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Computer Displays: Roll up, Paint on and Shrink down

Executive Summary

The relatively small windows we use as our main means of interaction with computers fall far short of the high contrast, nuanced, three-dimensional, 360 degree view the real world offers.

Researchers are working to close the gap by making larger, thinner, more flexible flat-panel displays; improving picture brightness, sharpness and contrast; making more realistic three-dimensional displays; and producing foldable electronic paper.

Many research efforts are aimed at making better components. These include thin-film silicon transistors, organic transistors, and organic light-emitting diodes that can be embedded in light, flexible plastic displays, and organic transistors and minuscule ink-like components for electronic paper.

Researchers are also looking for cheaper ways to produce screens, including literally painting screens on surfaces. In the not-so-distant future dirt cheap displays made from sheets of plastic could enable high-quality video on surfaces as diverse as books, T-shirts, and sides of buildings.

Other efforts are looking to bring to the real world a couple of future technologies previewed in movie special effects: transparent screens a la Minority Report and holographic video like that seen in Star Wars.

Several new technologies have recently matured enough to be tapped to make better displays. Nanotubes make cheap, efficient light sources for bright flat-screen displays. And arrays of very small, high-speed micromachines can now generate the millions of dots of light needed for three-dimensional displays.

What to Look For

Components and processes:

Printable organic transistors
Paint-on organic light emitting diodes
Displays made from nothing but plastic
Practical micromachine displays

Display performance:

High-contrast flat screen displays
Low-cost 10-million-pixel displays

Electronic paper:

Full-color electronic ink
Video-speed electronic ink
Fully foldable electronic paper
Inexpensive electronic paper production

3D technologies:

Practical glasses-free displays
Wider, deeper glasses-free images
Holographic video

Moving the box outside the box

Computer displays have come a long way since the large pixel, monochrome screens of 20 years ago. But the relatively small windows we use as our main means of interaction with computers still fall far short of the high contrast, nuanced, three-dimensional, 360 degree view the real world offers.

Researchers are working to close the gap by shifting the view outside the current box in several ways:

- Making displays larger and thinner
- Making them much more flexible
- Improving pictures to be finer and higher-contrast
- Increasing viewing angles
- Adding the third dimension
- Decreasing the amount of power displays require

Every type of computer display contains devices that reflect or emit dots of light, electronics that control these light sources, processors that coordinates the images, and a power source that drives the process.

Light emitters include phosphor and light-emitting diodes. Light reflectors include tiny mirrors and microscopic capsules of pigment. Control electronics range from the electron beam of boxy cathode ray tubes to the silicon thin-film transistors of more modern flat screens.

Today's display research is focused around three major efforts:

- Producing flat-panel displays that are cheaper, brighter, sharper, larger, and draw less power
- Making three-dimensional displays more realistic and practical enough to be used on the desktop
- Producing electronic paper that is as thin and portable as its namesake, that supports color, and that is fast enough to depict moving pictures

Each of these efforts involves many components. Making tomorrow's computer displays look more like the real world means finding ways to make components and manufacturing processes faster, cheaper, and more flexible.

Researchers working toward these goals are using a wide range of emerging technologies:

- Plastic transistors
- Plastic light-emitting diodes
- Carbon nanotubes
- Micromachines
- Computer-generated holograms
- Electrowetting

Cheaper, smaller, transparent

Transistors are microscopic switches that control electricity, and are most often found crammed by the millions on computer chips. They also control the electronics that produce pixels. Using them for displays means fabricating them directly on glass from films of silicon that are so thin they don't block light.

Transistors that are more efficient, cheaper and that can be built into plastic would improve today's computer displays. Researchers are working on increasing low manufacturing yields, improving transistor performance, and finding lower-temperature manufacturing processes so that thin-film transistors can be built on plastic surfaces.

There is also a major drive to make thin-film transistors out of polymers rather than silicon. These organic transistors can be made very cheaply, applied to nearly any type of surface including plastic, and can conform to curved and irregular surfaces. Because they are pliable and inexpensive to manufacture, plastic transistors promise to enable flexible computer screens, including e-paper, and reasonably priced very large screens, including billboards.

How It Works

Pixels

All displays form images from pixels, or spots of light that are small enough to blend together. Displays also must have some means of controlling the color and brightness of individual pixels. Different types of displays use different means to produce pixels and to control them.

Each pixel of the venerable cathode ray tube (CRT) display is produced by a set of three colored phosphor dots painted on the inside of the screen. The phosphor dots glow when hit by a beam of electrons. An electron beam sweeps across the inside of a cathode ray tube to illuminate the correct red, blue and green combinations at the right moment to form an image.

Liquid crystal displays (LCDs) generate pixels using tiny containers of liquid crystal that can be oriented electrically to allow light through. Each liquid crystal pixel is switched by an electric circuit, which is considerably more accurate than controlling phosphor glow using electron beams.

Plasma displays generate pixels using tiny containers filled with inert gases that form a plasma when electrified. The plasma emits ultraviolet light that excites phosphors like those used in cathode ray tubes.

Using mechanics

Another way to produce images is by manipulating light mechanically rather than electronically.
Micro opto electro mechanical systems, or MOEMS, generate pixels by moving microscopic machine parts like mirrors, shutters or strips of metal in order to transmit, block or reflect light.

Micromirror displays use computer-controlled mirrors to reflect pixels, and are found in some of today's large screen televisions and digital film projectors. Each mirrors is as small as a few tens of microns across. This type of display uses a chip that contains thousands of micromirrors that can be individually tilted to reflect light into or away from a magnifying lens.

Micromechanical diffraction gratings generate pixels using a set of six microscopic aluminum-coated semiconductor ribbons suspended above a surface. Applying a voltage to a ribbon causes it to bend down toward the surface. When all six ribbons are unbent the device acts as a mirror, and when every other ribbon is bent it diffracts, or bends, light at precise angles. Reflected light is blocked and diffracted light is directed to a display screen.

A third type of micromechanical display uses a microscopic version of the age-old shutter to generate pixels. Arrays of shutters built into computer chips can be opened and closed thousands of times a

Today's organic transistors perform as well as the amorphous silicon transistors widely used in liquid crystal displays, but fall far short of the crystalline silicon transistors used in computer chips. Plastic transistor performance is also not as consistent as that of silicon thin-film transistors.

There's a lot of potential for finding cheap ways to manufacture organic transistors.

Researchers from the University of Cambridge in England have devised a method that allows layered organic materials to be cut into individual transistors. (See "Plastic Transistors Go Vertical", page 13.)

Researchers from Lucent Technologies' Bell Laboratories have devised a simple process for stamping out plastic transistors as small as 150 nanometers long, or about twice the length of today's state-of-the-art silicon transistors. (See "Stamp Bangs Out Plastic Circuits", page 15.)

These methods could be used to manufacture transistors in three to five years.

Light-emitting diodes

One of the challenges of making very small computer screens is making them bright enough. Tiny computer displays can be mounted on eyeglasses and visors as components of wearable computers. One bright candidate is light-emitting diodes, which are simple devices that glow when electric current flows through them.

The trick to making next-generation screens from light-emitting diodes is finding materials that produce light whose wavelengths span the entire visible spectrum. Researchers are working on organic and inorganic light-emitting diodes for this purpose.

Light-emitting diodes made from the semiconductor materials used in computer chips are rugged, fast and can be manipulated using existing processes.

Researchers from Kansas State University have made tiny, very bright light-emitting diodes from a mix of the semiconductor materials gallium nitride and indium nitride, and have used the diodes to fashion a prototype microdisplay that is brighter, can be viewed from a wider angle and is more rugged than liquid crystal and organic light-emitting diode technologies. The key to making the microdisplay was finding a semiconductor that emitted the short wavelengths of blue light, which were then converted to also provide the longer visible light frequencies. (See "Chip Promises Brighter Wearable Displays", page 10.)

A group of researchers from the University of Southern California has found that a jellyfish protein can be tuned to produce the full spectrum of colors. Researchers are working to combine the molecule with metal in order to coax them to produce more light. (See "Jellyfish Protein Proves Promising Light Source", page 12.)

These technologies could be practical within two years.

Organic light-emitting diodes, like organic transistors, are potentially very cheap to manufacture and can be embedded in materials like plastic, but have historically been less efficient than those made from semiconductors. Organic light-emitting diodes are further developed than organic transistors, however, and are second to control the amount of light that passes through the chip any given point.

The key to micromachine displays is timing. In any of these three technologies, using a white light source and switching each pixel on and off at the right time produces black and white images. Video images are usually switched 24 or 30 times per second. The displays can produce grayscale images by switching more quickly. A pixel that is on only some of the time during a single video frame will appear gray. Devices that switch 240 times a second can produce eight-level grayscale images at 30 frames per second.

Color images can be produced by increasing the switching speed threefold and cycling the light source through red, green and blue. The method replicates the effect of the separate red, green and blue dots of cathode ray tube and plasma displays.

A fourth type of micromechanical display controls precise gaps between pairs mirrored surfaces to allow light of only a certain color to be reflected.

The gaps correspond to the wavelengths of the three colors the device allows through: red is about 700 nanometers, green 500 nanometers and blue 400 nanometers. A nanometer is one thousandth of a micron. When a gap is closed the device absorbs light and that area of the screen appears black. When the gap is open light of the appropriate color is reinforced and reflected. The surface of the device is coated with an iridescent material that makes the reflected color appear saturated and print-like.

Electronic ink

Making computer screens as thin as paper means working without a built-in light source. Instead of transmitting light through the screen, electronic paper reflects ambient light like ordinary paper. The lack of a light source makes it possible for electronic paper to be flexible and use little power.

The key to electronic paper is ink that reflects light and can be manipulated using electricity. Electronic ink consists of tiny amounts of substances sandwiched between thin layers of flexible material.

One prototype electronic ink consists of capsules that each contain black and white particles of pigment. A negative voltage causes the white particles in each capsule to move to the surface; a positive voltage causes the black particles to come to the surface. (See "Prototype Shows Electronic Paper Potential", page 20.)

The ink provides a contrast ratio of around 15, which rivals that of paper, and a reflectively of around 40 percent, which is brighter than many screens. It takes about a quarter of a second to refresh a page. The capsules measure as small as tens of microns across, or a few times larger than a red blood cell.

A second, very different scheme uses a sandwich of insulator, colored oil and water to produce a pixel. Because the insulator is hydrophobic, the oil resides beginning to be used in place of liquid crystals to form pixels in displays.

The combination of organic transistors and organic light-emitting diodes could make for extremely inexpensive displays and is one of the principal approaches to making flexible screens.

Reaching for Minority Report

Plastics and transparent inorganic transistor materials promise to enable see-through computer screens. The transparent screens seen in the movie Minority Report were made possible by special effects, but the real thing is on the not-to-distant horizon.

Researchers from the Tokyo Institute of Technology in Japan and the Japan Science and Technology Corporation have constructed a transistor from a transparent oxide, and researchers from Oregon State University have made a transparent transistor from zinc oxide, a cheap ingredient of suntan lotion. (See “See-Through Circuits Closer”, page 10.)

These technologies could produce transparent screens in 5 to 15 years.

Improving the contrast

One of the major limitations of today’s display screens is picture quality, and one particularly dismal aspect is a range of brightness that is far narrower than the human eye can discern.

The liquid crystal screens used in laptops, palmtops and cell phones have contrast ranges of about 300 to 1 on average, and 800 to 1 at best. Turn up the brightness of your computer screen and what you are really doing is shifting the whole range of what you see toward the brighter side.

In contrast, film has a dynamic range of around 8,000 to 1. But film also falls far short of real-life — the contrast between a bright sunny day and a moonless night, for example, is about one million to one.

Researchers from York University in Canada, the University of British Columbia in Canada, and Stony Brook Technologies Inc. have found a way to increase the dynamic range of liquid crystal displays to around 90,000 to 1. (See “Display Brighter Than Film”, page 15.)

It will take at least a year to develop this technology for practical use.

Sharpening the image

Another way to improve computer screens is to find ways to produce more dots of color per square inch. A typical 17-inch display, for instance, has a top resolution of 1,280 by 1024, or 94 pixels per square inch. Today’s typical laser printers, in contrast, print 600 dots per inch.

Researchers from IBM have shown that a perpendicular ion beam can be used to align liquid crystals, and have used the process to build a 22-inch 3,840- by 2,400-pixel screen, which works out to about 200 pixels per square inch. (See “Process Promises Better

between the insulator and water. When electric current is applied to a portion of the insulator, however, that portion of the surface becomes hydrophilic, and as water is drawn to the surface the colored oil is shunted to one corner, exposing the white background.

The method also has a contrast ratio of 15, and a 13 millisecond refresh rate, which is fast enough to display high-quality video.

The system generates color images using pixels generated by a set three sandwiches that each contain two layers of oil and a color filter, and employ the cyan, magenta and yellow subtractive color scheme used in printing. Displays usually mix red, green and blue. Having each pixel area able to represent any of the three primary colors boosts the second ink scheme’s reflectively to 67 percent, compared to 40 percent for standard liquid crystal displays.

Who to Watch

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LCD Production”, page 16.) IBM is selling a commercial version of the screen.

Most color screen technologies use separate devices to produce each of the three pixel colors that mix to form millions of hues. Devices that produce all three colors in the same space would increase brightness and resolution. Researchers from the University of California at Los Angeles have produced three colors in the space of a single pixel by stacking three light-emitting diodes and using a tiny plastic pyramid to direct light from all three. (See “Pyramid Pixels Promise Sharp Pictures”, page 11.)

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Flat-panel evolution

Flat-panel displays are used in all portable and handheld devices and are slowly but steadily replacing cathode ray tubes (CRTs) on the desktop. Most of today’s flat-panel displays are liquid crystal, though many larger displays use plasma technology.

Liquid crystal displays are made by sandwiching liquid crystals between sheets of glass. Liquid crystals are long molecules that are typically arrayed randomly, but line up neatly in the presence of an electric field. Polarized light passes through aligned liquid crystal molecules and is blocked by non-aligned crystals.

Plasma displays electrify gas to generate plasma, which emits ultraviolet light that in turn energizes phosphors on a screen. Plasma displays require more power than other flat-panel technologies and have larger pixels. The current generation of the technology is generally used for large, wall-mounted video displays.

Research related to flat-panel displays is focused on lowering the cost of producing the thin-film transistors that make up the displays’ control circuits, and improving the performance and yields of organic transistors and light-emitting diodes that can be integrated into transparent and flexible materials.

Other flat-panel display research efforts fall into two categories: cathode-ray-tubes-on-a-chip and arrays of movable microdevices.

Chips and nanotubes

Electroluminescent, or field emission, displays are similar in principle to cathode ray tubes but are made from semiconductor chips rather than vacuum tubes and electron guns. Like cathode ray tubes, electroluminescent displays have a glass surface coated with phosphors. The source of electrons for each pixel is microscopic metal or semiconductor cones mounted on a surface separated from the phosphors by a small gap. Electroluminescent displays are as bright as cathode ray tubes but draw much less power.

The technology has been under development since the 1980s but has only recently shown promise for making cost-effective, full-color displays. Electroluminescent displays are commonly used in the emerging field of wearable microdisplays because their simple design — no light sources or moving parts — makes them durable and scalable to small sizes.

The field gained momentum after the 1995 discovery that carbon nanotubes make good electron emitters.

Researchers from Northwestern University have produced a promising prototype electroluminescent display that uses carbon nanotubes. The nanotubes portion of the screen proved easy to make — the researchers chopped up a batch of nanotubes, mixed them with paste and painted them on the back of the screen. Each pixel is produced by many nanotubes, making for durable displays, and the method can potentially produce resolutions higher than the eye can detect — one million by one million pixels per square inch. (See “Nanotubes Paint Clear Picture”, page 17.)

The technology could be ready for practical use in two years.

Microscopic machinery

Micromachines, specifically micro opto electro mechanical systems (MOEMS), are a longer-term prospect for flat-panel displays. Large arrays of very small, high-speed micromachines can generate the millions of dots of light, or pixels, that make up the display. The challenge is coming up with designs that are mechanically sturdy, use ambient light and yield bright, full-color images.

One approach, developed by Massachusetts Institute of Technology spinoff Iridigm Display Corporation, uses tiny gaps to reflect specific colors through iridescent materials. (See How It Works, page 2.)

