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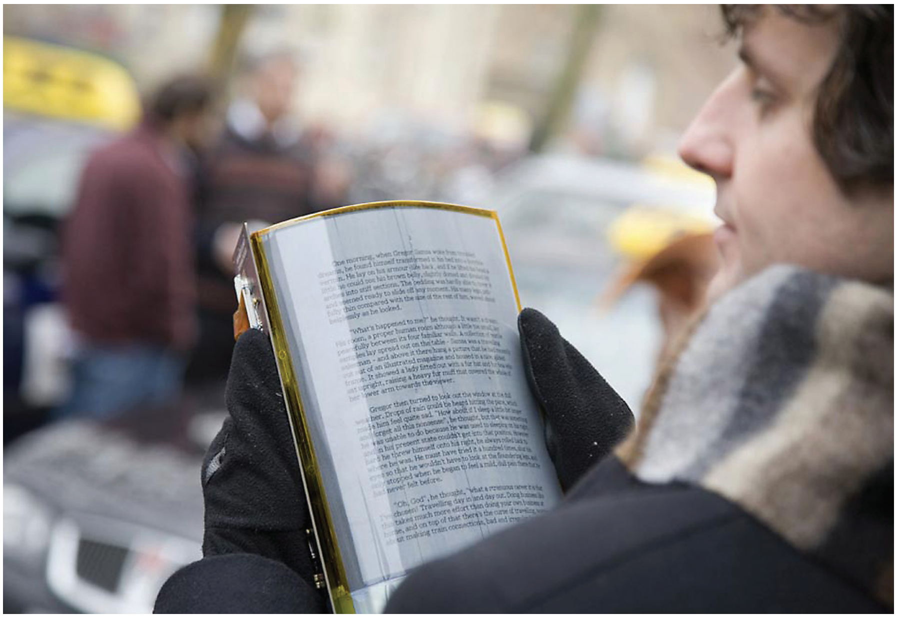
Electronic Paper's Next Chapter

The technological challenge for researchers working on the next generation of electronic paper is to render color as brightly as traditional paper, without increasing power requirements or end-user costs.

ELECTRONIC PAPER, FIRST created in 1975 by Nick Sheridon at Xerox PARC, has begun to proliferate in consumer electronic devices in recent years. Amazon's Kindle and Sony's Reader, two notable applications of the technology, have transformed e-paper into a mass-market phenomenon. New uses for e-paper technology, such as in advertising, wristwatches, smart cards, and even enhancements for computer peripherals, are cropping up regularly. The presence of e-paper in consumer electronic devices is increasing not only because of its minimal energy requirements, making it ideal for low-power devices, but also because its display quality approaches that of the printed page.

Still, by most accounts, the biggest technological hurdle facing e-paper is the fact that current e-paper color displays are either of poor quality or too expensive to be commercially viable. "Color is the next big challenge for e-paper," says Sheridon, a physicist who cofounded Gyricon LLC, as a spinoff from Xerox PARC, to manufacture e-paper displays. "This is not easy to do, and most of the monochrome technologies cannot be modified to do good quality color. New invention is needed." In addition, current e-paper technology cannot render moving images as well as other display technologies. However, that may soon change as improving the color and rendering capabilities of e-paper is the focus of several research labs.

Even with mass-market e-readers being limited to monochromatic displays, much is happening in this area. Prime View International, a Taiwanese company that manufactures the Amazon Kindle and other electronic readers, has put up $215 million to buy E Ink Corp., the company that develops the digital-ink technology for those readers. Also, brand-name companies are entering the e-reader market in droves, with Samsung being the most recent entrant with an e-reader that, at least for now, is only available in South Korea. According to the *Wall Street Journal*, Samsung plans to show prototypes of its e-reader for international markets in January 2010 and is negotiating with publishers for content.



An early prototype of a monochromatic Plastic Logic reading device featuring flexible display technology.

