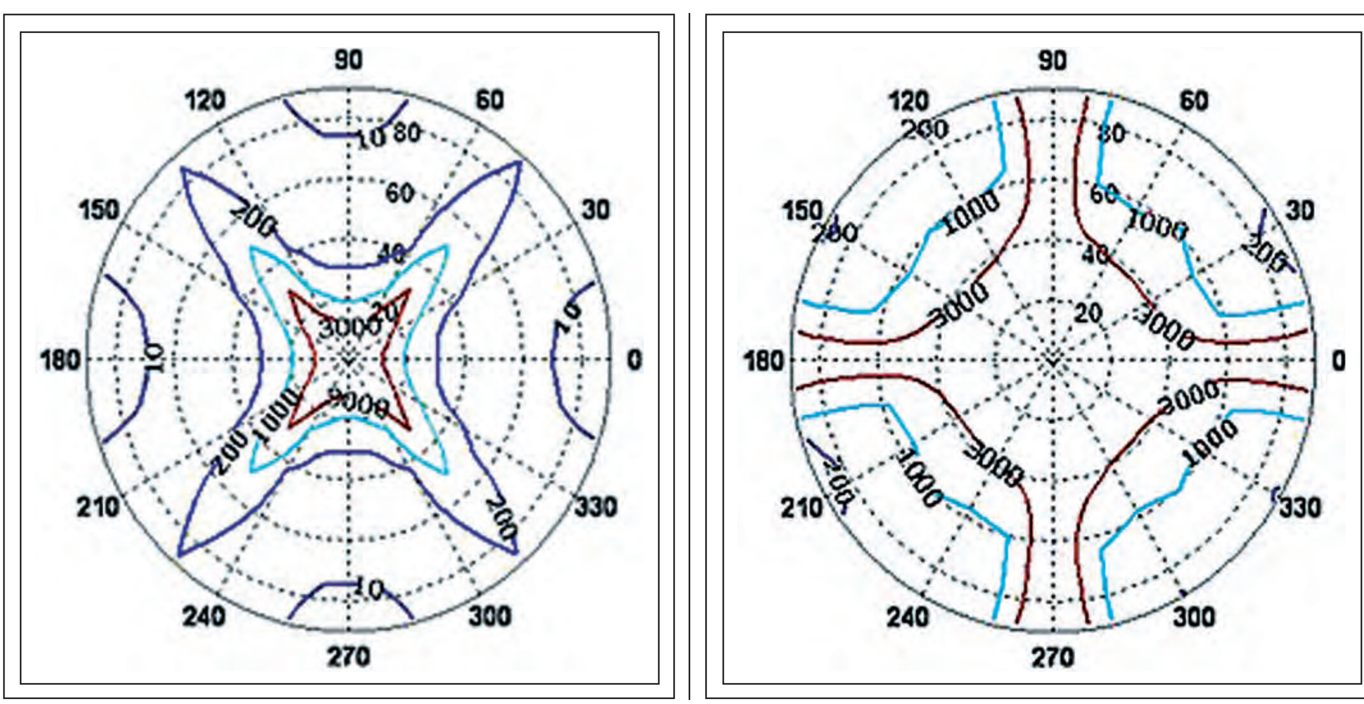
Fig. 3: *Shown are V–T curves with different electrode dimensions and Kerr constants at λ = 550 nm of the IPS LC cells based on the Kerr effect (K_1=12.7 nm/V^2 and K_2=10K_1).*

on-state voltage drops from ~40 V_{rms} at K = K_1 to ~ 12.5 V_{rms} by ~3.2X at K = $10K_1$. According to Eq. (1), we can estimate the operating voltage from the following relation: $V_1/V_2 \approx \sqrt{K_2/K_1}$. To reduce the driving voltage, an LC material with a higher Kerr constant, birefringence, and dielectric anisotropy would be a good choice.

The viewing angle of LCDs based on the Kerr effect is wide and symmetric. In the dark state, when no voltage is applied, the LC behaves like an optically isotropic material. Therefore, the light leakage occurs only at an off-axis incidence when two crossed linear polarizers appear to no longer be perpendicular to each other. For an on-state voltage, a multi-domain-like Δn profile is induced due to the electrical-field distribution in an IPS cell. Therefore, the iso-brightness contour of the cell is very symmetric, as shown in Fig. 4, for an IPS cell with strip electrodes (width W = 5 μm and spacing L = 10 μm) at λ = 550 nm. To compensate for the viewing angle, both uniaxial films and biaxial films can be employed to reduce light leakage in the dark state and to expand the viewing angle.[15] A contrast ratio of over 500:1 can be easily achieved for over 70°, as shown in Fig. 4(b), which is comparable to that of a conventional four-domain IPS structure.

To address the high-driving-voltage problem, some experts have also proposed a partitioned, wall-shaped electrode device structure driven with two TFTs to generate strong in-plane electric fields throughout the LC layer.[16] The ideal cell configuration is shown in Fig. 5(a). With this structure, the electric field intensity E remains the same throughout all the vertical positions of the LC layer. As a result, the uniformly distributed horizontal electric fields help reduce the required operating voltage significantly. LC cells in conventional LCDs are usually driven by AC voltage to eliminate image sticking. The conventional 1TFT driving scheme fixes the voltage of common electrodes at a certain value; *e.g.*, V_{on}, and then signals a change in the voltage of the pixel electrode from 0 to $2V_{on}$ in the dot-inversion driving scheme. Thus, the maximum possible voltage that can be applied to an LC cell (at V_{on}) is reduced to half of the TFT driver capability ($2V_{on}$). The proposed 2TFT driving method allows a separate control of pixel and common electrodes to maximize the possible driving capability of the IC driver. For example, when the potential of the TFT for pixel electrode is V_{on} (0 V), the corresponding voltage on the common electrode can be 0 V (V_{on}) to generate $+V_{on}$ ($-V_{on}$). In Fig. 5(b), the cell parameters are electrode width W = 5 μm, electrode gap L = 10 μm, and cell gap d = 10 μm (K = 7 nm/V^2). By simulating and comparing the results of (i) the conventional IPS device, (ii) the proposed device using partitioned wall-shaped electrodes with 1TFT driving, and (iii) the proposed device with 2TFT driving, the proposed structure (iii) shows an ~2.8× improvement in effectively reducing the operating voltage than the conventional IPS structure.

Thus far, we have investigated the device physics and analyzed, in detail, the LC electro-optics by numerical modeling. By using the correct concept, device structures can be optimized to reduce the operating voltage and further enhance the optical efficiency, just like the proposed partitioned wall-shaped electrode structure driven with 2TFT driving. On the other hand, employing a LC mixture with a larger Kerr constant is increasingly

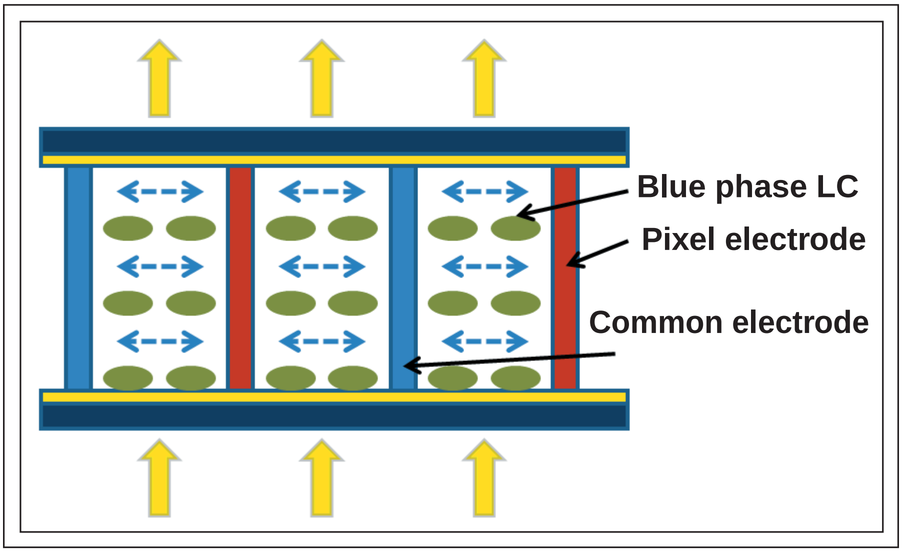


(a) (b)

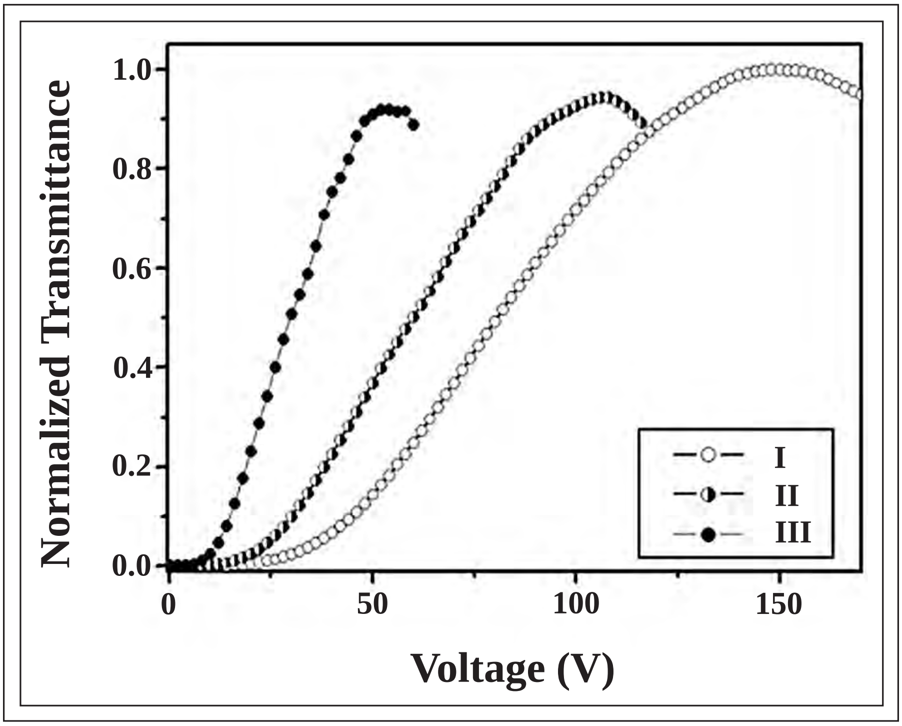
Fig. 4: *Simulated isocontrast plots appear (a) without any compensation film and (b) with a biaxial film with N_z =0.5, R_0 = (nx-ny)d = l/2. Cell configurations: d = 10 μm, W = 5 μm, L=10 μm, K=12.7 nm/V^2 at 550 nm.*

popular because the required electric-field intensity decreases as the Kerr constant rises.