Other micromechanical display technologies fall between flat panels and CRTs in bulkiness. Digital micromirror devices are currently used in some large-screen video displays, particularly home theater screens. Related technologies, including micromechanical shutters and micromechanical diffraction gratings, are in various stages of commercialization. The light sources and lenses involved in these technologies require an enclosure depth in the neighborhood of a foot and a half.

He took his screen out of his pocket and unfolded it...

The ultimate in flat computer displays is electronic paper — a screen so thin and flexible you can fold it. Today's prototypes aren't as paperlike as e-paper should be, but they're getting close.

E-paper pixels are made from ink rather than light. (See How It Works, page 2.) The technology promises to provide small, light, low-power computer screens for portable and wearable devices. Because it could be as convenient to carry around as paper, but is also reusable, e-paper has the potential to eventually shift the ways people buy and consume printed materials.

One key to e-paper is electronic ink that produces a resolution and contrast comparable to those of traditional ink on paper, supports color, can be switched like a computer screen, and can be switched fast enough for video.

The second key is control electronics that are flexible enough to be embedded in a foldable screen.

Research efforts aimed at making prototypes thinner and more flexible are focused on making faster plastic transistors and combining them with other plastic components on backings that are made only of plastic.

Research efforts aimed at improving electronic ink are focused on adding color and speed. Refresh rates of one-quarter second are enough to present printed pages. Video requires refresh rates of at least 15 times per second, and full motion video 30 frames per second.

Researchers from E Ink Corporation, using an electronic ink scheme first demonstrated by Massachusetts Institute of Technology researchers, have produced a high-resolution electronic display that is 0.3 mm thick — or about four times thicker than a piece of printer paper. The electronic ink consists of barely visible capsules filled with black and white pigments. (See "Flexible Display Slims Down", page 18.)

Researchers from Philips Research in the Netherlands have demonstrated a very different ink scheme that switches fast enough to display video and has the potential to produce bright, full-color images. The Philips electronic ink is made from oil and water, and is controlled by electrowetting, which involves using electricity to change a material from hydrophobic to hydrophilic.

University of Rochester researchers have found a way to manipulate particles of polymer cholesteric liquid crystal that are about half the diameter of a human hair and are suspended in silicone oil. Depending on the angle, the flakes appear shiny or black. (See "Flipping Flakes Change Color", page 23.)

Several research teams are working on making traditional electronic components from organic materials that are flexible enough to be embedded in sheets of plastic to make electronic displays. The challenges are finding ways to form organic components that are small enough and fast enough, and coming up with reliable methods of embedding them into thin plastic screens. (See "E-Paper Coming into View", page 19; "Flexible Displays Come into View", page 22.)

Grayscale e-paper using electronic ink schemes could be practical within a few years. Color e-paper could be practical in about five years. E-paper made from organic electronics embedded in plastic is 5 to 10 years away.

Paint-on screens

Key to next-generation computer displays — especially large ones — are cheap, reliable assembly processes. Today's liquid crystal displays are produced by sandwiching liquid crystals between carefully positioned sheets of glass.

Researchers are looking to find much simpler assembly processes, including ways to print screens onto large surfaces, and pixels that self-assemble. Assembly processes are also key to making screens thin and flexible enough to fold.

A team of researchers in Germany has developed a fast, simple method for producing organic light-emitting diode displays that have resolutions comparable to today's screens. The method, which involves spreading a liquid polymer mixture on a surface and exposing it to small spots of ultraviolet light, has the potential to produce even higher resolution displays. (See “Painted LEDs Make Screen”, page 25.)

Researchers from Philips Research Laboratories and Endhoven University of Technology in the Netherlands have come up with a method for layering liquid crystals on a single surface of glass, plastic or silicon. Such displays can be thinner than half a centimeter. (See “Plastic Makes Promises Big Displays”, page 24.)

Researchers from Siemens Corporation in Germany have found a way to efficiently spread polymers that form organic light-emitting diodes onto a large surface. (See “T-shirt Technique Turns out Flat Screens”, page 26.)

These techniques can be ready for practical use in less than two years.

Screens that construct themselves

Another possibility is a concept that’s coming on strong in nanotechnology research: self-assembly. It’s going to be a long time, if ever, before computer displays or even their components are assembled molecule by molecule. But self-assembly can also work at larger scales.

Harvard University researchers have made a prototype display of a cylinder of 113 light-emitting diodes four millimeters across that was assembled simply by shaking a vial of liquid containing electronic components and copper wires. (See “Shake and Serve”, page 27.)

Self-assembly techniques such as these could be used to manufacture displays in 5 to 10 years.

Making 3D deeper, wider and brighter

While there’s a lot of research going into making better two-dimensional displays, many other efforts are aimed at making display output more three-dimensional. People have been making computer-generated three-dimensional images for a long time; many techniques have emerged over the past four decades. Today researchers are working to improve three-dimensional images and make them practical enough to warrant common use.

These technologies have the potential to enable better data visualization in applications like medical imaging, more realistic virtual reality systems, three-dimensional movies and television, and three-dimensional billboards.

The major challenges to making three-dimensional displays are handling the increased amount of information that makes up a three-dimensional picture, making the pictures look brighter and deeper, widening the angle from which they can be viewed, and reducing system costs. There is also the issue of glasses.

Three-dimensional technologies fall into two categories — those that require special glasses, and those that do not.

Stereoscopic technologies require glasses that make the view through each eye different in order to fool the brain into perceiving depth. This technology showed up in movie theaters in the 1950s, and the glasses made for nifty group shots, but they are a limitation.

A researcher from the University of Toronto has found a way to turn a standard laptop screen into a 3D display using kitchen cellophane and polarizing glasses or a polarizer hung in front of the screen. (See “Cellophane Turns LCDs 3D”, page 30.)

Lose the glasses

The many autostereoscopic methods under development allow for three-dimensional viewing without the glasses. There are two distinct types of autostereoscopic viewing methods: screens that trick the brain into perceiving three-dimensional images by directing different views to each eye, and volumetric displays whose projected images actually occupy space.

Three-dimensional screen technologies include lenticular displays, parallax barrier displays, and integral imaging. Volumetric technologies include vibrating mirrors, rotating mirrors, laser-illuminated gases and holographic displays.

Lenticular displays use a series of vertical convex lenses to send light in different directions. This is an old technology based on on the same technique used to make three-dimensional baseball trading cards.

Parallax barrier displays use movable barriers or slits to control the timing of light emitted by a screen or projector. This type of display is susceptible to wear and breakdown, but advances in micromechanical engineering and liquid crystal displays promise to improve the technology.

Integral imaging displays use arrays of micro lenses to control where light falls. This is an old idea borrowed from nature and first used nearly a century ago in still photography. Many insect eyes are made up of clustered lenses. Advances in engineering have made it possible to make tiny, precisely positioned lens arrays. This has increased research interest in using the technology for three-dimensional displays.

Seoul National University have devised a way to widen horizontal and vertical viewing angles in integral imaging systems from 20 degrees to about 40 degrees. The researchers' system uses a pair of overlapping displays, one oriented horizontally and the other vertically, and switches between them more rapidly than the eye can detect. (See "3D Display Goes Vertical", page 28.)

Right there in the room with you

Volumetric technologies come in two forms, those that require a screen and those that project images into a volume of air a la Princess Lea's recorded plea to Obi-Wan Kenobi in the 1977 movie Star Wars.

One type of volumetric screen involves projecting a fast, synchronized sequence of images onto a rapidly rotating mirror. Another involves projecting images onto a vibrating mirror. In both cases three-dimensional images are broken down into a series of planes projected sequentially, but rapidly enough that the eye perceives them all at once. These displays involve bulky equipment and present poor quality images in a limited field of view, and there's little hope for improving them.

Look Ma, no screen

The greatest potential, and the biggest challenge, is in projecting three-dimensional images into space to provide a nearly unlimited field of view.

Researchers have made devices that use lasers to rapidly illuminate points in a volume of gas or gel. Current prototypes produce low-resolution monochromatic images.

High-quality volumetric displays are probably a decade or more away because they require a lot of processing power and precise optics. Compute power is needed to handle the huge amounts of information in three-dimensional images, and advanced optics are required to precisely position points of light in space and time. Holograms, which are the captured interference patterns of a pair of light beams, are likely to play a part in any useful volumetric display because they inherently contain spatial information.

Researchers from the University of Texas have cut the computer resources needed to present three-dimensional video by using a micromirror device as a virtual holographic film for computer-generated holograms. Being able to rapidly change the micromirrors also makes holographic video more practical. (See "3D Holo video arrives ", page 29.)

Applications like three-dimensional heads-up displays and billboards are likely to be practical within two years; live three-dimensional television is at least a decade away.

Putting it all together

Researchers are also working on making more useful types of displays.

Scientists from the Swiss Federal Institute of Technology have come up with a way to put the user into a three-dimensional, life size image in real-time. The key to the system is a way to switch a U-shaped glass screen between opaque and clear modes faster than the eye can see to allow cameras outside the screen to capture the user's three-dimensional image and place it on-screen. (See "VR System Grabs 3D Video ", page 31.)

There are also research efforts toward alternative ways of presenting data.

Georgia Institute of Technology researchers have written software that allows a display to present a picture embedded with information that is legible at a glance to users who know how the system is set up. (See "Artful Displays Track Data ", page 32.)

And many teams of researchers are working on technologies that will make larger displays more practical.

Researchers from Sandia National Laboratories have built a 10-by-13-foot screen using a parallel processing scheme that ties together 64 computer graphics cards and 16 projectors to render 20-million-pixel images for scientific visualization. (See "Teamed Computers Drive Big Display ", page 33.)

A bigger, brighter, cheaper future

Computer displays are relatively mundane, yet they encompass a remarkable range of technologies. Research into computer displays ranges from the minutiae of making pictures and words clearer, to the engineering challenges of making displays convenient to carry around, to the unfolding science of visually replicating the world.

In particular, the field of organic electronics — a recent blending of materials science and electrical engineering — is blazing a trail toward a not-so-distant future when dirt cheap displays made from sheets of plastic show high-quality video on surfaces as diverse as a book, a T-shirt, and the side of a building.

At the same time, the pale, low-contrast images we've grown accustomed to seeing on computer screens will give way to bright, rich pictures that rival film. What's not clear is which of myriad emerging display technologies will carry the day, and what trade-offs will be made along the way.

Recent Key Developments

Advances in components:

- A semiconductor nanowire thin film transistor, developed by Nanosys, Inc., September, 2003
- A brighter, thinner LCD for portable devices, developed by Philips Research, May, 2003
- A solid-state emissive device, aka cathode-ray-tube-on-a-chip, developed by Tokyo University of Agriculture and Technology, September, 2002
- Transistors made from transparent semiconductor materials (See-through Circuits Closer, page 10)
- A small blue semiconductor LED (Chip Promises Brighter Wearable Displays, page 10)
- A pyramid-shaped three-LED color pixel (Pyramid Pixels Promise Sharp Pictures, page 11)
- A protein from jellyfish for use in organic LEDs (Jellyfish Protein Proves Promising Light Source, page 12)

Advances in plastic electronics:

- A method for making smaller plastic transistors (Plastic Transistors Go Vertical, page 13)
- A process for stamping out plastic transistors (Stamp Bangs out Plastic Circuits, page 15)
- A more efficient hybrid quantum dot-polymer light-emitting diode, developed by MIT, December, 2002
- Plastic integrated circuits, developed by Siemens AG, August, 2002
- A more efficient plastic semiconductor, developed by Xerox Research Center, Canada, December, 2002

Advances in display performance:

- An ultra bright, ultrahigh contrast display (Display Brighter Than Film, page 15)
- A more efficient method for aligning liquid crystals that yields high-resolution screens (Process Promises Better LCD Production, page 16)
- A bright, ultrahigh-resolution display made from nanotube paste (Nanotubes Paint Clear Picture, page 17)

Advances in electronic paper:

- Video-speed color electronic ink, developed by Philips Research, September, 2003
- A flexible display only four times thicker than a sheet of paper (Flexible Displays Slims down, page 18)
- Flexible display circuitry capable of displaying grayscale at video speeds (E-paper Coming into View, page 19)
- A flexible black-and-white display (Prototype Shows Electronic Paper Potential, page 20)
- Flexible display circuitry (Flexible Displays Come into View, page 22)
- Liquid crystal particles that align in order to change color (Flipping Flakes Change Color, page 23)

Advances in assembly processes:

- A method for making liquid crystal displays on single surfaces rather than sandwiched between two (Plastic Mix Promises Big Displays, page 24)
- A simple process for making large, plastic LED-based displays (Painted LEDs Make Screen, page 25)
- A method for screen-printing plastic LEDs onto a surface (T-shirt Technique Turns out Flat Screens, page 26)
- A self-assembly process for making curved LED-based displays (Shake and Serve, page 27)

Advances in 3D technologies:

- A glasses-free 3D display with a greater depth of focus (3D Display Goes Deeper, page 28)
- A glasses-free 3D display with a greater field of view (3D Display Goes Vertical, page 28)
- A glasses-free 3D display with a wider field of view (3D Display Widens View, page 28)
- A three-dimensional holographic display (3D Holo Video Arrives, page 29)
- A method for using ordinary cellophane to turn LCD screens into 3D displays (Cellophane Turns LCDs 3D, page 30)
- A glasses-free 3D display with a greater field of view, developed by the University of Connecticut, July, 2002

Advances in display types:

- A display that projects images into the air, developed by IO_2 Technology, August, 2003
- A three-panel wall-sized immersive display (VR System Grabs 3D Video, page 31)
- A wall-mounted flat screen peripheral awareness display (Artful Displays Track Data, page 32)
- A wall-sized, 20-million-pixel display (Teamed Computers Drive Big Display, page 33)

Components

See-Through Circuits Closer

June 18/25, 2003

The transparent computer displays featured in the film Minority Report were made possible by special effects, but real-world transparent electronics are on the horizon.

Researchers from the Tokyo Institute of Technology (TITech) in Japan and Japan Science and Technology Corporation (JST) have altered a type of transparent oxide so that it conducts electricity, and have constructed a transistor from the material. And Oregon State University researchers have made a transparent transistor from zinc oxide, a common, cheap ingredient of suntan lotion.

Source: Oregon State University

An array of transparent transistors, visible as a green tint, covers the top three-quarters of this penny.

The two transistors are significant improvements over the first transparent transistors made in 1996. Plastic transparent transistors have been under development for several years for use in electronic paper and flexible displays. In contrast, the TITech/JST and Oregon State transparent transistors are made from sturdier inorganic materials.

The TITech/JST transistor is very efficient, but expensive to produce. The Oregon State transistor could increase display efficiency and brightness by 10 to 20 percent, according to the researchers.

Inorganic transparent transistors could find practical use in two to five years, and be used for transparent displays in 5 to 15 years, according to the researchers. The TITech/JST work appeared in the May 23, 2003 issue of Science. The Oregon State work appeared in the February 3, 2003 issue of *Applied Physics Letters*.

TRN

Chip Promises Brighter Wearable Displays

By Eric Smalley, Technology Research News
February 28, 2001

Tiny computer displays that can be mounted on eyeglasses and visors would be brighter, faster and sturdier if they could be made out of semiconductor chips rather than the liquid crystal and organic materials currently used.

It's hard to coax light out of silicon, however, and the semiconductor has to produce the right kind of light. Some common semiconductors like gallium arsenide emit red light, which limits their usefulness. The impetus to find an appropriate semiconductor has also been limited because liquid crystal displays and light-emitting diodes are generally cheaper than semiconductors.

Researchers at Kansas State University have come up with a viable semiconductor alternative by making tiny light-emitting diodes (LEDs) out of the semiconductor III-nitride.

The researchers used them to fashion a prototype microdisplay that is brighter and has a wider viewing angle than microdisplays based on today's technology.

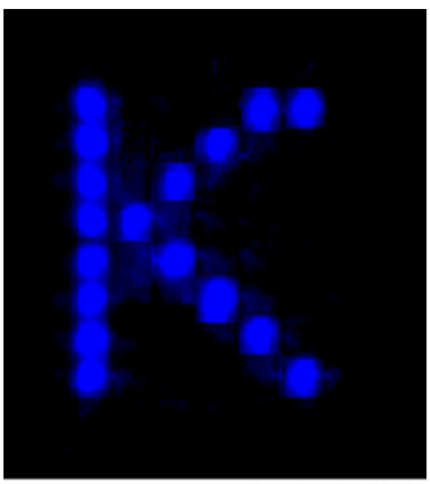
Semiconductor-based microdisplays are also inherently more shock-resistant and can operate in a wider temperature range than liquid crystal and organic LED microdisplays, making them more appropriate for the military, industrial and emergency services applications the displays are largely intended for.

