The Future of Color for Electronic Paper

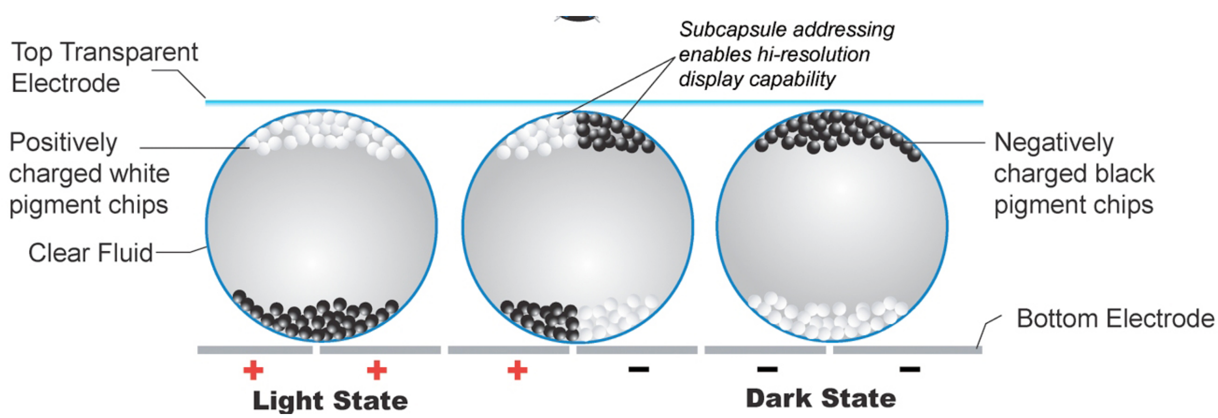
This article is based off the NanoMarkets report ***The Future of E-Paper: A technology Assessment and Market Forecast***

Displays pervade electronic equipment. At a basic level they provide information about the functioning of the device. For some, information processing and delivery may be their sole purpose. Most displays contain a light source, either from the display elements themselves (e.g. light emitting diodes) or provided separately (e.g. backlights in liquid crystal display monitors and TV screens). These work effectively in normal room lighting conditions, or even in darkness, but can't compete with bright or even moderate sunlight.

The term "electronic paper" covers displays that use reflective rather than emissive technology to create images. With reflected light (as with ink on paper) better sources (such as sunlight) usually mean clearer images for the viewer. Another advantage of this technology is that because e-paper doesn't have to feed hungry backlights, it uses much less power than other display types and often requires zero power needed to maintain images.

While simple reflective displays in the form of segmented black on gray LCDs (as used in low-cost digital watches) have existed for some time, it is new technological development that has given the sector renewed direction, optimism and interest. Indeed, when people refer to "e-paper," they often mean E Ink's electrophoretic display (EPD) technology (Figure 1) that has recently come into commercial use, particularly in electronic book readers, information signs and smart electronic shelf labels (ESLs) in stores.