LCDs based on the Kerr effect are attractive because of their fast switching time, very symmetric viewing angle, and ease of fabrication process without the need for alignment layers. If the challenges involving high voltage and low efficiency can be properly addressed, a new era of LCDs could be upon us.



(a)



(b)

Fig. 5: *At left, (a) shows a cross-section in which the glass substrates are connected (spaced apart) by conducting walls; red for pixel electrodes and blue for common electrodes. (b) shows (i) the conventional IPS device, (ii) the proposed device using partitioned wall-shaped electrodes with 1TFT driving, and (iii) the proposed device with 2TFT driving.*

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Adaptive Backlight Dimming for LCD Systems

Dimming technology has evolved dramatically over the last several years and is now enabling innovations in many LCD-based products such as TVs and monitors, which must continue to improve in terms of picture quality and energy efficiency while remaining cost effective. Although dimming is valuable for both CCFL and LED backlighting applications, it can be used most effectively with LED light sources. This article also discusses some innovative edge-lighting dimming solutions.

by Pierre de Greef, Hendriek Groot Hulze, and Jurgen Hoppenbrouwers

ONLY 5 YEARS AGO, consumer LCD TV represented a brand-new technology; today, 75% of all TV sets sold use liquid-crystal displays (LCDs). This mainstream technology is still maturing in terms of picture quality, cost structure, and power efficiency. The power consumption of display applications is highly impacted by the energy consumed by the LCD module, and more than 80% of this energy is consumed by the backlight in order to achieve the required luminance. This article examines the range of backligh1 technologies.

LCD-Panel Overview

LCD-TV systems must render video and multimedia images with optimal front-of-screen performance. They also must meet many other minimum performance expectations such as contrast, luminance, color fidelity, lack of flicker, minimum viewing angle, power efficiency, and cost effectiveness. All of the above are greatly affected by the functionality of the backlight. A backlight typically comprises multiple cold-cathode fluorescent lamps (CCFLs) or white LEDs. As shown in Fig. 1, the lamps can be mounted on the edge (edge-lit) of or behind (direct-lit) the LCD panel. A stack of optical filters ensures that the light from the lamps uniformly illuminates the LCD panel, thus enabling high-quality image. Lastly, the

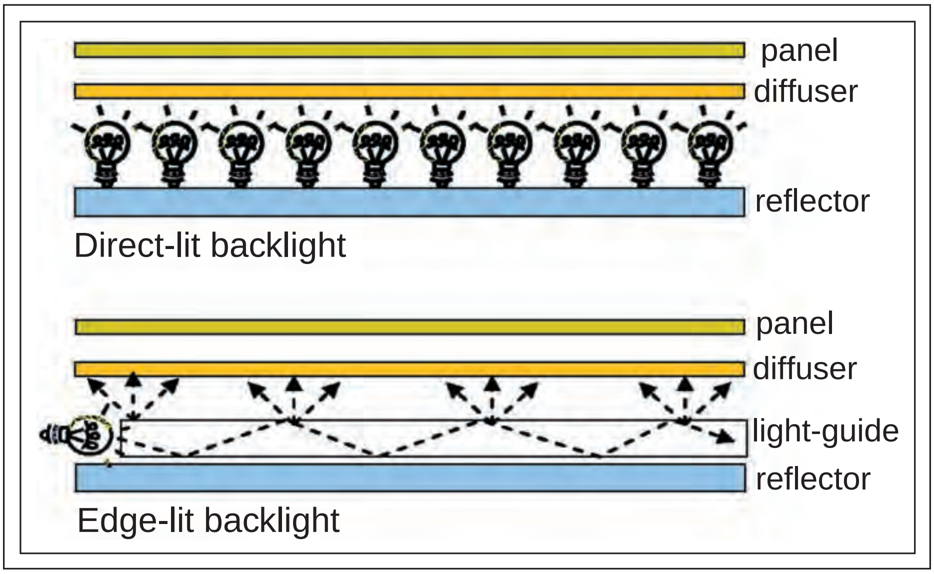

Fig. 1: *Cross-sections of LCD modules show direct-lit backlighting (top) and edge-lighting (bottom).*

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white light from the backlight is filtered by red, green, and blue (RGB) subpixels to enable the generation of colored images on the display.

This basic LCD-panel design has consequences in terms of energy efficiency. For example, the expected minimum luminance for TV applications is at least 500 cd/m^2; monitor applications need at least 300 cd/m^2. Yet, to enable this amount of light output, much more light needs to be generated. On average, only 1% of backlight luminance exits a display module because there is

- an 85% loss in light output to create images using the LC cell shutter
- a 70% loss in color filters to enable the colors
- a 50% loss in polarizers to enable light modulation by the LC
- 30% loss in optical stack in order to create uniform light.
- a 25% loss in pixel aperture (interconnect, transistors).

Additional limitations include light leakage through the LC cells, causing poor black levels, reduced contrast ratio, and a viewing-angle-dependent variation of display gamma.

The actual lights in the backlight – LEDs *vs.* CCFLs – also play a role in the efficiency of LCD panels. Conventionally, white LEDs were mainly used in mobile-display applications because CCFLs require high voltages and are comparatively fragile and bulky. White LEDs have now surpassed the classic CCFL in luminance efficiency for a given power input and are approaching the same cost-per-unit level. In the last couple of years, white LEDs have rapidly taken over market share from CCFLs in the notebook realm as well. The desktop-monitor market has also followed suit, and this year, LEDs began entering the LCD-TV market in full force, enabling 50-in. display modules of less than 10 mm in thickness.

The Green Screen

Depending on the application, about 20–50% of the overall energy of multimedia applications such as computing and TV is required by the display alone. This balance gets even worse for increasing screen sizes because the larger screens require the same luminance per square meter. For example, the display of a 21-in. monitor needs twice the energy of a 15-in. monitor, and the display of a 56-in. jumbo TV requires a factor of four more energy than a modest 28-in. TV.

Despite the energy cost of the larger panels, the market is trending toward bigger and bigger screens at the same time that government energy regulations and energy-label programs for TVs are coming increasingly into play. Successful display technologies for TVs must be able to display superior imagery while also using less energy. Due to advances in LED-backlighting technologies, LCD TV is well-suited to meeting those challenges. This article will discuss backlighting approaches with regard to CCFLs as well as LEDs where applicable, but the future of LCD-TVs appears to lie with LEDs.

Adaptive Dimming

The luminance for LCD TVs can now be controlled spatially as well as temporally, especially with the introduction of LEDs as a backlighting source. By tailoring the backlight to generate light only at the time and location where is it actually needed, image contrast can be improved, and at the same time less power is consumed. This technique is frequently referred to as “dynamic backlighting” or “adaptive dimming” and requires special driving electronics and algorithms to achieve an optimal system performance.

Adaptively dimming the backlight significantly improves the performance of an LCD module and enables better contrast and power efficiency. When the backlight in the darker parts of images is dimmed, the light leakage through the liquid crystal is reduced and the dynamic range is increased as well, thus improving the contrast of the panel. Also, the average power consumption is reduced because the LEDs are creating less light, they need less energy. Dimming also often improves picture quality for different viewing angles.

It is also possible to use the power saved by dimming in darker areas to locally boost the luminance of bright areas of images, thus achieving a more vivid picture. For this approach, LEDs can be conditionally boosted in luminance by being driven at a higher than nominal current for a short period of time. However, special care must be taken in the thermal design of the backlight and LED drivers to prevent overheating of the LEDs.

Global and Local Dimming

Two basic approaches toward dimming, which can be used with either CCFLs or LEDs, are global dimming, a methodology in which the entire backlight is dimmed by a single factor in each frame, and local dimming, in which regions within a frame can be dimmed separately. For global dimming, the luminance of a backlight is modulated with a dimming algorithm, relative to the video content (see Fig. 2). The dimming algorithm ensures that, while the backlight is dimmed, the video images are not reduced in perceivable luminance, so that picture quality is preserved. A complementary luminance modification of the image delivered to the LCD panel is required, which increases the video-processing requirements of the system.

A histogram is determined by analyzing the pixels of the image content in each region, which is used as input for the dimming algorithm. When a darker scene is detected, the backlight is dimmed in combination with a complementary change in the gain of the video content shown on the LCD. As light leakage is reduced, this also improves the saturation of the dark colors. For brighter

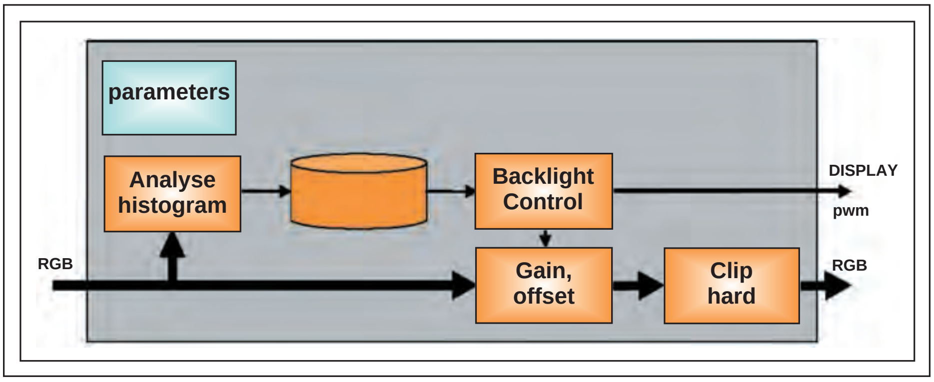


Fig. 2: A global-dimming algorithm is represented in a block diagram.