The key to making full-color semiconductor displays is that III-nitride emits blue light, said Jingyu Lin, an associate professor of physics at Kansas State University. Because blue light is at the high end of the visible light spectrum it can be converted to lower frequencies.

"We can downconvert some of the pixels for example to red, some of them to green, so we can actually get full color from our semiconductor," said Lin.

The prototype display is an array of 100 pixels that are each 12 microns in diameter. The display measures half a millimeter by half a millimeter. A practical microdisplay would probably need an array of 600 by 500 pixels and would likely measure about an inch by an inch, said Lin.

The device works much faster than either liquid crystal displays or organic LEDs, said Lin. While liquid crystal displays can be turned on and off on the order of milliseconds and organic LEDs in microseconds, "semiconductor is intrinsically below the nanosecond scale," she said.



Source: Kansas State University

Each pixel in this microdisplay is about 2.5 times the diameter of a red blood cell. The particular semiconductor material that makes up the pixels emits blue light.

This could make the researchers' III-nitride LEDs a good light source for digital communications devices that use ultrafast pulses of light to transmit large amounts of data over fiber-optic lines, she said.

The technology could be scaled up to make a practical microdisplay in a year, said Lin. "The material technology is all there," she said. The main challenge is making a display design that can be mass-produced, she said. "Each one of [the pixels in the prototype] has a wire attached to it," said Lin. "That's how we [power] them, which obviously won't be a smart way if you have a lot of them."

Lin's research colleagues were Hongxing Jiang, Sixuan Jin, Jing Li and Jagat Shakya of Kansas State University. They published the research in the February 26, 2001 issue of *Applied Physics Letters*. The research was funded by the Army Research Office, the Ballistic Missile Defense Organization, the National Science Foundation, the Department of Energy and the Office of Naval Research.

Timeline: 1 year
Funding: Government
TRN Categories: Semiconductors and Materials
Story Type: News
Related Elements: Technical paper, "III-Nitride Blue Microdisplays," Applied Physics Letters, February 26, 2001

TRN

Pyramid Pixels Promise Sharp Pictures

By Kimberly Patch, Technology Research News
October 18, 2000

Pyramids may be the key to sharper, cheaper electronic displays.

The color flatscreens used in electronic devices like laptops, cellphones and miniature television screens are made up of many tiny red, green and blue light emitting diodes (LED's) that produce the tiny dots, or pixels of light that make up the picture. One focus of flatscreen research has been cramming more pixels on the screen, because this makes for a higher resolution picture.

Researchers from the University of California at Los Angeles have come up with a different angle on the problem. They have devised a way to coax light from three colored LED's through a single, tiny plastic pyramid. Effectively, the three types of pixels are stacked into one space, tripling resolution in one fell swoop.

"We built the red, green and blue [LED's] in a vertical structure" said Yang Yang, an associate professor at UCLA. "They mix the light to give you any color that you want, [and] they do not take the real estate" of separate LED's, he said.

Because the pyramids mix light at the pixel level, a screen made with this technology will continue to produce a range of colors close up. In contrast, taking a magnifying glass to a conventional screen will reveal the separate red, blue, and green dots that give the illusion of many colors.

The pyramid pixel method may also prove cheaper than traditional flatscreens because it does not require shadow masking. Today's LED displays are manufactured using sheets of metal containing many tiny holes to guide the separate dots of red, green and blue organic materials as they are deposited on the screen. "The holes are so small it requires

[a] very thin metal sheet for the shadow mask. It's not easy to fabricate a large [shadow mask and] it's not easy to maintain," said Yang.

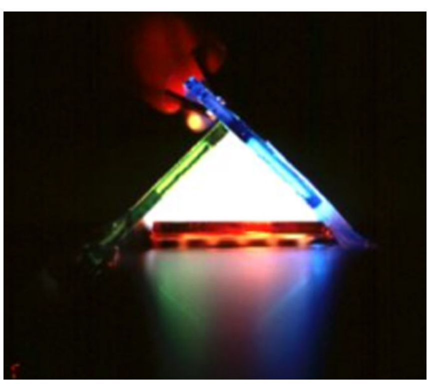
In practice, the pyramid shape acts like its own shadow mask, shielding the different color LED's from each other.

"Permanent shadow masks have been used ... but not in the way Yang has been using them here," said Mark Thompson, a chemistry professor at the University of Southern California. "I don't know that anybody else has looked at building structures and using those as sort of in situ shadow masks—using the shadowing of the pyramid," Thompson said. "It's an interesting approach that could have a lot of interesting applications," he added.

Some of the pyramid pixel's potential advantages are also shared by a pixel stacking scheme under development by Universal Display Corp. Thompson contributed to the basic research behind that scheme, which literally stacks red, blue, and green elements like pancakes into one pixel using a standard manufacturing process that includes shadow masking. The stacked pixels emit mixed light that changes color as the the ratio of currents in the three pixels is varied.

Like the pyramids, the stacked approach produces true color pixels that are effectively higher resolution and can be looked at closely without breaking up. The tricky part of the pancake pixel scheme was working out how to connect all the pixel elements, something Yang has not yet reported on, said Thompson.

In theory, the pyramid pixel displays could cost 30 percent less to manufacture then screens that use sheets of metal for shadow masking, Yang said. The manufacturing process for depositing the pyramid pixels has yet to be worked out, but it will be similar to a process used by a type of 3M film, Yang said.



Source: UCLA

This pyramid pixel prototype is glowing with white light that is a mix of the light from its red, green and blue LEDs.

Yang has implemented his scheme in a prototype pyramid about ten times the size needed. The next step is to shrink the prototype down to about 100 microns, he said.

According to Yang, the technology could be ready for practical use in about two years.

The pyramid pixel research was funded by UCLA and by a corporate partner who did not want to be named. Yang Yang's research partner was Shun-Chi Chang, also from UCLA. They published a technical paper on their research in the August 14, 2000 issue of Applied Physics Letters.

The research behind Universal Display's stacked pixel scheme was published in *Science* June 27, 1997 and *Applied Physics Letters*, November 11, 1996.

Timeline: 2 years
Funding: Corporate, University
TRN Categories: Semiconductors and Materials
Story Type: News
Related Elements: Technical paper, "Pyramid-Shaped Pixels for Full-Color Organic Emissive Displays," Applied Physics Letters, August 14, 2000; Technical paper "Three Color Tunable Organic Light Emitting Devices," Science, June 27, 1997; Technical paper "Color-tunable organic light-emitting devices," Applied Physics Letters November 11, 1996

Jellyfish Protein Proves Promising Light Source

By Kimberly Patch, Technology Research News
January 24, 2001

If in several years you find yourself praising the screen readability and long battery life of your nifty new PDA, you may have the jellyfish to thank.

A group of researchers is working with a fluorescent protein, or chromophore found in jellyfish in order to create better materials for LEDs.

Most commercial LEDs use semiconductors like gallium arsenide and indium phosphide, which glow when electric current flows through them. Organic, or carbon based materials, however, are potentially easier and cheaper to manufacture.

The few used today in commercial applications, though, are not particularly efficient. They are generally used only in applications like cellphones and car stereo displays where display power use is not a large issue.

The jellyfish protein is one of many organic chemicals that researchers are trying to coax into forms that will enable cheaper, more efficient LEDs that span the full color spectrum.

The jellyfish protein is a cleverly put together molecule, said Mark Thompson, a chemistry professor at the University of Southern California. "The structure of the protein itself is a barrel like structure and the middle of the barrel is the emitter."

Because the part of the molecule that emits light is contained within the base molecule of the protein, changing the molecule in order to tune the color doesn't affect the emitter, said Thompson. "The thing that's neat about it is what were doing to tune color is just adding appendages to the outside the molecule. We can go through the whole visible spectrum with the same core—the same central part of the molecule," he said.

This allows different aspects of the molecule, like the amount of energy needed to produce light or the amount of time the light lasts, to be changed, or tuned independently of the changes made to tune color, Thompson said.

Next, the researchers plan to subject the jellyfish chromophores to a process they have used before with other organic proteins. "We want to try to take our jellyfish chromophores, couple them with heavy metals— anything in the bottom row of the periodic table is fair game—and use the heavy metal to harvest [both] triplets and singlets in the device [in order to] get tremendously more light," said Thompson.

A singlet excited state involves one of a pair of electrons jumping to a higher orbital around an atom's nucleus, spinning in the opposite direction of the one that stays behind. In a triplet excited state, the separated pair of electrons spin in parallel.

These states produce light when an electron jumps back to a lower orbital, releasing energy in the form of a photon.

In the electroluminescence process one-fourth of the current passing through a device leads to a singlet excited state, or fluorescence, and the other three-fourths lead to triplets, which can potentially phosphoresce.

The trouble is, the triplet reaction does not produce light in the jellyfish protein, said Thompson.

"Triplets... cannot excite this molecule," he said.

This is because in the jellyfish protein, as in many organic molecules, electrons in the triplet excited state jump to another molecule rather than returning to the lower orbital and emitting a photon. "Most molecules in their triplet excited state... find some way to dump energy that is not making a photon," said Thompson.

Adding heavy metals to the chromophore molecules allows the molecule to produce light from both singlet and triplet reactions because the heavier atoms affect the spin of electrons, making it possible for the triplet excited state electrons to jump back by producing a photon, said Thompson.

It is difficult to say how useful the jellyfish protein may or may not turn out to be, said Lewis Rothberg, a chemistry professor at Rochester University. "It is a very long way from finding an emitter to making it transport charge and emit in the solid state for tens of thousands of hours. Any new class of compounds, of course, might turn out to be better than what is out there but a large number have been tried pretty thoroughly."

The strategy of incorporating heavy atoms is not a new one, but it has definite promise since it addresses the very real problem of the triplet state not producing light, Rothberg added.

If all goes well, the jellyfish chromophores could be ready to be used in LEDs "in potentially a couple of years. It just depends on whether we can get the metal incorporated or not," said Thompson.

Thompson's research colleagues were Y. You, Y. He, P. E. Burroughs, S. R. Forrest and N. A. Petasis. They published the research in the December 1, 2000 issue of *Advanced Materials*. The research was funded by Universal Display Corp., the Defense Advanced Research Projects Agency (DARPA) and the National Science Foundation (NSF).

Timeline: 2 years
Funding: Corporate, Government
TRN Categories: Semiconductors and Materials; Optical Computing, Optoelectronics and Photonics
Story Type: News
Related Elements: Technical paper, "Fluorophores Related to the Green Fluorescent Protein and Their Use in Optoelectronic Devices," Advanced Materials, December 1, 2000

TRN

Plastic electronics

Plastic Transistors Go Vertical

By Kimberly Patch, Technology Research News
June 4/11, 2003

Silicon transistors have proven to be extraordinarily useful—they are the nerve cells in the brains of desktop computers, laptops, handhelds and the computers embedded in everything from cars to watches.

But even though electronics have steadily grown cheaper, most researchers agree that it would be difficult to get the cost of even a simple silicon chip below 75 or 50 cents due to the cost of manufacturing silicon, which involves cleanrooms and etching processes.

At the same time, there are clear markets for cheaper electronics. Put a computer chip on every item in the grocery store, and checkout and inventory would become fast and automatic.

Inexpensive transistors can be made by printing organic polymer, or plastic, onto a surface with an inkjet printer rather than etching the devices into silicon, but today's plastic transistors are relatively large and therefore inefficient.

Researchers from the University of Cambridge in England have brought inexpensive, practical organic transistors a step closer to your grocery cart by devising a pair of processes that form small, vertical transistors from layers of printed polymer.

The processes could be used to print low-cost electronics onto flexible surfaces like plastic, leading to electronic tags that cost less than five cents, said Henning Sirringhaus, a reader in physics at the University of Cambridge. It could also enable very large active matrix display screens, he said. "If you can make electronics cheaply over large areas then you can do things that are not possible today," he said.

A transistor consists of source and drain electrodes that carry current into and out of a channel, and a control electrode that regulates the flow of current to turn the device on and off.

The trick to making small, efficient transistors is defining a clear channel between the source and drain electrodes. The smaller the channel, the more efficient the transistor.

One way to do this is to make the transistors vertically by stacking three layers of materials: an insulator, or channel, layer sandwiched between source and drain electrode layers. Using this method, the researchers were able to define a channel length as small as 0.7 microns, which is a little less than the diameter of an E. Coli bacteria. The transistor channel length in a Pentium 4 chip is around 0.1 microns.

Using the layering method, however, requires that layered materials be cut into individual transistors and a control electrode be added to each transistor.

Silicon transistors can be made this way by etching the layers with a beam of ions, but etching does not work well with polymers. Polymers break down under etching conditions, and layers of different types of polymer are etched away at different rates, yielding a corrugated surface rather than the requisite smooth sidewall, said Sirringhaus.

The researchers discovered that they could separate organic transistors by pressing a wedge into the polymer layers so that the layers were pressed apart sideways rather than smeared downwards, said Sirringhaus. "I compare this to... black forest tarts—they have layers of chocolate, layers of cream and layers of cherry. What we were trying to do is cut a black forest tart without getting cherries into the chocolate [in order to] maintain the integrity of that multilayer structure," he said.

The researchers first used the method to cut a transistor channel in a single layer of polymer to make a horizontal organic transistor. It worked well enough that they attempted to use the method with several layers, Sirringhaus said. "The surprise was that we got that relatively crude... approach to give such beautiful, well-defined vertical sidewalls," he said.

The process could eventually be used with even more complex multilayer structures, said Sirringhaus.

The method is compatible with the printing process, said Sirringhaus. "All you need to do is use printing to define the coarse features of the electrodes, and then use the embossing step to define submicron [gaps] and it's all compatible with competitive manufacturing techniques," he said.

For the vertical transistors to be practical, however, the researchers needed a way to add control electrodes that are the proper size. Oversize control electrodes slow down the electronics. The researchers used the vertical transistor method to make prototype transistors with 5-micron channel lengths, but they could not use the printing process to add a feature less than sixty microns in size because there's a minimum size droplet the printer can handle. "That is a large overlap. Ideally, if you have a 5-micron channel you would also like to have a 5- or 6- or 7-micron-wide gate electrode," Sirringhaus said.

The researchers solved the problem by taking advantage of a groove that is an artifact of the cutting method, said Sirringhaus. "The location of the topographic groove— that's where the channel is," he said. "The groove can be very narrow, so you can print a large inkjet droplet and all the ink is sucked into that narrow groove. That's a way of self-aligning the gate electrode."

The small channel length and the small, well-aligned gate electrode could produce circuits that are nearly two orders of magnitude faster than existing organic circuits, said Sirringhaus. The researchers have not yet tested the transistors in circuits.

The researchers have found a creative way to fabricate a short transistor channel, and the method is an advance in one step of device fabrication, said Sigurd Wagner, a professor of electrical engineering at Princeton University. The technique is novel because it combines two innovations, Wagner said. "It uses embossing, which in turn is enabled by employing a plastic substrate," he said.

The method is imaginative, and is a step forward in finding ways to produce high-resolution plastic circuits for flexible displays and other systems, said John Rogers, a researcher at Lucent Technologies Bell Labs. "This nano cutting approach, together with... stamping, molding and imprinting techniques that have been previously demonstrated, constitute a... toolkit of methods for building plastic electronic circuits," he said.

This type of work could yield flexible paper-like displays, and ultra low-cost sensors and ID tags "that have the potential to revolutionize the way that we think about consumer electronics," said Rogers.

The next step in commercializing the technology is testing how manufacturable the technique is, said Sirringhaus. This will fall to Cambridge startup company Plastic Logic, formed to commercialize the inkjet printing of transistor technology, Sirringhaus said. "We will need to see how well the technique compares in terms of manufacturing, yields, reliability—those are all things that we don't do at the University," he said.

The method could be used to produce inexpensive plastic electronics in two to five years, according to Sirringhaus.

