

Advanced Display Technologies

An Investigation of the Emerging and Developing Technologies Related to the Generation Beyond Print-on-Paper

By
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A Research Monograph of the
Printing Industry Center at RIT

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With Thanks

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Abstract

The purpose of this paper is to present information about new display technologies that are competing with print.

Display technology continues to mature [see *The Generation Beyond Print-on-Paper* (Printing Industry Center at RIT Monograph # PICRM-2002-01)], as in the case of full-color OLED, which has been incorporated into its first consumer product, The Kodak EasyShare LS 633 digital camera. Digital ink pioneer E Ink, through its partnership with Philips Electronics, will introduce its first commercial product in early 2004. Gyricon Media, the inventor of the electronic paper category, has opened its first manufacturing plant. In addition, new flexible display technologies have been introduced, such as SiPix Microcup, and the electronic display form-factor has been scaled up considerably by companies such as magink and NOVUS. These companies are poised to produce large-format electronic displays that rival the size of traditional 30-sheet billboards. Developments continue to evolve in displays of all sizes, from those the size of cell phone to those on the sides of buildings.

Introduction

The display market has undergone several changes recently. Not surprisingly, the sales of Cathode Ray Tubes (CRT) are down, and the sales of Liquid Crystal Displays (LCD) are up. The sales of CRT monitors fell 16% year-to-year in 2002, and fell 21% in the first quarter of 2003. CRT displays lost market share to LCD monitors, which in the first quarter of 2003 held 37% of the market. Not only are LCD monitors replacing CRTs, but the preferred size of LCD monitors has increased from 15 to 17 inches (Business Editors, 2003). Interest in OLED (organic light emitting diode) displays, a possible successor to LCD, remains high. OLED displays, which are composed of polymer materials, such as polythiophene (red), polyfluorene (blue), and polyphenylene vinylene (green), emit light when excited by an electric charge. The polymers are self-luminous and do not require back-lighting. They can be viewed at any angle, are very thin, and require less power than other forms of displays. In March of 2003, Eastman Kodak and Sanyo Electric announced the first commercial production of full-color OLED displays. The 2.2-inch displays were the first products from the joint venture formed by Kodak and Sanyo (SK Display), as well as the first commercial OLED displays from any manufacturer. Kodak's first implementation is in their EasyShare LS 633 digital still camera (see Figure 1).

The superior display quality and performance characteristics of OLED displays is well known to those familiar with the technology; however, the displays are approximately 50% more expensive than a comparably-sized LCD, which makes the cost of the devices that use them incrementally more expensive. In order to highlight the value that the OLED display brings to the products into which they are manufactured, Kodak and other manufacturers have chosen to identify their OLED displays under a brand name. Kodak identifies their OLED displays as "NuVue," (see Figure 2) while Dupont has branded their displays as "Olight" (see Figure 3).



Figure 1. The Kodak EasyShare LS 633 is the first commercial product to incorporate a full-color OLED display. The display is brilliant, and is readable in direct sunlight. (Photo courtesy of Eastman Kodak Company)

Introduction



Figure 2. Kodak announced the branding of its OLED displays in May, 2003 at the Society for Information Display (SID) conference in Baltimore.

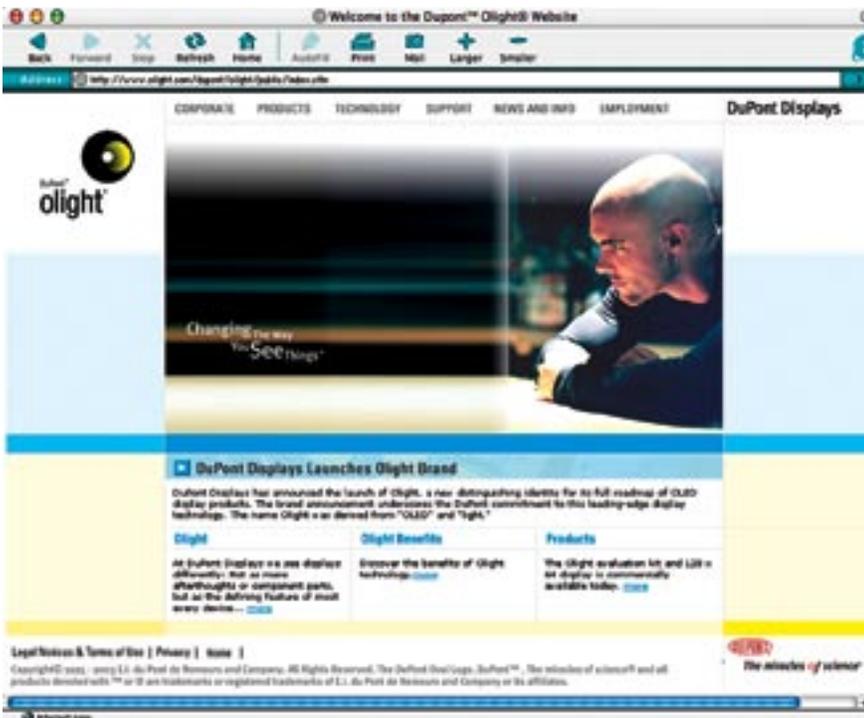


Figure 3. Olight, a name that suggests "the sensation of perceiving light, brightness," is derived from the words "OLED" and "light," and is the name for DuPont's brand of OLED display. The Olight brand represents two production methodologies: vapor deposited and solution applied. DuPont's first OLED product, a single-color display, was incorporated in an MP3 player. DuPont's manufacturing partner is RITdisplay of Hsin Chu, Taiwan. The company also has a development partnership with Universal Display Corporation.