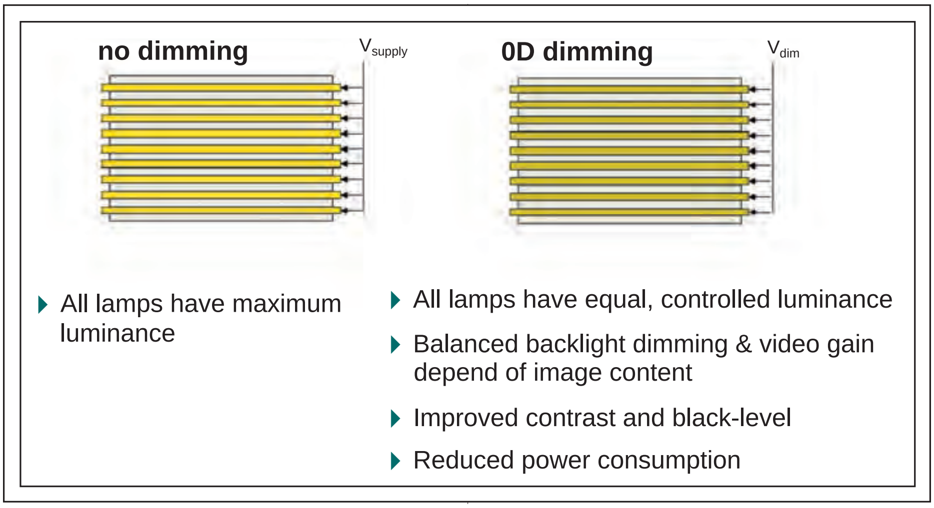


***Fig. 3:** The CCFL backlight example shows the advantages of 0D dimming or global dimming at right.*

scenes, the required higher luminance levels are driven and less video gain is required.

Because there is no control over the luminance in the spatial domain, the global dimming technology is sometimes called 0D dimming, as shown in Fig. 3.

In local dimming, the backlight comprises a number of small 2-D segments, each having a luminance that can be modulated. A segment may comprise single or multiple light sources. For CCFLs, which are shaped like tubes, local dimming can only be applied in one dimension (1D dimming).[1] 2D dimming, which is possible with LEDs, allows greater control, as shown in Fig. 4. However, as 1D and 2D dimming require individual drivers per segment, the cost for implementation will be greater.

When no regions are dimming, the backlight produces its maximum luminance and should have a uniform light profile. When there are differences between the segments, these need to be averaged out by the optical system, so a smooth light profile per region with overlap to its neighbors is desired. However, this optical mixing is actually a type of crosstalk that reduces the effective spatial bandwidth of the dimming backlight. An advanced local-dimming algorithm can compensate for this effect and improve the performance.[2,3]

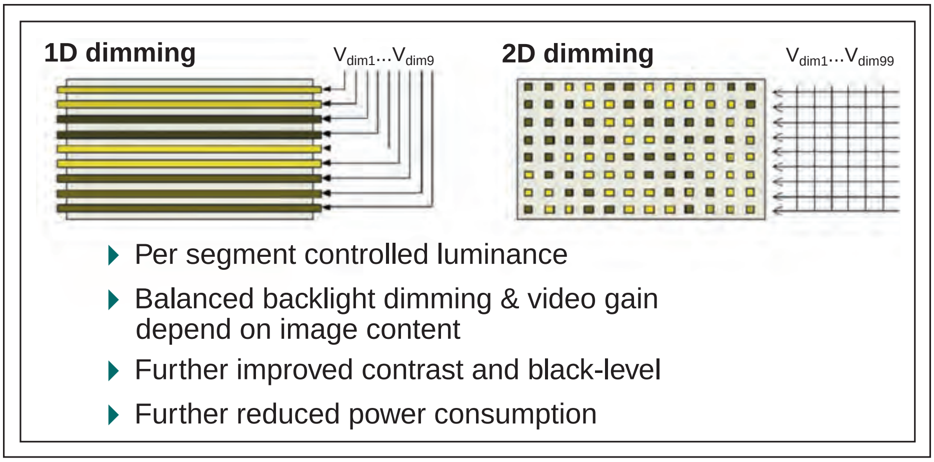


***Fig. 4:** Shown on the left is 1D dimming with CCFLs and on the right, 2D dimming with LEDs.*

RGB LEDs and Local Color Dimming

It is possible to employ a backlight with a combination of red, green, and blue LEDs that is driven at a constant, white color. However, RGB LEDs are expensive, less power efficient, and much more complex to work with compared to white LEDs. There is currently only one reason for using colored LEDs – their wider color gamut. Local color dimming is an approach toward a more power-effective RGB-LED solution. This technology involves executing the local-dimming algorithm independently for the red, green, and blue primary colors because the light sources are red, green, and blue LEDs with their luminance controllable per color and per region. This enables a larger color gamut. Still, the LED cost and power efficacy make this option unattractive.

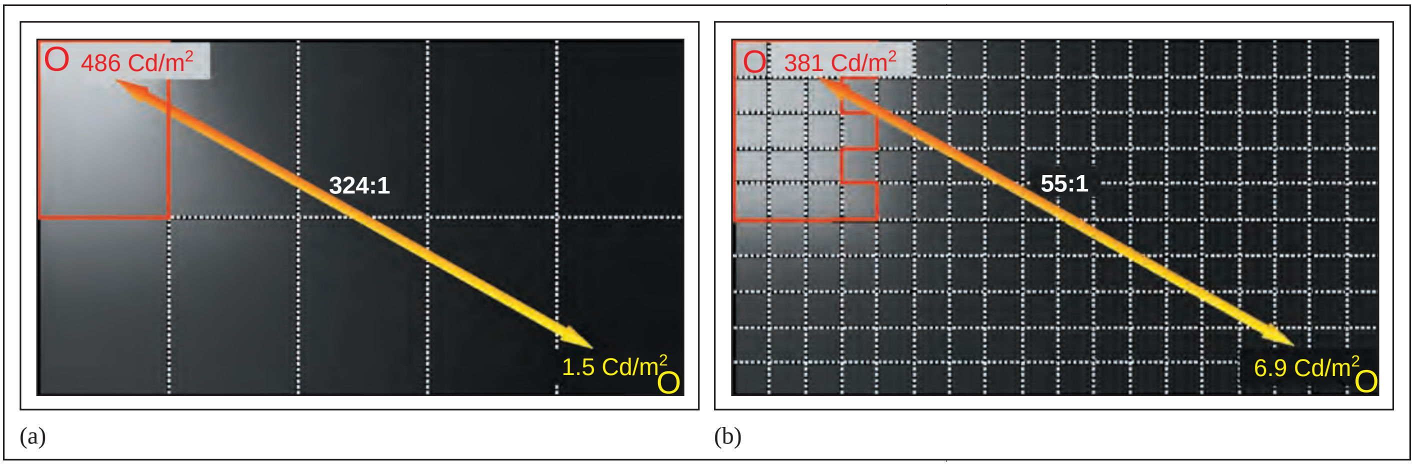
The light profiles for each color do not need to be identical, although all segments together need to be homogenous; the data of the segment profiles need to be stored per color. However, it is not necessary to put the R, G, and B triplet in a single package, which makes the thermal design easier because it leads to smaller temperature differences. Yet, this approach is expensive as well.

A big difference between local (white) dimming and local color dimming is that the latter offers more opportunity to compensate for color errors. But there is also more need to do so. Color dimming introduces larger temperature differences, which may cause drift in the color and brightness. There is a greater need to preserve the realistic colors, especially if RGB LEDs in a single package are used. If, *e.g.*, the blue and green LEDs are dimmed, the temperature of the red LED will drop as well because they share the same heat sink in the package. Hence, the red LED will become more efficient and, as a consequence, the color of the triplet may shift more towards red than desired.

Local Dimming and Edge Lighting

Thus far, this article has discussed backlighting for direct-backlighting applications. However, edge-lit backlights, in which all the light sources are placed at one or more edges of the display, are commonly used for notebook computers. A special light guide is required to distribute the light from the edges over the panel area for a homogeneous backlight. The main advantage of edge-lighting is the very thin form factor.

For TV panels, slimness is quite desirable, but until recently it was not possible for larger



(a) (b)

Fig. 5: The edge-lit example (a) at left shows relative spatial contrast (high dynamic range) improvements over the direct-lit example (b) right.

LCD screen sizes to also be very thin. This is due to the fact that the required amount of light (flux) is proportional to the screen area while the length of the edges is proportional to the square root of this area. Hence, the larger the panel, the higher the required light density at the edges.

With the development of more effective LEDs and improved optical design, it is now possible to produce very slim LCD panels with an edge-lit backlight, even for display sizes of 56 in. and larger. LEDs can generate the required light densities so efficiently that their temperature is still acceptable. The backlights are less complex and less expensive than a comparable direct-backlighting system; however, the power consumption of these solutions is about 130% of a comparable direct-lit backlight due to optical losses caused by the light guide.

Here, local dimming can provide a solution. While many believe that edge-lit backlighting technology cannot be combined with local dimming, it actually can. Obviously, edge-lit backlights with LEDs as the light source cannot be segmented in a narrow 2D grid as is the case with direct-lit LED backlights. But still, we can distinguish the top from the bottom of the screen. And in the horizontal direction the segmentation can be as narrow as the number of LED strings used in the design. In fact, as shown in Fig. 5, an LCD TV with a 2D edge-lit backlight can have a higher spatial contrast (with high-dynamic-range improvement) than a direct-lit backlight LCD-TV.