Sirringhaus's research colleagues were Natalie Stutzman and Richard H. Friend. The work appeared in the March 21, 2003 issue of *Science*. The research was funded by the Swiss National Science Foundation and Cambridge **University.**

Timeline: 2-5 years
Funding: Government, University

Categories: Integrated Circuits; Materials Science and Engineering
Story Type: News
Related Elements: Technical paper, “Self-Aligned, Vertical-Channel Polymer Field-Effect Transistors,” Science, March 21, 2003

Stamp Bangs out Plastic Circuits

February 26/March 5, 2003

Today’s transistors are etched from silicon wafers in a multi-step process that involves laser beams, chemicals and clean rooms. A simpler process would make for cheaper computer chips, and a gentler process would allow for transistors of different materials.

Researchers from Lucent Technologies’ Bell Laboratories have found a way to stamp out plastic transistors that range from 150 nanometers to 250 nanometers long, which is around twice the size of today’s commercial silicon transistors. A nanometer is one millionth of a millimeter.

The method could eventually be used to stamp out plastic circuits for uses like flexible electronic displays.

The stamping process is simple and doesn’t require clean rooms, and making the stamps is relatively simple as well. The stamps are cast silicone rubber covered with metal.

The stamping method can also be used to add electrical contacts to films of organic material that are one molecule thick. The method promises to make it easier to investigate the electrical properties of organic materials.

The stamping process could find practical use in three to five years, according to the researchers. The work appeared in the February 3, 2003 issue of *Applied Physics Letters*.

Display performance

Display Brighter Than Film

September 10/17, 2003
Kimberly Patch, Technology Research News

The human eye is capable of seeing the whole range of brightness the sun’s proximity brings to the earth—nearly seven orders of magnitude, or 10 million to 1. The contrast between a bright sunny day and a moonless night, for example, is around a million to one.

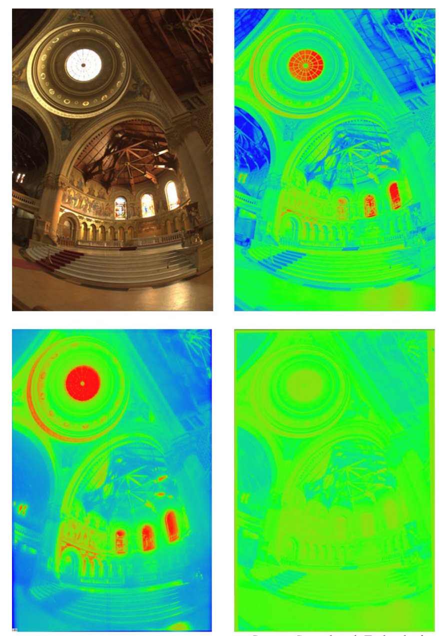
Today’s computer screens, however, display only a fraction of that range. The liquid crystal screens used in laptops, palmtops and cell phones average around 300 to 1, and top out at 800 to 1. Turn up the brightness of a liquid crystal display and the whole range changes—the black gets dimmer as other colors brighten.

Researchers from York University in Canada, the University of British Columbia in Canada, and Sunnybrook Technologies Inc. have devised a way to boost the dynamic range of liquid crystal displays to 90,000 to 1.

The technology promises to bring a more realistic brightness range to any type of computer screen, which will make for better and more informative pictures, according to Helge Seetzen, director of the Emissive Display program at Sunnybrook Technologies.

The human visual system has evolved to see the high dynamic range found in the world, said Seetzen. Many aspects of our perception are based on that evolution, including attention, aesthetics, 3D perception and emotions, he said.

A key application is improving the ability to view medical imaging data, Seetzen said. Like movie film, medical imaging data has a dynamic range as high as 8,000 to 1. But because of the limitations of today’s computer displays, data is often broken up into many pictures that show a series of brightness ranges. In order to avoid this problem, x-ray film is often still shown on light boxes.



Source: Sunnybrook Technologies

Clockwise from top left are a photograph of the interior of Stanford University's Memorial Church, a false color version of the original 16-bit digital image that shows its luminance range, the luminance range of the image shown on an ordinary computer display, and the luminance range on a high dynamic range display.

The display could also improve architectural rendering, including lighting simulations, flight and vehicle simulators, and military command and control viewers, said Seetzen.

In general, the system can display more life-like images, said Wolfgang Stuerzlinger an associate professor of computer science at York University. “Highlights on shiny objects look... more realistic, which in turn enhances the perception of the shape of the objects,” he said. The display can also generate much darker intensities than conventional monitors, he said.

The trick to increasing the brightness of a liquid crystal display is dividing the backlight into segments, and controlling those segments separately. A backlight shines through the pixels to provide most of the brightness of a screen. A conventional liquid crystal display is backlit uniformly and each pixel is adjusted to gain a brightness range.

The researchers' high dynamic range display technology uses a matrix of high brightness light-emitting diodes (LEDs) as a backlight. "Where the final image is very bright we increase the brightness of the LEDs and in the dark region the LEDs are very dim," said Seetzen.

Because there are two layers of light-emitting diodes, the brightness range is 300 times 300 to one, or 90,000 to one, he said. "This high contrast... allows us to use very bright LEDs without losing the perfect black of the displays," he said.

The key to making the scheme work was controlling the blur that resulted from using different size light-emitting diodes to produce the backlight and the pixels, said Seetzen. The researchers compensated for most of the blur using software. The remaining blur, at very high-contrast boundaries at the top of a single light-emitting diode, is imperceptible to the human eye, he said. The blur is hidden by an effect similar to the halos seen around streetlights at night. "The halo goes away if you mask the light source with your thumb even though the thumb doesn't mask the halo area," said Seetzen.

The displays consume about as much power as conventional displays, said Seetzen. "This sounds surprising, but is the result of controlled creation of light," he said. "Most areas in the average images aren't at the top brightness end—or we would have a desire for sunglasses all the time—so the vast majority of the LEDs are actually providing fairly little light at a given time and thus consume very little power."

Because the researchers' display uses hundreds of light-emitting diodes as a backlight rather than a pair of fluorescent tubes, it is potentially more expensive than current displays, said Seetzen. "For a 20 inch medical LCD the added costs will probably be around $500 or so," he said.

Prices for light-emitting diodes are decreasing by a factor of two every couple of months, however, said Seetzen. It is likely to take another two to three years of price decreases to make the screens cost-competitive for consumer products like televisions, he said.

The display is compatible with standard graphics cards, and is built from commercially available parts, Seetzen added.

According to the researchers' studies, it is possible to further increase the LEDs size without decreasing the spatial resolution and crispness of the image, said Seetzen. "This will further reduce complexity and cost," he said.

Seetzen and Stürzlinger's research colleagues were Andrejs Vorozcovs and Hugh R. Wilson from York University and Ian Ashdown, Greg Ward and Lorne Whitehead from the University of British Columbia. The researchers presented the work at the Association of Computing Machinery (ACM) Special Interest Group Graphics (Siggraph) 2003 conference in San Diego, July 27 to 31. The work was funded by the Canadian Natural Science and Engineering Research Council and Sunnybrook Technologies.

Timeline: > 1 year
Funding: Corporate; Government
TRN Categories: Graphics
Story Type: News
Related Elements: Presentation, "High-Dynamic-Range Display System," at the Association of Computing Machinery (ACM) Special Interest Group Graphics (Siggraph) 2003 conference in San Diego, July 27 to 31

Process Promises Better LCD Production

By Chhavi Sachdev, Technology Research News
June 13/20, 2001

The liquid crystal displays in your laptop screen and your cell phone were probably made using a process called rubbing that is almost a century old. The reason rubbing has prevailed is not because it is the best method— indeed, there are many drawbacks to implementing it — but because there has never been a viable substitute that could be used for large-scale manufacturing.

Researchers at IBM have endeavored to address the display industry's complaints by developing a cheaper, easier, higher-yield non-contact technique for aligning the liquid crystals.

In the process of rubbing, a giant roller wrapped in velvet is rubbed on a polymer surface that has been baked in a furnace. Liquid crystal molecules on the surface align themselves in the direction of the motion. The new process, in contrast, does not make any contact with the surface. Atoms shot from an ion gun to the surface knock out all but those molecules that are oriented in the same direction the ions are traveling, said Praveen Chaudhari, a scientist at IBM and the lead researcher of the project.

The biggest limitation of the rubbing technique is that it introduces debris. To keep fibers from the rubbing cloth out of other manufacturing processes, the rubbing machine must be placed in a separate clean-room environment.

The technique is also somewhat unreliable because the rollers can degrade unevenly, causing defects that may go undetected until hundreds of displays have been manufactured. Rubbing can leave streaks which degrade image quality and can produce an electrostatic discharge that affects the circuitry of the display. Replacing the rubbing cloth also delays production.

The idea behind the non-contact alignment method is simple, according to Chaudhari. An ion beam is fired at diamond-like carbon and the angle of the beam determines the alignment of the liquid crystal molecules. Atoms in diamond-like carbon are interconnected in a network that has no order. "The random network has rings of atoms in it. A given ring can be described by a plane," explained Chaudhari. A perpendicular ion beam, therefore, "tends to have a higher probability of knocking [perpendicular] atoms out, than if the plane is parallel to [it]" he said.

"What you're left with after you keep shooting atoms are those planes that are parallel to the ion beam. All the ones that are perpendicular are destroyed. It's like a Darwinian process of selection. The liquid crystals align themselves along [the surviving planes] and you're done," said Chaudhari.

The researchers replaced the baked polymer surface with a layer of diamond-like carbon film vapor-deposited on a substrate. Diamond-like carbon is widely used in the electronics industry, and therefore readily available. The low energy ion gun that replaced the rubbing roller is also commercially available. "So the tools and manufacturing experience already existed," said Chaudhari.

The result is a debris-free, reliable, cost-effective, highly scalable, and more environmentally friendly method than the one currently in use, according to Chaudhari. IBM used the process to make a prototype LCD, "Bertha," that measures 22 inches and has 3,840 by 2,400 pixels.

Source: IBM Research

This shows an image displayed on a prototype Liquid Crystal Display, which was produced using beams of ions to align the liquid crystals.

"The technique is certainly novel," said Satyendra Kumar, a professor of physics and chemical physics at Kent State University. "Although they have demonstrated in their laboratory it works very well, I have my reservations about its implementation on an assembly line. Basically, each plate will have to be put in a vacuum and bombarded by ions. This hardly appears more convenient or low cost than rubbing," he said. "Other techniques, such as UV exposure, appear far more attractive and practical," he added.

No other rubbing technique has been used to demonstrate a large display area, but the IBM researchers "have already demonstrated a working large area LCD using this technique," said N. V. Madhusudana, a professor at the Raman Research Institute in Bangalore, India. He also pointed out, however, that the IBM technique would require additional vacuum lines to process the displays.

IBM has established a pilot assembly line, Chaudhari said. The researchers expect large-scale production of the LCD's by the end of 2001.

The research was published in the May 3, 2001 issue of the journal *Nature* and prototypes of the display were shown at the Society of Information Display meeting in June, 2001. The research was funded by IBM.

Chaudhari's colleagues were James Lacey, James Doyle, Eileen Galligan, Shui-Chi Alan Lien, Alesandro Callegari, Gareth Hougham, Norton D. Lang, Paul S. Andry, Richard John, Kei-Hsuing Yang, Minhua Lu, Chen Cai, James Speidell, Sampath Purushothaman, John Ritsko, Mahesh Samant, Joachim Stöhr, Yoshiki Nakagawa, Yoshimine Katoh, Yukito Saitoh, Kazumi Sakai, Hiroyuki Satoh, Shuichi Odahara, Hiroki Nakano, Johji Nakagaki & Yasuhiko Shiota at IBM research.

Timeline: Now
Funding: Corporate
TRN Categories: Materials Science and Engineering
Story Type: News
Related Elements: Technical paper, "Atomic-Beam Alignment of Inorganic Materials for Liquid-Crystal Displays," Nature, May 3, 2001

TRN

Nanotubes Paint Clear Picture

By Kimberly Patch, Technology Research News
March 28/April 4, 2001

Once researchers figure out how to manufacture them in bulk, carbon nanotubes could be the key component of large, low-power flat screens that boast resolution higher than the human eye can detect.

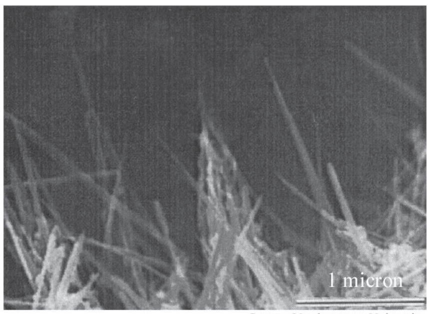
A group of researchers from Northwestern University has built a prototype flat screen that uses nanotubes to direct the photons that light up the screens pixels.

The screen works on the same principle as a standard cathode ray tube (CRT) field emission screen, which uses electrons streaming from a hot filament to light up phosphors on the back of the screen.

Using hundreds of thousands of stationary carbon nanotubes to direct the electrons rather than a filament that rasters, or moves back and forth across the screen 60-80 times per second enables the process to happen at room temperature and from very close to the back of the screen. This makes for a field emission screen that is very thin, very steady, and very high resolution, said Robert Chang, a professor of materials science engineering and director of the materials research Center in Northwestern University.

Nanotubes can do this simply because of the geometry, said Chang. "[Nanotubes] have extremely high aspect ratios—the tube diameter is always less than about 100 angstroms and the tube length is typically several microns and so it's very easy to put a field on the surface and to extract electrons out of [a nanotube] without having to heat it up," he said.

To make the prototype, which is a one centimeter square, white-on-black screen, the researchers chopped up a batch of nanotubes, mixed them with a paste, and literally painted them on the back of the screen.



Source: Northwestern University

This scanning electron micrograph image shows a side view of a nanotube-paste surface used in a flat-panel display.

To address each pixel, which is made up of hundreds or even thousands of nanotubes, the screen uses the same scheme as today's flat-panel screens—a grid of wires that turn each pixel on and off. "Each pixel has to have a signal that goes to it. In this case [each pixel] is lots of nanotubes," said Chang. The screen is also low-power; about 15 volts is needed to modulate the pixels, he added. In contrast, a standard CRT requires about 20,000 volts.

ecause the nanotube flat-panel works like a CRT by shooting electrons at phosphor it is as bright and can be viewed at as wide an angle as a CRT.

Multiple nanotubes per pixel also makes the screen durable, said Chang. "Because with each pixel you can have thousands of these carbon nanotubes, it's guaranteed redundancy—the pixel will not deteriorate over time. And because nanotubes are so small, the number of pixels that can be put on this type of screen could make for higher resolution than the human eye can distinguish. One million of the 10- nanometer nanotubes lined up side-by-side would measure only about a centimeter across. In theory, this type of screen could allow one million times one million pixels per square inch—a resolution so high there is probably no need for it, said Chang.

Once nanotubes can be manufactured in bulk, the screens would potentially be inexpensive, even for very large screens. "You could make huge screens very cheaply... without expensive lithographic techniques. You just get a roller in the paste and then you just roll it—this is called screen printing technology. So you can just roll [the paste on a screen] the size of a chalkboard or anything," Chang said.

Demonstrating a field emission screen that is easy to fabricate and uses low control voltages is a significant milestone, said Tsu-Jae King, associate professor of electrical engineering and computer sciences at the University of California at Berkeley, and director of its microfabrication laboratory. "The novelty lies in the development of a simple gated-cathode fabrication process. The resulting cathode array can be operated at low voltages to lower the cost of the display driver chips [and] to lower display power consumption," King said.

The technology could eventually provide a viable alternative to liquid crystal and organic light emitting diode (LED) flat screens for some applications, said King. "I think that field emission display technology has a chance of providing the lowest-cost approach to larger area displays," she said.

The next step is to figure out how to make large quantities of nanotubes, said Chang. "I've got to make kilograms of these nanotubes, [enough to] paint the wall, right? So I'm working feverishly to do that," he said.

This type of screen could be used practically in two years, Chang said.

Chang's research colleagues were Qunhua H. Wang and Min Yan. They published the research in the February, 2001 issue of *Applied Physics Letters*. The research was funded by the National Science Foundation (NSF).