Magink (see page 20) proposes not to replace the printed page, as a personal display might do, but to replace the printing press itself by serving as a publicly viewable wall-size or billboard-size display. They believe that their technology will fulfill the role of a newspaper, most immediately and most effectively, in underdeveloped countries where the cost of a newspaper may be prohibitively expensive.

While the cost of computer memory has dropped precipitously, and the processing power of CPUs has risen meteorically, the cost of computer displays has not kept pace. Despite the significant reductions in the costs of consumer electronics (see Table 1), display technology remains the barrier to truly low-cost computing, inexpensive and disposable electronic devices, and ubiquitous computing.

There is a tremendous research and development effort underway, as well as a strong determination to invest in technologies that will enable the production of low-cost displays and low-cost electronic devices—*both of which are likely to be enabled by some form of printing.*

This interest is evident in the level of commitment that is being made by companies in many industries (see Figure 4)—including investments by those in traditional media industries, including the printing industry itself.

METHOD

The proliferation of digitally delivered information has often been at the expense of traditional print. Digital delivery to the information end-user typically results in the display of the information, rather than the information taking a printed form.¹ This research looks at recent developments in display technology and, in a companion monograph on printed electronics, the opportunities for the application of conventional printing technology as a method not only of producing displays and their associated components, but electronic devices of all kinds. This paper is based on an exhaustive literature search (see bibliography), attendance at several industry seminars and events,² and interviews and correspondence with key players in the market.

1993 Device	Features	Price	2003 Device	Features	Price	Cost Reduction
Apple Newton MessagePad PDA	640 KB RAM	\$699	Palm Zire	2 MB RAM	\$99	-86%
Canon RC-570 (Intro in 1992)	.4 megapixels	\$4688	FujiFilm FinePix 3800	3.3 megapixels	\$328	-93%
Flash Memory	20 MB	\$1499	Flash Memory	1 GB	<\$200	-87%
Apple Macintosh Quadra 650	33 Mhz 8 MB RAM 80 MB HD	\$2700	Apple eMac	800 MHz 128 MB RAM 40 GB HD CD-ROM	\$799	-71%

