NANO TECHNOLOGY
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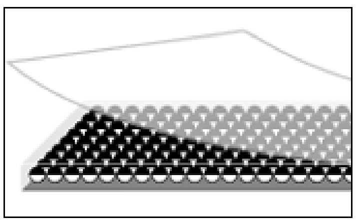

DISPLAY TECHNOLOGIES - DIGITAL PAPER

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INTRODUCTION

These days, many of us spend just as much time staring at an electronic screen as we do the real world. Work, play, entertainment, communications; virtually everything we do is reliant on some kind of electronic display. CRT's (Cathode Ray Tubes), LCD's (Liquid Crystal Displays), Rear-Projection and Plasma screens are everywhere. It is obvious, then, why the race for the cheapest, lightest, highest definition, brightest and most visually appealing display has some of the worlds biggest technological companies investing large amounts of money is an array of ideas, each with the potential to lead the way into the future.

DISPLAY TECHNOLOGIES: TUTORIAL DESCRIPTION OF CURRENT SYSTEM SPACE

Screen technology is a fast changing technology area. From the old/traditional technologies like cathode ray tubes, plasma, LCD and OLED etc., to the current & new technologies like LCos, CNT's, etc., screen technologies landscape is ever changing.

In general, there are THREE chief goals of new technology design:

1. Cheaper,
2. Better and
3. Smaller

Vendors have been pumping BIG research money to come up with new screen technologies that are bettering one or more of the above three goals.

Below listed is the broad description of the CURRENT system state of display technologies. Included are the some nanotechnology application areas in display technologies.

REAR PROJECTION

Good Old Rear-projection display technologies, with three cathode ray tubes, are making a big comeback.

We have already seen them replaced by tiny LCD screens. Now expect to see improved contrast as brands such as Samsung, Thomson Multimedia and Mitsubishi put another front-projector technology, DLP (digital light processing), into rear-projection TVs.

DLP uses tiny mirrors to reflect light to make a picture, rather than LCD's little twisting liquid crystals, which allow light to pass through to do the same job.

LCoS

LCD and DLP are small compared with the next couple of technology developments for rear-projection TVs. The first, liquid on silicon (LCoS) technology, offers a huge leap in quality.

With LCoS, light is shone through a polarising filter and is deflected (or not) by up to 2 million liquid crystal cells. It then bounces off a reflective surface behind them, through another filter and out into the lounge room.

Better than plasma, says the hype. "Great picture quality, excellent colour representation and no visible pixel grid," Philips says. No danger of phosphor burn, adds Toshiba, which goes on to praise the "extraordinary contrast" and "amazing detail".

SXRD

Earlier this year Sony announced that within the next 12 months it would weigh in with its own silicon-crystal reflective display technology for rear-projection TV. That is SXRD for short. Sony promises all the benefits of LCoS, such as a similar 2-million-pixel resolution (1920x1080) that will show high-definition TV in all its glory, plus a contrast ratio of more than 3000:1 for a much brighter and more dynamic image.

Part of SXRD's secret, Sony says, is the use of a different form of liquid crystal material, Sony's unique and thinner "Vertically Aligned Liquid Crystal".

You can expect LCoS and SXRD front projectors as well.

NEW COLOR SYSTEM

LCoS is a clever development of an existing idea but it becomes radical when combined - as Philips intends to do - with the new multi-primary color technology of Israel's Genoa Color Technologies.

The conventional wisdom is that color images are created by the combination of red, green and blue lights. Genoa says these three colors only allow TVs and projectors to deliver 55 per cent of the visible color spectrum. By combining five or six colors - let's call them red, magenta, yellow, sky blue, dark blue and green - Genoa says it is able to create 90 per cent of the visible color spectrum, delivering a more natural and colorful picture.

As if answering this challenge, Sharp and Microsoft have apparently found ways to wring more colors out of LCD's reds, greens and blues. Sharp's new LCD panel, which will be launched next year, is capable of delivering the billion colors demanded by the new Windows operating systems set to be launched in 2005.

Current LCDs apparently can only generate about 16.8 million colors.

3D TV

3D TV is capable of turning two-dimensional footage and pictures into three-dimensional images. Things are still a long way from being perfect, however, with issues with resolution, cost and limited points of view. Expect a long wait before you can buy a 3D TV.

ELECTRO LUMINESCENCE

OLED (Organic Light Emitting Diode) and OEL (Organic Electro Luminescence - These wafer-thin screens are built around "organic" elements that generate their own light when "tickled" with a discrete electric charge. This means they do not need LCD's backlight and can be printed on plastic for cheaper production and flexible screens.

That is good, but like all-first generation products, there is a caboose on the other side of that hill with a whole load of potential improvements.

DUAL-SIDED OEL

Samsung recently showed an OEL screen that emits light from both sides. This has immediate impact for mobile products such as phones and PDAs but may have design implications for future TVs.

QD-OLED

Researchers at the Massachusetts Institute of Technology have come up with a display using "quantum dot technology". This uses high-performing inorganic nanocrystals to create artificial atoms that selectively hold or release charges. These dots promise a more intense light emission and can be "tuned" to emit any color. The organic molecules used in OLED screens deliver the charge to the dots to make them emit light. Result - a brighter and more colorful display.

FIELD EMITTING DEVICES

Field Emitting Devices (FED) are described by many as the future of large-screen flat-panel TVs as they potentially offer the best of all possible worlds - the brightness, contrast and low production cost of a traditional CRT with the thinness of a plasma or LCD. Even better, they use less power. The trouble has been making them actually work.

The way this family of screens work is simple. Whereas a color CRT has three guns that fire electrons at a screen, FEDs use loads of minuscule electron guns - one for each pixel. Hit by their beam, these pixels, which are made of old-fashioned CRT phosphors, glow intensely.

CARBON NANOTUBES (CNTs)

Carbon nanotubes (CNTs), basically sheets of carbon atoms rolled up into tubes, are being used as tiny electron guns. These can be applied accurately by printing at low temperature on materials such as plastic, resulting in potential cost savings and screens that can be rolled up and curved. Motorola, which is keen to find partners to license its FED tech, is talking about a 50-inch, one-inch-thick CNT-based display costing the same as standard 32-inch CRT - eventually.

HyFED's

In February SI Diamond Technology demonstrated a 14-inch mono TV using carbon nanotubes (CNT) printed on to low-temperature glass. This is actually claimed as a HyFED display because each CNT addresses 10 pixels, not one, making the technology a hybrid of CRT and FED technologies. SI Diamond Technology says the price of this new generation of displays will be, inch for inch, the same as for current CRT TVs.

SED

Canon and Toshiba come out with what they call "surface-conduction electrode-emitter devices" (SEDs). Tipped to launch late next year, with large-screen product to be aimed at the booming plasma market. Expect SEDs to offer more brightness and contrast than plasma at a cheaper price with the same slim, sexy profile and screen size.

HEED

Pioneer's research in flat-panel display has taken it into the development of high-efficiency electro-emission devices (HEEDs). Using the regular CRT phosphor, this MIS (metal-insulator-silicon) diode cold-cathode device is claimed to emit a dazzling 80,000 candela per square metre. That's about 150 times brighter than a CRT. As yet no other cold-cathode technology, such as field-emission devices (FEDs), has achieved such brightness. Consumer applications are somewhat distant and are likely to be aimed at huge screens.

LCD Displays

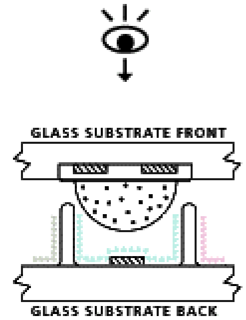
LCD's (liquid crystal displays) are the most common form of flat-panel display available today. They are used in an enormous variety of devices, ranging from the readout on your digital watch to laptop displays to desktop flat panel displays. Standard LCD construction is basically a sandwich of transistors, liquid crystals, and color filters between two pieces of polarized glass, which are oriented at 90 degrees to each other.