Because the optical segments of the local-dimming edge-lit backlight have an irregular shape, a special version of the 2D dimming algorithm is required.

NXP showed a prototype of an LCD TV with an edge-lit backlight with 10 segments at the CES 2009 and IFA 2009 shows and presented a paper on the topic at Display Week 2009.[4] In this example, the top and bottom of the backlight use five strings consisting of 16 LEDs to illuminate the panel, enabling a two-dimensional dimming-backlight algorithm. The average power savings through this architecture is twice the savings of a global-dimming algorithm. This means that a very slim LCD TV using this technology will on average consume less energy than a comparably sized CCFL unit.

Conclusions

Figure 6 shows the impact of the different backlighting technologies on the performance of an LCD system.

To summarize, dimming-backlight technology saves system power and improves the picture quality of LCD applications such as TVs. White LEDs are the best light sources to be used with dimming because they are small

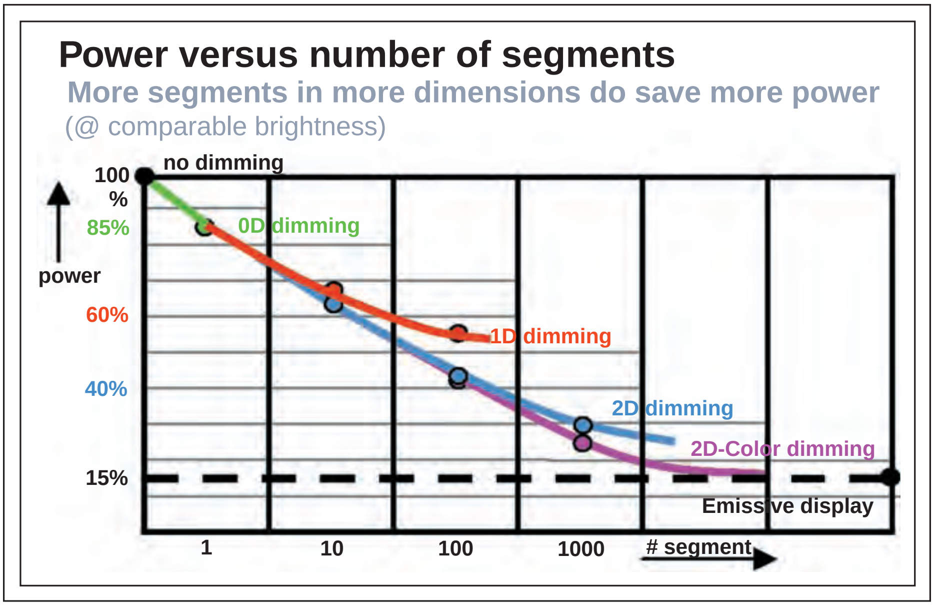


Fig. 6: In general, the more segmented the dimming technology, the more power is saved.

and have become power efficient and competitive in system cost. Both direct-lit as well as edge-lit LCD panels using LEDs enable 2D dimming, which saves the most power.

For wide-gamut applications, RGB-color LEDs can be used in the backlight, enabling local color dimming and increasing the gamut even more. Yet, this technology is currently too expensive for practical use. Lastly, local dimming introduces temperature gradients in the backlight, which change the efficacy of the LEDs. This has an impact on the optical uniformity as it introduces flux variations with respect to the measured backlight profile. The error is proportional to the optical crosstalk; hence, more power savings can be achieved when temperature feedback is included in the algorithm. The video processing required for local dimming requires significant processing power, yet this can be embedded in existing programmable video processors.

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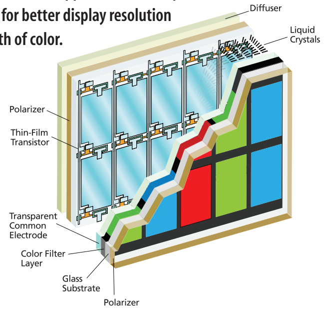

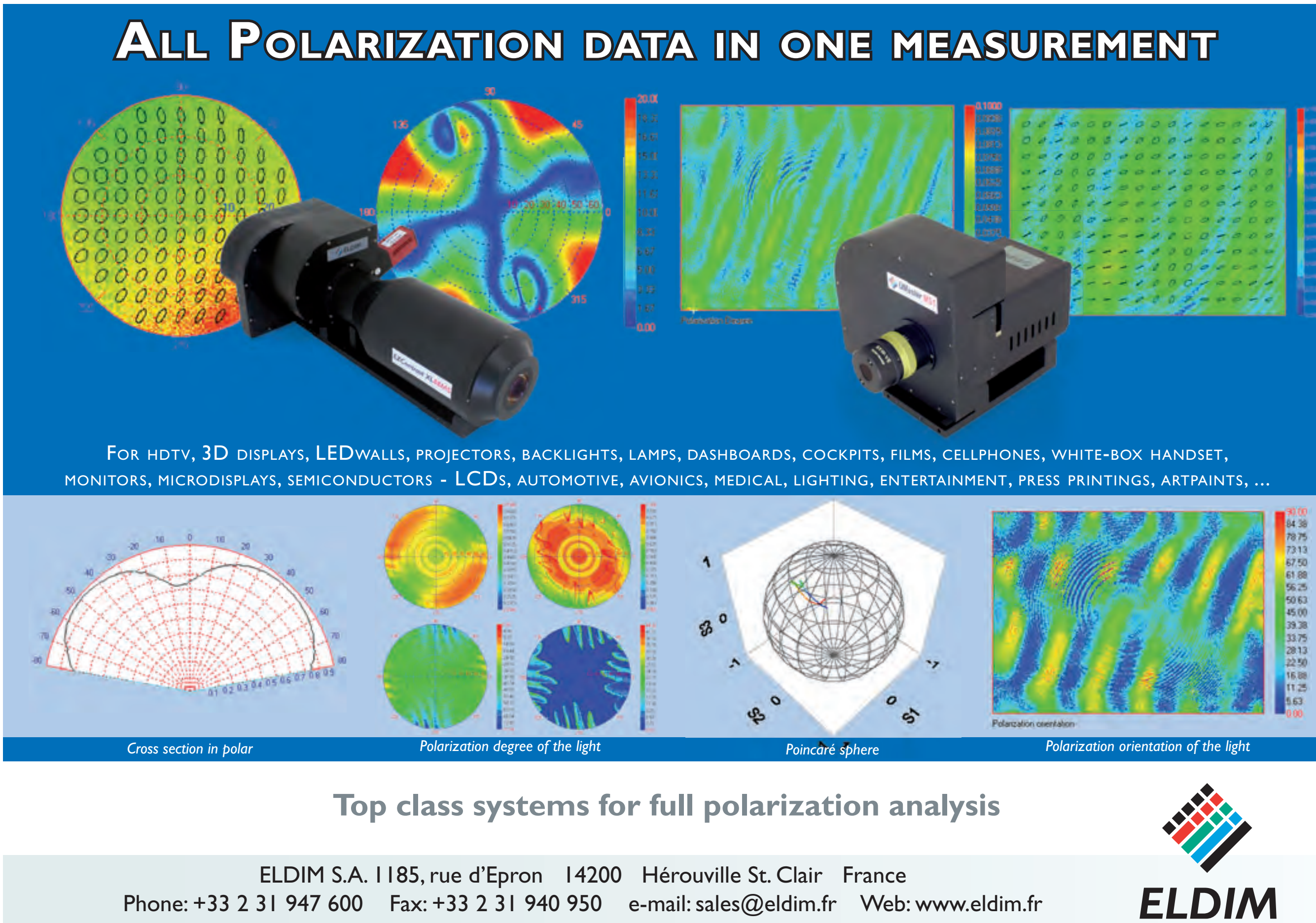
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LCD-TV Makers Go Thin and Green to Generate New Growth

LCD manufacturers are looking beyond pricing and volume to gain market share. Those that take the lead will do so by developing and optimizing slimmer, more energy-efficient models.

by Sweta Dash

AFTER YEARS of blistering increases fueled by booming television sales, global large-sized LCD-panel revenue growth is decelerating and profitability is dwindling, prompting suppliers to turn to thinner and more ecologically friendly products in order to spur consumer interest. This article, based on a recent report from market-research-firm iSuppli Corp., discusses recent LCD market statistics, then outlines several related trends.

Strong Shipment Growth, Weak Revenue Expansion

Worldwide large-sized LCD-panel unit shipments are expected to rise at a compound annual growth rate (CAGR) of 13% from 2008 through 2013. (iSuppli defines large-sized LCD panels as those having a diagonal dimension of 10 in. and larger.) The growth will be mainly fueled by a strong rise in TV sales, as well as increases in notebook- and netbook-PC demand. Desktop-monitor panels that are used for televisions and for all-in-one products will also experience growth during the next few years, despite a slowdown in desktop-PC shipments.

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Even with the expected increases in unit shipments, large-sized LCD-panel revenue is expected to rise at a CAGR of only 9.8% from 2008 to 2013. This contrasts with a rise of 22% for the 5-year period from 2002 to 2007. The slowing revenue growth is increasing price pressure on suppliers of large-sized LCDs, and this phenomenon is causing profits to dwindle as well.

Conditions in the large-sized-LCD market took a turn for the worse in late 2008, when the global economic recession pushed down panel prices to less than manufacturers' cash costs. This has cast a shadow over what is shaping up to be a strong 2009 for unit shipment growth. Shipments of large-sized LCD panels are set to increase to 516 million units in 2009, up 18% from 436 million in 2008. The increase is being spurred by a rise in end-demand in the second half of the year as economic conditions improve. Other factors contributing to the rise in unit shipments include inventory replenishment among brands and retailers, strong demand from the Chinese market, new model introductions, sales spurred by the shift in aspect ratios to 16:9 and similar panels, and the increasing use of light-emitting-diode (LED) backlights for notebook, monitor, and television panels.