PHOTOGRAPH COURTESY OF PLASTIC LOGIC

Plastic Logic, another company making headlines, is positioning its forthcoming e-reader not as a competitor to the Amazon Kindle or the Sony Reader, but as a device designed for business users. The company says its e-reader, which sports an 8 x 11.5 inch screen, will have 3G and Wi-Fi connectivity and a gesture-based touch interface specifically designed for reading and working with business documents. Also making headlines is Fujitsu, which earlier this year released the FLEPia, a color-capable tablet featuring Windows CE 5.0 software and also designed for business documents. While Fujitsu claims the FLEPia is the first color e-reader on the market, it can display only 260,000 colors (in contrast to the majority of desktop monitors, which can display 16.7 million colors) and is priced in the range of tablet PCs. Currently available only in Japan, the FLEPia costs $1,000. By comparison, Amazon's monochrome Kindle 2 costs $299.

Sheridon, who calls the Kindle a "brilliantly executed document reader," says it and other e-readers are appearing at a fortuitous time, particularly as vast libraries are increasingly being digitized. "The Kindle can access a significant part of this, meaning that

Kindle and other e-readers have created a tipping point for e-paper, but consumers will also want video capabilities, bistable pixels, and thin or flexible displays, says Jason Heikenfeld.

shortly anyone on the globe can selectively download books from a library of millions," he says. However, even with the promise of so much content, potential buyers may put off purchasing e-readers until the displays can support desktop-quality color in devices that do not cost as much as a tablet PC.

Kars-Michiel Lenssen and his team at Philips Research in Eindhoven, Netherlands, are working to solve this problem. Lenssen, who is director and principal scientist at Philips Research, started the color e-paper project several years ago with the goal of making low-power, color e-paper brighter than is currently possible. "We believed that electronic paper would enable new applications, but we also realized that bright colors would be required for a really broad market acceptance in the future," Lenssen says. "That's why Philips decided to start a dedicated research project on this topic."

Philips' technology, called in-plane electrophoretics, is different from E Ink's electrophoresis technique. With the electrophoresis technique, used in the Kindle and other popular e-readers, an electric field controls titanium dioxide particles that are suspended in capsules. By applying an electric current, the particles can be forced to the top of the capsules. When the particles are near the display's surface, the display appears white because light is reflected or scattered. When the particles are farther away from the surface, the display appears dark because light is absorbed. By selectively making certain areas light or dark, fonts and images can be rendered on the display.

Lenssen's in-plane electrophoretics technique, in contrast, relies on two particle-filled capsules for each pixel, one containing yellow and cyan, the other magenta and black. By controlling voltages, the colored particles either spread across the pixel or move out of sight altogether, making it possible to render different colors by controlling the number of colored particles shown. To create white, the particles simply shift to reveal the white substrate beneath the capsules. With in-plane electrophoretics research now maturing, Lenssen and his team are exploring several applications for the technology, with the next step being to bring the technology to production in real-world products.

Lenssen says he is looking beyond e-readers as the primary application. "We think there is more potential, particularly when bright color e-paper will be available," he says. "For example, replacing printed paper signs in retail with electronic paper could save a lot of money not only on printing costs, but also on distribution costs and labor costs for installing and replacing signs."

Besides display-type applications, such as e-readers and digital signage, Lenssen says there are many other opportunities for in-plane electrophoretics, such as digital surfaces on which color could be changed electronically. Such surfaces, which Lenssen calls "digital paint," could be used, for example, as electronic skins for consumer devices. Instead of physically exchanging a device's skin with one of a different color, a user could electronically choose his or her preferred color for each occasion.

"Our e-paper technology could also enable patterns that appear on the electronic skin of a device like a kind of electronic tattoo," he says. "Chameleons and cuttlefish are inspiring examples from nature in this respect."

Electrofluidic Display

Another approach to the problem of low-power, high-quality color in e-paper comes from the Novel Devices Lab at the University of Cincinnati. The technology, called electrofluidic display, uses voltage to manipulate colored inks in much the same way that print heads operate in color printers. Jason Heikenfeld, a professor of electrical engineering at the University of Cincinnati and head of the Novel Devices Lab, formed Gamma Dynamics LLC earlier this year to create products based on his electrofluidic display technology. He and his colleagues are considering a wide range of applications, from e-readers to e-windows to tunable casings for electronic devices. "One challenge," he says, "is picking a first target application out of so many opportunities."

