LIQUID CRYSTALS, FROM ODDITY TO NECESSITY | THE MAN WHO GAVE US LEADED GAS AND FREON

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IT'S A PLANE

One man's obsession, it helped get us to the moon

LIQUID CRYSTALS

HOW A USELESS LAB ANOMALY GREW UP TO BECOME AN INDISPENSABLE PART OF HUNDREDS OF EVERYDAY DEVICES

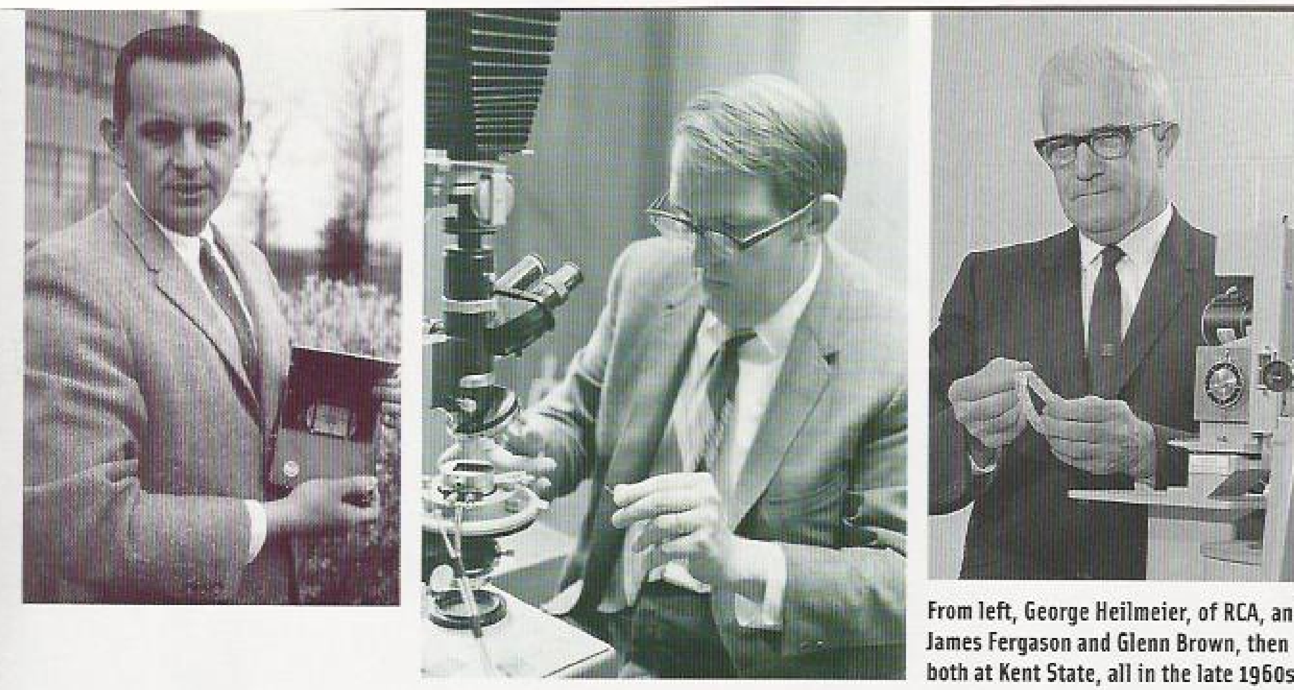
BY LINDA HAMILTON

In the 1960s liquid crystals hit the media as the stuff of sci-fi futuristic fantasy, a magical type of chemical that would soon be able to see through the human body and bring to life Dick Tracy's TV wristwatch or a television set you could roll up like a magazine and stuff into your back pocket. Then in the 1970s came the Mood Ring, color-changing jewelry that could supposedly reveal your true emotions and help guide your love life. There were serious innovations by scientists in industry, medicine, and academia too—and they also had a tint of unreality about them. The public saw numbers flashing and disappearing on wafer-thin screens, bodies painted black and turning colors in medical labs, and plates of clear plastic turning green and blue at the presence of dangerous gases.

Forty years later liquid crystals are everywhere around us, and we take them for granted. When you glance at your digital watch, you're looking at liquid crystals. Or when you read the thermometer in your fish tank, write an e-mail on your laptop, consult your Palm Pilot, or set your microwave or coffeepot, and probably when you look at the speedometer on your dashboard. Liquid crystals may be in every room in your house; they are used in tens of thousands of high-tech consumer and industrial products, adding up to a multi-billion-dollar industry that turns out new applications every day. Yet not so long ago scientists dismissed them as a laboratory curiosity.

The liquid-crystal phenomenon was first reported in 1888 by Friedrich Reinitzer, an Austrian botanist. (Previous researchers had observed unusual behavior that we now know was caused by liquid crystals, but

The cholesteric liquid crystals painted on the man's upraised hand changed color after he inhaled, illustrating the effect of smoking on circulation, 1967. Opposite: An RCA researcher peers at an early prototype clock, late 1960s.