Table 1. Examples of Declining Electronics Costs from 1993-2003

Introduction

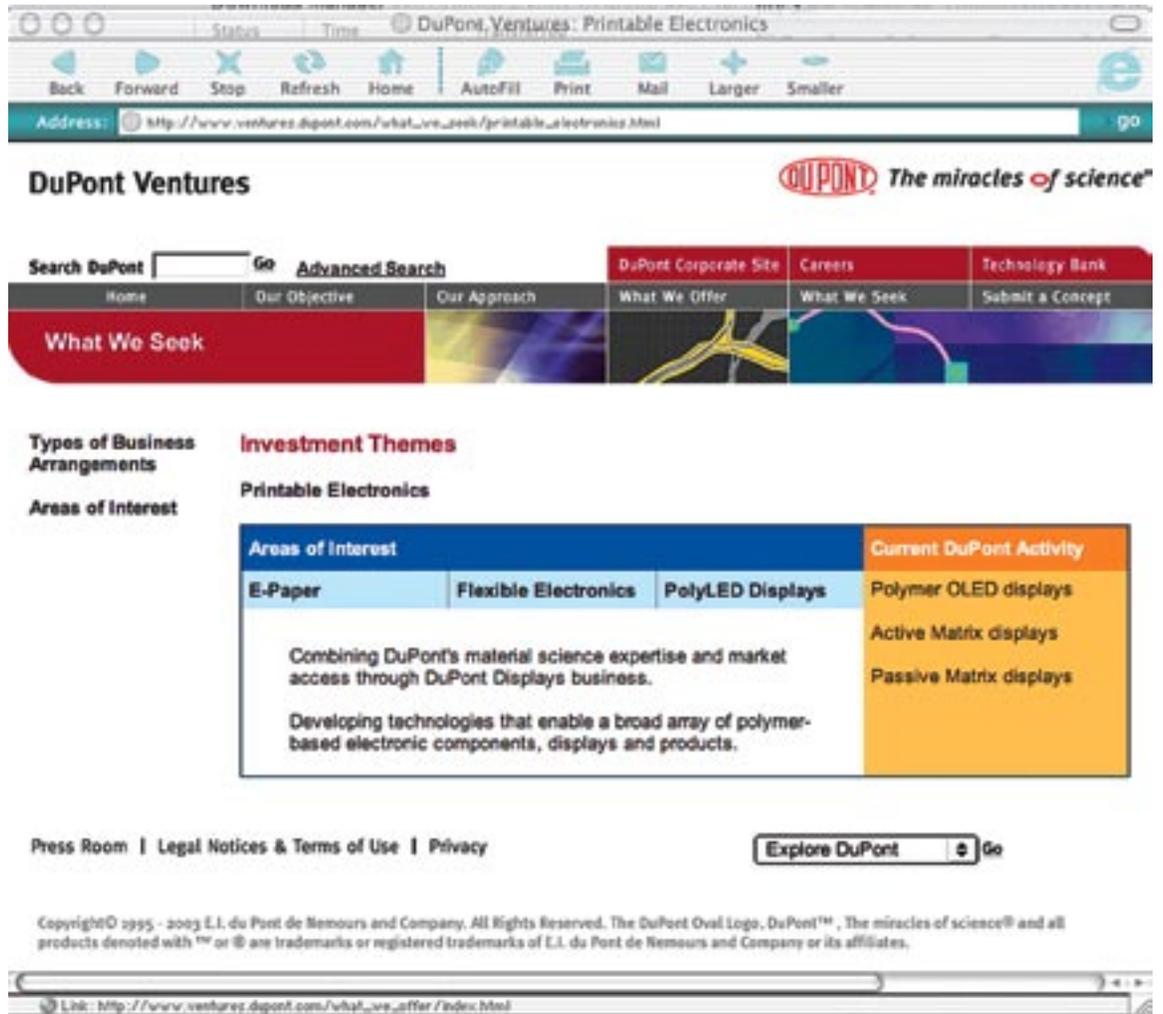


Figure 4. DuPont is one of many companies that is earnestly pursuing investments in the field of printed electronics and display technology. On March 12, 2003, Cambridge Display Technology (CDT) announced a transfer agreement with DuPont to provide proprietary inkjet manufacturing technology for full color OLED displays. The process uses CDT's inkjet technology applied using deposition tools supplied by its Litrex subsidiary. Although the licensed technology applies to fabrication on glass, there is speculation that the process can be applied to roll-to-roll manufacture of full color displays on plastic.

Display Technologies

Developments in display technologies continue at a rapid pace. This report deals with some of the significant technologies that are either in prototype testing or have recently been productized.

E INK

E Ink's³ (see PICRM-2002-01, page 26) collaboration with Philips (see Figure 5) is expected to result in their first commercial product in early 2004. The two companies began a formal partnership in February 2001. The product, a two-page e-reader (see Figure 6) shown in a prototype model at the Society for Information Display in May 2003, will be brought to market by a very large, as yet unnamed, Japanese consumer electronics company. The final design and packaging are yet to be determined. The e-reader combines the 160 pixels per inch (ppi) E Ink display with a Philips thin-film-transistor (TFT) backplane, driver electronics, and manufacturing processes. Despite the relatively low manufacturing cost of the E Ink material, the e-reader is expected to be priced similarly to other current display technologies.



Figure 5. E Ink works with manufacturing partners to produce their paper-like displays for the OEM market. (Illustration courtesy of E Ink, ©2003)



Figure 6. This prototype double-page e-reader, combining an E Ink display and Philips TFT backplane, is the first commercial product resulting from the E Ink and Philips partnership. (Photo courtesy of Philips. Used with permission.)

Display Technologies

E Ink sells its electronic ink (see Figure 7) to Toppan, which coats it on plastic. Toppan then provides it to the device manufacturer for final fabrication. The display material is produced on a roll-to-roll manufacturing line. According to Darren Bischoff, E Ink Marketing Manager, it is likely to result in a fully fabricated flex-

ible display in the five to ten year time frame (Personal Communication, March 27, 2003). Among the low-cost display applications that the technology will enable is an embedded smart card display (see Figure 8).

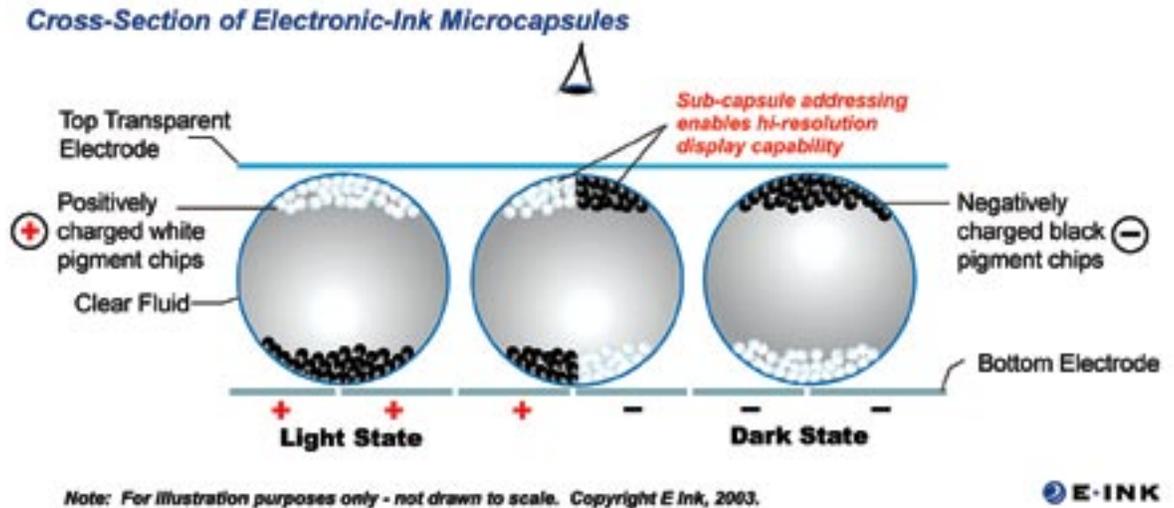


Figure 7. The E Ink display process is enabled by microencapsulated black and white pigments that are manipulated by an electrical charge to produce a paper-like image. (Illustration courtesy of E Ink, ©2003)



Figure 8. E Ink Corporation has introduced the world's thinnest active matrix display—just 0.3 mm thick, or half the thickness of a credit card. The company is working with leading device makers to integrate these ultra-thin electronic ink displays into next generation portable devices by 2004-2005. (Photo courtesy of E Ink, ©2003)

The E Ink/Philips display is unique in its paper-like readability, ultra-thin form factor, and low-power consumption, which is derived in part from its bistable display. This bistable display maintains a formed image almost indefinitely, without requiring further energy. Several other products are expected to be released in 2004 (see Figure 9). Among them may be a small portable display that can connect to a cell phone to make the reception of faxes, e-mails, and text messages easier and more efficient (see Figure 10).