The main advantages of LCD's over standard CRTs (cathode ray tubes, the kind of device that drives a normal monitor or TV) are their low power consumption and their lightweight and thin profile. They have several disadvantages though; compared to a CRT their colors are less bright, they have less contrast, and their viewing angle is very limited. Also, since the number of crystals and hence pixels is set when they are manufactured, the resolution they are manufactured at is the only resolution they can ever be used at without some sort of software interpolation which degrades image quality. Finally, since they are an emissive display (they emit colored light to create images), they cannot be used in direct sunlight or bright ambient lighting conditions. Several technologies are in development to correct these problems.

Toshiba is developing a LCD that works by reflecting ambient light rather than using a backlight. There is also a lot of research going on with low temperature polysilicon substrates that would allow both the transistors and liquid crystals be bound to the same substrate, greatly reducing manufacturing complexity. However, LCD's will not ever make a practical large-scale (wall size or bigger) display device, because of their manufacturing complexity, their fragility (two glass layers) and finally because they rely on emissive display.

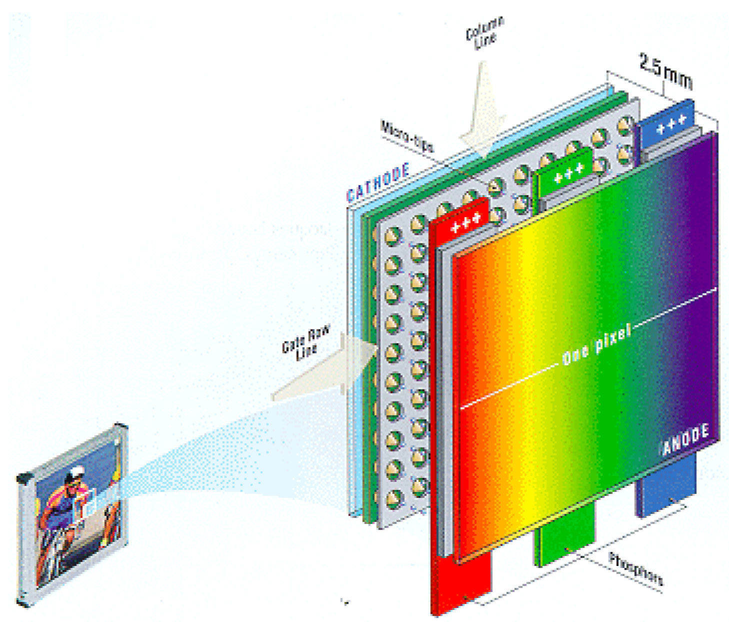
Plasma Displays

Gas plasma displays work much the same way LCD's do, but instead of liquid crystals passing light through a colored filter, they contain noble gasses that emit ultraviolet light when excited by the transistors that in turn makes some phosphors glow red, green, or blue, creating pixels. They are much easier to manufacture large than are LCD's, but cannot be made much smaller than 40". They have much wider viewing angles, but consume much power. They also have the drawback of color banding in low-contrast scenes. Other than that, their drawbacks and benefits are much the same as LCD's.



Field Emission Displays (FED)

FED's work using the exact same principal that a CRT does (electrodes striking a phosphor causing it to luminesce), but simply replace the big heavy electron guns used in classic CRTs with a thin array of hundreds of tiny little cathode tubes. The tubes are positioned in a flat plane a few millimeters away from the phosphor surface. The end result is a display that is as bright and fast as a CRT but as thin as a LCD. They also use less power than a normal CRT. They still, however, have the drawbacks of being inflexible and emissive, keeping them from being suitable for truly large-scale display. Also, I could not find examples of FED's larger than 5.6" or with resolutions greater than 320x240, leading me to believe they are difficult to manufacture at large scale or precisely.

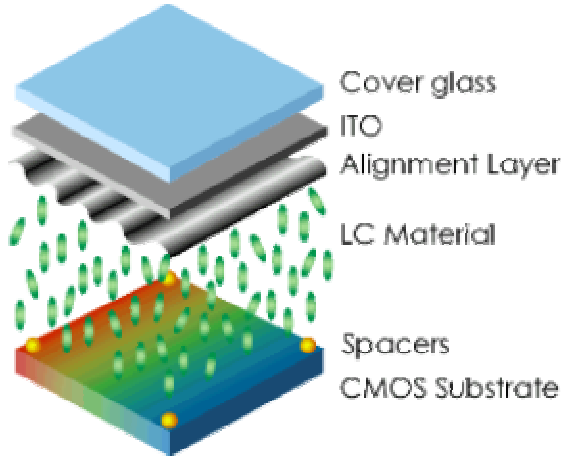


These new technologies offer several exciting new advantages over existing ones. Unlike most existing display tech, LEP's and Digital INK work on flexible substrates, meaning they can be configured into non-planar shapes. Also, since they are no longer constrained to being sandwiched between glass plates, they offer the possibility of being much tougher, cheaper products.

Microdisplays

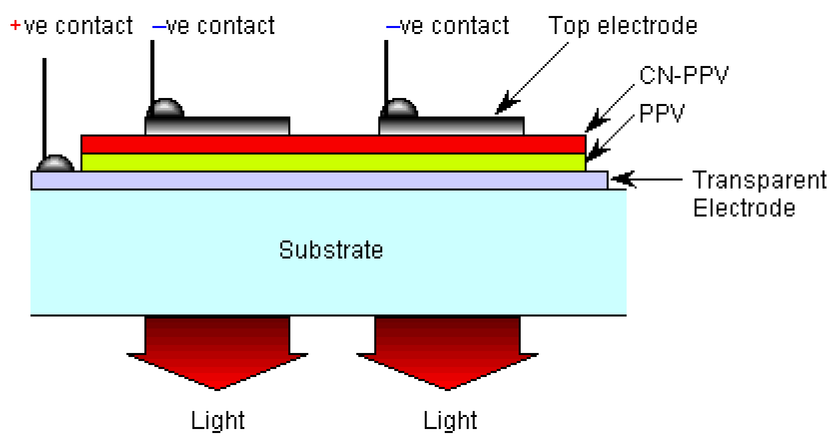
"Microdisplays" are tiny reflective LCD panels made by a company called, oddly enough, MicroDisplay. Their main advantages are that they are tiny, reflective rather than emissive, much brighter and with a wider viewing angle than today's LCD's, and since they manufactured right onto a silicon control back plate rather than between glass and a layer of transistors, they are much easier and cheaper to manufacture. They show promise as cheap and effective displays for use in wearables and other little gadgets like cell phones, in tiny little projectors. The only drawback right now is that the maximum resolution available is 1024x768 pixels, good enough for watching TV but not really

very high. Considering that is on a display that is only .63" across, however, that is quite good.
Microdisplays could be useful in tiny projectors that could easily be built into ceiling panels or behind walls to use as display devices in the home.



LEPS

LEP's, or Light Emitting Polymers, are exactly what the name says; they are polymers that, when excited by an electrical current, give off light. Red, green, and blue polymers have all been successfully manufactured, and a prototype display demonstrated. They are turned into a display by ink jet printing them onto a transistor matrix like those found in LCD's, but unlike LCD's, printing them on is more or less the last step. Since they emit colored light, none of the mess and expense associated with the layers of polarized glass, color filters, and liquid crystals that a LCD uses are needed at all. LEP's are as efficient as today's LED's, which are very efficient. They have the potential to be used as flexible, cheap, and tough displays. Their only drawback is that they still depend on emitting light to create an image, making them impractical in daylight or other brightly lit environments. They are a very young technology, and it will be several years before real consumer products start appearing.



