

ELECTRONIC MATERIALS

The rise of OLED displays

Organic light-emitting diodes are becoming a major market for advanced materials suppliers



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LG showed off banks of OLED-containing TV screens in January at the Consumer Electronics Show in Las Vegas. (Credit: Newscom)

Periodic visitors to the TV section of large electronics stores are usually impressed by how display technology constantly improves. At each new visit, the screens are larger, thinner, brighter, and often cheaper than they were during the previous trip to the shop a year or two earlier.

Visitors to a store today will see that more than two-thirds of TV screens on the market are now larger than 40 inches. They'll notice that Samsung and a few other firms are pushing a technology called quantum dots that seems to enhance colors and brightness. At some point, a TV model promoted by LG might attract attention, but perhaps more for its higher price than the performance



trickle into the market. Although they currently represent only a small slice of the total pie and are so far mostly used in mobile phones, OLEDs are poised to rapidly gain market share in the coming years.

This growth will open up billions of dollars of market opportunity for chemical companies that supply materials to the electronics industry. But at the same time, such firms are keen to hold on to the business they have with makers of displays based on incumbent liquid-crystal display, or LCD, technology.

“The OLED display industry is at tipping point,” says David K. Flattery, business development manager for OLEDs at DuPont. “LG is the only producer of OLED TVs currently, but several others are building pilot plants, and we expect a few to proceed with commercialization.”

Like DuPont, market research firms expect the market for OLED displays—in both TVs and smaller devices such as smartphones—to grow significantly. IDTechEx, for example, forecasts that global sales of OLED displays will increase from \$16 billion this year to \$42 billion in 2020. Samsung, which uses OLEDs in its Galaxy smartphones, is currently the top manufacturer of OLED displays. But others, such as LG, are entering the market, lured by what OLED technology makes possible.

“OLED displays can be lighter, they can be flexible, and they allow designers more leeway with the shape of their devices,” says Guillaume Chansin, senior technology analyst at IDTechEx. Theoretically, he adds, OLEDs can be far more energy-efficient than the LCDs found in most TVs today. And because they are now manufactured on a plastic substrate instead of a glass one, “OLED displays can make phone screens shatterproof, or even foldable.”

The promise of OLEDs has generated much interest among researchers for decades. In an LCD, images are generated by a backlight—a light-emitting diode nowadays—that sends light through liquid crystals, polarizers, color filters, and several image-enhancing filters. The color black in an LCD is created not by turning off the backlight but by electro-orienting the liquid crystals to affect the angle at which the passing light hits the polarizers.

OLED displays are much simpler and thus can be far thinner than LCDs. Instead of a backlight, OLEDs feature pixels that individually emit the red, green, and blue lights required to form an image. OLEDs consist of organic molecules positioned between two electrodes. As current flows from the cathode to the anode, electrons and electron holes in the molecules combine, emitting flashes of light.

In an OLED display, black is created by leaving the corresponding pixels off rather than by blocking a backlight. OLED advocates claim that the resulting “true black” is one reason OLEDs can display sharper images. And energy is saved, because the parts of an OLED display that are dark don’t consume electricity.

down, partly because they are fluorescent rather than phosphorescent and require more electricity to operate. In addition, the charge carriers in blue OLEDs recombine through the absorption of ultraviolet light. Moreover, from a performance point of view, the energy efficiency of blue OLEDs is also lower than for other colors.

When it comes to blue, says a spokesperson for the Japanese OLED materials supplier Idemitsu, display manufacturers can only convert about 40% of the electricity used into visible color. For red and green, the efficiency is already at 100%, she adds.

And OLED displays are prone to image retention, says Tadashi Uno, a senior analyst at the market research firm IHS Technology. This occurs when a display keeps showing the ghost of a previous image. Unless that problem is completely resolved, OLED will not gain widespread adoption among manufacturers of TVs and laptop computers. Currently, a temporary solution for owners of mobile phones with OLED displays is to download an app that reduces image retention.

The cost of making OLED displays is another issue. The core compounds at the heart of OLED displays are often made with expensive substances such as iridium, a rare metal that sells for nearly \$19 per gram.