Despite the rise in shipments and these positive factors, global large-sized LCD-panel revenue will fall by 11% this year, declining to $65 billion, down from $73 billion in 2008, as shown in Fig. 1.

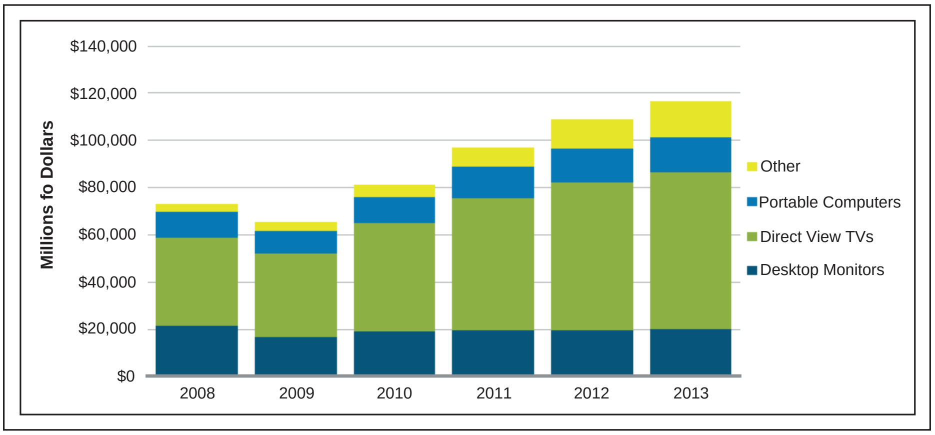

***Fig. 1:** Worldwide large-sized TFT-LCD-panel revenues for 2008–2013 show a market rebound starting in 2010. Source: iSuppli Corp.*

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Television Brightens LCD Picture

We expect worldwide LCD-TV-panel shipments to increase to 131 million units in 2009, up 29% from 102 million in 2008. This growth is due to a number of factors, including the recovery of end-user demand in the second half of 2009, a pull-in of panel orders, and strong sales increases in China. The Chinese government's consumer stimulus package has boosted sales throughout most of 2009. However, the U.S. market also will play a key role in the rise of LCD-TV-panel shipments in 2009 due to very aggressive price reductions by branded manufacturers that have increased sales.

Worldwide, the 32-in. size is the dominant LCD-TV dimension in 2009. Its popularity is attributable to increased sales in emerging economies, especially in China, where consumers are seeking less expensive models. Strong growth is expected for 40-in. and larger panels during the following years due to the shift to newer fabs, such as Gen 8.5 and 10 facilities, which will help to reduce the cost of larger-sized panels.

By 2013, we expect the worldwide TV-panel market to exceed 234 million units.

Monitor Panels on the Rise

Shipments of LCD panels for desktop-PC monitors are also forecast to grow in 2009 and beyond as a result of various factors. These factors include the rising use of monitor panels for the small-sized-television market, consumers' increasing utilization of multiple monitors to further productivity, and the arrival of low-priced all-in-one products and net-tops (small-form-factor desktop units designed for basic tasks). In the fourth quarter of 2009, more than 47% of desktop monitors shipped will employ the 16:9 format. This will rise to more than 73% by 2013. The monitor-panel market is expected to reach 200 million units in 2009 – 14 million of which actually will be used for televisions, with the remaining 186 million utilized as pure monitor panels or for all-in-one products. We project that monitor-panel shipments will reach 253 million units by 2013.

Notebook Panels Perk Up

Shipments of LCD panels for notebook PCs – including 10-in and larger screens for netbooks – will reach 170 million units in 2009, up 24% from 137 million units in 2008. Shipments should reach 272 million units by 2013, driven by rising sales of low-priced notebook computers, increased demand for systems with wireless capabilities, and the shift to larger display sizes. Shipments of 10-in panels increased to 4 million units in the first quarter of 2009, up from 50,000 units during the same period in 2008. They are expected to reach 30.6 million for the entire year of 2009, reflecting growth in the netbook market.

The 16:9 format is expected to account for 62% of notebook-PC-panel unit shipments by the end of the fourth quarter of 2009. In the fourth quarter of 2008, the 15.4-in. size in 16:10 format was the dominant dimension in the notebook market, commanding a 35% share of unit shipments, with only 8% of units accounted for by the 15.6-in. size. By the second quarter of 2009, the share of the 15.6-in size increased to 12%. We expect the majority of notebook panels to shift to the 15.6-in. size in 16:9 format.

Korea Takes Top Spot — but China Rising in LCD-Panel Production

The weaker South Korean won, bolstered by strong internal sales, rising utilization rates, and low-cost structures, has helped both Samsung and LG Display in 2009 to offer more competitive prices than their competitors and allowed them to gain market share. Higher utilization rates for their fabs and aggressive expansion plans in the second half of 2009 will allow them to remain the world's leading panel suppliers.

As shown in Table 1, South Korea has therefore become the world's largest national producer of large-sized LCD panels in the second quarter of 2009, accounting for 50% of global unit shipments. In the second quarter, it took the number one spot from Taiwan, which lost 6 percentage points of share during the period from the second quarter of 2008 through the same period in 2009.

While South Korea is on the rise, China is emerging as the next major growth country for large-sized LCD-panel production. Samsung and LG Display, along with Japan's Sharp Corp., have announced plans to invest billions of dollars to establish Gen 7.5 and 8 fabs in China during the next few years.

China is expected to achieve strong growth in the LCD-TV market, increasing its share of global unit shipments to 20% in 2011, up from 19% in 2009 and 13% in 2008. It is going to be the dominant region for LCD-TV sales in terms of units in 2013. Future growth in LCD-TV demand will be coming from emerging economies such as India and China, spurring the rise of production in those nations. Furthermore, concern about tariffs on imported LCD TVs is promoting the migration of LCD-panel production to China.

Revenue Slowdown Spurs Strategy Shift

For years, the global large-sized LCD-panel industry has been following a simple strategy of expanding capacity and reducing prices to stimulate consumer demand and to fuel the expansion of the industry. This approach has been wildly successful, causing notebooks to migrate to larger-sized panels, triggering the replacement of CRT desktop-PC monitors with LCDs and enabling the growth of the LCD-TV market. The strategy has continued to succeed to a degree in 2009, with very low prices for LCD-TV panels at the beginning of 2009 propelling LCD-TV shipments to new heights for the year.

However, to ensure continued growth during the next several years, large-sized LCD-panel suppliers must adopt a new strategy that departs from the conventional approach of increasing capacity to spur demand. The new approach is based on three factors: technological innovation, product differentiation, and

Table 1: Regional shipment shares for LCD panels larger than 10 in. through Q2 '09 show Korea eventually exceeding Taiwan.

Country	1Q08	2Q08	3Q08	4Q08	1Q09	2Q2009
China	6%	5%	5%	4%	4%	4%
Japan	6%	6%	7%	8%	7%	5%
Korea	42%	42%	43%	49%	52%	50%
Taiwan	47%	47%	45%	39%	37%	41%
	100%	100%	100%	100%	100%	100%

cost reduction. These efforts must focus on producing LCD panels that are thinner and thus more attractive to consumers, but that are also less harmful to the environment and consume less energy.

We believe the next wave of growth in the large-sized LCD-panel market will be driven by consumer demand for thin, green, and power-stingy displays. These attributes will change from being "nice-to-have" features to "must-haves" features in the minds of consumers.

LCD TVs Slim Down

To capitalize on the trend for thinness, the LCD-TV-panel industry currently is focusing on creating thinner form factors by using edge-lit, white LED backlights. Ultra-slim 10-mm LCD-panel modules started to appear in the first half of 2009 and are expected to enter mass production in 2009. Most panel suppliers have introduced prototypes of slim LCD TVs during the last few quarters.

Samsung has demonstrated a 40-in. TV panel that is extremely thin at only 10 mm. The panel employs a white LED backlight rather than a conventional cold-cathode fluorescent lamp (CCFL), to achieve its thin form factor. LG Display has shown a 42-in. TV panel measuring just 19.8 mm thick. Sharp demonstrated a 52-in. TV panel just 20 mm thick, and AU Optronics introduced a 42-in. panel with a 10-mm module thickness that also is 44 % lighter in weight than conventional products.

Eco-Friendly LCD TVs

In pursuit of becoming more eco-friendly, LCD makers are concentrating on backlighting technology. In the CCFL backlight realm, LCD-panel makers are striving to reduce mercury levels and lower power consumption. By using different types of phosphors, lowering mercury use by 25%, and utilizing half the number of lamps, designer can enable advanced CCFLs to achieve color gamuts much wider than those generally offered today, while also offering reduced power consumption, slimmer form factors, lighter weight, and reduced use of a material harmful to the environment.

For example, AU Optronics demonstrated a 46-in. eco-friendly TV panel that cuts power consumption by 50% compared to conventional units by optimizing the CCFL design. Some newer LCD TVs are using 50% fewer CCFLs for same-sized panels by employing highly efficient optical films that refract or recycle light to improve brightness and color gamut. For example, a 46-in. TV using these techniques can employ just 12 CCFLs, compared to 24 for a conventional set.

Samsung has shown a 52-in. green LCD-TV panel that achieves ultra-low power consumption by using optimized CCFL backlighting with low mercury content. The panel also featured a reduced number of CCFL units, at only 14 instead of the conventional 26. AU Optronics recently demonstrated a 32-in. TV panel using only four CCFLs, down from 16.

LED Backlights Highlight Eco-Friendliness

The focus on thin LCD TVs, as well as on environmentally friendly green initiatives, will lead many panel suppliers to use LED backlights. LED backlights reduce power consumption and are free of the toxin mercury. Beyond these green attributes, LEDs also offer the advantages of wide color-gamut ratios and dynamic-area control capability.