Figure 1: Cross Section of Electronic-Ink Microcapsules

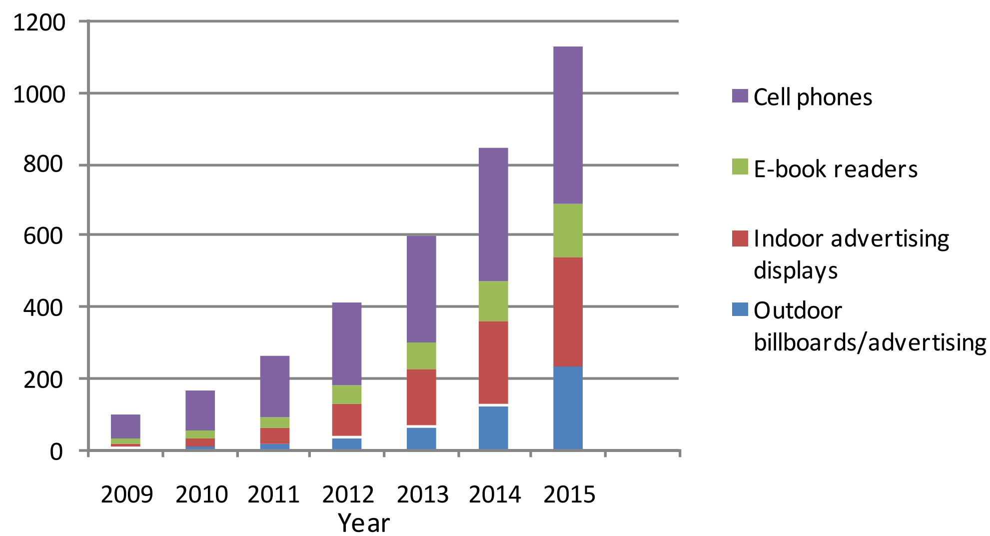


Source: E Ink Corp.

Sunlight readability and low power consumption are key attractors for application in mobile devices and in signs and advertising, both indoors and outdoors. However, the leading drawback to wider application is that high quality full color image creation is not yet available. Another drawback that is a killer for more advanced applications is a slow page update for most e-paper technologies, which rules out video display as needed for most computer monitors and mobile phones (at least according to the network operators, if not the consumer). Here we focus on the first problem—that of full-color e-paper development.

In an earlier age, when newspapers were predominantly black ink on "white" paper and even some advertising posters were less than full-color, one could imagine a gradual development of e-paper technology in this direction. Now, however, high-quality, low-cost full-color is mandatory to move e-paper from niche monochrome applications into the mass markets of mobile phone displays, electronic newspapers and magazines (where advertising revenue is usually more important than the cover charge), electronic advertising hoardings, etc. Figure 2 shows NanoMarkets' projections for markets relevant to color. These projections were made before the current crisis in financial markets had emerged. One can expect that one impact will be a flattening of sales growth in the near term, pushing out commercial development by a couple of years at least. The electronic book reader application is taken to include possible e-newspaper and e-magazine development that require color in the long term; however, monochrome readers can also be expected to show growth in the next few years.

Figure 2: Summary of E-Paper Revenues ($ Million)



Source: NanoMarkets, LC (The Future of E-Paper: A Technology Assessment and Market Forecast, June 2008)

One aspect in assessing color e-paper is to understand that photographic evidence of performance is not that reliable. Some images may be "enhanced in post-production," like cosmetic ads, or even be computer graphic preconstructions from the design process. In the other direction, the human eye-brain machinery is far more sophisticated than the most advanced camera and carries out all sorts of correction so the human experience of an image will usually be much better than a quick snapshot taken at an exhibition or in the lab. Consumers may be willing to adjust to less than perfect images for the sake of convenience as with the transfer from cathode ray tube to LCD monitors. Advertisers are not likely to fall into this category.

Side-by-side

It is no surprise that the early deliveries of multicolor e-paper have taken their cue from the LCD industry where there is an extensive infrastructure for producing and applying red, green and blue (RGB) filters. Indeed, some of the first multicolor prototypes have been reflective variations of LCD technology with different colored pixels placed side-by-side.

Nemoptic (based in France) has color capability at the "demonstrator" level using standard LCD manufacturing technology. Its LCD technology is called "Bistable Nematic." The BiNem Demonstrator 1000 (BD 1000) e-paper display has 100 dots/inch (dpi) and a 5.1-inch diagonal (Figure 3). The brightness of the image has been increased 20 percent over Nemoptic's previous attempts at color (going back to 2004), largely through adding a white subpixel to the previous RGB regions. A subpixel measures 127 x 127microns and has up to 32 levels, so more than a million colors can be represented by the RGBW combination.