Timeline: 2 years
Funding: Government
TRN Categories: Semiconductors and Materials
Story Type: News
Related Elements: Technical paper, "Flat-panel Display Prototype Using Gated Carbon Nanotube Field Matters," Applied Physics Letters, February 26, 2001

Electronic paper

Flexible Display Slims Down

By Eric Smalley, Technology Research News
May 21/28, 2003

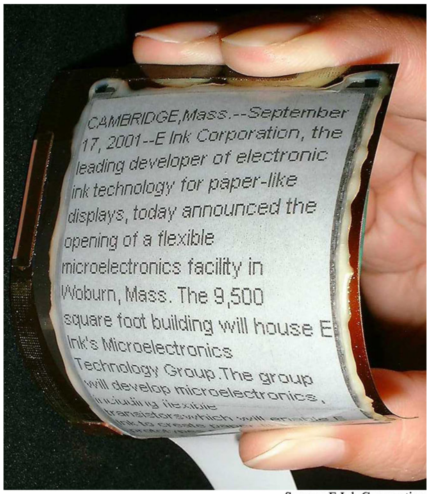
The long-running quest to build a computer screen that you can fold up like paper and put in your pocket is a little closer to reality.

Researchers from E Ink Corp. have produced a high-resolution electronic display that is 0.3 millimeters thick—about four times the thickness of a typical piece of printer paper—and can be rolled into 4-millimeter cylinder.

The researchers' prototype is a little larger than a business card and has a resolution of 96 dots per inch, which is comparable to today's handheld computer screen resolutions. The screen has an ink-on-paper appearance, a 180-degree viewing angle, and can be bent into a curve 3 centimeters in diameter without affecting the picture, said Yu Chen, a senior engineer at E Ink.

The device could eventually be used in electronic books that are more paper-like that today's tablets, and it paves the way for lightweight screens for wearable computers, said Chen.

There are two major challenges to making electronic displays in a paper-like form, said Chen. The first is developing an electronically controllable ink that has the optical properties of regular ink and can retain its image without any applied power, he said.



Source: E Ink Corporation

This prototype flexible display has a resolution of 96 dots per inch and can be bent without distorting the image.

The electronic ink used by the researchers' prototype was first demonstrated by Massachusetts Institute of Technology researchers in 1998.

It consists of many tiny capsules of charge-sensitive pigment. The capsules are tens of microns in diameter, said Chen. A red blood cell, in comparison, is 5 microns across. In the researchers' black-and-white prototype, capsules contain both black and white particles of pigment. A negative voltage causes the white particles to move to the surface, and a positive voltage causes the black ones to move to the surface. When the power is off, the pigment stays put.

The second challenge is to to produce a thin, flexible network of electronic circuits that connect every pixel in the display so they can be turned on and off.

The researchers' relatively thin display is a four-layer sandwich of electronic ink capsules, thin-film transistors that switch each capsule on and off, an insulating material and a 75-micron-thick steel-foil substrate, or backing. The researchers used standard photolithography processes, which employ light and chemicals to etch out tiny features, to form transistors in the thin-film layer. They laminated the electronic ink layer on top of the electronics.

The researchers increased the speed, contrast ratio and image stability of the electronic ink by improving the materials and chemistry involved, said Chen. The researchers' device switches pixels between black and white within a quarter of a second, which is considerably slower than a computer screen, but is sufficient for an electronic book page-turn.

The researchers' next steps are to improve the ink switching speed, make the device thinner, and add color, said Chen.

The ink switching speed would have to improve from 250 to 15 milliseconds to be able to support today's computer video applications, said Chen. And to make the device thin enough to be folded like a piece of paper, the thickness of the steel-foil substrate must be reduced to 25 microns, he said.

The device is currently ready for black-and-white applications like electronic readers and smart ID cards. It will probably take several years to develop a full-color display that switches quickly enough to support video and is thin enough to be folded into a pocket, said Chen.

Ultimately, "electronic paper and wearable computer screens... might have a large impact on environmental protection... and how our society distributes information," said Chen. "Just imagine the billions of trees we can save each year."

Chen's research colleagues were Joanna Au, Peter Kazlas, Andrew Ritenour, Holly Gates and Michael McCreary. At the early stages of the prototype's development the researchers also worked with Sigurd Wagner and James Sturm of Princeton University, said Chen.

The work appeared in the May 8, 2003 issue of *Nature*.
The research was funded by E Ink.

Timeline: Now, > 3 years
Funding: Corporate
TRN Categories: Materials Science and Engineering
Story Type: News
Related Elements: Technical paper, "Flexible Active-Matrix Electronic Ink Display," Nature, May 8, 2003

TRN

E-Paper Coming into View

By Kimberly Patch, Technology Research News
December 12, 2001

We've been hearing about electronic paper and how useful it will be for more than a decade now.

Scientists at Philips Research in the Netherlands have pushed the electronic paper chase a big step forward with a prototype two-inch active matrix display that depicts high-contrast text, and gray-scale pictures.

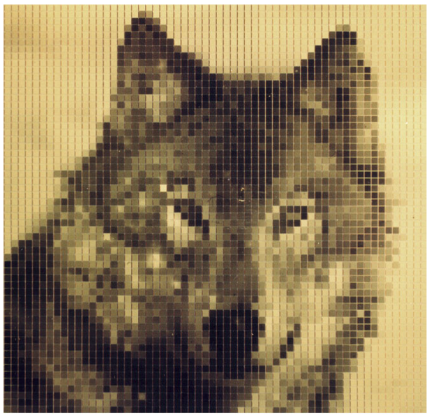
The electronic components of the display are organic materials flexible enough to eventually be embedded in sheets of plastic two-tenths of a centimeter thick, said Edzer Huitema, a senior scientist at Philips research in the Netherlands.

The 4,096-pixel prototype, which is made of glass, can depict fairly detailed images using 256 shades of gray.

The electronics are also fairly low-cost, said Huitema. "It is low-cost because we use very simple processing from solution. Only simple equipment is needed and processing temperatures are low," he said.

The researchers are working on putting the electronics into large sheets of plastic that can be used as roll-up displays, said Huitema. "This is just like rolling up the newspaper after reading it on the train. It will be small when carried and large when used for reading," he said.

The two keys to the quality of the image are a high refresh rate and a high contrast ratio. The refresh rate is as high as 100 Hz, which means the information on the screen is repainted 100 times a second; this is fast enough that the human eye sees no flicker, and more than fast enough to support video.



Source: Philips Research

This 2-inch glass display uses plastic circuits, which sets the stage for plastic computer screens that can be rolled up.

The screen has a contrast ratio of 8.6, which is high for a low-power display that uses no back light, said Huitema. The contrast ratio is comparable to that a black ink on paper, and better than that of ink on newsprint, he said. The contrast in the Wall Street Journal, for example is 5.3, he said. The contrast ratio is the amount of light reflected into the eye when it is looking at a white pixel divided by the amount of light reflected into the eye when the pixel is black.

In April, Bell Labs researchers demonstrated an electronic paper prototype made of flexible plastic that had an even higher contrast ratio, but it was black and white rather than grayscale, had only 256 pixels and took a full second to refresh.

The flexible electronics that make up the active part of the Philips display are similar to the electronics that make up the active matrix displays found in many computers today, except they are made of plastic instead of silicon.

Varying the amounts of electrical current coursing through each pixel causes the liquid crystalline material it contains to react, changing the look of the pixel. "At low voltages... the liquid crystalline material is hardly switched, resulting in a white pixel. At intermediate voltages it is halfway switched, resulting in a gray pixel. And at high voltages the liquid crystalline material is fully aligned in the electric field, resulting in a black pixel," said Huitema.

The challenge was making the transistors that guide electric current of plastic rather than silicon. The polymer semiconductor material they used consists of thousands of strands of connected molecules that form a layer 50 to 100 microns thick. "The semiconductor can be depicted as a big pile of spaghetti," said Huitema.

The researchers put together the display by covering the glass with a layer of gold, an insulating layer, and another layer of gold to form electrodes. On top of these layers, they put a layer of the plastic semiconductor material, then used photolithography to pattern the semiconductor into transistors. Photolithography uses light and chemicals to pattern shapes. To protect the semiconductors, they added a second coating of a different kind of plastic.

To sandwich the active matrix layer, they added an indium tin oxide layer to the back of the screen and filled the display with liquid crystals.

Because the semiconductor layer starts out as a solution, the researchers may eventually be able to use printing technology to form and place the plastic transistors rather than the more expensive photolithography methods, said Huitema. "If it is possible to print it in the future [there's] an additional cost advantage," he said.

It will take about five years before the technology is ready for commercial use, said Huitema.

Huitema's research colleagues were Gerwin Gelinck, Bas van der Putten, Karel Kuijk, Cees Hart, Eugenio Cantatore and Dago de Leeuw from Philips Research, and Peter Herwig and A. J. J. M. van Breemen of the Netherlands Organization for Applied Scientific Research. They published the research in the December 6, 2001 issue of *Nature*. The research was funded by Philips and the European Union.

Timeline: > 5 years
Funding: Corporate, Government
TRN Categories: Semiconductors; Integrated Circuits
Story Type: News
Related Elements: Technical paper, "Plastic Transistors in Active-Matrix Displays," Nature, December 6, 2001

TRN

Prototype Shows Electronic Paper Potential

By Chhavi Sachdev, Technology Research News
May 23, 2001

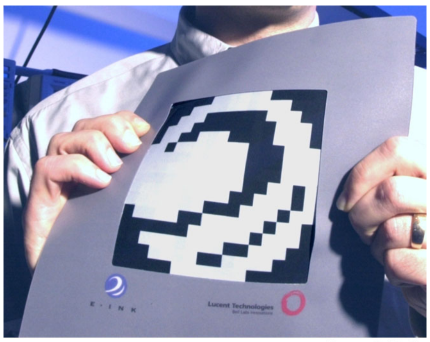
Computers, someone said, will never replace newspapers because you can't use a computer to swat a fly. This wry observation may not hold true for long, however.

Researchers at Lucent Technologies' Bell Labs and E Ink have created electronic displays comparable to what the computer monitor was originally intended to replace: paper. So, in a few years, your electronic newspaper may be able to swat that fly and do everything a computer monitor can.

Real paper has all the characteristics electronic paper would like to emulate: low cost, flexibility, mobility, good image resolution, and contrast that doesn't change with the viewing angle. Perhaps most importantly, paper does not require power in order to display text or images.

Researchers at Bell Labs have used plastic to create an electronic paper that is bendable, unbreakable, lightweight, low cost, and very low power. In short, it's a reasonable stand-in for paper.

The researchers' brand of electronic ink has been around since 1999, but the display itself has taken longer to evolve because the researchers chose to make it out of plastic. Because plastic cannot tolerate the high temperatures of silicon photolithography techniques, different processing and manufacturing techniques had to be employed, said John A. Rogers, director of Condensed Matter Physics Research at Bell Laboratories at Lucent Technologies.



Source: Bell Labs

This 6- by 6-inch piece of electronic paper is thick and weighs about five grams. It's contrast ratio is 10:1, which is better than that of newsprint.

The most common displays are the cathode ray tubes (CRT) found in boxy TV and computer monitors, and the liquid crystal displays (LCD) found in cell phones, wrist watches, laptops and personal digital assistants (PDAs).

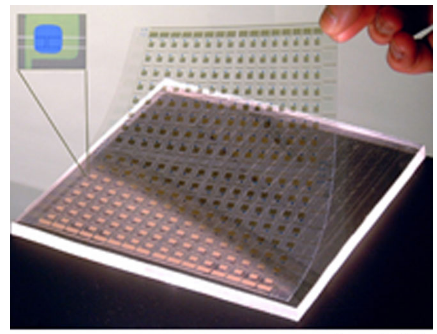
While silicon circuits are made using photolithography, the gold film used for the electronic paper circuits is patterned using microcontact printing, an ultrahigh resolution form of rubber stamping, which is fast, continuous and efficient, according to Rogers. It is also cheaper than photolithography, he said.

"From a scientific standpoint there's nothing particularly new" about the approach, said Vivek Subramanian, assistant professor of electronic engineering and computer science at University of California at Berkeley. "But what is interesting is how they've brought everything together, including E Ink's system, to try to make a full system," he said.

Two layers of plastic make up the display. One layer provides the optical contrast and the second layer houses the circuitry that controls images. Microcapsules of ink— each one containing chips of white particles suspended in a black dye—are sandwiched between the layers. The white particles congregate at the front or the back end of the microcapsule depending on the electric field generated by transistors in the plastic circuits.

Each transistor acts "as a voltage controlled switch [that] controls the color of the electronic ink pixels," said Rogers. "When the particles are at the front of the display, the pixel appears white; when they are at the back, the pixel takes on the color of the dyed fluid in which the pigments are suspended—black in this case," said Rogers.

The black-on-white display can be made any size. The current model measures 6 square inches, is just under a millimeter thick, and weighs about five grams, or one tenth the weight of a thin film transistor (TFT) LCD of the same size, said Rogers. "For a backlit [liquid crystal] display with 6- by 6-inch viewing area, the power consumption is about seven watts," he said. Electronic paper consumes about one thousandth as much power because it does not require backlighting and because the system is bistable, meaning no power is needed to display a pixel's color, only to switch it, according to Rogers.



Source: Bell Labs

This figure shows an active-matrix plastic circuit. The inset shows an optical micrograph of a typical transistor.

It is, however, low resolution, containing just 256 pixels compared to about 1.3 million in a standard 17-inch LCD.

In addition, although the transistors allow a switching speed of about 2.5 milliseconds, the total time for an image to change smoothly is about one second; typical LCD's pixels are refreshed 70 times a second. "Currently the electronic ink, and not the transistors, limit the speed," Rogers said. "The first applications of this technology might not require high speed operation," he added. Devices such as PDAs and cell phones could work well even if refresh rates are as low as half a second, he said.

The electronic paper could also be used in everyday paper products such as newspapers, magazines and books. "An electronic newspaper…will consist of only one or a small number of sheets of electronic paper, onto which daily, or hourly, information content will be downloaded via a wireless connection to the Internet," said Rogers. By the same token, cereal boxes, wall paper, and flyers could eventually be made from electronic paper.

"I don't know if it will change electronic displays a whole lot because the pixels are too slow," said Subramanian. Meanwhile, we continue to demand more from our electronics, he said. "I'd be surprised if they could do PDA displays without substantially improving their refresh rates. You need a refresh rate of about [17 milliseconds] to prevent flicker," Subramanian said. "However, it would probably be adequate as a note-taking device or electronic book, since…the pixels hold their state once addressed," he said.

Electronic paper displays could be in use within five years, Rogers said. The researchers are currently working on developing new transistor geometries and semiconductors that will improve the switching time. They also aim to speed up the refresh rate and to use the technology in non-display applications such as radio frequency ID tags that can replace bar codes, said Rogers.

Full motion video could also be possible with newer inks that change color more rapidly. "I think that this … will be possible within one to two years. The circuit part is, more or less, done already," he said.

The printing methods for the circuits and the use of organic semiconductors make this research important, said Sigurd Wagner, a professor of electrical engineering at Princeton University.

Rogers' colleagues were Zhenan Bao, Kirk Baldwin, Brian Crone, Anant Dodabalapur, Howard Katz, Valerie Kuck, and V.K. Raju at Bell Labs, and Karl Amundson, Jay Ewing, and Paul Drzaic at E Ink, Corporation. They published their findings in the *Proceedings of the National Academy of Sciences*, April 24, 2001. The research was internally funded by Lucent Technologies and E Ink, Corporation.

Timeline: 3 to 5 years
Funding: Corporate
TRN Categories: Human-Computer Interaction; Integrated Circuits;
Materials Science and Engineering
Story Type: News
Related Elements: Technical paper, "Paper-like Electronic Displays: Large-Area Rubber-Stamped Plastic Sheets of Electronics and Microencapsulated Electrophorectic Inks," *Proceedings of the National Academy of Sciences*, April 24, 2001

TRN

Flexible Displays Come into View

By Kimberly Patch, Technology Research News
October 11, 2000

Scientists at Philips Research have taken the first steps toward making active matrix computer screens both cheaper and more flexible.

The researchers have incorporated semiconductors that are made of flexible polymer instead of silicon into a computer screen. Active matrix computer screens have high resolutions because each pixel, or dot of color, is controlled by its own semiconductor, or switch.

Polymer-based switches are a major step toward producing flexible screens.

The researchers have produced a prototype display that contains 4,096 polymer-based semiconductors deposited on a glass screen.

The next step is combining the polymer-based switches with a plastic display, said Dago de Leeuw, project leader of polymer electronics at Philips Research. The researchers are also working toward enlarging the display beyond its current 4,096, or 64-by-64, pixels.

The advantages of using plastic semiconductors for displays, as well as other electronics, are both flexibility and cheaper manufacturing methods, de Leeuw said.