Furthermore, LED backlights can be combined with dimming or scanning technology to improve color contrast and black levels. RGB LED-based local-dimming technology can achieve a 100,000:1 dynamic contrast ratio, a color gamut more than twice the area of current offerings, a 20-mm thickness, and a 40% lower power consumption than CCFLs. However, the advantages of RGB LEDs are offset by their higher costs relative to that of white LEDs.

White-LED-based backlights also offer a slimmer form factor and lighter weight compared to RGB LEDs. On the other hand, they lag behind RGB LEDs in terms of color gamut. Many suppliers use low-power edge lights or side-mounted white LEDs to minimize differential degradation, reduce costs, and solve thermal issues.

Cost issues continue to prevent LED backlights from being adopted more widely, but the gap in pricing between LEDs and CCFLs is narrowing for television and monitor panels. Television makers are increasingly combining LED backlights with higher refresh rates of 120 or 240 Hz in their high-end sets. Many consumers are finding it hard to justify the higher costs of 240-Hz models. However, panel and television suppliers are offering 240-Hz sets with LED backlights at very aggressive prices in the hopes of making them more appealing. The reduction of the price gap between LED- and CCFL-backlights also is spurring adoption of LEDs in the monitor and notebook markets. Notebooks already are rapidly shifting to LED backlights because of their slim form factor, instant-on capability, and longer battery life.

You Can't Be Too Thin or Too Green

The large-sized LCD panel market is undergoing a fundamental shift from focusing on volume and price to embracing innovation and differentiation. Panel suppliers and OEMs that succeed in using these competitive weapons to attain thinner form factors and become more eco-friendly will be the market winners in the coming years. ■

The Future Is Here...

Standard Active Matrix OLED Products

Panel Size (diagonal)	Resolution	Color Depth	Active Area (mm)	Outline Dimension (mm)	Brightness (cd/m^2)
2.0"	176 x RGB x 220	262k	31.68 x 39.60	37.30 x 50.25 x 1.60	190
2.4"	240 x RGB x 320	262k / 16.7M	36.72 x 48.96	42.00 x 58.60 x 1.65	200
2.8"	240 x RGB x 320	262k / 16.7M	43.20 x 57.60	49.10 x 67.30 x 1.75	200
3.4"	480 x RGB x 272	16.7M	74.88 x 42.43	82.80 x 54.30 x 1.60	200
4.3"	480 x RGB x 272	16.7M	95.00 x 53.80	103.50 x 67.00 x 2.05	200
7.6"	800 x RGB x 600	16.7M	165.60 x 99.36	177.30 x 118.32 x 5.40	200

Active Matrix OLED Advantages

Supreme Image Quality

Wide Color Gamut (>70% NTSC)

High Contrast Ratio (>10,000 : 1)

Ultra Thin (typical module thickness 1.3mm)

Virtually Unlimited Viewing Angles

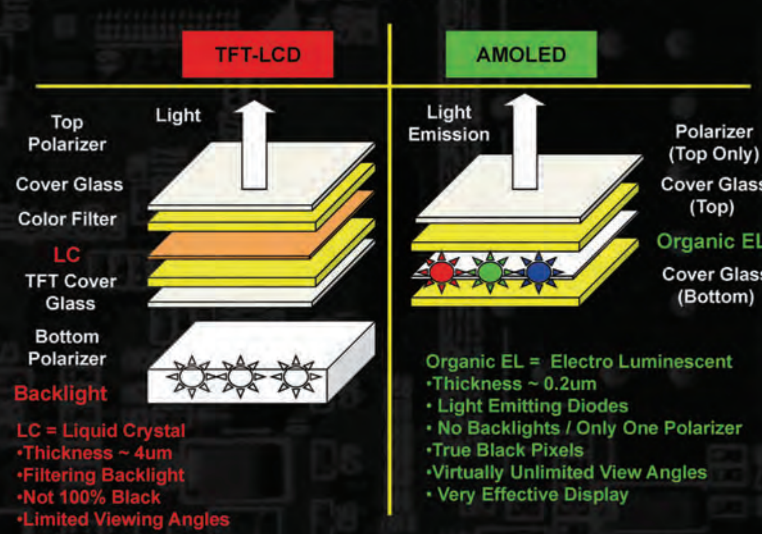
Fast Response Time (<50us)

Wide Operating Temperature Range (-40C to 70C)

Low Power Consumption (30% less than TFT-LCD)

Resistive and Capacitive Touch Screens Available

TFT-LCD vs AMOLED



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The Surprising Success of Netbooks

With smartphones getting smarter, e-readers on the upswing, and laptops growing ever-more powerful, can the market really support a device bigger than a PDA but smaller and less powerful than a typical notebook? The answer is yes, and display and PC makers alike have been happy to meet the growing demand for netbooks.

by Jenny Donelan

NETBOOKs: miniature marvels or watered-down lightweights? It all depends on how you look at them. With regard to netbooks, note-PCs, sub-notebooks, or mini-notes (they go by many names), opinions are divided. There is definitely an appeal to a sub-$300 computer that is so small and light (less than 3 pounds) that you can toss it into a briefcase or handbag and take it wherever you might be heading. Just about every netbook is WiFi-enabled (hence, the "net" in the name), and many also offer connectivity to broadband networks, so a netbook makes it convenient to carry on with remote e-mailing and Web browsing as well. At the same time, because a netbook looks like a laptop computer, albeit smaller, you might expect it to perform like a laptop computer, and that would be expecting too much. A netbook comes in a small size with a low price tag because it has been intentionally divested of many of the robust features that have enabled today's laptops to take the place of a desktop model. Because of their slower processors and smaller memories, netbooks are just not as fast or powerful as their larger counterparts.

One way in which netbooks have surpassed expectations, however, is in sales. Over the last year, netbook sales were a bright spot in an otherwise gloomy notebook market. According to a recent survey from market-research-

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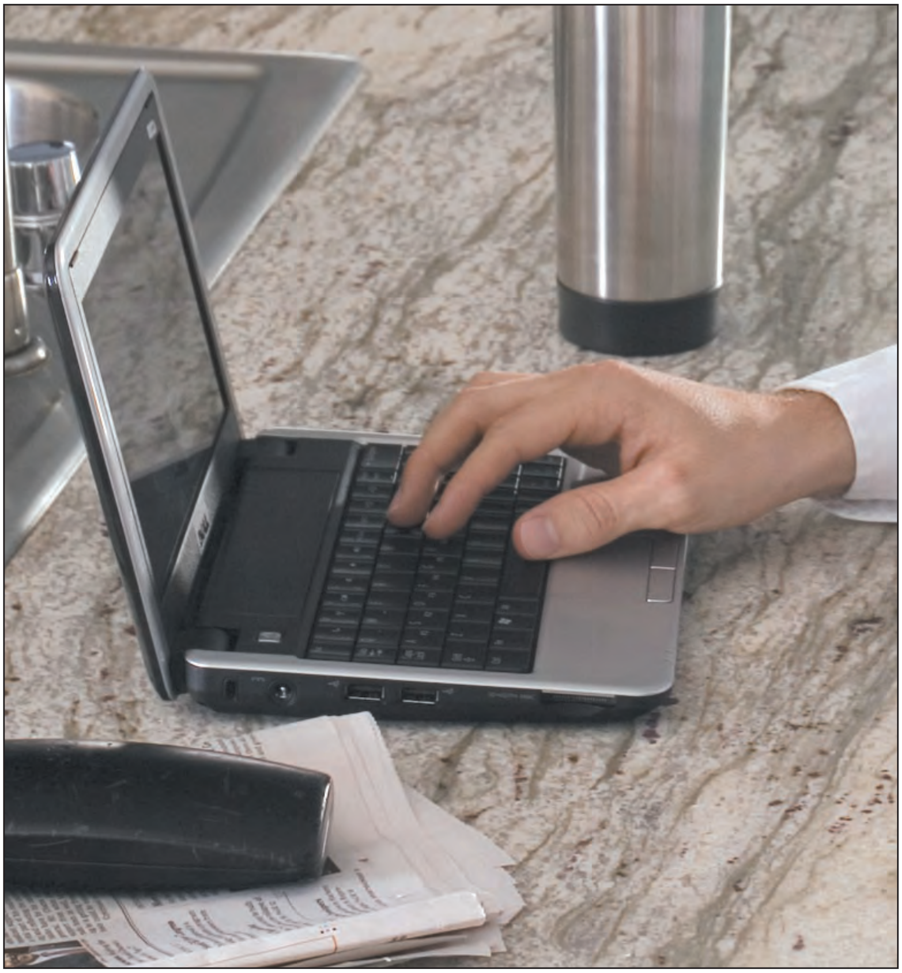


***Fig. 1:** The Inspiron Mini 9 from Dell is based on the Intel Atom processor and has an 8.9-in. display. Image courtesy Dell.*

