E-Paper (using an Indium based layer) Marches Forward

E-paper was 2008's curiosity display, challenging established display technologies in a few low-end applications such as electronic shelf labels (ESLs) and successfully entrenching itself in a new application realm: the e-book reader. A few companies had a few products here and there, representing a few technologies.

In just one year, the story has changed considerably in 2009. A growing slate of technologies is now in play from a whole new raft of competitors that have moved beyond the prototype stage to offer real products. The e-paper technology contestants now include:

- Bistable TN (twisted nematic) liquid-crystal displays (LCDs) from such companies as Nemoptic, ZBD Displays and Seiko Epson;
- Ch (cholesteric) LCDs from Kent Displays Inc., Fujitsu Frontech, Varitronix International and others;
- Electrochromic, or electrochemical displays (ECDs) from Acreo, Aveso and Ntera;
- Electrophoretic displays (EPDs) from E Ink Corp., SiPix Imaging Inc. and Bridgestone Corp., with several new EPD module makers;
- Electrowetting displays (EWDs) from Advanced Display Technology and Liquavista; and
- A Micro-electro-mechanical system (MEMS) entry called IMOD (interferometric modulator) with displays from Qualcomm MEMS Technologies, Inc. (QMT).

Several characteristics define the class of displays known as e-paper. E-paper displays are reflective displays that deliver crisp black and white text and images for very little power. They are also typically thin, lightweight, rugged and conducive to flexible substrates. Most e-paper is bistable--that is, it retains screen contents without consuming power. E-paper is, in short, very much like ink and paper, with high contrast ratio, sunlight readability (a major appeal of reflective devices) and the potential for high resolution. E-paper's hallmark low-power consumption and compatibility with high-volume manufacturing on plastic substrates makes it a very appealing next-generation technology play.

Changes that Impact E-Paper

A number of things have changed in the past year. For one, the understanding of the term e-paper itself has become muddled. Initially referring specifically to this class of reflective, low-power displays, the word has now attracted a number of other connotations. The newspaper industry, for example, has adopted the term e-paper to mean electronic newspaper; Adobe has adopted the word to mean a

particular line of content creation products; etc. The term e-paper retains its original meaning in this report.

What has changed dramatically in the past year, of course, is the economy, which is impacting the progress of e-paper market in various ways. Many of the financial institutions that were vigorously ramping up smart cards with a one-time programmable (OTP) e-paper display have taken a step back, for example. On the other hand, the dwindling market for newspapers and other printed matter has publishers scrambling for e-reader devices, which are the exclusive realm of e-paper today.

Those companies that have gotten over the hump of viability by fielding displays for real-world products should be able to ride out the economic storm. Their progress in pushing the state of their technologies, however, will certainly be delayed, as research-and-development dollars get shifted to cover practical near-term necessities, and customers move some projects to the back burner. And, e-paper companies still relying on recurrent rounds of outside financing to develop their technology will certainly feel the pinch.

E-paper displays implemented as bells and whistles in luxury products are very likely to suffer in the current economic bust, as even the affluent scale back on discretionary purchases. Devices that provide real, perceived value for little extra cost, on the other hand, could prosper.

As in the past half dozen years, the e-paper arena continues to nurture corporate partnerships, though their nature has changed somewhat. The early rounds of partnerships centered around cooperative development of technologies, manufacturing processes and equipment. Some of these carried over into technology insertion, infrastructure, manufacturing capacity, supply chain and marketing issues. Today's partnerships, in contrast, tend to couple the maker of an e-paper device with a media company, telecommunications service provider, and/or some other link in the chain.

E-Paper Applications

E-paper materials, structures and manufacturing processes have all reached sufficient maturity to readily meet the needs of some very large markets in a number of different areas, including electronic signage, mobile communications, handheld computing and disposable electronics. Display technology does not traditionally come to market in a state of perfection, but instead, when it's "good enough" to meet the needs of some market niche; and e-paper has arrived at this stage.