Polymers are easier and cheaper to work with than silicon, said de Leeuw. "Polymer [can] be processed more easily—clean-room conditions do not have to be so strict, and [fewer] process steps are needed," he said.

Source: Philips Electronics

The key to making plastic displays is using integrated circuits made from flexible polymers.

Although working circuits made with polymer semiconductors are still novel, it is clear that organic semiconductors will be "increasingly important—both because the science is proving to be very interesting and also because the technology [has] the potential to be widely used," said Richard Friend, a physics professor at the University of Cambridge, England.

Friend added that there's a lot of research to go before polymer-based components like semiconductors reach their true potential. For example the Philips circuit still requires "a lot of conventional lithography, so the actual process for manufacture is not very different from inorganic semiconductor methods," said Friend. "The virtues of organic semiconductors [will only be realized] when all the process steps dispense with traditional semiconductor technology," he said

It will take one to two years to produce a flexible prototype display, three to five years before polymer-based components in general will be ready to use in commercial products, and five to 10 years before a flexible screen that incorporates plastic semiconductors is likely to be ready for production, said de Leeuw.

Timeline: 3-5 years, 5-10 years
Funding: Corporate
TRN Categories: Semiconductors and Materials
Story Type: News
Related Elements: None

Flipping Flakes Change Color

By Chhavi Sachdev, Technology Research News
November 14, 2001

Someday, we will all have computer screens we can fold up and tuck into our pockets. Researchers at the University of Rochester are trying to make that reality a colorful one.

Though color electronic paper won't be available any time soon, it is becoming more feasible thanks to the researchers' work with polymer cholesteric liquid crystal (pCLC), which could be used in electronic ink and a variety of other colorful applications.

Objects absorb certain wavelengths of light and reflect the balance, which we see as color. Depending on their composition and angle, the liquid crystal particles reflect only a specific color, said Kenneth L. Marshall, a research engineer at the Laboratory for Laser Energetics at the University of Rochester. The effect is like looking at an iridescent insect from different angles, he said.

The flakes could have a wide range of applications—in smart windows to conserve energy or protect privacy, as a camouflage or decorative coating, and embedded in documents or objects for security, tagging and identification, said Marshall.

Each particle of polymer cholesteric liquid crystal is about 40 microns across, or about half the diameter of a human hair. The uniformly aligned flakes are suspended in silicone oil. Light striking these flakes is reflected back selectively, making them appear shiny. When an electric field is applied, the flakes rotate, changing angle and alignment, so that "the color appears very muted grey or even black," Marshall said.

Coatings of the flakes could allow large objects like helicopters to change color. "If the coating contained flakes with different colors and the flakes of each color type were treated to respond differently to electric fields, one could switch different colors on and off in different areas," Marshall said. "One could change the surface from one of high reflectivity, say green, to one of low reflectivity, for example... flat black."

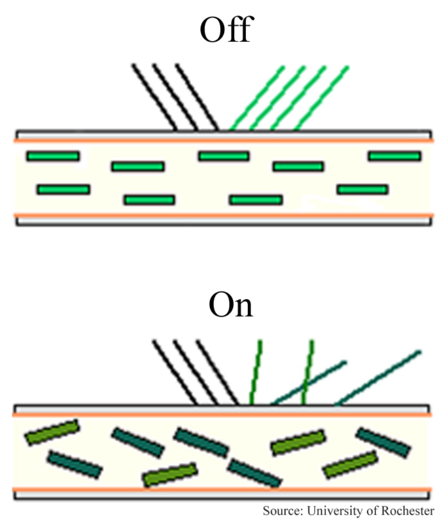
Cholesteric liquid crystals reflect different colors at different angles because their molecules form tiny spiral structures. The flakes are made of many of these spirals, and each spiral has a slightly different orientation than its neighbors, said Marshall. When light hits these structures, it splits into two circularly polarized, or spiraling, beams; one beam twists in the same direction as the spiral, and the other twists in the opposite direction.

The color of the particle comes from the reflection of the light component that corkscrews in the same direction as the spiral. If a spiral of the cholesteric liquid crystal material is the same size as the wavelength of green light — about 543 nanometers—then only green light will be reflected, said Marshall.

The physical and optical properties of these flakes make them well-suited for use in colored ink, said Marshall. They continue working despite large changes in temperature and they can withstand force that might otherwise cause misalignment, he said.

The flakes switch in 80 to 500 milliseconds, depending on their size and shape and the type of electric field used. This rate is comparable to that of conventional, or nematic, liquid crystal displays. The trick to forming letters, numbers and pictures is getting the flakes to orient consistently and in unison.

Both the type of electric field and the strength of the current affect the rotation of the flakes. With an alternating electrical current, the flakes rotate a full 90 degrees. With a direct current, the angular rotation is only about 5 to 10 degrees. A rotation of 5 to 10 degrees is enough to change a flake from reflecting a color to not reflecting any color, he said. "The particle charging is nearly instantaneous" and it changes back when the electric field is removed, Marshall said.



Microscopic flakes suspended in fluid reflect a single, intense color, but when an electric field is applied, the flakes move out of alignment, scattering the wavelengths. This makes them appear dull.

The general area of technologies for electronic paper "is an exciting one that could have enormous impact on consumer electronics," said John A. Rogers, director of condensed matter physics researchat Lucent Technologies' Bell Labs.The flakes are one of three or four emerging technologies thatcould be suitable for the ink part of a flexible pocket-display, he said. The other crucial piece is making the circuitry that would control the flexible screen, he added.

It is too early to say the liquid crystal flake technology is better than the rest, Rogers said. It is at "a very early stage of development, and it is not clear… that it offers compelling advantages" over the other approaches, he said.

The flakes could be very useful encapsulated in a solid film, said Sigurd Wagner, a professor of electrical engineering at Princeton University. "In the overall scheme of developing electronic books, the display technology is just one of many technical problems that must be solved. [This work is] one of many that will be needed," Wagner said.

The researchers are working with the flakes "in very small quantities in order to understand the fundamental physics and switching mechanism," said Marshall. Their aim is to more closely control the flakes' motion. "We have some measure of control over the angular flip, but we don't have complete control yet," Marshall said. Part of the control problem is that the flakes are irregular in shape.

In theory, the different colors could be addressed individually or in combinations depending on voltage or frequency of the electric field, Marshall said.

They will also focus on encapsulating the flakes and host fluid in a flexible polymer binder in order to make plastic coatings with the color-changing property, Marshall said.

A full-color electronic paper prototype could be ready in two or three years, he said. It will take about five years to produce practical devices using the flakes, he said.

Marshall's research colleagues were Tanya Z. Kosc, Stephen D. Jacobs, and Brett Klehn at the University of Rochester. They presented the research in the Novel Optical Materials and Applications Meeting at Cetraro, Italy, held May 20 to 27, 2001. The research was funded by Reveo, Inc., and the Center for Electronic Imaging Systems at the University of Rochester.

Timeline: 5 years
Funding: Corporate; University
TRN Categories: Materials Science and Engineering
Story Type: News
Related Elements: Technical paper, Polymer Cholesteric Liquid Crystal Flakes for Display and other Electro-Optic Applications," presented at the Novel Optical Materials and Applications Meeting at Cetraro, Italy, May 20 - 27, 2001

TRN

Assembly processes

Plastic Mix Promises Big Displays

By Eric Smalley, Technology Research News
May 15/22, 2002

Big city newcomers can be overwhelmed by a blur of shapes and colors as buses, trolleys and delivery trucks wrapped in photo-quality advertising images whiz by. Imagine how much more disorienting the experience would be if the vehicles sported giant video displays.

There's a long way to go from today's flatscreen technology to something that can be painted on a large surface, but researchers at Philips Research Laboratories and Eindhoven University of Technology in the Netherlands have taken a big step in that direction.

Liquid crystal displays (LCDs) are usually made by sandwiching liquid crystals between two carefully positioned sheets of glass. Liquid crystals are long, randomly arranged molecules that line up in crystal-like order in the presence of an electric field. The molecules reflect light differently when they are ordered and disordered, which allows them to form pixels in a display.

The researchers have come up with a method for layering liquid crystals on a single surface of glass, plastic or silicon.

Source: Philips Research Laboratories

This cross-section diagram shows how Philips' prototype liquid crystal display was made. When researchers exposed a mix of liquid crystals and plastic to ultraviolet light, the plastic hardened into pixel-size cells that contained the liquid crystals.

Because there's only one substrate rather than a sandwich of two, the displays can be very thin. "The single-substrate technology reduces the thickness of the display [to] smaller than 0.5 millimeters," said Dirk Broer, a research fellow at Philips Research Laboratories and a professor of polymer chemistry at Eindhoven University of Technology.

The process could lead to displays that are larger, thinner and more flexible than today's screens, said Broer. "It opens ways to make portable equipment smaller, [lighter] and more robust," and to make displays large enough to cover walls, he said.

To make the single-substrate screen, the researchers spread a liquid blend of plastic and liquid crystals onto a surface containing a grid of electrodes. The electrodes produce the electric field necessary to power individual pixels. The researchers then used two types of ultraviolet light to harden the plastic in the blend, forming a covering to contain the liquid crystals.

The researchers formed plastic walls on the substrate by shining 400-nanometer wavelength light in a grid pattern. Then, to form a top coat of plastic, they shined 340-nanometer light on the whole assembly. The end result was a grid of 500- by 500- by 10-micron boxes that contained the liquid crystal. Five hundred microns is about the diameter of a period-size dot. The grid walls were 100 microns thick and the cover layer 10 microns thick.

The researchers' prototype display takes 5 to 40 thousandths of a second to switch a pixel on and off and produces images with a contrast ratio of 1 to 20, according to Broer. Typical commercial LCDs have comparable switching times that range from 10 to 200 milliseconds, but better contrast ratios of at least 1 to 200, which result in clearer images and more vibrant colors.

The researchers' next steps are to improve the contrast ratio and brightness of the display and develop pilot production lines, said Broer. They are also working on using substrates with thin film transistors in order to use active matrix addressing, he said. Active matrix addressing systems are faster, enabling displays to show video.

The process could be used to make simple displays in two to five years, said Broer. The LCD process might never come to market if an alternative technology, organic light emitting diodes (OLEDs), matures sooner, he said. OLEDs could lead to displays made entirely out of sheets of plastic.

Broer's research colleagues were Roel Penterman, Stephen I. Klink, Henk de Koning and Giovanni Nisato of Philips Research Laboratories. They published the research in the May 2, 2002 issue of the journal *Nature*. The research was funded by Royal Philips Electronics.

Timeline: 2-5 years
Funding: Corporate
TRN Categories: Materials Science and Engineering
Story Type: News
Related Elements: Technical paper, "Single-Substrate Liquid-Crystal Displays by Photo-Enforced Stratification," Nature, May 2, 2002

TRN

Painted LEDs Make Screen

By Kimberly Patch, Technology Research News
March 28, 2003

A research team from Germany has developed a process for producing plastic, full-color flat screen displays that is simpler and potentially cheaper than today's manufacturing methods for organic light-emitting diode screens.

The researchers made the displays by spreading light-emitting plastic, or polymer, molecules on a surface and exposing the polymers to spots of ultraviolet light.

The method could produce color screens that are comparable in quality to current flat screens, but are more rugged and require less power, according Klaus Meerholz, who conducted the research at Munich University in Germany and is now a professor of physical chemistry at the University of Cologne. The method allows for "flat panels with high brightness, extremely large viewing angle, and fast switching times," he said.

The method is "really fantastic," said Yang Yang, a professor of materials science and engineering at the University of California at Los Angeles. "The idea... has been discussed for years," he said. "However, the device performance is always much poorer than... traditional devices." The researchers did an excellent job of pushing the device performance to a practical level, he said.

The researchers' prototypes produced pixels of comparable size, sharpness and thus resolution as today's state-of-the-art flat screens. The method has the potential to produce even smaller pixels, which would make for screens of higher resolution than today's models, according to Meerholz.

The process is also "much simpler" than existing flat-screen manufacturing methods, said Meerholz. This could translate into cheaper and more rugged full-color screens for devices like cell phones and laptops.

The process could also be used to pattern polymers to make electronic devices like transistors, sensors, and even wires, said Yang.

Key to the method is a polymer molecule that emits light and also has photoresist properties. Photoresists are soluble in water, but shining ultraviolet light on them causes the polymer molecules to link to each other, rendering them insoluble.

This property allowed the researchers to pattern the polymer into the separate, tiny dots, or pixels needed to produce a screen. The researchers spread the polymer on a surface, shined ultraviolet light through a shadow mask that contained 125-micron holes, then washed off the polymer that was not cured. A micron is one thousandth of a millimeter.

By repeating the process with red-, blue- and green-emitting polymers, the researchers were able to produce a full-color screen.

The method produced sharply defined dots, and in theory could produce dots only a few microns wide, which would allow for even higher resolutions, according to Meerholz.

The process is quite promising for full-color flat-panel displays, mechanically flexible displays and, potentially for color image sensors, said David Braun, a professor of electrical engineering at California Polytechnic State University. The simultaneous control over pixel color and pixel patterning, and the ability to produce nonsoluble electroluminescent films, are novel, he said.

Source: Klaus Meerholz

The plastic light-emitting diodes that form this prototype screen draw little power and can be made more cheaply than existing flat screens.

The researchers are currently testing the long-term stability of screens produced using the method, according to Meerholz. They are also working on producing true RGB colors, which are the standard colors displayed by computer screens.

The method could produce practical displays within two years, said Meerholz. "The technology is almost ready to go."

Meerholz's research colleagues were C. David Müller, Nina Reckefuss, Paula Rudati and Holger Frohne from Munich University, Aurélie Falcou and Heinrich Becker from Covion Organic Semiconductors in Germany and Marcus Rojahn, Valérie Wiederhirn and Oskar Nuyken from the Technical University of Munich.

The work appeared in the February 20, 2003 issue of *Nature*. The research was funded by Covion Organic Semiconductors, the German Research Foundation (DFG) and the Bavarian Government.

Timeline: < 2 years
Funding: Corporate, Government
TRN Categories: Materials Science and Engineering; Optical Computing,
Optoelectronics and Photonics
Story Type: News
Related Elements: Technical paper, "Multi-Color Organic Light-Emitting Displays by Solution Processing," Nature February 20, 2003

T-shirt Technique Turns out Flat Screens

By Kimberly Patch, Technology Research News
July 25, 2001

The current technique for spreading light-emitting polymers on glass to make passive matrix computer screens is wasteful, according to researchers from Siemens Corporation in Germany. It's also not something you want to try with a screen surface the size of a wall or billboard.

Spin-coating, which uses centrifugal force to spread polymers on a surface that's spinning 2000 times per minute, results in a nice even coat of the polymer diodes that light up an organic light emitting diode (OLED) computer display. But it's a messy business.

Somewhere between 5 and 10 percent of the polymer actually ends up on the surface; the other 90 to 95 percent either flies off during the process or ends up in the works, said Georg Wittmann, project manager for the OLED project at Siemens.

In addition, it becomes more difficult to use spin coating as the screen size gets larger, said Wittmann. "The larger [the surface] the more difficult it is to coat the outer areas of the glass," he said.

The researchers modified an existing printing process to provide an alternative way to spread polymers on large surfaces. Screen printing, which guides inks onto a surface through fine mesh, is an order of magnitude less wasteful than spin coating. "We use 80 or 90 percent," of the polymers, said Wittmann.

The process has the potential to produce relatively inexpensive computer screens large enough to cover a wall or billboard. The catch is the researchers' modified printing process cannot print the polymers in as fine a resolution as they can be spun. This means the printing technique is only appropriate for fairly large screens. In addition, although the process allows for different colors to be printed in different places on the screen, the resolution is not high enough to produce full-color screens that can make any color appear anywhere on the screen.

Screen printing is an established process used not only to guide heavy inks onto T-shirts, but also to lay down electric conducting pastes on printed circuit boards.

The catch to adapting screen printing for making computer displays was the viscosity of the polymer the researchers need to print on the glass part of a computer screen. "The tricky part is the emitting layer in this screen printing technique is extremely low viscosity... we managed to develop a process that we can use with very low viscous printing solution," Wittmann said.

The viscosity of water, for instance, is 1 millipascal seconds, while the viscosity of the pastes traditionally used in screen printing are much higher—more like 1,000 or 2,000 millipascal seconds, Wittmann said. The OLE polymer is much more like water than paste, with a viscosity of 10 to 20 millipascal seconds, he said. "It's almost water-like. You wouldn't be able to distinguish it [by] feel."