0362-0972/11/2009-030$1.00 + .00 © SID 2009

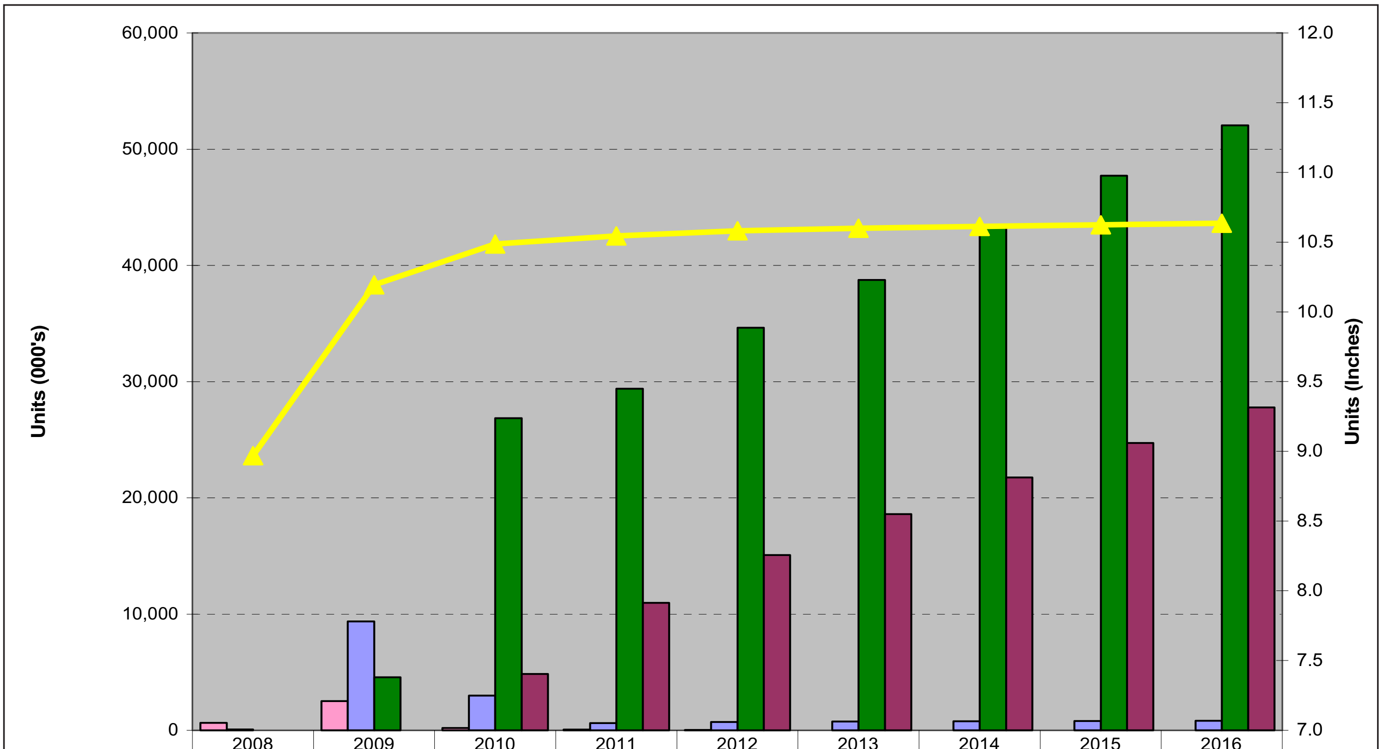
firm DisplaySearch, mini-note market revenues were up for Q2 ’09 both quarter to quarter (37%) and year to year (264%), whereas the portable PC market as a whole was down year to year by 5%, including mini-notes, and down 14% without them.[1] So, obviously, netbooks, despite their lack of bells and whistles, have tapped an unsolved consumer need.

Anatomy of a Netbook

“Small notebooks have actually been around for a long time,” says John Jacobs, Director of Notebook Market Research for DisplaySearch, adding that in Japan, tiny (5.6-in. displays) full-featured devices have been an option for several years, if you were willing to spend $1500–2000 for them. The netbook as we now know it is generally considered to have gotten its start in 2007 with the ASUS Eee PC, which was originally designed for emerging markets. It used the Linux OS and had 4 MB of flash memory. The Linux interface was not universally popular, however. “People did not know Linux; it did not look familiar, and there was a high return rate [on these devices],” says Jacobs, adding that within 6 months, Microsoft had “essentially gutted” a version of Windows XP for netbooks. When HP and Dell entered the market as well in mid to late 2008, the netbook market began to take off.

Many netbooks even today do not come with an internal optical drive, although external drives are usually available as options. These units generally rely on a solid-state drive instead; users upload and download files *via* the Internet or with a USB device. The processors most commonly used in current netbooks are the 1.6-GHz Intel Atom or the x86-compatible VIA Technologies C7 (1.5–2.0 GHz). Most of these devices run either Linux or some version of Windows XP and do not support x64 operating systems.

Another drawback for netbooks is the keyboard, which is fine for occasional e-mailing and Web surfing, but not for creating detailed spreadsheets or writing and formatting large documents. This is not any kind of design flaw – if manufacturers started making keyboards comfortably larger, then the netbook would no longer be small enough to be classified as a netbook. Still, companies are doing what they can to offset this particular disadvantage. Dell’s mini 10 and mini10V units, for example, have keyboards that Dell advertises as “92% of the size of a standard keyboard.” [2]



	2008	2009	2010	2011	2012	2013	2014	2015	2016
5.0" - 7.5"	648	2,505	196	64	11	0	0	0	0
8.0" - 8.9"	71	9,362	2,997	621	711	752	779	801	818
10.1" - 10.2"	0	4,568	26,865	29,388	34,637	38,744	43,297	47,712	52,036
11.6" - 12.0"	-	-	4,841	10,963	15,079	18,603	21,746	24,723	27,770
Average Size	8.97	10.19	10.49	10.54	10.58	10.60	10.61	10.62	10.64

Fig. 2: *Mini-note PCs with displays smaller than 8 in. on the dagonal are forecast to exit the market in the next few years. 10.1–10.2-in. products are forecast to remain the dominant size in the mini-note market. Image courtesy DisplaySearch.*

Display sizes for netbooks range from 7 in. to somewhere beyond 10 in. They are almost without exception LCDs with LED backlighting. For the most part, no special adjustments have been made to the composition of the displays themselves to make the overall devices smaller and lighter. In fact, according to Jacobs, many of the earliest netbooks used the same 800 × 480 displays that had been designed for portable DVD players. Although customizing the displays for netbooks in order to make the devices lighter and more energy efficient sounds like a good idea, any such efforts would push the price too far beyond that desirable sub-$350 price point. "We're not seeing the extra-brightness-enhancement films or the highest-performing LEDs on these units," says Jacobs. "There are technologies out there that would enable better power management, but because of the initial expense, [companies] are not doing it."

Still, 70–80% of any notebook's power is being used by the display, and the batteries in tiny notebooks cannot be large or expensive, so battery life is an issue. "This has been one of the big criticisms of mini-notes all along," says Jacobs. Many units come with a three-cell lithium-ion battery and an option for a six-cell version. For the time being, he observes, most users simply recognize the necessity of having to plug in the units on a frequent basis. At the present time, there is a certain acceptance on the part of consumers of the netbook's limitations, especially in light of the price.

According to a Dell spokesperson, however, manufacturers are indeed looking into optimizing the displays. "There is movement toward slimmer panels, which would help reduce the weight," she says. "And color-engine/dynamic-backlight-control technology that would help reduce power consumption while displaying multimedia programs is being evaluated." She believes it would be a good idea for display suppliers to continue to research such efforts. "LCD suppliers will need to continue focusing on technologies to reduce power consumption – efficient LEDs, for example," she says.

The Need for Netbooks

If netbooks are not as powerful as notebooks, and not as portable as PDAs, and not exactly free, why do they sell so well? Says Dell's spokesperson, "We believe they are so popular because of the combination of mobility, quality, and, of course, price point." Most companies that make computers do not envision the netbook as a replacement for a main computer, but more as an ancillary device, an accessory to your base computer, as it were. But plenty of users are compelled to buy them as their sole computers as well. College students represent one such user base and were sought after with "back to school" advertisements last fall featuring netbooks in a variety of colors

Certainly, if an individual has never had any other computer, a netbook does not feel lesser by comparison. This is the case in developing economies, where mini-notes are now moving briskly. "In China, and in Latin America, they are selling well," says Jacobs. "In fact, in my mind, the mini-note is the free-market solution to One Laptop Per Child."

What's Next for Netbooks?

As is typical in the ever-expanding, ever-contracting world of mobile devices, netbooks began to grow back toward notebook size almost as soon as they were introduced as miniature versions of notebooks. As shown in Fig. 2, the 10.1- or 10.2-in. display size is projected to be the most popular, and PC makers are continuing to come out with larger screens. In the last few months, several companies have introduced 11.6-in. products in the $450 range that use a chipset (the CULV from Intel) somewhere in between the Atom and the regular Intel processor in terms of processing power. Jacobs believes, however, that the much larger display sizes will not do well in terms of sales. "Just because there is a market niche does not mean it has to be filled," he says.

Another possibility includes the addition of touch to netbooks, but this is another cost-incurring proposition that could add as much as 10% to the street price, according to Jacobs. He also suggests that the hinge on most netbooks would not withstand even the gentle force that a person would need to exert in order to activate touch. Touch-enabled netbooks could easily topple over backwards as a result.

The latest trend for netbooks, as seen in the last few months, is packaging with mobile services. Walk into any carrier storefront, for example, and you will see at least a couple for sale. Verizon was recently carrying a Dell and a Gateway model. Adding another device to a user plan is obviously a good way for carriers to grow income, and some broadband providers are also offering free netbooks as incentives for signing on to 2-year plans. It seems as if companies cannot stop coming up with ways to enhance and capitalize on netbooks – yet it may be that all that consumers want out of a netbook is an inexpensive PC. ■

References

[1]"Q3 '09 Quarterly Advanced Notebook PC Shipment and Forecast Report," DisplaySearch, www.displaysearch.com

[2]http://www.dell.com/content/topics/segtopic.aspx/laptop-mini2?c=us&cs=19&l=en&s=dhs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Eurodisplay 2009 Takes Place in Rome — New LCD and Plasma Developments, Environmental Concerns Highlighted

by Jyrki Kimmel

The 29th International Display Research Conference (IDRC), Eurodisplay 2009, took place in Rome, Italy, on September 14–17 in scenic surroundings at the Consiglio Nazionale delle Ricerche (CNR) and Università di Roma "La Sapienza" (University of Rome). Almost 250 attendees were on hand to learn about the latest display science and technology developments amid the splendor of the Eternal City. Among the prominent themes at the conference were environmental and energy-saving issues. Many of the technologies discussed will provide better energy efficiency for the future needs of consumers. In all, more than 150 presentations arranged in three parallel session tracks, plus a poster session, provided a broad view of display science and technology today, as well as a look at technologies that will be powering the products of tomorrow.