What's more, the standard technique for depositing organic materials on an OLED substrate is a vacuum evaporation process in which a mask is laid over a substrate, molecules are deposited, the mask is taken off, and the mask is cleaned in a vacuum chamber. Industry insiders estimate that the process "wastes" between 70 and 90% of the expensive materials coated on the mask.

Despite these challenges, the number of OLED displays hitting the market is steadily rising, with some occasional setbacks. In 2013, both Samsung and LG launched OLED TVs, but Samsung quickly withdrew from the market because of prohibitive production costs.

However, with its launch of the Galaxy S4 smartphone that same year, Samsung put OLEDs in the hands of millions of customers worldwide. Last year, LG launched a new series of TVs with a higher resolution than its 2013 model. So far, LG's TVs do not implement a [full OLED design](#) but rather use OLED technology as a sophisticated white backlight while colors are generated by color filters. Because each pixel can be individually turned off, the LG TVs can generate true black.

In recent months, commitments to OLED production have multiplied. In November, LG Display announced a massive \$9 billion investment in an OLED TV plant scheduled to open in 2018. Numerous reports say Apple is going to source billions of dollars' worth of OLED displays from Samsung for use in future iPhone models. Meanwhile, Applied Materials, a supplier of precision manufacturing equipment, disclosed last month that demand for tools to make OLEDs is sharply strengthening in 2016.

facilities, Universal Display uses PPG Industries as a contract manufacturer of the materials it sells.

With OLEDs constantly in the news, Universal Display's stock has gained 25% in the past two months, a turbulent period for financial markets during which the S&P 500 stock index ended up flat. In late June, Universal Display announced the acquisition of Adesis, a contract research firm that was one of its partners. It also announced the acquisition of BASF's OLED materials patent portfolio.

The growth of the OLED display market will likely accelerate once device designers start to fully take advantage of the technology's potential, says Janice DuFour, vice president of technology commercialization at Universal Display. Given that OLEDs can operate even if the substrate is a thin sheet of plastic instead of glass, "the fixed shape of a device is not a given," she says. ["Imagine a display you can carry by rolling it up."](#)

Universal Display expects to be a major player as demand for OLED displays expands. "We made major discoveries on phosphorescent illumination back in the 1990s," DuFour notes. "Today, we practically own specific colors that OLED displays can emit."

Red and green light are now created with phosphorescent organic compounds that have greater quantum efficiency than the fluorescent compounds traditionally used in OLEDs. More research still has to be done on phosphorescent blue, DuFour says, but "we are hoping for a breakthrough soon."

The high cost of display materials and the waste that occurs during mask cleaning will not hamper the growth of the OLED display market, DuFour adds. "One gram of an expensive metal may be used to make 3,000 displays," she says. Meanwhile, PPG, Universal Display's manufacturing partner, is developing techniques to reduce the materials loss, she says.

DuPont is betting that reducing the cost of OLED displays and improving their performance will require ink-jet printing processes and suitable inks. Whereas OLED displays are typically created with mask-based deposition of organic materials, DuPont has been conducting research for about 15 years on printing the materials. Last September, it opened a prototyping plant in Newark, Del., that allows its customers to test the viability of printing processes.

The manufacturing requirements for key OLED display materials are as exacting as they are for drug ingredients, Flattery notes, and it makes sense not to waste these materials. So far, DuPont's proprietary ink-jet inks are producing good results, especially with the color blue. "We worked for years on blue materials," Flattery says. "Currently, our blues perform at 95% after 2,000 hours of continuous use."

To speed development of printed OLED technology, DuPont last year teamed up with the ink-jet equipment manufacturer Kateeva. But Flattery notes that DuPont has other undisclosed partnerships and that it won't be long before a display manufacturer announces the construction of

officer of Kyulux, a developer of OLED display materials based in Fukuoka, Japan. The question, he says, is whether materials developers will succeed in designing inks that can last long enough for use in a television.

“The high energy that blue materials are put through, it creates oxidation, causes all sorts of reactions, breaks bonds,” he says. So far, he says, phosphorescent blue materials aren’t commercially available because their metallo-organic bonds are relatively weak and achieving long lifetimes is difficult. Kyulux has developed fluorescent blue materials that it claims perform almost as well as phosphorescent ones.