The idea is a "fresh and useful manufacturing approach for large-area polymer OLED displays," said David Braun, an associate professor of electrical engineering at California Polytechnic State University in San Luis Obispo.

Although the idea is not novel because silk screening T-shirt designs is well-established, the research is important because "screen printed displays work, perhaps better than one might have predicted," Braun said. "The simple printing technique allows people to make relatively complex electronic devices. It's potentially useful for printing large area... displays [and] I suspect that there are some cost advantages," he said.

The research could help polymer OLED displays to gain wider acceptance of the market in the next few years, Braun added.

The researchers are working spreading the polymers more evenly, making the edges where the ink ends sharper, and improving the resolution, said Wittmann. The current process can print a spot of polymer, or pixel, 300 microns away from the next one. Spin coating can achieve a resolution an order of magnitude better, with pixels separated by only 20 or 30 microns, he said.

Wittmann's research colleagues were Jan Birnstock, Jörg Blässing, Arvid Hunze Matthias Stößel, Karsten Heuser and J. Wörle from Siemens in Germany, and Albrecht Winnacker of Erlangen-Nürnberg University in Germany. They published the research in the June 11, 2001 issue of *Applied Physics Letters*. The research was funded by OSRAM GmbH.

Timeline: Now
Funding: Corporate
TRN Categories: Materials Science and Engineering

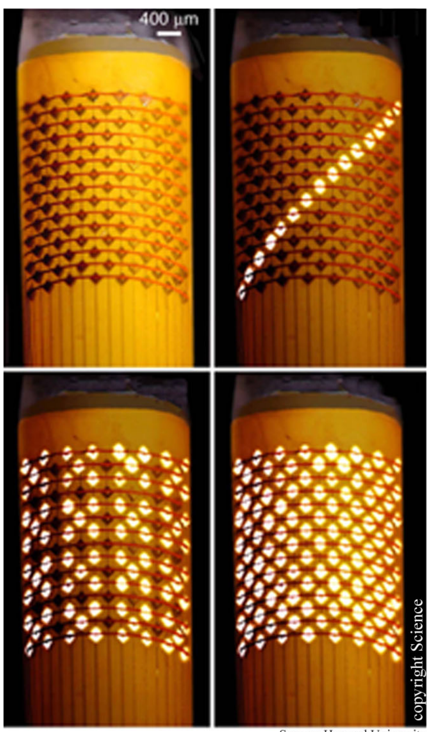
Story Type: News
Related Elements: Technical paper, "Screen-Printed Passive Matrix Displays based on Light-Emitting Polymers," Applied Physics Letters, June 11, 2001

Shake and Serve

By Eric Smalley, Technology Research News
April 17/24, 2002

Shaking is a good way to break things, especially electronic devices that contain many components. A team of researchers at Harvard University has found that shaking can also have the reverse effect.

The researchers have developed an assembly process that boils down to making a cocktail—shaken, not stirred—of electronic components and copper wires in a vial of hot water. The technique is one of a growing number of self-assembly processes that could dramatically lower manufacturing costs for electronic devices ranging from sensors to computers.



Source: Harvard University

The 113 pixels in this cylindrical display, which is narrower than a pencil, are LEDs that literally fell into place during the assembly process.

The Harvard team demonstrated their patterned self-assembly process by making a cylindrical display about 4 millimeters in diameter that contained 113 light-emitting diodes (LEDs). The shape of the display proves the process is not restricted to flat surfaces, which is a limitation of current manufacturing techniques, said Heiko O. Jacobs, a member of the team who is now an assistant professor of electrical and computer engineering at the University of Minnesota.

The researchers began with an array of 113 copper squares that were connected via copper wires and mounted on a plastic sheet. The squares, which measured 280 microns each, were coated with a solder that melts at relatively low temperatures.

The first steps in the process were rolling the sheet into a cylinder, putting it in a vial of water, adding 113 280-micron-square LEDs, and heating the water above the melting temperature of the solder.

The researchers found that they could get the LEDs to adhere to the copper squares by gently shaking the vial by hand for one to two minutes. Tapping the vial with a metal rod shook loose LEDs that adhered to wires between squares or that stuck two to a square, and shaking the vial some more got these last LEDs to stick to the right places.

The gold contacts on the bottoms of the LEDs stuck to the liquid solder because of the same force that causes adjacent drops of liquid to merge. Molecules on the surface of a liquid have higher energy, and are therefore less stable, than molecules within the liquid, said Jacobs. Drops of liquid merge because liquids naturally reduce surface area to become stable, he said. "In our system, the solder bumps capture light emitting diodes for the same reason," said Jacobs.

They finished the display by hand positioning another plastic sheet with copper squares on top of the LEDs.

The advantages of the researchers' patterned self-assembly process are that it does not require expensive machinery, it works on curved and flexible surfaces, and it handles small components, said Jacobs. Because the process handles smaller components it could be used to make higher-resolution displays than are possible with conventional approaches, he added.

A display like the researchers' small cylinder prototype could be used for a future combination pen and cell phone or similar device, said Jacobs.

Making more complicated devices that have different types of components is likely to require shape-selective recognition and hierarchical self-assembly techniques in addition to the researchers' cocktail-mixing approach, according to Jacobs. Shape-selective recognition is a process for building components with shapes that combine in only one way, said Jacobs. "Hierarchical self-assembly is self-assembly of tiny things into small aggregates, and then further self-assembly of the small aggregates into larger aggregates, and so on," he said.

The researchers' patterned self-assembly process could be put to practical use in five to ten years, said Jacobs.

Jacobs' research colleagues were Andrea R. Tao, Alexander Schwartz, David H. Gracias and George M. Whitesides of Harvard University. They published the research in the April 12, 2002 issue of the journal *Science*. The research was funded by the National Science Foundation (NSF), the Defense Advanced Research Projects Agency (DARPA), the German Science Foundation and the Swiss National Science Foundation.

Timeline: 5-10 years
Funding: Government
TRN Categories: Materials Science and Engineering
Story Type: News

Related Elements: Technical paper, “Fabrication of a Cylindrical Display by Patterned Assembly,” Science, April 12, 2002

TRN

3D technologies

3D Display Goes Deeper

Technology Research News, September 24/October 1, 2003

When it comes to three-dimensional displays, there are usually compromises. Some methods have narrow viewpoints that require a user to view the image from directly in front of a screen. Some methods require that the user look through special glasses. Other methods don’t provide a lot of depth.

Researchers from Seoul National University in Korea have found a way to deepen one type of three-dimensional display method— integral imaging—that has historically suffered from relatively shallow depth, but does not require users to wear glasses.

The method could eventually be used to make three-dimensional billboards and three-dimensional television.

The method makes images appear at three distinct depths by controlling the polarization and direction of the light rays that the display generates. The researchers’ prototype display contains a polarizer and sliding slit mask, a calcite crystal, and an array of lenses.

The polarizer switches the display’s light among vertically polarized, horizontally polarized and unpolarized light more quickly than the eye can detect. The crystal changes the angles at which the two types of polarized light travel to the lenses. This causes the three types of light to focus at three different depths.

three-dimensional television in 10 or more years, according to the researchers. The work appeared in the August 11, 2003 issue of *Optics Express*.

TRN

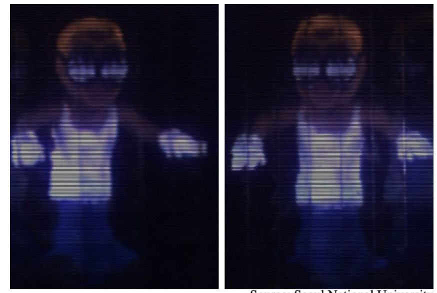
3D Display Goes Vertical

Technology Research News, July 16/23, 2003

Researchers from Seoul National University in Korea have devised a method that widens both the horizontal and vertical viewing angles of three-dimensional integral imaging systems, which use the clustered-lenses arrangement of insect eyes.

Although flies-eyes-arrays can provide high-quality three-dimensional pictures and don’t require special viewing aides like polarization glasses, they tend to have a narrow viewing angle—about 20 degrees.

The researchers previously widened the horizontal viewing angle using a system of fast mechanical shutters that blocked all but the appropriate portions of a three-dimensional image for a given angle. Their latest method is non-mechanical, and thus less prone to wear, and it increases the viewing angle both horizontally and vertically. The method uses a beam splitter to produce two, overlapping displays.



Source: Seoul National University

The beam splitter separates images into two opposite polarizations, one of which is used to widen the horizontal angle and the other the vertical. The system switches between the two polarizations faster than the eye can detect, creating a single, three-dimensional image that has twice the viewing angle of the original.

The technique could be used in simple applications like three-dimensional advertising displays within two years, and in three-dimensional TV systems in a decade, according to the researchers. The work appeared in the June 16, 2003 issue of *Optics Express*.

TRN

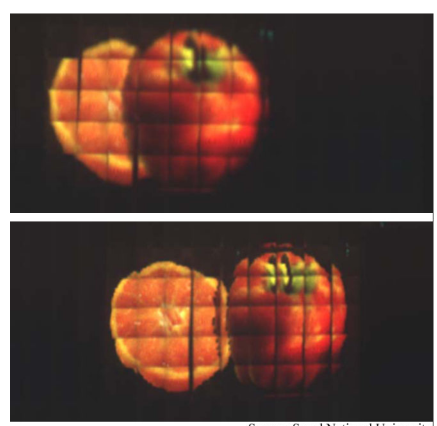
3D Display Widens View

June 4/11, 2003

Researchers from Seoul National University in Korea have fashioned a three-dimensional display that has a wider viewing angle then existing 3D screens.

Three-dimensional displays draw on the same working principle as dragonflies eyes. Dragonflies see three-dimensional images with each eye because each is made up of many lenses that view an image from slightly different angles.

The tricky part of displaying three-dimensional images is keeping the separate views from interfering with each other on their way to the



Source: Seoul National University

These images show two different angles of the same 3D screen.

screen. This is generally achieved by putting an array of barriers between the display panel and the lenses that project the image. This limits the viewing angle of the display, however.

The Seoul researchers have fashioned a dynamic shutter array that rapidly tilts from side to side to allow observers viewing the screen from different angles to see the three-dimensional images from the proper perspective.

Applications like three-dimensional billboards are possible in a few years; three-dimensional television systems are a decade or more away according to the researchers. The work appeared in the April 21, 2003 issue of *Optics Express*.

TRN

3D Holo Video Arrives

By Eric Smalley, Technology Research News
March 26/April 2, 2003

Although three-dimensional video has long been imagined — Princess Lea's recorded plea to Obi-Wan Kenobi in the 1977 Star Wars movie comes to mind—it has been slow to show up in the real world. This is because three-dimensional video is orders of magnitude more complicated than ordinary video.

Researchers from the University of Texas have devised a three-dimensional video system that cuts down the compute power needed to project three-dimensional images by using an 800,000-mirror device designed for two-dimensional digital projectors as a sort of holographic film. "Our system provides a simulated hologram capable [of] dynamic, truly holographic 3D images like 3D movies," said Michael Huebschman, a research physicist at the University of Texas Southwestern Medical Center at Dallas.

The approach could be used to make three-dimensional heads-up displays, medical images, and computer games. It could eventually lead to three-dimensional movies and television.

Our sense of sight depends on the way light reflected from an object's surface hits our eyes. Light from a dark area of the object has a smaller amplitude than light from a bright area. Light waves also interfere with each other. When waves are in opposite phases, meaning the crest of one light wave coincides with the trough of another, the waves cancel each other. When two crests coincide, they are in phase and they reinforce each other. And how out of phase two light waves are determines the amplitude of the point where they intersect.

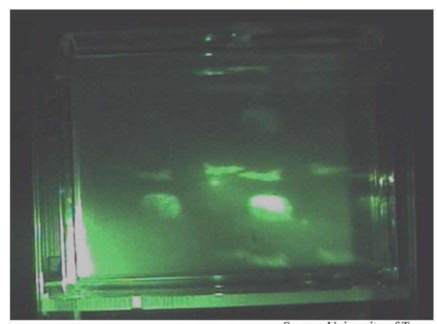
A hologram is a representation on a single plane of all of the phase information, or interference pattern, of the light coming from an object. It creates a three-dimensional image by projecting the interference pattern reflected by a real object.

Holograms are made by bouncing a laser beam off an object and having a second laser beam intersect the reflected light. The laser beams interfere with each other, producing the requisite pattern of bright and dark areas. The pattern is captured in a light-sensitive medium. Holograms are seen when light hits the storage medium at the same angle as when the hologram was recorded.

The researchers hit on the idea for their holographic video when they realized that the mirrors of a digital micromirror device could function like the light-sensitive grains of holographic storage media, said Huebschman. In the researchers' system, the hologram is stored as information in a computer rather than physically stored in a medium. The computer controls the digital micromirror device.

In their original use projecting two-dimensional digital video, the micromirrors project light waves of different amplitudes. The researchers modified the device so that the mirrors projected the phase interference pattern of a hologram. "The inspiration was realizing that the micromirrors of the DMD are just large grains in a piece of film, and if a suitable hologram could be computed and that image placed on the DMD, it would interact with coherent light and then should function like a film hologram," he said.

The digital micromirror device is made up of 800,000 mirrors that are 16 microns across, which is about three times the size of a red blood cell. It is connected to a computer that controls the angles of the mirrors. Any of 256 shades of gray can be projected onto each of the mirrors at any time, providing a black and white holographic projection that can be controlled in real-time to make three-dimensional video.



Source: University of Texas

This image is a still taken from a 3D holographic video of a pair of jets flying past each other.

"The mirrors... being off or on are like the grains in a film emulsion being exposed or not," said Huebschman. "The shades of gray on the DMD hologram are analogous to the shades of gray of the grains in the emulsion hologram," he said.

One challenge to getting the device working as a holographic projection system was the size of the mirrors, according to Huebschman. Despite their relatively small size, the mirrors are larger than the grains of material that make up film, which limits the available projection angles.

The method can eventually be used in several types of three-dimensional displays, according to Huebschman. It is especially appropriate for heads-up displays in aircraft, military control systems and air traffic control systems, he said.

These applications have three things in common, said Huebschman. A three-dimensional view would allow a viewer to gain an additional element of information from a device he ordinarily uses; the device can be updated quickly; and all that needs to be projected to provide the extra information is a simulated object.

Further down the road, with better three-dimensional resolution, the method could be used to bring three-dimensional images to scientific workstations, computer games, flight simulators, x-rays and other types of medical imaging, and movies.

The combination of the device and real-time digital hologram recording equipment, which is yet to be developed, would make three-dimensional live television possible, said Huebschman.

Several other research projects are also aimed at providing three-dimensional video. A system developed by Actuality Systems, Inc. projects pixels in space to build a three-dimensional scene. These pixels are timed to reflect off a rotating plate so that they scatter to the correct locations at the right times. The University of Texas method takes less compute power than the three-dimensional pixel system because it uses the hologram to organize light patterns, said Huebschman. "That information is already available in a hologram," he said.

Another method developed at the Massachusetts Institute of Technology converts holograms into a pair of two-dimensional stereo views, then projects the images onto a user's eyes. "We start with a similar computer-generated hologram but rather than using complex opto-electric elements to project a stereo image, we project the image which results from the defraction of... light by the hologram," Huebschman said.

The Texas work takes a new approach to three-dimensional holographic video, said Hiroshi Yoshikawa, an associate professor of electronics and computer science at Nihon University in Japan. The interesting point is that the researchers are using phase modulation rather than amplitude modulation to achieve the dynamic three-dimensional projections, he said.

The researchers' next steps are making color holograms, improving the display equipment, and making a mobile, heads-up virtual image viewer, said Huebschman. "We are ultimately aiming for 3D TV," he said.

One of the main challenges is making larger arrays of digital micro mirror devices that have smaller mirrors, Huebschman added.

The method could yield practical three-dimensional heads-up displays in 1 to 2 years, x-ray machines in 2 to 3 years, workstations and flight simulators in 3 to 5 years, medical imaging equipment and movies in five to ten years, and live TV in 10 to 15 years, according to Huebschman.

Huebschman's research colleagues were Bala Munjuluri and Harold R. Garner. The work appeared in the March 10, 2003 issue of *Optics Express*. The research was funded by the Texas Board of Higher Education Advanced Research Program, the University of Texas Southwestern Center for Biomedical Inventions and the National Cancer Institute.