E Ink has strategic investors in a variety of fields including *media* (Hearst, Gannett, Havas, Interpublic, CNI, McClatchy, L'Espresso, and Langenscheidt), *electronics* (Motorola and Lucent), and *displays* (Philips and Toppan). Financing has reached approximately \$100 million.



Figure 9. Electronic ink displays are currently being developed for many applications spanning handheld devices, wearable displays, and transportation signage under two main product platforms: high-resolution active matrix displays and low-to-medium pixel count segmented displays. Active research is also being done on next generation paper-like displays with color and flex capabilities. (Illustration courtesy of E Ink, ©2003)



Figure 10. This add-on display is what E Ink calls a "peripheral monitor." Its purpose is to enable mobile phone users to have small handsets while also having the capability to display high-information content when necessary. (Photo courtesy of E Ink, ©2003)

Display Technologies



Figure 11. The Philips-Norelco 8894XL (on the left), introduced in July, 2002, was the first consumer product to incorporate a single color PolyLED display (enlarged on the right). (Photo courtesy of Royal Philips Electronics)



Figure 12. The Philips HomeLab observation room enables researchers to observe and record the behaviors of test subjects in the house. (Photo courtesy of Royal Philips Electronics)

ROYAL PHILIPS ELECTRONICS

Philips⁴ has developed and delivered (or is poised to deliver) products using virtually every display technology that has been invented. They were the first to introduce a consumer product incorporating a single-color OLED display (see Figure 11). That product, and others, are tested in lab situations as well as their HomeLab (see Figure 12), which is a research incubator for future products that show potential for the consumer market. The HomeLab is a complete two-bedroom home that contains 34 hidden cameras and an observation room that enables researchers to study the ways in which people interact with new technologies. The first product to emerge from the HomeLab is the Mirror TV (see Figure 13), which is either a 17-, 23- or 30-inch LCD display (and optional computer monitor) that is integrated into a wall mirror. According to a Philips press release, “The Mirror TV uses a unique polarized mirror technology, which transfers close to 100 percent of the light through the reflective surface...it’s an early example of the Philips vision of Ambient Intelligence in that the ‘technology’ is embedded and easy to use” (Royal Philips Electronics, 2003). Philips display technologies, which are still under development, include flexible, paintable, and projection display systems.



Figure 13. The Mirror TV appears as a normal mirror when the display is not on. It provides the benefits of hiding the TV from sight as well as making the room or workspace appear larger. Philips anticipates that the display will be popular in hotels which need to conserve space as much as possible.

GYRICON MEDIA

Gyricon Media's⁵ (see PICRM-2002-01, page 23) commercialization plan for their SmartPaper™ media moved forward with the opening of their 48,000-square-foot, \$10 million manufacturing plant in Ann Arbor, MI, on August 20, 2002 (see Figure 14). Gyricon SmartPaper is a patented, reusable display material that resembles paper, yet can be “written” and “erased” electronically. Among its first applications is in-store signage, which provides dynamic pricing to retailers, and pricing integrity to customers (see Figure 15). Pricing integrity enables consumers to have confidence that they are paying fair and accurately-computed prices. Unfortunately, such confidence is not always warranted. For example, the State of Arizona Department of Weights and Measures found that 88% of the department, food, toy, home improvement, and pet stores that were checked failed to have 100% accurate prices at their checkout scanners. These findings were reported in *The Tucson Citizen* newspaper on December 23, 2000, based on results tallied from 187 inspections, conducted over a one year period commencing on December 1, 1999.⁶



Figure 14. The Gyricon Bead Machine, in the background, produces the 90 μm (micron) beads that form the active layer of the Gyricon media material. Pictured here are Martin Lu, director of Research and Development, and Kailin Chen, engineer. The company was spun off from Xerox Palo Alto Research Center (PARC) in 2000, although the company still has research labs in that facility. (Photo courtesy of Gyricon Media)

Display Technologies

Figure 15. Twenty-two Gyricon Media SmartSigns were used during the first phase of a test period at Macy's Bridgewater New Jersey Kids World department during the busy holiday season in 2001. The second phase of the test ran from November 15, 2002 until February 28, 2003 in their Braintree, MA store (Men's, Men's Casual and Ladies Casual Department). The content of the signs was changed using WiFi (802.11b), which was controlled from the existing Macy's IT infrastructure. The signs were driven by three AA batteries, which last up to one year, and require one-hundredth the power of an average computer display. (Photo courtesy of Federated Stores)

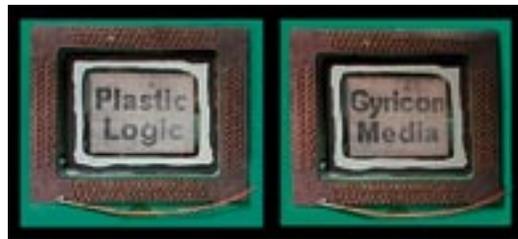


Figure 16. These 3000-pixel prototypes are the world's first bistable reflective displays (made by Gyricon Media) driven by a backplane that was produced using inkjet printing technology (made by Plastic Logic).
(Photo by the author of a booth display presented by Plastic Logic at SID 03)