Where these markets are currently addressed by real paper, such as e-readers and e-billboards, e-paper matches the visual quality of paper, while offering a major advantage that paper cannot match: the ability to continually change

content electronically. In the e-book arena, e-readers store many different books in about the same physical space as a single real book, a major draw for serious readers. In the billboard arena, e-paper slips in nicely where hard copy is now the norm, utilizing the same front lighting as conventional billboards and selling the same screen real estate to different advertisers at different times of day and night. The list goes on.

The fact that e-paper is readily readable outdoors is a major advantage over established display technologies. Unless they're post-engineered for special markets, transmissive devices such as conventional LCDs, wash out in bright ambients, as do emissive devices such as organic light-emitting diode (OLED) displays and plasma display panels (PDPs). As reflective displays, e-paper devices overcome that usability issue, actually becoming brighter in response to increases in incident light. Some day, our current inability to read our cellphone and laptop screens outdoors will seem a bizarre historical hiccough.

Smart cards: E-paper applications range from the very small to the very large. At one end of the spectrum, smart cards are a natural home for simple displays. Many smart cards already contain a fair amount of information on board. That we as users are not now given access to that information by means of a display will become another historical curiosity.

Two or three e-paper makers have design wins at smart card companies, and several others are in trials. The bistability of e-paper displays means that there's no need to incorporate a battery into a simple card displaying a unique OTP code.

Small e-paper displays will also have a future in portable peripherals where, for little cost, they relate some useful information to the user, such as the capacity remaining on a hard disk drive. E-paper is a natural fit for smart packaging, especially for pharmaceuticals.

ESLs: Up a few inches in size, ESLs continue to be a natural home for e-paper. (Electronic signage in general is a huge opportunity for electronic displays, and some of that is accessible to e-paper alternatives.) Updating pricing with paper labels is extremely slow and labor intensive; and conventional passive LCDs being used for ESLs have very limited screen capability. Moreover, the bistability of e-paper means the labels draw no power except when they are updated, and therefore do not require large batteries. In ESL and some POP/POS (point of purchase/point of sale) signage applications, a five-year battery life is becoming the norm.

The ability to dynamically update prices is said to contribute to the bottom line of groceries, department stores and other retail establishments--especially for time-sensitive foodstuffs such as sushi and produce. The proven gains of automating pricing at the shelf level make increased use of e-labels likely for those that have

already paid to put the basic infrastructure in place. For those who have not, e-shelves will probably have to wait until economic conditions improve.

Niche consumer applications: Elsewhere in small screen sizes, e-paper is finding some very nice applications in watches, cellphones and a number of novelty items, and it appears likely to develop a lock on rugged "no glass" sports watches. In cellphones, E Ink's e-paper enables a display screen that is sunlight readable, always on and very low power--in stark contrast to mainstream LCD-based, and the latest OLED-based, cellphones.

Motorola has one E Ink cellphone on the streets in the third world, where there is not necessarily easy access to an AC power source for recharging. We believe that its characteristics would also be welcomed in the U.S. among users who value display function and low power over bells and whistles.

Elsewhere in cellphones, e-paper is being implemented in so-called cellphone "shells," which switch among different colors and/or graphic patterns to fit the user's current mood or desire to make a fashion statement. These shells represent a promising item in a high-volume market where glitz matters.

The potential is great for e-paper to impact a wide range of small- and medium-screen applications in consumer gear of all kinds, where one or more of e-paper's virtues will be valued--such as bistability, flexibility or sunlight readability. But will tight economic conditions mean that consumers will carry more inexpensive single-function devices or will they try to consolidate into a single platform that covers a number of functions? The next big thing in portable electronics platforms is impossible to predict.

E-readers: For e-readers, however, great things are happening. With the popularity of the Kindle e-reader, Amazon has obviously hit the right mix of characteristics to catch the public's imagination and make it open its wallets. Further, the world is rife with e-newspaper activity and larger-screen e-readers with a business document orientation are here and on the way, both very promising markets where e-paper serves a real need.