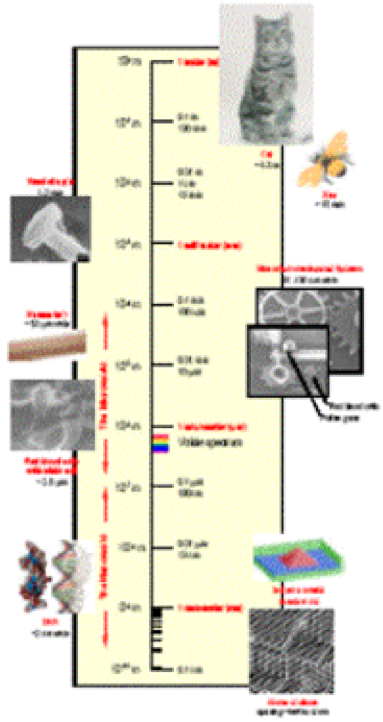
NANOTECHNOLOGY OPPORTUNITY DESCRIPTION

If widespread discovery and usage of nanoscience and technology can be achieved then the development of nanotechnology offers a great deal of invention.

It is the alignment of this technology to a structured strategy that will allow discrete inventions of nanotechnology to take shape in our origin. This section will describe the fundamentals of how some organizations approach a business alignment strategy to foster opportunities of nanotechnology. In particular the European Commission is conducting nanotechnology hearings and in 2002 the commission set up areas of investment that will focus on value add opportunities, listed below are the various categories.

Shifting from traditional to high added value industries – New materials and hybrid technologies that will contribute to the development of new knowledge based, added value and more environment friendly technologies (ie. print media)

Developing new concepts for flexible and intelligent production systems – The global community will move towards knowledge based economies that will call for breakthroughs in organizations, regulatory, and technological joint developments.



Improving sustainability and safety of industrial systems - Integrating nanotechnologies and new material into production systems will help introduce new designs and new ways of making things smaller, cheaper, better to run, fighting pollution and developing clean and less source intensive technologies.

Fostering industrial technologies for security of citizen – Nanotechnology based sensors and central systems will make it possible to detect hazards of chemical, physical or biological origins, to monitor reliability of safety systems and to provide timely feedback for the initiation of protective actions.

Supporting industrial technologies for health – Development of advanced intelligent bio-hybrid systems and their production lines in context of biosensors and of nanobiotechnologies in the public health sector.

Enhancing urban environment – New concepts based on new nano materials that are able to adapt to their environment, and extend their useful lifetime and save energy.

Expanding knowledge in nanoscience and engineering – Research development in the area of new tools for characterization, investigation and future manufacturing allowing for precision and accuracy at the atomic and molecular scale.

Developing new materials technologies – Fostering and promoting the creation of new RTD intensive industries in existing, emerging and promising areas, generating new knowledge based jobs and encouring a multi and trans disciplinary culture in the field of materials science.

Pure strategic alignment to business opportunities has no value if it is not for sources of funding. As described in this paper various outcomes of this science will penetrate consumer markets immediately while other enhancements of this technology yet need to be realized. With that said, research by various industries and commissioned US Government reports indicate that nanotechnology will blossom into a trillion dollar global industry over the next ten (10) to fifteen (15) years, create as many as 7 million jobs by 2015, and create the same revolutionary changes as information technology (IT). As far the financial landscape and support is concerned the US Government has invested $847 Million in the National Nanotechnology Initiative (NNI), and recently signed the 21st Century Nanotechnology

Research and Development Act of 2003 authorizing an additional $3.68Billion in research spending. Aside from government research venture capitalist have shown tremendous interest by investing an estimated $1.2 Billion in nanotechnology in 2003.

WEAKNESS/DEFICIENCY IN CURRENT EFFORTS THAT YIELD THIS OPPORTUNITY

It is clear that momentum is clearly taking shape, however barriers to entry start right at the gate. In many nanotechnology companies that look for venture capital, the entrepreneurs cannot convincingly articulate the realistic and fundable strategy. Take for example nanodevices, where new materials and development of a new manufacturing methodology needs to be utilized, it is difficult to position your explanation to articulate the significant amount of capital it would take to bring the product to market. Take this concept to the next level when talking about "platform technologies", where different application domains become into view. A few examples of this are quantum dots, carbon nanotubes and nano wires technologies used in various industries for various applications. The focus is lost on the technology and the application leading to additional difficulties in lining up funding for your product. If the incumbent entrepreneur is successful in obtaining seed money in this field another common pitfall is nano startups to plan for progress of this technology. The classical mistake does not take into account the disruption of existing markets when their product is introduced. Additionally there are technology complexities that still need to be overcome, product life cycle issues and integration, regulatory limitations, and as described above financial barriers. Below is a research slide by Mckinsey at AtomWorks.

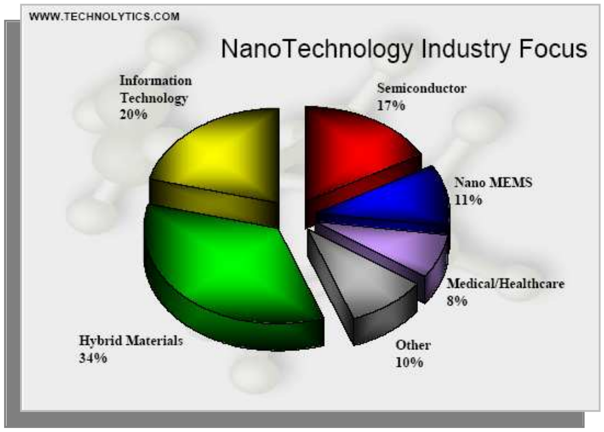
KEY DRIVERS WILL LIMIT RATE OF MARKET PENETRATION…

Consideration	Effect	Examples
Technological complexity	Integration requirements and interdependency delay penetration for complementary designs	• New chip architectures require integration with peripheral providers
Product life cycle	Limits integration of new and improved components into systems	• Automobile models (3 - 4 years) • Aerospace (decades)
Regulatory limitations	Rigorous regulatory approval process limits adoption, success rate	• FDA approval • FAA approval
Investment requirements	Creates significant switching cost, raising required value for innovation to penetrate	• CMOS chip fabrication facilities (> $ 2B)

Source: McKinsey; AtomWorks

CHALLENGES THAT MAY REQUIRE NANOTECHNOLOGY SOLUTIONS

The current climate shows that nanotechnology is moving at a slow place when penetrating the consumer markets. Although some quick wins have been accomplished, more technology will hit the streets as development take full speed. The C60 that functions as a monitor of the Nanotechnology industry reports that in 2003 there was 11 months of upside value in this industry. Much upside advances have been made in real world consumer product categories. With the advances in quantum dots and flexible display material technologies we'll soon see how this product fairs in the consumer arena.



With a 34% stake of Nanotechnology focus in the hybrid materials area, we'll soon see that some nanotechnologies have overcome barriers to entry successfully. As noted in the United Press International "In sign of the digital times, commercial paper signage advertising retail outlet customers on everything from new arrivals to sales prices may be going the way of the typewriter". This was in reference to Macy's corporation a retail clothing chain utilizing new flexible display technologies in their stores. This technology possible by nanotechnology is dubbed "Smart Paper" and its manufacturer Gyricon LLC. will be gearing for rollout next year. Further information can be found in later sections of this paper.

