Electrofluidic displays could broaden electronic paper uses

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Electrofluidic pixel, one of the newest reflective display technologies, will allow an even larger, second wave of e-paper products and applications.

Electronic paper or ‘e-paper’ has moved out of the lab and into the marketplace. The monochrome Amazon Kindle and other e-readers using reflective displays have created an enormous buzz, a moment many researchers have been intensely pursuing for the past decade. The Kindle™ uses E-Ink technology, which elegantly transposes (moves) charged white or black pigment particles toward or away from the display’s front surface. However, the excitement over e-paper has been dampened to some degree by the success of tablet personal computers such as the Apple iPad®. Without a compelling technology ready to provide full-color reflective screens, how can e-paper compete? The answer is that a larger, second wave of e-paper products is coming. E-paper will flex its biggest strengths of superior energy savings, rollable or foldable formats, and perfect contrast even in sunlight. It will do what LCDs or organic LEDs cannot, that is, appear indistinguishable from real print.

The second wave of e-paper will involve three major commercial endeavors. First, e-paper will satisfy the consumer excitement for color e-paper that is also fast enough for multimedia (seamless web surfing, at least crude video capability). Second, there is an enormous amount of printed media that is high-contrast black/white, because often the goal is to convey basic information as clearly as possible. For example, consider the growing market for electronic shelf-labels where prices could be updated wirelessly and display as clearly as possible, only requiring a new coin-cell battery every five years. Third, once thought dead, rapidly reemerging is the push to commercialize rollable e-paper for unprecedented display portability. We are working on one of the newest technologies, the electrofluidic display,¹ which is poised to excel in all of these second wave, e-paper applications.

Figure 1 shows several types of electrofluidic pixels ranging from ~20–70 μm thick. All pixel types use the term electrofluidic because there is an electrically driven flow through microfluidic cavities when ~15V is applied. An enabling feature for electrofluidic devices is transposition of a pigment dispersion (similar to ink-jet fluid) at speeds of tens of milliseconds. (Interestingly, the pigment dispersions used in electrofluidic displays are made by Sun Chemical, a leading expert in colored fluids for conventional printing.) The fluid can be revealed over nearly the entire pixel area and hidden to less than 5–10% of the pixel area. As a result, we achieved ~70% reflection.² Unlike electrophoretic technology, which moves pigment through fluid, electrofluidic moves the entire fluid itself with the pigment inside. Fundamentally, this provides about 100X faster switching speed over comparable length scales. The devices can also hold their image without voltage in so-called grayscale stable operation. We have found that the fluids are robust, with operation demonstrated over the range of ~30 to +60°C.

Fundamentally, electrofluidic technology is well suited for monochrome operation. A simple and high-efficiency white reflector can be used as the background, and a carbon-black pigment can be moved over this white background. We found that beyond the 10% loss at the internal aluminum mirror, the only significant optical losses are due to total-internal reflection, pixel borders, and the visible reservoir area. These losses are small...
compared to the ~50% loss associated with polarization-based technologies such as liquid crystal. Also, our researchers have newly reported an electrofluidic technique using Laplace barriers for simple shape change or segmented displays.\textsuperscript{3} Up to 90% white state reflectance and >30:1 contrast ratio has been measured for these devices. Laplace barriers also enable pixels to operate without pixel border loss, even further reducing the optical loss.

Most e-paper applications may still be monochrome, but electrofluidic technology is also being applied to the lucrative color-video market. As we have mentioned, video capability is inherent to electrofluidic pixels. So how do we achieve color? The first and most conventional approach is to use red-green-blue-white color filtering over a high efficiency black/white pixel. This particular type of color filtering causes a 50% reduction in total brightness and produces adequate but muted color. We believe a potentially more compelling approach is to use a bi-primary color system where each electrofluidic pixel has two reservoirs, one of which displays a red, green or blue primary, and the other the compliment from cyan, magenta, yellow primaries. Compared to conventional color-filtering, the bi-primary approach roughly doubles the color saturation and brightness.\textsuperscript{4} Importantly, the approach uses only a single layer of pixels, avoiding costly multilayer stacked pixel schemes that make video difficult or impossible.

Electrofluidic technology has been moving out of the lab for about a year now, with commercialization led by Gamma Dynamics, which is prototyping electrofluidic displays in the US Army Flexible Display facility, the same facility that is currently producing flexible E-Ink prototypes. Although electrofluidic displays and Gamma Dynamics are relative latecomers to the business, the timing might be perfect to catch significant parts of the second wave of e-paper products. Once electrofluidic technology is in the market, engineers and designers will likely use it to broaden e-paper’s applications. While commercialization of existing electrofluidic technology moves forward, we will continue to experiment with device structures that can potentially be even brighter, faster, and at the same time, further simplify manufacturing.

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References