Significantly, Savoie explains, the materials that Kyulux offers don’t contain expensive metals such as iridium. Using materials that do not contain rare metals reduces the cost of making displays, even with the deposition process, Savoie says.

As OLED displays mature, progress also continues for mainstream LCD technology. Led by Samsung, more and more TV manufacturers are incorporating quantum dots in their models to boost color performance and image quality without having to switch to a completely new technology and manufacturing process.

[Quantum dots are semiconducting nanocrystals](#) that increase the range of colors an LCD can emit. They can be fitted into an LCD TV with only a minor modification to manufacturing processes, according to Jason Hartlove, CEO of Nanosys, which calls itself the leading manufacturer of quantum dots. Currently, Nanosys supplies 95% of the quantum dots used in displays, he claims.

In the TV market, quantum dots are far more popular than OLEDs, Hartlove says, appearing in about 40 models to date. He expects that, within five years, as much as 30% of the TV market, measured by total display area, will implement quantum dots.

“OLEDs should theoretically offer a better performance, but we’re very cost-effective,” Hartlove says. OLEDs are uniquely capable of displaying true black, he concedes. But the human eye can only detect true black in a completely darkened room, blurring the performance differences between OLED displays and LCDs with quantum dots. “It’s quite rare to watch TV in a pitch-black room,” he notes.

With OLED technology rapidly emerging but LCDs remaining competitive, established suppliers of display materials must allocate their R&D resources to best take advantage of the emerging market while still supporting the LCD business. JSR, a major Japanese supplier of LCD materials, is hedging its bets by developing OLED materials while continuing to vigorously support LCDs, according to Hiroaki Nemoto, general manager of JSR’s display solution division.

“At JSR, we think that the OLED market will be a good opportunity for us to expand our portfolio,” Nemoto says. At the same time, “LCD technology can be further improved in terms of thinness,

as color resists and color films, so that they can be used in OLEDs. The company has also developed a new desiccant to protect water-averse OLED materials.

With OLED technology becoming standard in mobile phones but making only hesitant progress in TVs, the display industry is currently at a crossroads, says Uno, the IHS analyst. "It all really depends on the adoption rate by companies like Apple," he says.

But OLED displays provide such significant advantages over LCDs in terms of weight, thinness, robustness, and flexibility that change will happen fast once key hurdles are overcome, Uno adds. "If manufacturers can develop a process that achieves high yields," he says, "I am certain the whole display industry will shift to OLEDs." ■

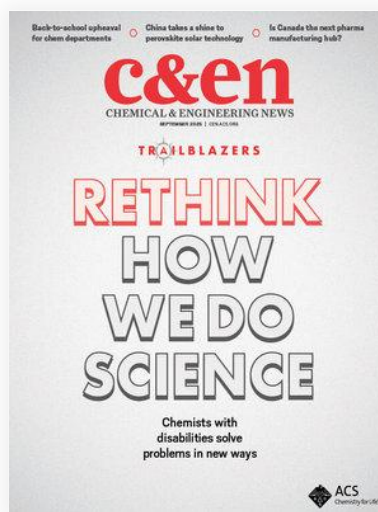
In brief

Long researched in labs worldwide, OLED displays are becoming a market reality, especially in mobile phones. OLEDs offer the potential for vast improvements in image quality and also open up new possibilities for device design—such as TVs that can be rolled up. But for the time being, several challenges must be overcome for OLEDs to become mainstream in TVs. In particular, manufacturing costs need to come down and durability has to improve. As the following pages show, chemistry will play a key role in enabling the growth of the OLED display market.

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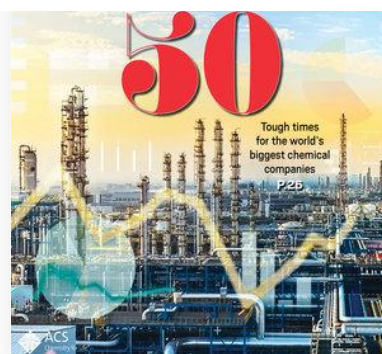
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