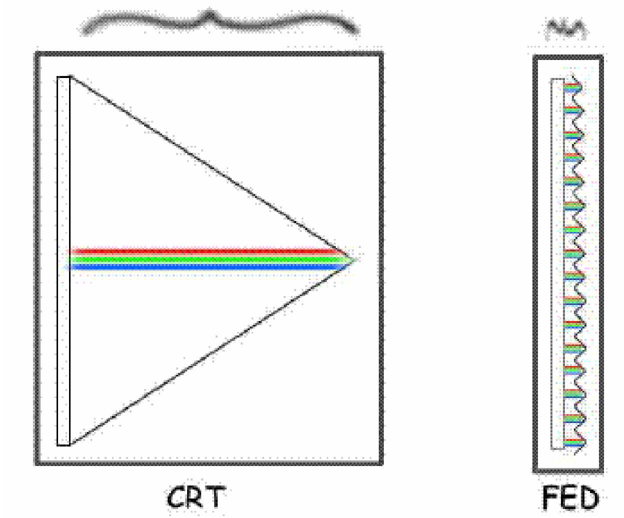
NANOTECHNOLOGY APPLICATIONS IN DISPLAY TECHNOLOGIES

Out of the many possible future display possibilities, several of them are based on nanotechnology. The utilization of quantum dots and carbon nanotubes both provide exciting new possibilities for development.

CARBON NANOTUBES

FED's or Field Emitting Devices is one possible evolution of today's CRT's. A CRT functions by firing three beams of electrons (one for red, one for green and one for blue) in a scanning pattern on the backside of the display screen. The back of the display screen is coated with phosphors, which when hit with the electron beam, emit light. This display's primary drawback is the need for a relatively deep product. In order to properly activate the phosphors, the beam must hit the phosphors at a certain angle and intensity.

Working together, Candescent and Sony Inc. have been developing FED display technology for small screens that are now finding their way into the market. They hope to soon scale their technology in hopes of breaking into the existing TV market. However, many hurdles exist that must be overcome in order to refine this technology. One of nanotechnology's basic building blocks may be the solution that takes this 80-year-old technology into the 21st century.



The concept is simple. Rather than use a single electron gun responsible for lighting the entire screen, why not have an electron gun for every pixel on the screen? This previously unheard-of idea may be made possible by the use of Carbon Nano-Tubes. CNT's are an attractive option due to their electron emission and mechanical properties, which could, in addition to many other benefits, extend the lifetime of FED's. Planning to use CNT's as electron guns, manufacturers like Motorola and SI Diamond Technology are researching how to densely pack electron guns, eliminating the need for product depth (see illustration above). In fact, SI Diamond Technology has already produced a working model of this technology. Not quite FED, their model, referred to as HyFED (hybrid FED), has an electron gun for every 10 pixels. Clever processes like Motorola's existing process of growing CNT's directly on glass or even screen printing a layer of CNT's on glass keeps the price low. In fact, HyFED TV's are expected to be priced comparable to current CRT technology. SI plans to scale its technology as large as 150 inch diagonal TV's to address current trends. Developed by FEPET (Field Emission Picture Element Technology, Inc.), a recent 14.5 inch version of a CNT-FED using grown carbon nanotubes to form nanoparticles between 50 and 100μm, is planned to be the basis for Japan's Ise Electronics' 40-inch CNT-FED wall hanging TV.

QUANTUM NANODOTS

QD-OLED's (Quantum Dot Organic Light Emitting Diode) has been developed by researchers Moungi G. Bawendi, professor of chemistry, and Vladimir Bulovic, assistant professor of electrical engineering and computer science at the Massachusetts Institute of Technology. Utilization of the OLED backbone allows for the quantum dots to be activated easily using existing technology. QD-OLED's are created artificially using high-performance inorganic nanocrystals and are placed, as a single 3 μm thick layer, between two thin organic films, one rich in electrons and one lacking. This 3 μm thick layer is made up of a single layer of quantum dots and is what separates MIT's work from their peers who are still sandwiching dots ten to twenty layers thick and proportionally less efficient. The quantum dots themselves can be individually and fairly easily modified to emit a color of choice. This is achieved by modifying the size of the dot or the configuration of the electrons within the dot. This change in physical structure amazingly alters the way light is reflected dramatically. The combination of organic and inorganic components is one of the properties of this technology that makes it special. The impressive power efficiency of QD-OLED technology in comparison to current LED and LCD technology could have our future handheld devices not only looking better, but lasting much longer.

A trend towards high quality large displays has been prevalent over the past few years in the business world as well as in the personal home entertainment arena. High-resolution small portable devices are finding their ways into our pockets in the form of PDA's and cell phones. The ability to provide a display capable of producing minimally 200 pixels per inch will be paramount and will require components much smaller than those in most of today's devices. Regardless of what the future actually holds for display technology, it is obvious that nanotechnology will play a key role in its development.

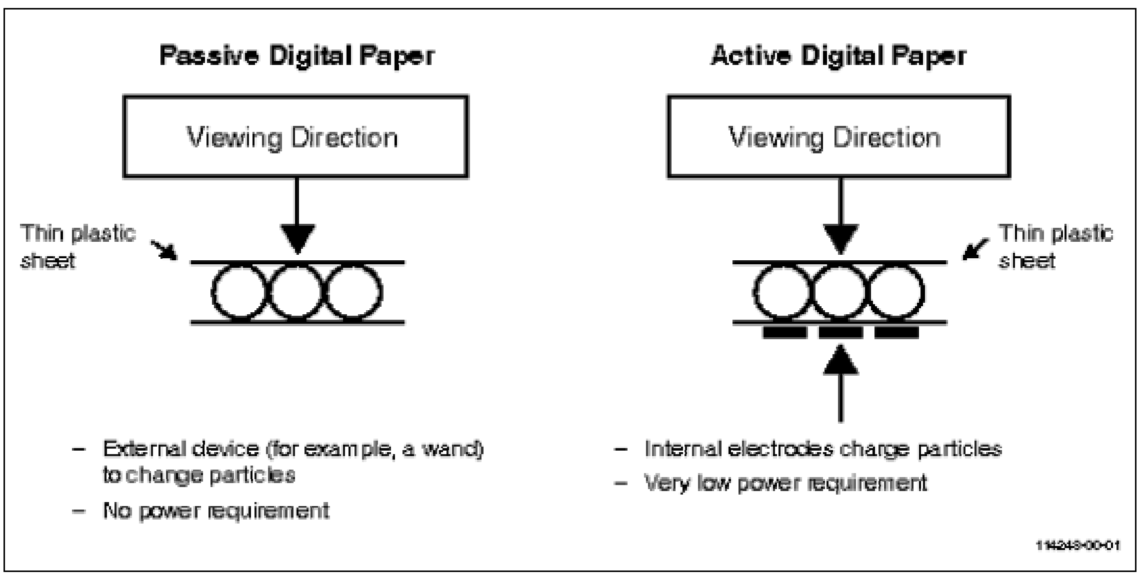
DIGITAL PAPER

Digital paper, also referred to as digital ink, electronic paper or electronic ink, is a technology intended to produce a display that is similar to paper in many ways. It resembles a sheet of plastic-laminated paper. Beneath the plastic are tiny microscopic beads that change color to form text and images. The result is a nearly paper-thin, rewritable display.

The need to capture the tangibility of paper has been apparent to technology developers for years, but limitations on thinness, flexibility, power consumption and cost has, until now, made the development of such displays a topic only seen covered by science fiction and dreamed of in the imagination. But developments in display technology have been making science fiction a reality in several market sectors (Seen on the left is TV's "Earth Final Conflict's" Global Communicator. Provided by MCI, this possible future application of digital paper coined a 'global' uses a pull out screen capable of displaying video conferencing sessions and acting as a palmtop computer).

ACTIVE & PASSIVE DIGITAL PAPER

Digital paper comes in two forms: active and passive (see Figure below). In passive form, an external device like a wand or a specially designed printer head supplies the electrical charge needed to change bead color. The active form is used when digital paper is needed for a device display. In this case, a back-pane of electrodes is laid behind the digital paper, allowing the image to be updated as desired.