Elsewhere, active-matrix LCDs are making major inroads into information signage--not just in airports anymore, but also in retail establishment, hotel lobbies, shopping centers and fast-food restaurants. LCDs will be hard to displace, but e-paper in the form of Ch LCDs has found a small niche in information displays located at transit stations, in hotel lobbies, outside conference rooms, etc.

Signage: The e-paper presence in signage should increase as companies become more energy-conscious and take energy-saving technologies such as e-paper more seriously. Especially in well-lighted environments, it makes far more sense to use the ambient light with a reflective display than to try to overpower

the light with an emissive or transmissive display by churning out more and more watts.

There's one particular signage niche that e-paper has all to itself: the standalone, battery-powered, promotional POP/POS sign, where the ability to operate for a reasonable period of time from a battery is especially important. Here (as in ESLs), bistability helps free the sign from reliance on an AC power cord and, thus, removes the hindrance of having to locate the device near a power outlet. In conjunction with today's wireless LANS, battery power allows e-paper signs to be placed where they will have the greatest impact, not just those areas that are already part of a hard-wired infrastructure.

With the recent economic collapse, though, the proliferation of POP signage will likely be negatively impacted. Paper and cardboard do a good job at what they do, and it takes a compelling reason to go electronic.

In the large-screen arena, a number of different e-paper types are in field trials for information displays of all kinds. Several companies are fielding bulletin-board size e-paper displays for signage apps, and some of these are specifically designed to function as the "tiles" of larger displays made up from a matrix of tiles.

Conventional inorganic light-emitting diodes (LEDs) are having some success in high-profile billboards in urban areas, and they will be a difficult competitor to displace. E-paper offers a significant value proposition here, though, providing a much simpler transition from paper to electronics, as well as major power savings.

Technology Directions for E-Paper

The technical demands on e-paper in established markets such as signage have been very modest. Here, resolution is quite coarse and high speed is unnecessary; what matters is being big and having high contrast. For newer e-reader type applications, conventional active-matrix technologies are sufficient to drive e-paper to very high resolution; and tweaks at various places in the design chain have made good progress on speeding e-paper up.

E-paper excels in two-color implementations, whether that's black and white, red and amber, yellow and green, pink and peach or one of the other display combinations offered by various e-paper makers. It is less commonly multi-color, which is a prerequisite for expanding into many applications.

Even in the e-reader space, while good, crisp black and white is an excellent solution for best selling fiction and nonfiction, other niches such as textbooks and medical books require the use of multiple colors. Other arenas such as ESLs and signs are adequately served by two-color devices or area-color devices in which

different parts of the sign provide a different color pair. Here, multicolor displays represent unnecessary complexity and cost.

Multicolor implementations of the most popular e-paper type, the EPD, have been demonstrated for several years, but as of mid-2009, none has yet been commercialized. These have been based on the same kind of color filters used by LCDs, which significantly reduce reflected light and severely limit color saturation. More highly reflective e-paper materials in the future could improve the picture, as would the application of color patterning techniques to the display material itself. Multicolor bistable LCDs using color filters also have been demonstrated.

Multicolor Ch LCDs are already available, claiming better color saturation than the alternatives. These displays take the stacking approach to multicolor, combining a trio of individual displays, each displaying one primary color: RGB (red, green blue) for additive color, CMY (cyan, magenta, yellow) for subtractive color. Other alternatives such as QMT's IMODs could conceivably be made in multicolor versions by means of spatial patterning.

In addition to full color, flexibility would also help to expand e-paper's reach. Flexible e-paper displays are already on the market, but active-matrix varieties lag somewhat. The reason is that the high temperatures traditionally involved in fabricating thin-film transistors can distort a flexible plastic substrate, introducing imprecision into the TFT patterning.

A number of alternative techniques are being applied, however, including more robust flexible substrates such as metal foil; lower-temperature deposition; circuit transfer techniques with rigid carriers for flexible substrates; and organic TFTs.