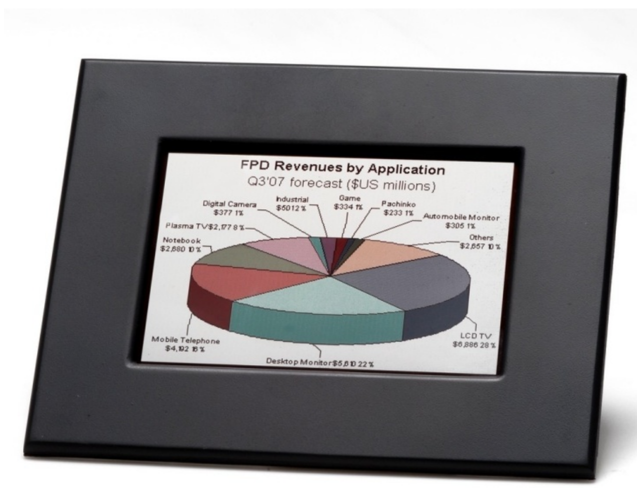


Figure 3: The BiNem Demonstrator 1000

Since the device is bistable, it needs no power to maintain a displayed page. Nemoptic claims that the BD 1000 is "mass-production ready." The company sees potential for ESLs, point of sale terminals, e-newspapers, e-magazines and toys. Seiko Instruments has taken up a subcontract for manufacturing Nemoptic's displays.

Companies using E Ink's electrophoretic display technique have also largely opted for RGB-based color. One of the most recent announcements in this direction has been a flexible, A4-size (14.3 inch) 16.7-million color, 1280 x 800 pixel display from LG.Philips (Figure 4). Along with Philips, E Ink has also worked on color with Toppan Printing since 2002.

Figure 4: LG.Philips' A4 14.3inch 16.7 million color e-paper display (left).

Qualcomm MEMS Technologies (QMT) has a somewhat different approach to producing an image—its mirasol display uses light self-interference in a micro-electro-mechanical system (MEMS) to produce reflected color. Since MEMS has similar production capabilities to silicon microchips, it is not surprising that the displays are small. The color display is 0.9 inches. The format is 128 x 64 pixels giving 160 pixels/inch. Higher resolution is possible due to the microtechnology used in manufacture. Larger displays are in the works.

Initial mirasol color displays generate the equivalent of 4K colors using both spatial color depth and half-toning techniques. QMT believes that 256K and beyond should be possible. Reflectivity is quoted at 25 percent with 7:1 contrast. The target application is for mobile devices such as phones, Bluetooth headsets, MP3 players, indicators and industrial displays.

In May, the first announcement of a color mirasol application was made: Freestyle's a rugged Audio Soundwave Limited Edition MP3 player (Figure 5). Since then, Skullcandy has said it will incorporate the display into a headset that features a music player (Figure 6). Both products are designed for sports use.

Figure 5: Freestyle Audio Soundwave Limited Edition sports MP3 player with color mirasol display.

Figure 6: Skullcandy sports headset with color mirasol display.

Stacking

Rather than having the pixel colors side-by-side, some companies have stacked the color layers on top of each other. This means the color effect is less spread out, giving a clearer image when viewed straight on, although the colors can shift at an angle. The display is also thicker.

Fujitsu Frontech's e-paper display, developed jointly with Fujitsu Laboratories, consists of three layers on a flexible substrate (Figure 7). The layers contain cholesteric LCD (ChLCD) material colored red, green and blue, avoiding the need for separate filters.

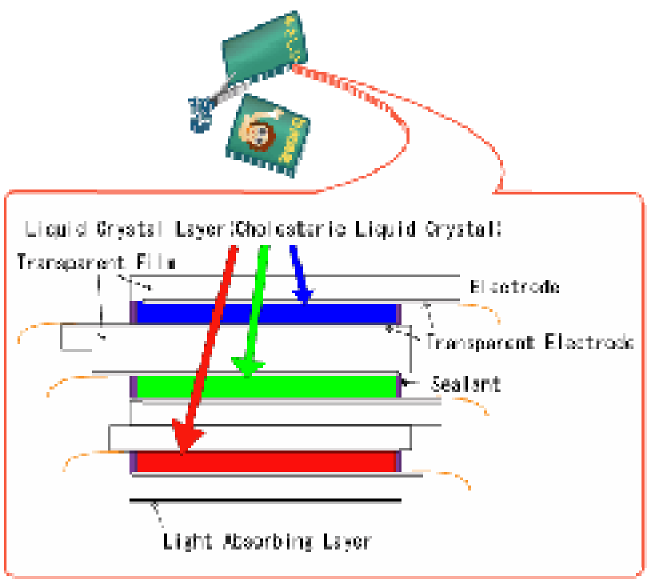


Figure 7: Fujitsu Frontech uses stacked RGB layers of its ChLCD material to produce its full-color displays.