Heikenfeld says the Kindle and other e-readers have created a tip-

PHOTOGRAPH COURTESY OF JASON HEIKENFELD

Jason Heikenfeld, head of the Novel Devices Lab at the University of Cincinnati, is working on electrofluidic display technology based on a process involving pigment dispersion.

ping point for e-paper, but maintains the technology hasn't yet come of age because consumers will eventually want video capabilities, bistable pixels (giving displays the ability to operate for long periods on very little or no power), thin or flexible designs, and, of course, vivid color. "No product or technology on the market is even close to offering this, including the FLEPia," Heikenfeld says. "With our technology, we are aiming to provide the revolutionary increase in brightness that is not possible using the technologies currently available as a product."

Heikenfeld's electrofluidic display technology is based on a process called pigment dispersion. "The pigments look as good as they would on paper," he says. The technology, which Heikenfeld calls a "major step forward" in color e-paper research, consists of an insulator film situated between the pigment dispersion and an electrode film. When voltage is applied to the electrode film, it creates an electrical force that can stretch the pigment dispersion. "We don't mix the pigments," he says. "We display them in different areas, on demand." Obtaining red, for example, requires overlaying yellow and magenta. When the voltage is removed, the pigment dispersion bounces back to its favored geometry of a small droplet or bead shape.

"We have a lot of approaches under development that we have not published yet, so I can't go into all the details," Heikenfeld says.

Heikenfeld's electrofluidic display technology is one of almost a dozen different technologies being developed to create low-power e-paper that can render colors as brilliantly as traditional paper can. Judging by recent developments in terms of display size and power consumption in e-readers coming to market, the future for e-paper technology appears bright. In 10 or 20 years, Heikenfeld says, consumers might see large e-paper modules that are as thin and as flexible as magazines are today, with display brightness approaching that of conventional print.

In Heikenfeld's imagined future, these solar-powered devices will have touch interfaces, communication capabilities, and be so energy efficient that charging them will be an afterthought. "You might click on an image in a story, and it will provide video or animation," he says. "There is nothing fundamental from an optics or electronics perspective that makes this impossible."

For his part, Sheridon believes e-paper eventually will make power-hungry desktop displays obsolete, and will help make heavy, back-breaking textbooks something school children might learn about in a history lesson on their lightweight e-readers, not lugged around with them in their backpacks. But when it comes to betting whether all paper books will become a thing of the past, the inventor of e-paper is cautious about predicting the obsolescence of the printed page. Sheridon simply suggests that in the future books might be printed on paper.

"E-paper will continue to find important applications, such as in fabric, large displays, and home and building decoration, to mention a few," says Sheridon. "The surest way to predict the future is to invent it. E-paper is rich in potential."

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Kirk L. Kroeker works in communications and has written extensively about the impact of emerging technologies.

Belated Apology For Turing

British Prime Minister Gordon Brown apologized for the British government's "horrifying" treatment 50 years ago of Alan Turing, the mathematical genius and a founder of modern computing, who was criminally prosecuted and convicted of "gross indecency" in 1952 after admitting to a homosexual experience. To avoid imprisonment, he underwent chemical castration. Two years later Turing committed suicide at the age of 41.

Earlier this year, British computer scientist and blogger John Graham-Cumming launched an online petition campaign urging the British government to apologize. The petition was supported by scientist Richard Dawkins, writer Ian McEwan, and gay-rights activist Peter Tatchell, and it received 31,612 signatures from British citizens and residents before Brown issued an apology.

Graham-Cumming has also written to Queen Elizabeth II, asking that Turing be awarded a posthumous knighthood.

In 1936, Turing wrote his seminal paper, "On Computable Numbers," which established the conceptual and philosophical basis for modern-day computers, and consequently developed the Turing Test, an important measure of success in the field of artificial intelligence. During World War II, Turing developed the Bombe, an electromechanical code-breaking device that enabled Britain to read secret messages encoded by Germany's Enigma cipher machines, complex typewriter-like devices that generated a constantly changing code for its military communications.

ACM President Dame Wendy Hall issued a statement applauding Brown's apology, recognizing his computer science and wartime contributions, and noting that "ACM looks forward to joining with other organizations to celebrate the centenary of Turing's birth in 2012."