Source: Gartner Dataquest (April 2003)

KEY ENABLING NANOTECHNOLOGY CONCEPTS

Today's digital display domain is made of up several competing display technologies all striving for many of the same goals. Particularly, companies are continuing to push the envelope for crisper and brighter displays. The reason for this is clear: human vision is capable of viewing very high resolutions, especially up close. Current technology limitations are posing hurdles to achieving this goal, however, several ideas spawned from nanotechnology research offer hope in solving this dilemma.

Pixel size is the key. Current incarnations of this technology are achieving about 100 dpi, which pales in comparison to the 1,200 dpi seen in many of today's magazines (considered to have fine enough resolution for comfort and clarity). Today's already small 100 μm embedded beads may have to be reduced in size in order to achieve the desired clarity (depending on the implementation). Advances in plastics and the ability to print components directly onto a substrate with nano-scale accuracy efficiently, have provided the current versions of digital paper the backbone needed to begin development. Advancements in nano-scale printing of electrode matrices, providing charges to 'pixels,' will allow for increased resolution and contrast.

ITEMIZATION OF COMPONENTS (and how they are interconnected)

Regardless of the implementation, the images or text appearing on today's digital paper is generated by a computer display driver. Sometimes sent directly to the device via the system bus, actual end user implementations of digital paper technology often have the raw data for presentation sent via wireless 802.11(x) technology. Receiving the signal from the display driver is the dynamic backbone, similar to that present in LCD and OLED technology. These matrices of electrodes are printed on a flexible substrate using some fancy chemistry, self orientating materials or screen printing techniques and are used to control the state of the individual pixels of the display. Attached to the backbone is a transparent elastomer, or equivalent. A second transparent layer, capable of being inversely charged, sandwiches the shading/coloring components.

The method of shading or coloring digital paper varies slightly with different implementations; however, the core concept remains the same. Very fine, magnetically sensitive particles, colored or shaded relative to their poles (and each other) are placed between the two layers. Currently used procedures either have very small particles suspended in oils or contained within clear beads. Charges from the electrodes alter the magnetic fields and reorient the 'pixels,' sometimes consisting of the individual particles themselves and sometimes modifying all or part of an individual encapsulating bead. The smaller the distance between different magnetic charges the smaller the individual magnetic field, thus the finer the resolution of the image. The faster the backplane is able to change the magnetic charge, the faster the frame rate. A challenging task, the improvements in the components implementing these two objectives will increase the usefulness and marketability of the resulting product.

ADVANTAGES AND WEAKNESSES

ADVANTAGES

- Low power requirement: The display is bistable; once it has been "set" by applying current, the digital paper maintains the image even when the power is turned off. Power is needed only to update the display.
- Wide viewing angle: Unlike many traditional display types, digital paper can be viewed from any angle. LCDs have a much narrower viewing angle.
- High contrast: The contrast ratio for digital paper is more than twice that of traditional LCDs. It also has a much greater brightness. This makes viewing easier even in low-light conditions — display illumination is needed less often, resulting in further power savings. Digital paper displays do not "wash out" in bright light, which is a problem with LCDs.
- Form: Digital paper is light, thin and flexible (though this depends partly on the backpane to which it is attached). Therefore, it can potentially be used where it is unsuitable to use traditional displays (for example, smart cards) and to reduce the weight of devices using traditional screens.

TECHNICAL WEAKNESS OF CURRENT SOLUTIONS

- Resolution: Digital paper technology offers resolution of about 100 dots per inch. While this is close to the resolution of LCDs used in personal digital assistants (PDAs), it is somewhat below that of higher-range thin film transistor (TFT) screens and far behind paper printouts produced by even relatively inexpensive inkjet printers.

- Refresh rate: Digital paper has a far lower refresh rate than that of LCDs, making it unsuitable for fast-moving images such as video.
- Color: Digital paper is largely limited to two-color output, though multicolor output is being researched and developed.

APPLICATIONS AND MARKETS

Digital paper represents a potentially revolutionary technology. Digital paper devices offer light weight, power efficient, high contrast monochromatic displays for retail advertising and message boards, but as the technology moves toward commercialization, consumers will expect better color handling, sharper image quality, and refresh rates suitable for multi-media presentations. Nonetheless, digital paper in its current state of development is well matched for electronic books, newspapers and magazines, since these mediums of entertainment call for lower refresh rates. The digital paper incorporated in these electronic displays offer a springboard for developing a truly digital paper—flexible sheets that are capable of changing text as well as images, providing higher resolutions, brighter contrast, a capability that far exceeds what computer CRT/LCD displays presently do, but a look and feel similar to paper.

SUMMARY OF APPLICATIONS

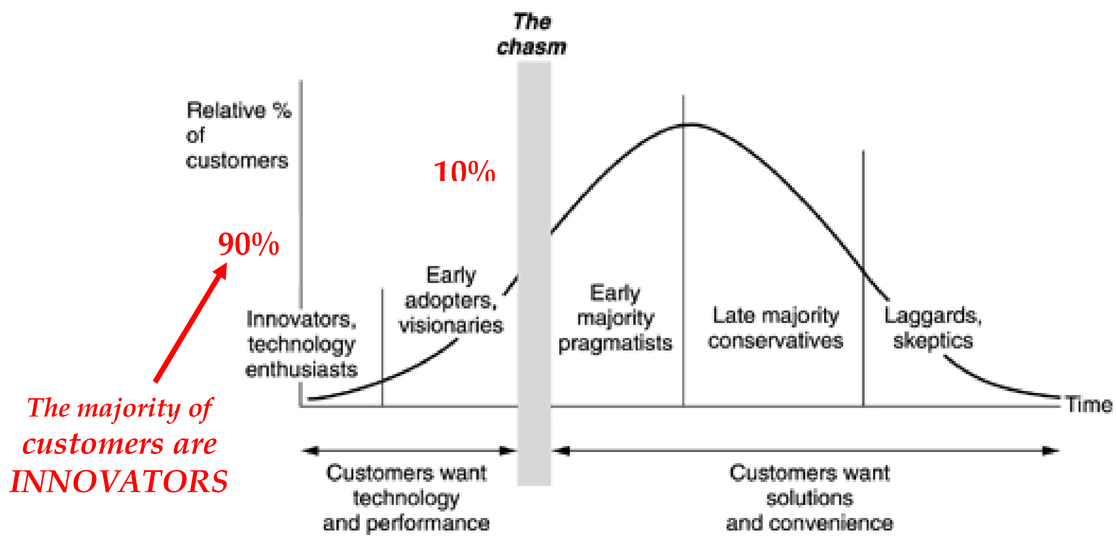
Digital paper was originally developed for point-of-purchase displays for retail environments, enabling retailers to instantly change the prices of products across all outlets in real-time. This saves department stores the substantial costs of regularly updating their paper advertising signage. While the main focus has been on in-store POP displays, developers are now turning their focus to smaller applications. As example, E Ink is currently collaborating with Lucent Technology employing Bell Labs' proprietary flexible transistors embedded within thin sheets of plastic. The company's aim is to produce ultra-thin, lightweight displays for mobile phones, PDAs and electronic books.

DESCRIPTION AND MARKET SIZE

It is predicted that devices displaying digital information on paper-like devices, electronic newspapers and books made from e-paper will be a commercial reality by 2005 with markets becoming large-scale by 2010. Whether digital paper becomes a commercial reality in the near-term will depend on the developers' ability to scale down the technology. However, the current rate at which nanoscale technology is developing suggests that this is feasible.

MARKET DEMOGRAPHICS

Current technology adoption percentage for Digital Paper looks as in the picture below. As we can see below, 90% of the customer base of Digital Paper is the INNOVATORS, with only 10% in the EARLY ADOPTERS. There are still NO customers that have crossed the chasm.