The technology has been applied to Fujitsu Frontech's FLEPia portable information terminal for the Japanese market that comes in two sizes, A4 (12 inch) and A5 (8 inch), weighing 480g, and 320g, respectively (Figure 8). The device thickness is 12mm. The range is 8 or 4096 colors. Both devices contain XGA standard 768 x 1024 screens. The terminals are designed to interface with wireless networks, SD Flash memory cards or USB 2.0 ports. The initial device was equipped with the Japanese version of Windows CE with a production schedule of 1000 units for 2007.

Figure 8: Fujitsu Frontech's FLEPia information access terminal.

Global sales were planned for this year, but Frontech is currently evaluating whether it can provide FLEPia overseas with a relevant market demand. The price of ~$1500 each (¥1.6 million for lots of ten) for the lower cost A5 version, and the 2007 production schedule, suggests that they are not aimed at the mass market as yet. The accumulated sales target set when the product was launched for the period up to 2010 was ¥10 billion (~$100 million, ~60,000 A5 units at 2007 prices).

Magink also uses ChLCD technology in a RGB stack formation to produce displays aimed at indoor and outdoor signs, including advertising. Testing and deployment in several cities globally is underway. The pixel pitch is 9mm, suitable for viewing at some distance from the board. The design was finalized in 2007. Kent Displays has also developed RGB stacks of ChLCD material to produce full-color flexible displays (Figure 9).

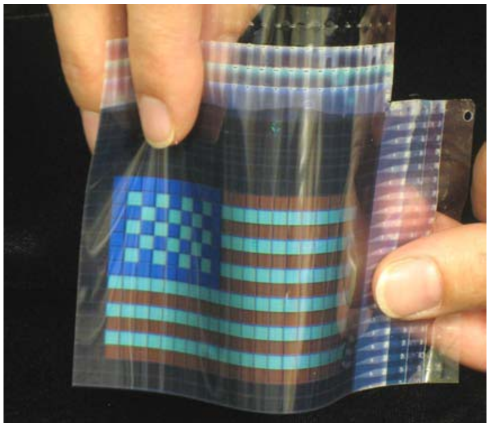


Figure 9: Kent Displays demonstrator based on stacked RGB colors.

CMYK alternative

Although RGB and RGBW filters based on the infrastructure of the LCD industry are probably the easiest to plug into for a new technology, it is not necessarily the best for e-paper. In the paper printing industry, the overwhelmingly predominant full-color technology is based on cyan, magenta, yellow and black (CMYK; K = "key" = black) inks. The CMYK color system depends on subtracting light to form colors, unlike RGB that adds light. The additive colors of RGB are more suited to emissive display systems such as cathode-ray tubes, plasma displays, and backlit LCDs. An RGB filter subtracts about two-thirds of the light from a white source, while CMY filters subtract only a third. Since the base reflectivity of e-paper is usually around 50 percent it is desirable to reduce the loss of light from color filtering.

Liquavista, spun out from Philips Research, uses a stacked combination of CMY "electrowetting" elements. The company has recently received a GBP12 million (~$20 million) grant from the U.K. government's Technology Strategy Board to develop full color flexible electronic displays with video capability (based on a switching speed of less than 10 milliseconds). The project includes Plastic Logic (a company developing printed electronics on plastic that works with a range of e-paper companies). Liquavista claims the highest black and white reflectivity of 60 percent, 10 percent short of ordinary paper's 70 percent. Ntera is another company that has discussed the CMY/CMYK option, but a demonstration is a couple of years off at least.

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