The field trial of in-store electronic signage at Macy's in Bridgewater, NJ, which ran from June 1 until December 1, 2001, used a series of printed circuit boards, with segmented fonts, as the backplane for the screens. In time, an active matrix backplane will be used, and the screen content will be totally modifiable. One of the ways in which the backplane may be made was demonstrated by Plastic Logic at the Society for Information Display International Symposium and Exposition in Baltimore in May 2003. Plastic Logic demonstrated the "first bistable reflective display driven by an inkjet-printed active matrix backplane." The prototype, which contained 3000 pixels (63x48) at 50 dpi, was considered, by Gyricon Media CTO Dr. Robert Sprague, to be a breakthrough in the development of all-points-addressable displays (see Figure 16).

Of the many advantages that electronically-imaged signage has over conventionally-printed signage, perhaps the most important is *immediacy*. Personnel in the store, or at a remote headquarters location, can change signs to reflect marketing conditions, weather, inventories, competition, etc. According to Jim Welch, public relations manager for Gyricon Media, "Back-to-school signs have to be made six weeks in advance. What if we had signs we could wirelessly send messages, each with its own IP address and pricing information sent from our server?" (Fendelman, 2002).

SIPIX MICROCUP

Microcup is a form of plastic electrophoretic display (see Figure 17) that is ultra thin and ultra lightweight, and manufactured using a roll-to-roll process by SiPix.⁷ Microcups, which are minute cells or cavities measuring from 50-180 μm (width, length, or diameter) \times 12-40 μm (high) \times 8-25 μm of partition width. The Microcups are formed using either an embossing or lithographic process, and are filled with an electrophoretic fluid that is made of charged pigment containing submicron-sized particles dispersed in a colored dielectric solvent (see Figure 18). The fluid is sealed within two layers, each containing an electrode and laminated to a release layer. Color is achieved by using either a color filter or sequentially filling and sealing R, G, B electrophoretic fluids in the Microcups. The resolution of the Microcup process compares favorably with LCD. "Since the resolution of a typical Microcup is quite high, 50-180 μm or 120-1500 cup-per inch, as compared to the pixel resolution of a typical LCD, high quality image(s) may be achieve..." (Liang, et al., 2003).

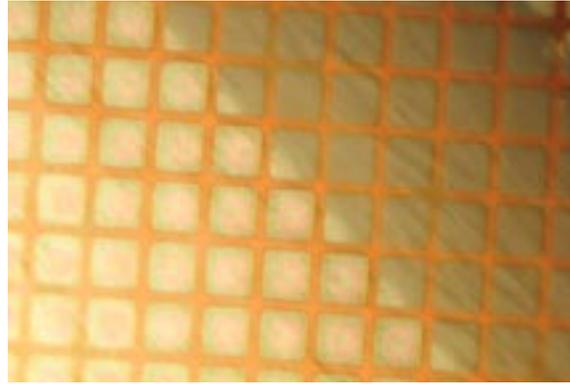


Figure 17. A photographic enlargement of a Microcup[®] electrophoretic display showing sub-Microcups[®] addressing along a 400 mm electrode line. (Photo courtesy of SiPix)

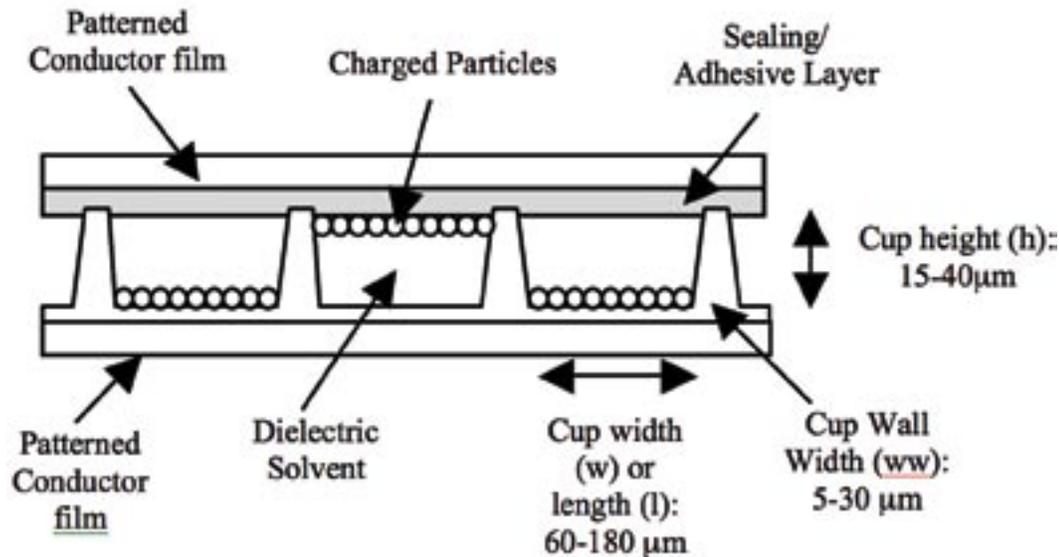


Figure 18. A schematic illustrating the construction of a typical Microcup. (Illustration courtesy of SiPix)

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Figure 19. A small Microcup display fabricated in a smart card prototype. (Photo courtesy of SiPix)

The Microcup material is provided to customers in either rolls or cut pieces. The customer peels off the release layer and adheres the material to a patterned electrode backplane of some kind. The material is appropriate for entirely new display applications (see Figure 19) as well as fulfilling needs that have previously been met with other display technologies (see Figure 20).