GLOBAL vs UNITED STATES MARKETS

In Europe and Asia, digital paper is still in its infancy, not yet fully commercialized for established marketing data. However, an analogy for digital paper can be illustrated using current day electronic print. The European market for commodity print products still grows at an average of 2-3% per year, but their IT market is much greater, growing at 10-15% annually. And one of the primary drivers of digital printing is *electronic commerce.* To meet that challenge lithographers on the Continent have gone digital. Moreover, the influence of color is quite significant. Although more than 80% of the pages printed by European lithographers are black & white, this represents only 53% of the total market share. The major revenues earned from the use of color was almost double in 2002 ($US2.6B B&W and $US4.7B). Given this background:

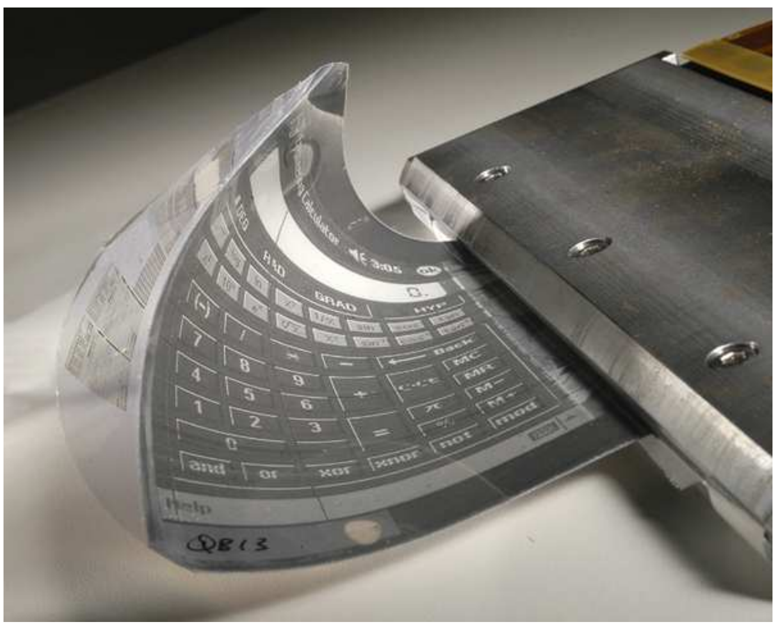
- Physicists in Sweden have teamed up with Europe's leading paper and packaging manufacturers to develop a new breed of electronic devices made from paper and conductive inks. The first product was a simple paper display (28 x 39 inches) based on electronically active pigments, which updates information and images. The inks can turn from one color to another, but researchers are also developing pigments that can change into any color state. Dynamic inks have been successfully demonstrated in large billboards to introduce animated areas to an otherwise static image. As discussed earlier in the paper, the electronic ink of digital paper stays in the same state and only need power to change from one color to the next is known as bistable display technology. Similar to progress made in the US, the prime focus for bistable display technology for Europeans is for retail displays, price tags, and researchers are focusing on large paper billboards as well;

- September 26th 2003, Robert Hayes and Johan Feenstra, physicists at Philips Research (the Netherlands) reported development of a new way to make digital paper that displays moving images, known as "electrowetting" technique. They claim *electrowetting* could be used to make a reflective display that show 10ms refresh rates and are four times brighter than reflective LCD displays;

- During the month of December 2003, Tsunemasa Mita, General Manager of Advanced Devices and Materials Group of Fuji Xerox (Japan) reported his company was investigating the commercialization of electronic paper from two approaches, photo-addressing electronic paper consisting of cholesteric liquid crystal (ChLC) and stand-alone toner display-type electronic paper for a public display. Mr. Mita claims its photo-addressed image can be kept for more than one year using the ChLC material in memory. Fuji Xerox's target market is large electronic bulletin boards or electronic posters for usage in public facilities like hospitals (see below) applications for smart card technology;

Prototype of a toner electronic paper display. Source Advanced Devices & Material Group, Fuji Xerox.

- And in January of this year, researchers at Philips Research (the Netherlands), demonstrated an active-matrix display with the flexibility characteristics of paper that overcomes limitations of LCDs by being made almost entirely of plastic (see below). Researcher Gerwin Gelinck says the displays offer contrast similar to that of magazines. The electronics also have the potential to operate at video rates. But because they rely on silicon-based electronics grown on glass, they are still too costly and too rigid for many applications, such as electronic paper. The current prototype 5-inch grayscale displays are 300 µm thick and can be repeatedly rolled up into a 1.5-inch diameter tube without damaging the display material (see below).



World's thinnest flexible active-matrix display using Philips' ultra-thin back plane with organics-based thin film transistors, combined with E Ink's electronic ink front plane. Source Philips Research.

The effort of these researchers provides an important next step towards the development of low-cost electronic paper, whereby in the not too distant future, receiving a daily newspaper will be as simple as unrolling a sheet of digital-paper and downloading it from your cell phone.

MAJOR DIGITAL PAPER MANUFACTURERS: GYRICON, LLC.

Gyricon, LLC makes SmartPaper™. Smartpaper is poised to change communication forever. Developed at the renowned Palo Alto Research Center, SmartPaper is a reusable display material like paper, but is electronically writeable and erasable.

Gyricon's growing portfolio of product offerings provide customers in retail, hospitality, educational and other markets the ability to manage and display dynamic content on new electronic media. These innovative business solutions are practical, labor saving and cost effective

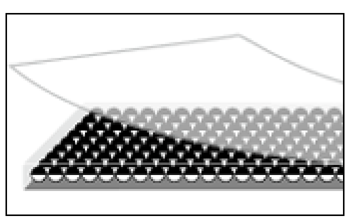
TECHNOLOGY

When personal computers were in their infancy, Nick Sheridon, a physicist at Xerox Corporation's Palo Alto Research Centre (PARC), began researching alternatives to computer display screens, which at the time were plagued by poor viewing quality and constant flickering. His goal was to create a solution that would not only have the benefits of paper but could improve upon its qualities. Since images on paper are essentially series of bitmaps or dots, Sheridon conceived of having electrically activated micro-spheres that could emulate these bitmaps. These "beads" were black on one side and white on the other and encapsulated within pockets of oil on a sheet of transparent elastomer. Depending on the electrical field produced, be it positive or negative, the orientation of these beads would change showing either black or white and collectively would create images. In fact, the images were almost as clear as ink on a sheet of paper, but eminently more useful as the page could be changed at will. Gyricon SmartPaper ™ was born.

SmartPaper™ is reusable display material that has many of the properties of traditional paper:

- Stores an image
- Viewed in reflective light
- Has a wide viewing angle
- Flexible
- Relatively inexpensive

Unlike regular paper, however, it is electrically writeable and erasable and is the main media component of our eSignage solutions.



Produced in a roll, like conventional paper, SmartPaper is actually two sheets of thin plastic with millions of tiny bichromal beads embedded in between. Each bead is smaller than a grain of sand and has a different color on each half or " side ". The hemispheres are also charged differently (i.e. positive or negative).

SmartPaper beads reside in their own cavities within the flexible sheet of material, so that under the influence of a voltage applied to the surface, they rotate to present one side or the other to the viewer. This image stays in place until a new voltage pattern is applied, which erases the previous image and generates a new one.

