

Sponsored By

SPECTRUM

Winner: Black, White, and Readable

By: **Tekla S. Perry**

How many little monochrome displays do you have in your house? Lots, probably. They're on alarm clocks, the digital tuner on your radio, the bathroom scale, and the thermometer in the medicine cabinet. There's one on the control panel of your microwave, and yet another, probably, on your refrigerator or dishwasher. Don't forget the thermostat in your living room, your calculators and wristwatches, the indoor-outdoor thermometer, and your MP3 player. You'll likely find even more if you look in your briefcase or car.

For 30 years, at least, the mainstay of the market for these simple numeric and alphanumeric displays has been liquid-crystal-display technology. LCDs are cheap—a 5- by 8-centimeter display can cost a product manufacturer as little as 60 U.S. cents if bought in quantity—but they leave a lot to be desired. Without backlighting, they have poor contrast ratio and poor brightness, so they're hard to read in ambient light that's very bright or dim. With it, though, they consume too much power and are nearly unreadable in bright environments. LCDs are also rigid and difficult to make lightweight, which further inhibits their use in mobile gadgets. What manufacturers have long wanted is a display that is power-thrifty, cheap to make, and as crisp and easy to read as ink on paper, in all lighting conditions. A display like that could carve out a huge piece of the consumer market for LCDs and other low- information displays, a market valued at US \$1.2 billion annually.



PHOTO: NTERA LTD.

ON TIME: Ntera's high-contrast displays, such as the one in this alarm clock, could soon replace many of the liquid-crystal displays found in homes and offices.

Now a Dublin, Ireland, company with a total of 35 employees says that after 7 years of intensive development it is about to introduce just such a product. Engineers at Ntera Ltd. are ramping up the first commercial production line to produce a technology the company calls the NanoChromatic display (NCD). "I first saw the technology four or five years ago," says Nick How, a display industry veteran who joined Ntera as president in 2003. "That was the first time I had seen something stunning and different that could compete with LCDs." He expects the first products to use these displays—a thermostat and a wall clock—to hit the market in a matter of months [see photos, "Razor Sharp" and "On Time"]. After that, Ntera executives hope, the display industry will never be the same.

Though located in Europe, Ntera is something of a throwback to the glorious beginnings of Silicon Valley, when people with plenty of ideas and fervor and not much money started companies in garages and strip malls. Ntera's modest laboratory in an industrial park on the outskirts of Dublin is in a cement-block building next to a small furniture distributor. Ntera's own desks and chairs are mismatched, and the walls are unadorned. It's quite a contrast with Microsoft's lavish Ireland campus, just down the street.

In October, a visitor found Ntera's offices eerily quiet, suggesting the calm before the storm the company will unleash on the display market. Only a couple of engineers, the product manager, one executive, and a receptionist were on hand; everybody else was in Taiwan, transferring the technology to a rented production line, or elsewhere in Europe or the United States, lining up customers.

The first thing that strikes you about the NCD is its stark, razor sharpness, with nearly black images on an almost luminous, paper-white background. Text is easy to read in most lighting conditions, with a contrast ratio of 6:1—and a brightness of at least 4 times that of an LCD. It's that stunning white that sets the display apart from an LCD. Nevertheless, the two display technologies do share a few traits: they both have two glass sheets, separated by a fluid-filled gap; they therefore weigh about the same. From a commercial perspective, the similarities mean that the two technologies can be manufactured on almost entirely the same equipment, hence at almost equal costs.

But in power consumption, there's no contest. NCDs are power-frugal because of two factors. First, the high contrast ratio eliminates the need for any kind of separate lighting system, even when viewed in bright sunlight. Second, unlike LCDs, NCDs do not need to be constantly refreshed.

An LCD contains liquid-crystal molecules that are sandwiched between two coated sheets of glass that are polarized at 90 degrees to one another. The liquid crystals have a natural twist that allows light to enter one end and exit the other. By varying the electric field through the display, the crystals are made to untwist, blocking the passage of light. That creates dark areas—pixels—on the display, for as long as the voltage is maintained.

With an NCD, on the other hand, the principle requires electrically charging a material to change its color. Placing another charge-storing layer on the second glass sheet as a source of charge for the electrochromic material lets the image remain for as long as several hours. This is because both plates separately retain their opposite charges, in much the same way as a capacitor retains its charge. To clear the display, the voltage is reversed, sending the ions back to the storage layer. Depending on the chemicals used and the application, a new jolt of current may be needed infrequently, from every 10 minutes to once an hour. Basically, the display draws current only when the image is changed.

Electrochromism has been known for decades: IBM, for example, had a major development program in electrochromic displays in the 1970s and early 1980s. Bayer AG, in Leverkusen, Germany, also researched the technology and was even awarded several patents, but it also failed to make a practical display. Today, a number of companies in Europe and the United States are still trying to turn the phenomenon into products, including Siemens, Aveso (a Dow Chemical spin-off), and Acreo.

