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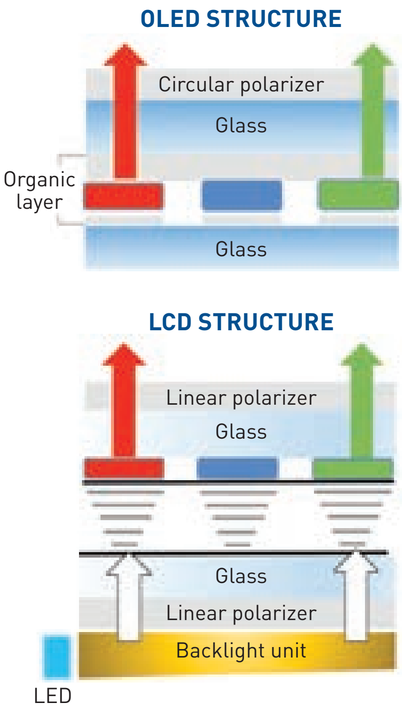
OLED Versus LCD: **Who Wins?**

Zhenyue Luo and **Shin-Tson Wu** analyze liquid-crystal display and organic light-emitting diode technologies to see which one will dominate the market.

The global display market has exceeded US$120 billion, making it one of the largest optics and photonics industries. With so much to gain, there is strong competition for market share between organic light-emitting diode (OLED) display and liquid-crystal display (LCD) manufacturers. The consequences of that competition are showing up in people's hands: Apple's recently released iPhone 6, for example, uses a state-of-the-art LCD screen, while Samsung's flagship Galaxy S5 gave the nod to OLED.

So which display will take the largest piece of the pie? Even though the answer depends on more than just performance (marketing strategy and capital investment also influence success), it is interesting to take a look at each display's market potential from a technical point of view.



Operating principles

Before examining the pros and cons of OLED displays and LCDs, it's important to understand the difference between their operating principles: OLED displays are emissive—they produce their own light; LCDs are non-emissive—they are illuminated with a backlight.

An OLED display is composed of multilayer film-stacks and a circular polarizer that mitigates ambient-light reflection. Each pixel can be turned on individually and requires multiple thin-film transistors (TFTs) to ensure stable current flow.

LCDs have a modular structure and require a backlight that illuminates the liquid-crystal module to create images on the screen. The liquid-crystal cell can be optimized for specific applications, like high-contrast televisions or touch-panel mobile devices. But unlike OLED displays that are driven by current, LCDs are voltage devices. So, each pixel only requires one TFT as a voltage switch.

Performance metrics

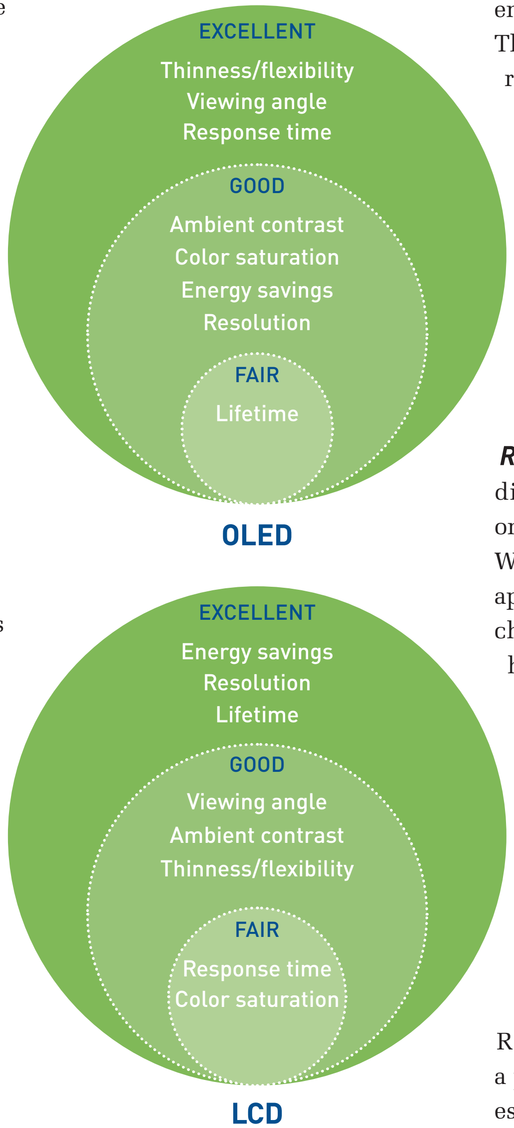
To determine which display is technically superior, we conducted a quantitative comparison for eight performance categories:

Color saturation. Most LCDs use a white LED backlight and color filters to display images. The color gamut is usually limited to 75 percent Adobe RGB (a defined color space for displays). OLED displays, however, can cover 100 percent Adobe RGB and deliver better image quality.