Figure 20. A personal digital assistant (PDA) prototype utilizing the Microcup display technology. (Photo courtesy of SiPix)

ROLLTRONICS

Rolltronics⁸ (see PICRM-2002-01, page 38), has narrowed its focus in roll-to-roll electronics fabrication to the production of thin film battery cells (see Figure 21). To this end they have spun off a new company, VoltaFlex (<http://www.voltaflex.com>), to design and manufacture the internal battery components. The components are sold to companies that will package them into finished goods or incor-

porate them directly into other products, such as PDAs or cell phones. Since the polymer is solid, it will not leak; keeping out water is the only packaging requirement. According to VoltaFlex's Michael Sauvante, it is expected that by 2005 their battery technology will account for a significant part of the \$50 billion battery market.

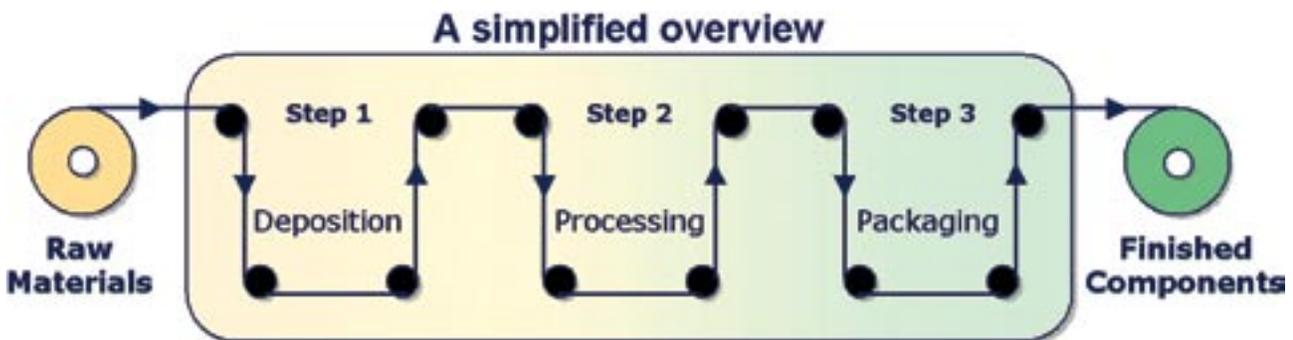


Figure 21. A simplified view of the manufacturing process. A similar process is used for printing other types of components such as memory and displays. The differences are in the chemicals used, the patterning necessary for non-battery applications, and the method of deposition. According to Rolltronics COO, Glenn Sanders, "Wet deposition will be used for all parts of the batteries, and for some layers of the TFT and memory products. Vacuum (dry) deposition will be used for most of the TFT semiconductor layers."

(Image courtesy of VoltaFlex)

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Figure 22. Thin film flexible MIT battery prototype, laminated to the back of a flexible solar cell. The new battery process inhibits the formation of dendrites—the crystal formations that are the main source of battery failure, and usually occur with frequent recharging. The MIT process seems to block the formation of dendrites which results in the production of a battery with a longer life expectancy. Lab tests at MIT have found no measurable degradation after 700 recharge cycles. *(Photo courtesy of VoltaFlex)*



Figure 23. A sample of the polymer invented at MIT which is used in the VoltaFlex batteries. *(Photo courtesy of VoltaFlex)*

VoltaFlex rechargeable lithium and lithium-ion batteries use technology developed at MIT⁹ which endows them with several important characteristics (see Figure 22). They contain two to four times the power density of standard lithium-ion batteries, and are thin, flexible, light-weight, safe, and low-cost.¹⁰ They are produced using the roll-to-roll manufacturing process developed by Rolltronics, which “prints” the power cells on a flexible sheet of material that is one meter wide and several kilometers long. Rather than producing batteries one at a time, as in traditional battery manufacturing, the VoltaFlex method prints a solid block copolymer electrolyte (BCE) and pure lithium metal deposition contained within a thin film cathode and anode. The battery is the first true solid polymer battery electrolyte medium (see Figure 23). This medium is solid at the macro level, but acts semi-liquid at the nano level, thus allowing the usual electrolyte processes to occur.

The batteries will be sold to OEMs either in rolls or cut up into rectangles (see Figure 24). The OEMs will do the final packaging. The companies can shape them, stack them, or otherwise convert them into any form factor and voltage that they may require. Applications will include replacements for standard batteries as well as power for smart cards, RFID tags, consumer electronics, and devices as yet not invented.

An interesting contrast to battery manufacture is the use of elastic polymer in a shoe heel to generate electricity.¹¹ SRI International (formerly Stanford Research Institute) has developed a prototype boot for the Department of Defense, which incorporates a specially-formulated flexible polymer which is positively charged by a tiny battery on one side, and negatively on the other. Through the movement of walking the polymer is compressed and released, changing the distance between the positive and negative sides, and producing electricity.