All have been stymied by the limitations of electrochromism. One of the most significant problems is the delay needed to produce an optical change, one full second or more. Because of this delay, electrochromic applications have shown up only where the tint doesn't need to change quickly—for example, in an automobile's rear-view mirror. A number of cars today are equipped with automatically darkening mirrors, which Gentex Corp., of Zeeland, Mich., began selling to the automotive industry in 1987. (The more commonly known self-tinting sunglasses, for example, work by a different process, called photochromism. Sunglasses are coated with silver chloride or silver halide or impregnated with a photosensitive compound that changes chemically in the presence of ultraviolet light. The molecules morph into a new shape that blocks more light. That won't work for a rear-view mirror, because car windows are themselves tinted to block UV.) By the 1990s, electrochromism started falling out of favor among researchers looking to build the next big thing in digital displays.

The Ntera story actually begins in the early 1990s in a laboratory in Switzerland. It was there, at the École Polytechnique Fédérale de Lausanne (EPFL), that Donald Fitzmaurice, a postdoctoral student from University College Dublin, and Michael Graetzel, a professor in EPFL's Institute of Chemical Sciences and Engineering, began investigating how nanosized particles, placed in a nanostructured film, retained many of the properties of the film material used. The technique also created a huge surface area, one that was the sum of the individual nanoparticles' surface areas. The research goal at the time was to build better solar cells. But one day in 1991, Fitzmaurice noticed that these nanostructured semiconductors darkened slightly when he applied current. Exploiting this electrochromism, he reasoned, would be useful in his research, because the darkened areas would let him see the paths the electrons were following through the nanostructures.

Fitzmaurice and Graetzel attached electrochromic molecules to a film of semiconducting nanoparticles, effectively creating a film that was many hundreds of layers of electrochromic molecules thick. A charge applied through the semiconducting particles caused the molecules at the surface to be charged and therefore to change color. Because the film was many layers of particles thick, the optical change, barely detectable in only one layer of particles, was surprisingly dramatic. The two researchers immediately began thinking of applications. Perhaps they had a better contender for the rear-view mirror market, or could even realize the longstanding goal of creating windows that changed tint, making buildings more energy-efficient.

And then they realized that if they put a white layer of film behind their device, they would have a reflective, high-contrast display that had a wide viewing angle, switched fairly quickly, and consumed little power. For some uses, it would be darn near perfect. "We thought we had a candidate for the electronic paper market," Fitzmaurice says. "There were electronic paper technologies out there, but there was no clear winner."

Fitzmaurice finished his postdoc year in Lausanne and returned to University College Dublin. He continued to work with nanostructures and electrochromic materials with a group of about 15 graduate students. The group applied for two basic patents on the technology, and on the basis of those patents in 1997, got a grant totaling \approx 250 000 (about US \$295 000) from the European Union to set up a company to commercialize the technology.

Fitzmaurice hired David Corr, now Ntera's chief technology officer, to run with the technology. Fitzmaurice himself took an 18-month sabbatical in 2000 to work with Ntera full-time. That was also the time of its first venture funding, from Cross Atlantic Capital Partners, in Radnor, Pa. Some \$35 million has been poured into Ntera so far by Cross Atlantic and other investors.

Moving such a new technology from the laboratory to the marketplace isn't for the faint of heart. The researchers had to find a good substance for the white coating—the reflective layer. They settled on titanium dioxide, which also whitens toothpaste and the coatings on pills. (It's the active ingredient in many sunscreens, too.) They adopted techniques such as etching the glass substrate in order to group particles into pixels. Their biggest hurdles, though, were electrochemical.

Within the display, the two sheets of glass are bonded together at their edges. The inner area between them is filled with an electrolyte solution that balances the charges on the two sheets. The color-changing layer is attached to the piece of glass that forms the front of the display. This layer is, at heart, a film of titanium dioxide particles 15 nanometers in diameter—smaller than the wavelengths of light and therefore transparent. The electrochromic molecules are coated on each of the nanoparticles, forming a layer a bit like the coating on a tennis ball.

The developers struggled to find the perfect electrolyte—one that would help stabilize the system as a whole. Ultimately, they found a suitable one, which they won't identify; it is their most important trade secret.

There were other challenges: they had to figure out a way to protect the device from sunlight, which also degraded the molecules. That problem was solved with a UV-blocking film. Finally, they developed and patented an electronic drive system and worked with display manufacturers on the electronics that would switch each pixel on or off.

Ntera's researchers had solved most of the fundamental problems of the technology and could now consider fabricating its first product on glass. While Ntera's researchers worked on the design, the company's founders, at the urging of their investors, narrowed their market ambitions. They discarded color-changing glass and mirrors, such as self-tinting windows, because these were difficult markets for a small, new company to break into. They also decided to defer pursuing e-books, which would have required them to develop completely new manufacturing equipment. That left them with the low-information display business—a huge market that was already well established and one whose existing plants could be used with virtually no changes. "We realized that with a judicious choice of materials and structure, we could make this on a basic LCD line," Corr says.