MAJOR DIGITAL PAPER MANUFACTURERS: E-INK

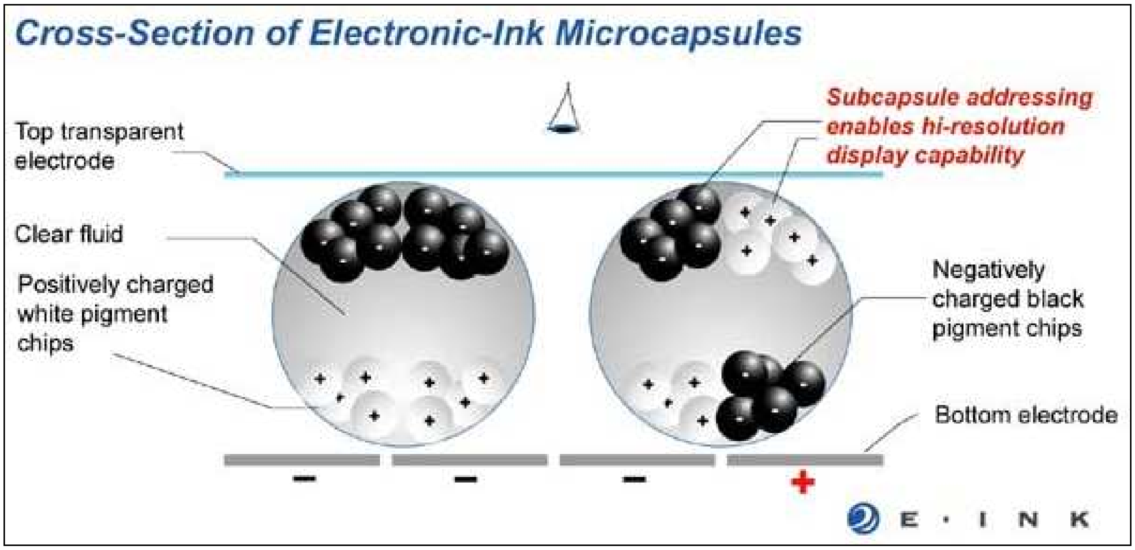
E Ink Corporation was founded in 1997 to create the next medium for visual communications. E Ink's electronic ink display technology helps unleash the full power of our connected world by uniquely combining a paper-like reading experience with the ability to access information anytime, anywhere. E Ink's technology delivers the look, form and utility of paper encompassing broad design freedom, manufacturing flexibility and the ultimate in readability and portability. E Ink is headquartered in Cambridge, Massachusetts and has an office in the Tokyo, Japan area.

The investors of E Ink include leading technology companies, publisher and venture capitalists. E Ink has raised over $100 million, largely through strategic investors. $15.8 million was raised as its first equity round in 1998. In January 2000, the company completed its second round of equity financing of $37.1 million. In February 2001, E Ink secured its third round of financing with a $7.5 million investment from Philips Components as part of joint development for the use of electronic ink in handheld device displays. In February 2002, TOPPAN added to its initial $5 million investment in 2001, with an additional $25 million in connection with a significant expansion to their strategic partnership to commercialize electronic paper.

E Ink has won many prestigious awards and accolades, including Fortune's "Cool Companies," Upside's "Hot 100" Private Companies, Industry Week's "Technology of the Year," Popular Science's "Best of What's New" and a Technology Partners' Technology Outlook "Investor's Choice."
E Ink is a privately held company and is not currently traded under any exchanges.

TECHNOLOGY

Electronic ink is a new material that will have far-reaching impact on how society receives its information. It is a proprietary material that is processed into a film for integration into electronic displays. Although revolutionary in concept, electronic ink is a straightforward fusion of chemistry, physics and electronics to create this new material. The principal components of electronic ink are millions of tiny microcapsules, about the diameter of a human hair. In one incarnation, each microcapsule contains positively charged white particles and negatively charged black particles suspended in a clear fluid. When a negative electric field is applied, the white particles move to the top of the microcapsule where they become visible to the user. This makes the surface appear white at that spot. At the same time, an opposite electric field pulls the black particles to the bottom of the microcapsules where they are hidden. By reversing this process, the black particles appear at the top of the capsule, which now makes the surface appear dark at that spot.



Source: E-Ink, Inc.

To form an E Ink electronic display, the ink is printed onto a sheet of plastic film that is laminated to a layer of circuitry. The circuitry forms a pattern of pixels that can then be controlled by a display driver. These microcapsules are suspended in a liquid "carrier medium" allowing them to be printed using existing screen printing processes onto virtually any surface, including glass, plastic, fabric and even paper. Ultimately electronic ink will permit most any surface to become a display, bringing information out of the confines of traditional devices and into the world around us.

In addition, E Ink has a line of simple signage products for integration into retail Point-of-Purchase (POP) and other signage applications. E Ink will launch its paper-like display technology for high volume availability in 2004. This new product platform will target high-resolution active matrix displays for mobile applications as well as segmented displays. E Ink will supply an electronic ink component, a front plane laminate (FPL), directly to manufacturing partners who in turn make displays and supply them to manufacturers of electronic products.

The E Ink and Gyricon technologies both show promise, but industry analysts aren't yet ready to declare that one product is superior to the other. There haven't yet been enough real-world applications to make a judgment on quality or cost. But E Ink has taken the early lead in at least one area: marketing. While Gyricon has been working on digital paper technology for more than a decade, the company has fallen behind E Ink in developing marketable products and building bridges with potential partners. Although E Ink has already started testing digital paper-based products with customers and has established development links with Lucent Technologies, Philips and others, Gyricon has kept a low profile.

COMPETITION

COMPETING TECHNOLOGIES

In Japan, Sony Corp. and Matsushita Electric Corp. plan to start selling electronic books (e-books) the size of DVD cases early this year. Since their debut in the mid-90s, e-books have earned notoriety for being hefty, expensive, and not interchangeable among publishers. The new versions promise to be lighter, easier to use, and eventually less expensive. Initially, both the Sony and Matsushita e-books, which use active matrix technology, will be monochrome, but color versions are expected in a few years.

Matsushita's e-book, called Sigma Book, will be sold under the Panasonic brand. It uses cholesteric liquid-crystal display (LCD) technology, with dark blue pigment on a light background. Cholesteric LCDs create images by switching between a color and black when a small electric field is applied. The images may not be as crisp as active-matrix ones, but the displays cost less, says Prof. John West, director of Kent State's Liquid Crystal Institute, where the technology was developed. Both the Matsushita and Sony e-books will have dual screens that open like a paper book and both will be readable under sunlight, says Dr. West. They eventually could be made of a pliable, polymer backing that resembles paper. Bill Doane, head of Kent Displays, says his company may have flexible plastic cholesteric displays ready by 2006. "You can make large volumes of them at very low cost," he says.

T-Ink Inc. of New York is taking a different approach with an electrically conductive ink that can make sounds or light up. It already is being used by McDonald's Australia in Happy Meals. The Happy Meal toy lights up as it interacts with ink printed on the meal box or tray liner. Likewise, children using Super Color educational products hear feedback if they write a correct answer to math or spelling questions. The marker they write with activates the conductive ink on the paper. "The ink is printed on regular, disposable paper," says Andrew Ferber of T-Ink. He says the ink can be printed onto almost anything, including garments, wallpaper, automobiles, and devices like cellphones - and it will be washable. "There's no industry we can't go into."

A Swedish startup called Anoto has developed a new approach for digital paper. The technology works like this: The pen has a built-in pressure sensor, which activates a digital camera that records your exact strokes. There's a Bluetooth transceiver in the pen, which can communicate the captured strokes to a Bluetooth-equipped phone or laptop nearby. The phone or computer then sends the note over the Internet. The real magic, however, is the paper. The special pen isn't taking pictures of the pen marks -- it's recording the position of the pen on the paper. It can do this because the paper is preprinted with thousands of tiny, nearly invisible dots. As for the paper, 3M, Mead, and other manufacturers will initially print it. The dots can be printed on any kind of paper, and it's not hard to think of other useful applications. For instance, Franklin Covey wants to make organizers that incorporate the technology. The paper could also digitize any kind of form: 1040s, exit polls, health care records, marketing surveys, or warehouse invoices.