Timeline: 1-2 years, 2-3 years, 3-5 years, 5-10 years, 10-15 years
Funding: Government, University
TRN Categories: Data Representation and Simulation; Optical Computing, Optoelectronics and Photonics
Story Type: News
Related Elements: Technical paper, "Dynamic Holographic 3D Image Projection," *Optics Express* March 10, 2003

TRN

Cellophane Turns LCDs 3D

By Eric Smalley, Technology Research News
August 27/September 3, 2003

Sometimes ordinary items have more to them than meets the eye.

For the past couple of decades research teams have worked to make various types of three-dimensional displays; most methods include fairly complicated hardware.

A researcher from the University of Toronto has taken a different tack. As it turns out, a trip to the kitchen and a pair of polarizing glasses can turn an ordinary laptop screen into a 3D display.

The method could lead to extremely low-cost three-dimensional applications for scientific and medical imaging, and for games, according to Keigo Iizuka, a professor emeritus of electrical and computer engineering at the University of Toronto.

Source: University of Toronto

Cover half of a laptop screen with an ordinary sheet of cellophane, put on a pair of cross polarized glasses, and stereoscopic images like this doubled picture of an orchid will appear three-dimensional.

Iizuka's tests verified that a sheet of ordinary cellophane possesses the properties necessary to rotate the direction of white light polarization 90 degrees. Polarization has to do with the electric field of a lightwave. This electric field vibrates in a plane perpendicular to the direction of the light beam, and polarized light vibrates in only one direction in this plane. Glare is light that becomes horizontally polarized by reflecting off a surface, and sunglasses work by blocking horizontally-polarized light.

The combination of a computer screen showing two copies of an image that are polarized differently and a pair of glasses that blocks light polarized in different directions for each eye, will allow a viewer to see a different copy of the image with each eye.

This creates the illusion of three dimensions because the human brain judges distances based on the differences in the views seen by each eye.

Iizuka's method takes advantage of a property of the liquid crystal displays used in laptops and flat screen monitors. The top layers of the displays are polarizer sheets, which block polarized light that has been rotated by the liquid crystals that form characters and other marks on the screen, but let through the background light that remains polarized parallel to the polarizer sheets.

Because the light coming from a screen is already polarized, it is possible to rotate the polarization of the light coming from one half of the screen 90 degrees by simply covering that side with cellophane, said Iizuka. "The advantage of such a 3D display is that it is easy to fabricate with readily available components at minimum cost," he said.

The colorless, 25 micron-thick cellophane the researchers tested was better than the commercial half-wave plates usually used for the job, according to Iizuka.

"Cellophane's performance in rotating the direction of polarization of white light was superior to that of commercially available half-waveplates designed for a specific wavelength," he said.

Half-waveplates of the size needed to turn a laptop into three-dimensional display also cost 3,500 times that of an appropriately-sized sheet of cellophane, Iizuka said.

Cellophane's polarization properties are a byproduct of the strain it bears during its fabrication process.

Cellophane is made by extruding a cellulose solution through a narrow slit into an acid bath, said Iizuka. The unidirectional strain during the extruding process makes cellophane an anisotropic material that behaves like a calcite crystal, he said.

Anisotropic materials, which include wood, contain physical properties that are different in different directions. Wood strength, for example, is different along the grain than perpendicular to the grain.

In the case of cellophane, the refractive index of light, meaning the amount that light is bent as it passes through the material, is different in different directions. This makes light polarized in one direction pass through the cellophane at a different speed than light polarized in the other direction. "After transmission through such a medium, a phase difference arises between the two types of light," said Iizuka.

The refractive index and the thickness of the cellophane determine the amount of the phase difference between the components polarized in the x and y directions, said Iizuka. The 25 micron thickness used in kitchen cellophane turns out to make the phase difference 170.2 degrees— close enough to the 180 degree phase shift needed to rotate the polarization by 90 degrees. Twenty-five microns is about a third of the thickness of a human hair.

Not only is cellophane available at an extremely low cost, said Iizuka, it is available in large sheets, making very large three-dimensional displays possible.

In addition, the necessity of wearing polarized glasses can be eliminated by replacing them with a large crossed polarizer sheet suspended between the screen and the observer, said Iizuka. "In other words, let the computer wear the glasses," he said. This is possible in applications that have only one viewer at a time, he added.

Iizuka is working on making the technique more suitable for displaying sign language, he said.

The work appeared in the August, 2003 issue of *Review of Scientific Instruments*.

Timeline: Now
Funding: University
TRN Categories: Data Representation and Simulation; Applied
Technology; Graphics
Story Type: News
Related Elements: Technical paper, "Using Cellophane to Convert a Laptop Computer Screen into Three- dimensional Display," *Review of Scientific Instruments*, August, 2003

TRN

Display types

VR System Grabs 3D Video

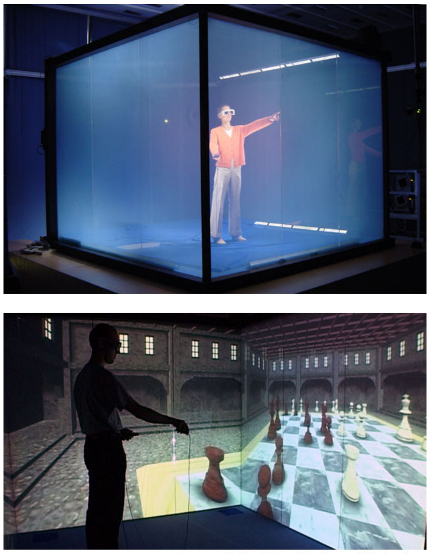
September 10/17, 2003

Technology has held out promises of virtual reality for years now, and such environments are slowly getting better. Researchers from the Swiss Federal Institute of Technology (ETH) have taken another step toward making virtual reality more real.

The researchers have expanded their blue-c virtual reality environment to include three-dimensional video acquisition. The system consists of a U-shaped portal of three glass-panel screens, and several video cameras that take pictures of the user in order to place him in the virtual scene in real-time.

The system could be used to more easily visualize large data sets, as a design tool for architects and engineers, for entertainment, and for collaborative applications, including videoconferencing, according to the researchers.

The glass-panel screens can be switched between a whitish, opaque state for projecting images onto, and a transparent state. The screens switch rapidly between the two states, and are synchronized with projection equipment and glasses worn by the viewer. This allows the cameras to



Source: Swiss Federal Institute of Technology

The glass walls of this virtual reality environment switch between clear and opaque faster than the eye can detect. This lets a user to see images on the walls while cameras outside capture a three-dimensional image of the user.

be placed out of sight behind the projection screens. The user stands in the U-shaped structure, and by looking to the front, left and right, gains an immersive view with his own real-time image included.

Real-time 3D video should be ready for commercial use in three to five years, according to the researchers. The researchers presented the work at the Association of Computing Machinery (ACM) Special Interest Group Graphics (Siggraph) 2003 conference in San Diego, July 27 to 31.

TRN

Artful Displays Track Data

By Chhavi Sachdev , Technology Research News
June 4/11, 2003

Taking a break from work to check email, a stock quote or airport delays may be easy as pie, but making these Internet rounds on a busy day can be an annoyance.

Many research projects are dedicated to making this information easy to monitor with a minimum of clicking. Researchers at the Georgia Institute of Technology have written software that also aims to make the experience aesthetically pleasing.

The InfoCanvas system displays an electronic painting that contains movable elements that represent categories of information. The elements shift as information changes. There are a variety of scenes—a desert, window view, aquarium, beach, and mountain camp. It's "a nice way of persistently communicating … information in a consolidated manner, one that is even a little fun," said John Stasko, an associate professor of computing at the Georgia Institute of Technology. The software, written in Java, runs on a PC with an always-on Internet connection.

The dedicated information screen in Stasko's office displays a beach theme. A sailboat moves from left to right between 9 a.m. and 6 p.m. to keep time. The type of clouds in the sky reflect the weather in Pennsylvania where his parents live. A large seagull shows the Dow Jones performance: minus 200 points is the left edge of the screen and plus 200 is the right. Mousing over elements in the image makes small text balloons pop up to display, for instance, "42 degrees." When Stasko gets email from his wife, a towel appears on the beach chair.

The software can handle 15 to 20 pieces of information, said Stasko. The researchers' current prototypes top out at 10 pieces of information.

The software is meant to run continuously on a dedicated display so people can check information simply by glancing at the picture. "We're exploring ways of helping people stay aware of secondary information in a peripheral manner, one that does not distract, interrupt, or annoy them," said Stasko.

And because the display uses abstract elements that can be customized, it allows people to monitor sensitive information, like bank balances, without revealing the information to everyone who enters the office.

Graphical elements can be made to appear or disappear, change form, move along a path, scale up or down, rotate, or populate an area according to changes in the associated data. News headlines and images can appear in the context of the scene, on a billboard or towed by an airplane, for example.

The software is valuable because it provides useful information in a way that does not demand immediate attention, said Scott Hudson, an associate professor of computer science at Carnegie Mellon University. In a world of ubiquitous computing, where each person has several electronic devices, "we can't continue to design systems so that they are only useful when they are the center of our attention," he said.

If information displays spread into places like living rooms, they will have to go with the other things there in terms of aesthetics, said Hudson.

Source: Georgia Tech

The elements in this scene move and change to present information without demanding a person's full attention.

To produce the prototypes, the researchers interviewed potential users and had them position paper cut-outs of images on a canvas and describe how they would like the cutouts to represent data, said Todd Miller, a Georgia Tech researcher.

The researchers are currently working on interactive software that will allow users to customize their own pictorial displays, Miller said.

Making sure there is an easy way for users to personalize the displays is important, said Hudson. "Given how many households have flashing 12's on their VCRs it should be clear that most end-user's don't have the patience for anything that looks remotely like programming," he noted.

The researchers are also working on adding voice and touch screen capabilities to the pictures, Stasko said.

Stasko and Miller's research colleagues were Shannon Bauman, Julie Isaacs, Jehan Moghazy, Chris Plaue and Zack Pousman. They presented the research at the Computer-Human Interaction (CHI) 2003 meeting in Fort Lauderdale, Florida, on April 7, 2003. The research was funded by the National Science Foundation (NSF).

Timeline: Now
Funding: University
TRN Categories: Human-Computer Interaction; Graphics
Story Type: News
Related Elements: Technical paper, "InfoCanvas: A Highly Personalized, Elegant Awareness Display" at Computer-Human Interaction (CHI) 2003 Conference, April, 2003; Shareware customized for the Atlanta region is available for download at www.cc.gatech.edu/gvu/ii/infoart/downloads.html

TRN

Teamed Computers Drive Big Display

By Chhavi Sachdev, Technology Research News
October 17, 2001

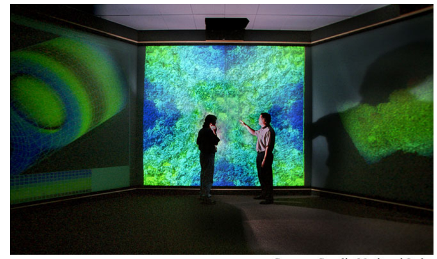
Remember the big board that dominated the Pentagon's War Room in Dr. Strangelove? On it, tiny warplanes inched relentlessly towards Russia and a nuclear nightmare. Researchers at Sandia National Laboratories have built a high-resoultion large screen display that exceeds the speed of current graphics rendering systems more than 50 times. The display will be used for, among other things, simulating nuclear weapons like those that closed out Kubrick's masterpiece.

The 10- by 13-foot display turns large sets of visual data into three-dimensional images. "The data is continuously being rendered such that it can be rotated or panned or zoomed... it's fully three dimensional. Move the mouse and the application will update the… fully three-dimensional data," said Carl Leishman, a principal member of technical staff at Sandia. Users can also change and animate objects, he said.

The system takes six seconds to render a complicated image containing about 470 million of the triangles that graphics programs use to render the different shapes and edges of images, Leishman said. Current high-end graphics systems would take five minutes to do the same, he said.

The researchers were able to render a large amount of data quickly by processing the images in parallel. The Sandia system ties together the outputs of graphics cards from a cluster of 64 computer processors. Each computer handles about 7.3 million triangles of data for a total of 470 million.

A high-end graphics card in an individual PC can render 10 to 15 million triangles per second on a single screen, said Leishman. "Since we have 64 of these cards, the theoretical maximum rendering rate we can achieve is around 350 million triangles per second," said Kenneth Moreland, a member of the technical staff at Sandia. The images are then combined on a 4x4 array of 16 projectors that beam the composite image onto the large screen.



Source: Sandia National Labs

This 10- by 13-foot high-resolution computer display is driven by 64 computer processors.

The researchers were able to render 300 million triangles per second on a single screen. However, when more screens were added, the rendering rate decreased. The current system renders about 80 million triangles per second on the 16-screen array with each of its 64 graphics cards, Moreland said.

The 10x13-foot display has a total of 20 million pixels or exactly 16 times as many as a high resolution 1024x1280 pixel computer monitor and about 80 times as many as a typical television. Having more pixels when rendering very complex computed data means more detailed data can be shown, Leishman said.

There are many other large display arrays in use today, mostly in control rooms, flight simulators and planeteria, but with much lower resolutions, said Leishman. The Hayden Planetarium, for instance, uses seven projectors to put about 7.4 million pixels on its ceiling display. None can manage as many pixels or as much data as the Sandia display, however, he said.

The researchers estimate that a person with perfect visual acuity cannot see individual pixels on a high-end computer screen beyond 2 to 3 feet. For their screen, they estimate the greatest distance from which a person can see a clear picture is more like 10 feet. "The point isn't that the display is exceptionally fine grained, but that it's exceptionally high resolution and that we have the ability to interactively render [it]," Leishman said.

Resolution is a function of how many pixels a screen contains, while grain is a function of how close the pixels are, according to Leishman.

Rendering extremely large datasets is particularly important for the extremely high fidelity simulations programs must compute for the Department of Energy's Visual

Interactive Environment for Weapons Simulations (VIEWS) program, Leishman said.

The system will find practical applications in weapons simulations, biological investigations, nanotechnology and other areas, he said. "Keeping in mind our program's engineering requirements for nuclear weapon stockpile stewardship, we think we have an important practical use right now. We expect much of the software to be made available via open source distribution within one year," said Leishman.

The research area is interesting and large high-resolution screens could be produced on a mass scale in a few years, said Terry Winograd, a professor of computer science at Stanford University.

The screens could be used as big picture windows and also as interactive tools, he said. "Think of people who work in non-computer settings—they put things on boards, they put things on walls, they move them around, they do things with them. I think there's a lot of interesting potential for interacting with the wall, with the stuff that's up there instead of interacting with a keyboard and small screen," Winograd said.

Back-projected screens are expensive and awkward, he said. Front projection "has obvious problems like when you stand in front of it you block it." They can't be used in a conference room in general. But when large self-contained displays like Sandia's become more practical and can essentially just be nailed to a wall, they will become more commonplace, he said.

The researchers plan to increase the system's capacity and capability by improving both software and hardware, Leishman said. The Sandia system uses commercially available graphics cards, he said. "Everything is built from normally available commodity hardware." This allows quick and easy integration of next generation equipment, he said.

Work on the next generation system should begin within 2 to 3 years, he said. "We will soon have 48 projectors in a 12x4 array displaying 64 million pixels," said Leishman. That projector screen will be 38.1 feet wide and 10.2 feet high. The rendering will not be as fast because more pixels mean slower rendering, said Moreland. To overcome this, the researchers plan to upgrade to a larger cluster of more than 64 processing units, Moreland said.

Leishman and Moreland's colleagues were Brian Wylie, Constantine Pavlakos, Vasily Lewis, and Philip Heermann. A part of their research was published in the July/August 2001 issue of the journal IEEE Computer Graphics Applications and a second part was presented at the IEEE Symposium, Parallel and Large Data Visualization and Graphics, 2001. The research was funded by the Department of Energy (DOE).

Timeline: >1 year
Funding: Government

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Related Elements: Technical paper: "Scalable Rendering on PC Clusters," IEEE Computer Graphics and Applications, July/August 2001. Technical paper: "Sort-Last Tiled Rendering for Viewing Extremely Large Data Sets on Tiled Displays," submitted to IEEE Symposium, Parallel and Large Data Visualization and Graphics, 2001

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