MAGINK

Magink display technologies, Inc.,¹² founded in 2000 and based in Neveh-Ilan, Israel, and headquartered in New York City, recently entered into a manufacturing agreement with Mitsubishi Electric Corporation to fabricate billboards using magink's reflective display full-color electronic ink organic paste. Magink is the "world's first full-color *digital ink*." The RGB displays, capable of 4096 colors, were officially launched in April 2003. They consist of glass panel modules measuring 7" x 14", which are slightly overlapped along the bottom edge (shingled) to form large display surfaces of 10 feet by 20 feet (about the size of a traditional 30-sheet poster), but ultimately of any size required.¹³ Although the seams between the display modules are slightly visible, especially close-up (see Figure 25), there are no apparent gaps from a distance. Because the display is reflective, it requires no backlight during the daytime, and is illuminated with conventional floodlighting at night like a standard billboard.¹⁴ The displays have a viewing angle of +/- 60 degrees.



Figure 24. A prototype of the MIT battery.
(Photo courtesy of VoltaFlex)



Figure 25. The 1m x 2m prototype display was shown first in Nagasaki, Japan in September, 2002. (Photo courtesy of magink display technologies Inc.)

Display Technologies



Figure 26. A 3m x 6m pilot display erected in London, England in February 2003. The upper photo is the daytime view, and the lower is at night. (Photo courtesy of magink display technologies Inc.)

The magink display marks a milestone in the history of display surfaces. It offers the potential for large outdoor (and indoor) variable resolution signs that have the appearance of printing,¹⁵ with the advantage of remote imaging through the transmission of a standard JPEG file (see Figure 26). It thus offers a new publishing platform, with the potential for full-motion video, animation, and sound. In addition, since it is infinitely changeable, the message can be adjusted to correspond with traffic patterns, weather conditions, and special events, and rather than selling the billboard to a single advertiser for a fixed period of time, it can be sold to many advertisers for whatever units of time they require (see Figure 27).¹⁶ In this regard, the marketing of the display space is similar to that of selling air time on radio or television. According to magink chairman, Don Davidson, who recently served as president of Gannett Outdoor, "One advertiser or several could buy part of the network to carry their messages relevant to times of day" (Prentice, 2003).

Unlike printed billboards, which are static and solitary, magink displays are connected in a network, permitting an advertiser to select the times, durations, and locations that their messages will be "broadcast." The displays are driven by a proprietary, patented, software application called magink NSDD (networking solutions for digital displays) which is used for planning, managing, and controlling display content. The NSDD can operate using satellite, Internet, ADSL (Asymmetric Digital Subscriber Line), cellular modems or dedicated modem lines (T1, T3), and other communication technologies. Full or split screen images can be changed almost immediately, although the shortest span sold would be in the range of two to three seconds. The immediacy of the process provides the potential for an advertiser to have their message displayed anywhere on the network almost immediately after it has been created and approved. This applies both to local and national advertising.

The magink technology consists of a proprietary e-ink paste that is sandwiched between two thin sheets of glass or rigid plastic forming a 1/8-inch thick sandwich. An electronic

charge delivered through the display back-plane causes the paste to change its color wavelength. According to the magink prospectus, “magink manipulates the size and angle of the molecules in the ink to generate all colors of the visible color spectrum, including all gray scales.” Once imaged, the display, which has a 1:15 contrast, does not require additional electrical current to preserve the image for an unlimited length of time.¹⁷ This effective use of energy results in lower operating costs and a minimum of heat creation. Its 5 mm pixel resolution¹⁸ is sufficient for the given distance that it is typically viewed (5 meters or greater), wherein it appears to have the quality of print. *The display becomes, in essence, a printing press, that can display anything, at any time.* It has no downtime while the images are changed, and does not require the labor involved in changing conventional paper billboards. It has no printing production costs for materials nor labor. It can serve information display needs beyond advertising, such as transportation schedules and information, electronic newspaper and magazine page delivery, storefront window dressing backgrounds, on-premise commercial messaging, stadium signage and scoreboards, interactive road signs, street furniture applications (on bus shelters, street benches, taxi-tops, kiosks, etc.), and other uses yet to be conceived. Davidson predicts that eventually all current billboards will be converted to digital. “It will probably be in our lifetime, even though the traditional poster hasn’t changed in 100 years” (Prentice, 2003).

The first installations of this nascent technology took place in early 2003. The display maintains, from the start, a significant cost advantage over similarly-sized LED signs; it costs between \$80,000 to \$90,000 for a 12 x 24 foot billboard, which is about 20% of the cost of a similarly sized LED sign. The nature of the proprietary chemical e-ink paste is such that it can be spread on any material, and can enable the use of an unlimited number of applications, including television, building or wall coverings or curtains, taxi top and truck side signage, cell phone displays, etc. The magink display is the first of a technology build out that will include electronic display screens, smart windows, e-paper, and digital books all by the year 2010.



Figure 27. A billboard sign showcasing changeable advertisements. (Photo courtesy of magink display technologies Inc.)

DISPOSABLE DISPLAYS

A printed display system is composed essentially of three components: the display, the back plane, and the power source. The display may be in the form of a variably-sized sign, a tag, a label, or an indicator. Whatever its nature, it must be driven by some form of electronic backing which controls what appears on its surface. The process also requires an energy source which may be a printed, fabricated, or conventional battery. Precision printing processes have already been applied to produce printed advertising and promotional displays that are flat, thin, flexible, and relatively robust. They are as simple as flashing graphics, which merely attract attention, or more sophisticated in form, wherein they utilize motion and animation to demonstrate product capabilities and benefits.