Etching pixel patterns on the glass mimics the analogous method in LCD manufacture, and the screen-printing process is used in both manufacturing schemes. LCD panels are then coated with a layer to allow alignment of the liquid crystals, and NanoChromics panels are dipped in a solution that contains the electrochromic molecules, which attach themselves to the semiconducting particles in the nanostructured titanium dioxide film. In fact, would-be manufacturers of electrochromic displays need to add just one piece of equipment to their LCD setups: an oven, to bake the nanoparticles that form the film. "We believe that we can take an existing LCD manufacturing facility and change it into an NCD producer for about \$250 000," says Ntera's CEO, Peter Ritz.

Ritz expects that in the long run, manufacturing NCDs will prove to be cheaper than producing LCDs. For one thing, NCDs have a greater tolerance for defects, and therefore yields are expected to be higher.

Exactly how to make a business out of a technological advance wasn't immediately clear to the Ntera founders. Seeing themselves as researchers more than businessmen, the team initially envisioned Ntera as a holding pen for intellectual property, licensing their breakthroughs to others who would turn them into products.

But after a few years the executives realized that they would have to make products themselves, at least initially—hence the fabrication line in Taiwan. After the technology catches on, Ntera plans to get out of the manufacturing business. What it wants to do is control production of the inklike slurries of nanoparticles and electrochromic molecule formulas, which it will sell to licensees, much in the way Coca-Cola sells its secret syrup to bottlers. The company also expects to collect royalties from products made with its inventions.

Meanwhile, Ntera plans to continue developing and extending its basic technology, in hopes of moving beyond the low-information display market into sexier stuff. Ntera envisions three such product extensions already—full-color, active-matrix displays, like those ubiquitous in laptop computers; flexible plastic displays for use in clothing and packaging; and transparent displays, for which a first application might be an electronic iris for cellphone cameras.

Right now, NCD displays are monochromatic, though they can come in different colors, depending

on the specific oxide used. But Ntera executives see no reason why they can't get a piece of the market for full-color active-matrix displays in mobile devices like phones and PDAs. So far, they've identified electrochromic molecules that reflect blue and green—two of the three primary colors needed to make all of the colors visible to the human eye. The third color, red, has been more elusive, but, says CTO Corr, a solution for red appears to be close.

Nor has Ntera entirely given up on the still-nascent—but potentially huge—market for roll-up newspapers and other flexible displays.

"One of the big advantages of our technology is that it can be migrated onto plastic," Corr says. Plastic can replace the glass plates of an NCD because the technology does not require a precise and stable distance between the two plates, as is the case with an LCD. Warping or bending the display may push the electrolyte around a little but has little or no effect on the color-changing molecules that create the image. Yet another possibility is transparent displays, which Ntera has already begun experimenting with. Making an NCD transparent simply means leaving out one of the layers of titanium dioxide particles.

In any of its markets, the NCD will face off against a variety of contenders. LCDs, of course, have the benefit of industry inertia. In addition, several companies have their own electrochromic displays in the works. Siemens AG, in Munich, Germany, recently demonstrated a small printable display, which it hopes to have on the market in 2007. Printable, flexible electrochromic displays are also under development at Acreo AB, in Kista, Sweden, and Aveso Inc., in Fridley, Minn. Given the number of options available, "any display technology is in for quite a challenging time," says Adrian Geisow, manager of displays research at HP Labs Bristol, in England.

But Ntera seems to stack up well against many of its apparent opponents developing new flat-panel technologies. Organic electroluminescent display (OLED) technology, which, like NCD, is potentially flexible, requires a large capital investment—tens of millions of dollars at least—and costs, Nick How estimates, about \$3 per square inch to make. A product of equivalent size containing Ntera's technology would cost a fraction of this—as little as one-tenth, by some estimates.

"Perhaps somebody we don't know about has a cracking good idea that is so good and easy to make that in two years they'll have a jump on us," Corr says. "But I sure don't see anybody like that out there."

Meanwhile, as this article was going to press, the first commercial NCD products were rolling off the assembly line. You'll see them soon on store shelves. And Corr and Fitzmaurice will be proud papas. "To this day, eight years after we made the first one, I do believe it really is a thing of beauty," Corr said. "And it is just cool to say that this is something I helped bring to life."

With additional reporting by Steven Cherry.

NanoChromics Display

GOAL: Create an electronic display for the consumer market as easy to read as paper.

WHY IT'S A WINNER: It looks like ink on paper, and it has a high contrast ratio and a wide viewing angle. It's visible everywhere, even in bright sunlight. It consumes little power and is cheap to manufacture.

ORGANIZATION: Ntera Ltd.

CENTER OF ACTIVITY: Dublin, Ireland.

NUMBER OF PEOPLE ON THE PROJECT: 35 and growing.

BUDGET: Approximately US \$35 million to date.

Figure 1



RAZOR SHARP: David Corr, chief technology officer of Ntera, thinks the high-contrast, low-power display of the future is at hand.

PHOTO: PETER EVERS; IMAGE MANIPULATION: MIKE VELLA