ASSESS ADVANTAGES OVER COMPETING TECHNOLOGY

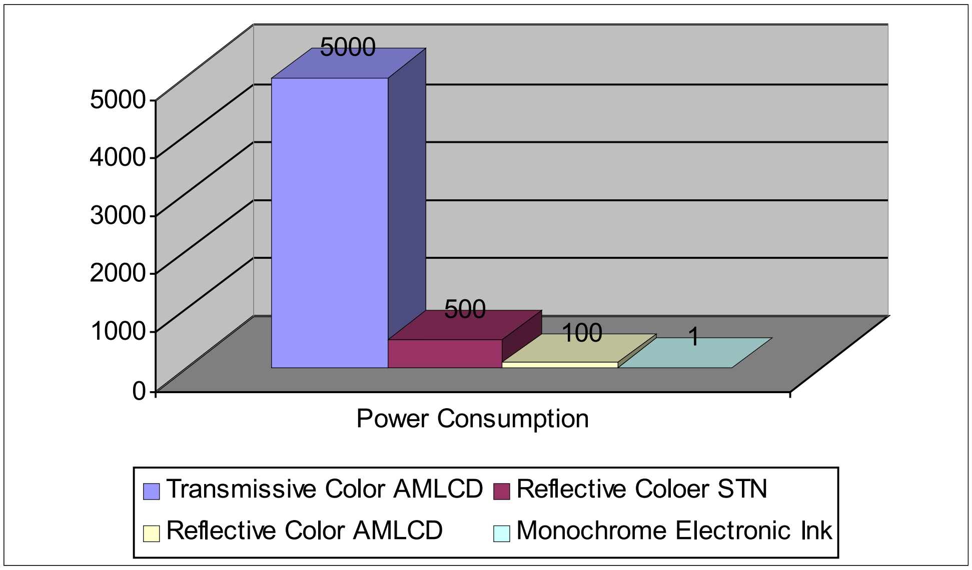
In order for a display technology to be suitable for large-scale (on the order of wallpaper) integration into the home, it has to fulfill some rather exacting performance requirements. It has to be energy efficient, flexible enough to withstand spills and dings, have good picture quality, and be able to perform in an environment with direct sunlight. Requirements of new display technologies

- Performance- brightness, color accuracy, contrast, refresh rate, show up in direct light
- Efficient energy use
- Flexibility- where can it be used? How much punishment can it take?

Under equivalent conditions, the E Ink display sample with touchscreen is nearly three to six times brighter and has more than twice the contrast of the LCDs measured. In fact, the contrast of E Ink is notably greater than that of printed newspaper.

Display Technology	White State Reflectance	Contrast Ratio
Transflective Mono STN LCD (Common PDA with touchscreen)	4.2%	4.1
Transflective Mono TN LCD (common eBook with touchscreen)	4.0%	4.6
Monochrome Cholesteric (with touchscreen)	31.7%	10.8%
E Ink (with touchscreen)	31.7 %	10.8
E Ink (no touchscreen)	41.3%	11.5%
Wall Street Journal Newspaper	64.1%	7.0

Electronic displays offer greatly reduced power consumption as compared to transmissive LCDs as well as newer emissive technologies (OLED, FED, PDP). Lower power consumption translates to longer battery life, and perhaps more importantly, the ability to use smaller batteries in electronic ink devices – reducing device weight and cost.



Electronic ink display modules constructed using E Ink's technology will be thinner, lighter weight and more robust than conventional LCD modules. These benefits, coupled with the ultra-low power requirements of electronic ink displays, translate directly into thickness and weight savings for smart handheld devices, such as PDAs, mobile phones and electronic readers; or any applications requiring a high degree of display legibility in dynamic lighting environments, where portability is paramount.

ASSESS DISADVANTAGES OVER COMPETING TECHNOLOGY

Despite the apparent benefits, opinions vary on digital paper's prospects. The technology will be limited to specific niches—mobile phones, PDAs and Billboards, for example. Thus, it's not exactly clear whom they're targeting -- people left behind by the digital age, or techno geeks? The former is not likely to be buying PDAs or laptops anytime soon, and the latter already has PDAs and laptops. So why do they need to carry around yet one more thing? Second, in most instances these just capture writing as a picture. It's digital, but it's still static. That means you can't search through the text of your messages for keywords or phrases, and you can't copy and paste the text to other programs or applications. Some people will be reluctant to swap pulp for plastic. There will be a different page size, and some individuals may miss the feel of physically flipping through pages or having the ability to snip out coupons. Third, this may just be another case of a solution looking for a problem. Paper, after all, has a way of bending the digital world to suit its quirks, rather than the other way around. The major drawback, however, is the lack of full-color imaging. This is a big drawback in a world where color plays a major role in most printed materials. Inadequate image resolution and tardy refresh rates—the number of times per second a screen is updated—are two key barriers.

CONCLUSION

"Books that change content on request. Computer displays so thin they can be manufactured on a roll and cut to size like kitchen foil. Even paper that emits sounds or can be erased and reused thousands of times".

They above are some very realistic applications of emerging electronic-display technologies. And some will hit the market as early as this year. Technologists hope the new displays will usher in an era in which users drop clunky screens for flexible, portable ones so thin they can be rolled up like a newspaper.

Digital paper actually has the potential to erase the word indelible from the dictionary. It is more than likely that consumers will encounter digital paper-based price tags. We would see a product's price change before our eyes. Retailers will be able to instantly update prices throughout a store, or even in stores around the world, with just the push of a button. On the whimsical side, digital paper could open new doors for novelty product manufacturers. We would have baseball caps with digital paper logos (change your team allegiance depending on who's winning the game) or bumper stickers that change messages. Digital paper ID cards may also be on the way. A pass or license, for example, could be instantly updated to show an updated address or new restrictions or privileges.

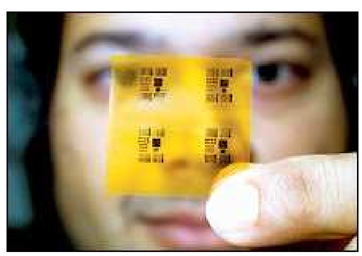
The benefits of the new gadgets are obvious: One such display could replace stacks of books that weigh down a vacationer's suitcase or a student's backpack and provide content that can be updated instantly. While many of these scenarios are at least 10 years away, precursor products such as DIGITAL or SMART papers and ultra-thin glass displays are already showing up:

- In Japan, Sony Corp. and Matsushita Electric Corp. plan to start selling electronic books (e-books) the size of DVD cases early this year.

- E-Ink is already being marketed. E-ink, which closely resembles printed text, comprises tiny capsules filled with positively charged white pigment chips and negatively charged black ones. They respond to electric charges to create text and images. Content is downloaded via wireless networks.

- E Ink is moving in the same direction with its "Radio Paper." The goal is to have a display that looks and feels like newspaper, but can be updated wirelessly. This will be ready by 2007 or 2008.

- Researchers at Xerox Corp.'s Palo Alto Research Center recently devised a technique to "print" plastic transistors similar to the type used to control today's flat-panel displays. The new process uses semiconductor ink and a modified ink-jet printer. The transistors can be used to produce electronic displays that roll up.



MICROPAPER: Xerox's Palo Alto Research center has developed a semiconductor ink that prints transistors, which can be used to make digital displays that roll up. XEROX PARC

Yet people wonder if it is an innovation that they really need—or want as digital paper inches closer to reality. Past predictions that technology would eliminate the need for physical documents have proved to be wrong. Many may also wonder if digital paper will really be as sharp, flexible and portable as its advocates promise. It is rare, however, for any technology to immediately live up to its advance hype.

Nearer term, DIGITAL PAPER companies will face more traditional challenges, such as working out intellectual property, royalties, and other content issues with publishers.

APPENDIX [A]

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