Response time. OLED displays can be turned on in microseconds by applying electric current. This translates to visually undetectable frame changes—i.e., no motion blur. LCDs suffer from slow response time and motion blur because the liquid crystals are unable to change their orientation fast enough from one frame to the next.

Thinness/flexibility. OLED displays are thinner and more flexible than LCDs because they have fewer components; they do not need a backlight and they have a solid rather than modular structure.

Performance comparison between OLEDs and LCDs



Comparison is for an LCD with a white LED backlight.
Infographic by Alessia Kirkland

Lifetime. In contrast to LCDs, sensitivity to air and moisture greatly reduce an OLED display's long-term stability. However, short lifetime may not impede OLED technology's potential to capture the mobile display market, because device lifetime isn't a main concern—smartphone lifespan is typically only two to three years.

Energy savings. OLED displays require multiple thin-film transistors (TFTs) per pixel to ensure stable current control. The grouped TFTs cause high resistive and capacitive loss and a reduced aperture ratio. OLED displays also require a circular polarizer to mitigate ambient light reflection from metallic anodes and cathodes, which cuts screen brightness in half. LCDs consume less power than OLED displays for the same size, brightness and resolution.

Resolution. In LCDs and OLED displays, each pixel is addressed by one or multiple TFTs, respectively. When you increase resolution, aperture ratio decreases and TFT charging time increases. Therefore, higher-electron-mobility TFT materials (e.g., low temperature poly-silicon and oxide semiconductors) should reduce TFT size, which in turn increases light output, especially for OLED displays, which require multiple TFTs per pixel.

Ambient contrast ratio. Readability in bright light is a problem for both displays—especially for mobile devices. OLED displays have superior contrast ratio in dark light, because individual pixels in the display can be switched off when not in use. However, when viewed under direct sunlight, the ambient light reflected off a smartphone screen degrades the color and image contrast ratio, because a portion of the reflected light is observed as noise. LCDs do not have a strong reflection component, but their 75 percent color gamut in low ambient light drops to less than 50 percent in bright light, resulting in washed-out images.

Viewing angle. OLED pixels feature a Lambertian-like radiation pattern that creates pleasing wide-view matte images. State-of-the-art LCDs use compensation film and multidomain structure to expand the viewing angle. Both displays offer picture accuracy at viewing angles ±30 degrees from the center of the screen.

Potential game-changers

OLED's superior response time and color saturation are being challenged by recent LCD advances. Conventional LCDs rely on molecular reorientation to control light transmittance, making response time relatively slow (more than five milliseconds, compared with microseconds for OLEDs). But emerging blue-phase liquid crystals based on Kerr-effect-induced isotropic-to-anisotropic transition can achieve a sub-millisecond gray-to-gray response time. With blue-phase, LCD response time would only be governed by the TFT frame rate, so an LCD with a 240 Hz frame rate will have a sharper image than an OLED display with a 120 Hz frame rate.

Emerging fast-response liquid crystals could enable field sequential color (FSC) displays. In a FSC display, the backlight sequentially emits RGB lights. The LCD panel is synchronized to the backlight to display gray levels of each color. This method of color generation does not require spatial color filters or subpixels to reproduce colors. As a result, it could offer significantly higher optical efficiency and resolution density than OLED displays.

New quantum dot (QD) technology would also give LCDs an edge over OLED displays in color saturation, or at least level the playing field. LCD color reproduction has been limited by white LEDs and color filters. But with today's blue LEDs, down-converted QDs added to an LCD can create emission spectra optimized to match the transmission spectra of color filters, thereby simultaneously boosting LCD optical efficiency and color gamut to be equal to or better than OLED. (This QD technique is used in Amazon's Kindle Fire HDX 7 and Sony's Triluminos televisions.)

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There are also new methods for increasing OLED display readability in bright light, like better green phosphorescent emitters and light-extraction techniques. For LCDs, sunlight readability could improve with a "smart" backlight that concentrates illumination toward the viewer's eye or with a QD-enhanced backlight to precompensate the color-gamut reduction.

OLED manufacturing can be expensive and complicated because of the required special vacuums and hermetic packaging—especially for larger displays. For example, a 55-inch OLED screen can cost US$5,000—5 times more expensive than the equivalent LCD. However, as manufacturing technology continues to evolve, the price gap should gradually narrow.

And the winner is?

Our assessment suggests that there's no clear winner in the match between OLED and LCD. Each technology has its own unique characteristics to distinguish itself for different applications, and each camp has invested tremendous resources to perfect the device performances.

Thankfully, no matter which technology dominates, the true winner will be consumers and the optics and photonics industry as a whole. Consumers will enjoy cheaper, lighter, smarter and brighter displays, while the companies that make them will benefit from component sales and manufacturing. LCDs and OLED displays are like twin stars; their healthy competition will light up our sky. OPN

For readers interested in comparing specific brands of LCDs and OLED displays, we recommend the shootout series from www.displaymate.com.

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