The program kicked off with a one-day workshop consisting of several seminars. Werner Becker from Merck in Darmstadt focused on the environmental aspects of display technology and liquid-crystal panels in particular. Well-known RoHS and REACH laws govern the application of chemical compounds in consumer goods, from the production phase through usage to the disposal and recycling of the devices. These are important considerations for display-panel makers, and Becker's talk described how Merck is concentrating on meeting these standards in several ways, with a fully recyclable LCD module, processes used in the recovery of noble metals and catalyst materials, and the incineration of hazardous (non-display specific) waste.

Other seminar highlights:

- Kazuaki Tarumi, also from Merck, provided a comprehensive overview of new liquid-crystal materials that advance the technology of display panels, from well-known, basic configurations to energy-efficient, fast, and high-contrast electro-optic effects such as PS-VA and "blue-phase" LCDs.
- Vladimir Chigrinov from the Hong Kong University of Science and Technology gave a presentation about new trends in LC devices. He highlighted key aspects of field-sequential color LCDs, photo-alignment technology, transflective LCD technology, and flexible LCDs, and also provided a glimpse into applications of LC technology used in optical communications.
- John Chen from ITRI in Taiwan discussed flexible display technology and presented recent results in web-processed ChLC display technology as well as flexible active-matrix display technology. These displays can provide rugged, economic alternatives in applications where high image quality is not yet absolutely required.
- Eugen Onac from Philips described innovative architectures for the ultimate in LCD-TV applications. His talk spanned TV system-development aspects from backlight alternatives to the color-filter matrix to obtaining best front-of-screen technology through novel hybrid color and backlight addressing.
- Ryuichi Murai from Panasonic provided an industry outlook regarding plasma and also a description of the evolution of PDP technology. It seems that in the near future, plasma panels will be able to provide energy efficiency that rivals that of LCDs, with new technology that triples the energy efficiency of the plasma panels introduced last year.
- Ian Underwood from the University of Edinburgh touched on a very topical area with his presentation on pico-projectors. He gave a structured overview of pico-projector technology alternatives as well as the commercial offering of today. It seems that the commercial opportunities are awaiting the integrator companies, as the killer application is yet to be found.
- Finally, in the last talk of the workshop, Eugen Onac presented the state of the art of autostereoscopic display technology, concentrating on switchable 2-D/3-D lenticular screens and display systems. In contrast to 3-D systems based on adaptations of commercially available panels through the use of polarizing or shutter glasses, these displays offer a 3-D experience without additional glasses. Their drawback is that no fully artifact-free technology for switching back to 2-D exists as of today.

Four keynote presentations were the highlight of the start of the Symposium. Augusto de Albuquerque from the EU Commission

Program Chair Norbert Fruehauf (left) presents a gift to Professor Shunsuke Kobayashi in a special Eurodisplay 2009 session honoring Kobayashi's 77th birthday.

The keynote presenters and conference organizers behind Eurodisplay 2009 helped make the conference a great success. From left: Gerrit Oversluizen, Augusto de Albuquerque, Didier Zwierski, Kari Kulojärvi, Alasdair Jelfs, Norbert Fruehauf, Jyrki Kimmel, and Paul Drzaic.

explained the European Framework Programs 6 and 7, which involve funded research for displays and related technology areas. A funding opportunity in excess of 100 million euros has been invested with regard to upcoming calls for proposals. Kari Kulojärvi from the Nokia Devices Business Group presented a view of the mobile phone as a window to the Internet. Because the usage model of mobile phones is becoming more and more data-centric, with talk use narrowing toward 10% of actual use time, displays are becoming ever more important in achieving an optimal user experience. Alasdair Jelfs from Merck investigated the display material supplier's perspective on the industry, and Didier Zwierski from Philips TV looked at television now and in the future. He highlighted the trends toward wide cinemascopic TV displays with a 21:9 aspect ratio, as well as trends toward 3-D and touch-interface TVs that will be connected to the Internet.

A special session was organized in the honor of Professor Shunsuke Kobayashi's 77th birthday, highlighting his achievements in the field of liquid-crystal displays and the way in which his work has had far-reaching implications for the flat-panel devices of today. He was introduced by acting session chair Hoi-Sing Kwok and received a standing ovation. Many of Prof. Kobayashi's former colleagues and students came together for this special occasion.

In the Markets and Technology Outlook session, analyst Sweta Dash from iSuppli Corp. discussed the current state of the display market, which looks as though it will recover from this year's dip in 2010. Barry Young, Managing Director for the OLED Association, presented a look at the OLED industry in the current difficult economic environment, while also predicting multi-billion dollar revenues in the future. With five OLED suppliers in 2015, predicted Young, the revenues could be up to $US12 billion. Peter Knoll from the University of Karlsruhe described automobile night-vision systems and user experiences with different classes of related technology, offering some interesting insights into the utility of simple indicator systems and augmented reality in terms of providing driver alerts for night-vision displays.

On Wednesday, September 16th, a sold-out special event included a historical tour following a dinner at the top of the Capitolium hill, overlooking Rome's skyline. The guests enjoyed a thorough presentation on the history of the city and were given an opportunity to explore the famous sights close at hand on the guided walk to the Capitolium. The dinner itself was an event to remember, as top-level Italian cuisine was served accompanied by appropriate wines for the occasion.

In conclusion, it appears that Eurodisplay 2009 just set a new standard over prior Eurodisplay conferences in terms of location, scientific content, and general proceedings. The information presented at this conference was extraordinarily timely and invaluable to anyone involved in displays. The Eurodisplay 2009 team worked very hard to bring about this conference, and we are confident that the next team from the SID France Chapter will rise to the challenge and host an even better Eurodisplay Conference in Bordeaux in 2011. ■

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editorial

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consumer really need to know to make a fair and balanced purchasing decision? I think it depends on the degree of technical understanding the consumer has and how critical the decision is to achieving a good ownership experience. What does that mean? It means that a $300 TV does not come with the same burden of expectation that a $3000 TV does, and a person who buys a $3000 TV is a lot more likely to want to understand and appreciate the performance they are buying. That's where I think manufacturers are still doing a disservice to the industry. When manufacturers do not make the effort to educate consumers, retailers pick up the slack, and in some cases we know they can do it very poorly. I would rather see more effort from manufacturers going into improving product descriptions and specifications that are more relevant to consumers than contrast in the dark and color gamuts compared to NTSC. Let me know if you agree or disagree by writing to *ID* magazine at press@sid.org with your opinions.

I'm very pleased this month to welcome as our guest editor Professor Shin-Tson Wu from the University of Central Florida. Dr. Wu has arranged two very significant and instructive Frontline Technology articles covering the latest advances in the research of the blue-phase LC mode and the latest ideas on creating LCDs utilizing the Kerr effect. You can read more about both of these in Dr. Wu's guest editorial.

"Adaptive Backlight Dimming for LCD Systems" is the title of this month's Making Displays Work for You feature and you will be hard pressed to find a better survey of the state of the art in backlights than this article by authors Pierre de Greef, Hendriek Groot Hulze, and Jurgen Hoppenbrouwers from NXP, Inc.

Our monthly look at the Display Marketplace is brought to us by iSupply Senior Director of LCD Research Sweta Dash, who describes a fairly optimistic picture for unit growth of panel shipments worldwide but points out how pricing has slipped and warns of a growing gap between unit and revenue growth. Another very interesting revelation for me is the amount of investment in Gen 7+ LCD fabs in mainland China by LG, Samsung, and others. Some of this is apparently motivated by the China domestic marketplace and some may be motivated by protectionist trade practices in China, which I sincerely hope do not escalate.

Miniature laptops nicknamed "netbooks" are all the rage this season. I have purchased one myself and find it very useful. Managing Editor Jenny Donelan surveys the technology behind netbooks and explains what this new application could mean to display makers. Netbooks may not have created a new category for displays, but they have established 7–10-in. wide-format LED-backlit LCDs in an application with a lot more demand than personal video players.

Thank you once again for reading *ID* magazine and we look forward to your comments and feedback. ■

guest editorial

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motion-image blur and, more importantly, enables field-sequential-color displays without color filters if an RGB LED backlight is used. The elimination of the color filters results in several significant impacts: (a) it enhances optical efficiency by ~3x, resulting in lower power consumption if the same display brightness is compared; (b) it increases device resolution by 3x (*i.e.*, crisper images); and (c) it reduces production cost.

(3) The dark state of a blue-phase LCD is optically isotropic so that its viewing angle is wider and more symmetric. Compensation films may or may not be needed, depending on the actual applications.

(4) The transmittance is insensitive to the cell gap, as long as the cell gap exceeds 2–3 μm depending on the birefringence of the LC composite employed. This cell-gap insensitivity is particularly desirable for fabricating large-screen LCDs, in which cell-gap uniformity is a big concern, or single-substrate LCDs.

Although polymer-stabilized blue-phase LCDs hold so much promise, some tough technical issues remain to be overcome before widespread applications can take off. The major challenges are in three areas: (1) The operation voltage is still too high (~50 V_{rms} *vs.* 5 V_{rms} for conventional nematic LCDs), (2) the transmittance is relatively low (~65% *vs.* 85% for nematic LCDs), and (3) the mesogenic temperature range is still not wide enough for practical display applications (from –40 to 80°C).

The operating voltage of a blue-phase LCD is primarily governed by the induced birefringence, which, in turn, is dependent on the Kerr constant of the LC composite and the electric-field strength. Therefore, developing new blue-phase LC materials with a large Kerr constant and new device structures for enhancing the horizontal electric-field intensity in the in-plane-switching electrode configuration are equally important.

We hope you enjoy this look into the latest in LCD developments. In the interest of providing practical solutions, our authors placed special emphasis on the approaches for lowering the operating voltage while maintaining a good optical efficiency. ■

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