The time and expense of producing electronic displays will never make them as inexpensive as process color printing; however, they are likely to emerge as a recognized media form that will vie for product marketing dollars and prove effective against more traditional forms of media.

One of the largest potential markets for printed display systems is likely to be in packaging and point of purchase and specialty advertising.¹⁹ The packaging market in the U.S. in 2002 was \$114 billion, the advertising specialty market

\$16 billion, and the Point of Purchase (POP) market was approximately \$15.5 billion. There it is possible to leverage the decreasing cost of electronics with the latest advances in materials and processes. These markets are characterized by relatively short lives (3 days to 6 months or more), small size, fast product development cycles, low durability, and low price. Similar, though more robust displays, will be applied in the electronics and hand-held appliances to replace LEDs and two-dimensional printed graphics and provide capabilities that are not presently possible at low cost, such as indicating the remaining life of a replaceable furnace filter, or the ink left in a pen (Steinberg, 2003).²⁰

ADDITIONAL INFORMATION

Other display technologies which utilize conventional and modified printing methods are covered in another monograph by the author entitled, "Printed Electronics and the Automatic Identification of Objects." This monograph is also available from the Printing Industry Center at RIT (<http://print.rit.edu>).

Endnotes

¹The information consumer may print what they view locally on a desktop or networked printer, however, the significance is that the information was not delivered to them in printed form from a commercial source.

²Comdex, November, 2002; 2nd Advanced Technology Workshop on Printing an Intelligent Future, March, 2003; Smart Labels USA, March, 2003; Society for Information Display (SID), May, 2003.

³E Ink Corporation, 733 Concord Avenue, Cambridge, MA 02138, 617 499-6004, <http://www.eink.com>, fax: 617 499-6204.

⁴Philips Electronics, Mobile Display Systems, Components Division, 1000 West Maude Avenue, Sunnyvale, CA 94085-2810, 845 246-2811, <http://www.philips.com>.

⁵Gyricon Media, Inc., 6190 Jackson Road, Ann Arbor, MI 48103, 734 222-8142, <http://www.gyriconmedia.com>, fax: 734 222-8231.

⁶Gyricon has an impressive listing of facts and figures related to retail sales and paper production at <http://www.gyriconmedia.com/press/didyou.asp>.

⁷SiPix Imaging, Inc., 1075 Montague Expressway, Milpitas, CA 95035, 408-719-8888, <http://www.sipix.com/>, e-mail: contact@sipix.com, fax: 408-719-5548.

⁸Rolltronics, 750 Menlo Avenue, Suite #200, Menlo Park, CA 94025, 650 566-8471, <http://www.rolltronics.com>, e-mail: info@rolltronics.com, fax: 408 734-9620.

⁹VoltFlex has obtained the exclusive worldwide rights to the intellectual property developed by Dr. Donald Sadoway, and held by MIT.

¹⁰The cost is expected to be lower than conventional batteries based on the same watt-hour rating.

¹¹<http://www.technologyreview.com/articles/prototype71001.asp>

¹²Magink display technologies Inc., 304 Park Avenue South, 11th Floor, New York, NY 10010, 212 590-2381, <http://www.magink.com>. Another billboard-size display technology is being developed by NOVUS Communication Technologies, Inc., 4480 Lake Forest Dr. Suite 412, Cincinnati, Ohio 45242, 513 769-5741, <http://www.novusct.com>, e-mail: info@novusct.com, fax: 513 769-1921. Details about the NOVUS system were not available as of presstime.

¹³Initial production display sizes are 3m x 6m, 3m x 4m, 2m x 3m, and 1m x 2m. Eventually the displays will be able to take advantage of roll-to-roll manufacture.

Endnotes

¹⁴ The displays have a temperature-control system built-in so that the paste can be maintained at its optimum temperature for re-imaging. The environmental conditions for optimal optical performance for cold environments is $-20^{\circ}\text{C}/-4^{\circ}\text{F}$ to $+45^{\circ}\text{C}/113^{\circ}\text{F}$, and for standard environments is $-10^{\circ}\text{C}/-14^{\circ}\text{F}$ to $+45^{\circ}\text{C}/113^{\circ}\text{F}$.

¹⁵ Magink signs are 35% reflective, which is about half as reflective as an average vinyl billboard.

¹⁶ According to Ruth Poliakine, magink spokesperson, in response to a question by the author regarding the licensing or sale of the magink technology: "The simple model would be to sell displays to the media companies who will sell the ad space, as they usually do. A variation on that would be to contact for distribution of one or more custom-designed display formats on an OEM basis to a company already in the business of supplying display structures to the industry. A final, more complex, model would be to create a joint media company to market displays for a new application or perhaps for a very large, high-profile location sign."

¹⁷ Since magink does not require constant refreshing, it does not exhibit the objectionable flickering phenomenon that characterizes active matrix digital displays.

¹⁸ The standard pixel size for LED billboards is in the range of 15-20 mm.

¹⁹ Items in this category include: shelf talkers, matrix signage, active coupons, price danglers, endcaps, table tents, shopping cart decals, floor decals, packaging, and more.

²⁰ Rob Steinberg, formerly Business Director of the Electro-Graphic Displays Division of Avery Dennison, reported to the author that the company suspended all operations in their Electro-Graphic Display (EGD) division in mid-2003.

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