From left, George Heilmeier, of RCA, and James Fergason and Glenn Brown, then both at Kent State, all in the late 1960s.

they had not investigated it further.) Studying the compound cholesteryl benzoate, he discovered that it had two distinct melting points. At 145 degrees centigrade it turned from a solid to a cloudy liquid; at 179 degrees the liquid became clear. The next year, a German physicist, Otto Lehmann, found using a polarizing microscope that the cloudy liquid had a crystalline molecular structure. He suggested the name *liquid crystal* (along with the now-discarded *crystal liquid*) and earned the not widely recognized title of father of polarizing microscopy.

Liquid crystal refers to any substance that behaves as both liquid and crystal at the same time. This sounds contradictory. A liquid flows; a crystal is rigid. Indeed, in ordinary liquids, such as water, molecules move around, spin, and bump into one another; in solid crystals, molecules are no longer free to move or spin but sit stiffly in space, all oriented the same way (though they are free to vibrate about their positions in the crystal lattice). Because of this, the optical and electromagnetic properties of an ordinary liquid are isotropic, meaning that they are the same in all directions, while those of a crystalline solid can be anisotropic, varying strongly with direction. A liquid crystal combines these characteristics, behaving mechanically like a liquid but optically like a solid.

Liquid crystals usually consist of long molecules, shaped something like a cigar, that can move about somewhat, as in an ordinary liquid, but that all always point nearly the same way, as in a solid crystal. They so align because they are packed too closely together to move freely. This explains how a substance can be as runny as glue yet have optical properties like a prism's, reflecting and scattering light, often in a rainbow of colors, in response to a number of stimuli.

Imagine a tray filled with pencils. If you shake it very gently, the pencils will stay in place. If you shake it violently, the pencils will orient themselves in more or less random fashion. If you shake it at a moderate rate, however, the pencils will move freely from side to side, up and down, or along their axes, but they will always stay pointed in the same direction. This intermediate state corresponds to a liquid crystal.

Liquid crystals can be divided into three classes. In the first, nematic, the molecules all line up in the same direction but exhibit no other large-scale structure and are free to move about. In the second, cholesteric (also known as chiral nematic), the molecules are arranged in layers and are oriented parallel to the layer planes (that is, the molecules in each layer are lying on their sides). In the third, smectic, the molecules also form layers, but they are perpendicular to the layer plane (that is, they stand on end). For this reason, the layers in smectic liquid crystal are much thicker than those in cholesteric. Most of the early applications of liquid crystals involved the first two classes, though in recent years smectic applications have started to be developed.

Otto Lehmann observed that liquid crystals are remarkably sensitive. They respond to heat, light, sound, mechanical pressure, electromagnetic fields and radiation, and some chemical vapors. They can register the minutest fluctuations in temperature with a change in color, like a highly responsive chemical chameleon. Lehmann dedicated 25 years of work to studying the strange chemicals, producing four books and ending his career in 1915 with the first paper in English on the subject. In his last book he suggested many applications, mostly in power generation and transformation, but none of them proved practical. Liquid crystals in thermometers, thermographs, computers, TVs, and solid-state devices were too far in the future to imagine, and his contemporaries didn't take his work seriously. Many of them wrote off liquid crystals as chemical impurities with no scientific or practical merit.

Still, chemists still played around with liquid crystals in the lab. In the 1930s John Dreyer, an American scientist, discovered that liquid-crystal molecules would align themselves along a surface that had been rubbed repeatedly in the same direction. He used this technique to make polarizers, with which he fabricated polarized lenses for sunglasses. He also made the first 3-D movie glasses. For the next 20 years,

OVERLEAF, LEFT—DAVID SARNOFF LIBRARY; RIGHT—J. R. EYERMAN/TIMEPIX; THIS PAGE: LEFT—DAVID SARNOFF LIBRARY; CENTER AND RIGHT—KENT STATE UNIVERSITY ARCHIVES; OPPOSITE: COLLECTION OF LOUIS A. ZANONI, COURTESY OF DAVID SARNOFF LIBRARY

polarizers were the main use for the materials, and most scientists still saw the field as a laboratory circus act, while most of the industrial world knew nothing about it. Then, in 1956, Glenn Brown, a chemistry professor at the University of Cincinnati, happened on liquid crystals while looking for a research topic for his graduate students.

Brown became fascinated and started to read whatever he could find about liquid crystals. Together with W. G. Shaw, a graduate student of his, he wrote a review of the existing literature in *Chemical Reviews*; the article, called "The Mesomorphic State," was widely read and stimulated new interest, and it spurred Brown on to a lifetime of study of the materials. That same year, 1956, Westinghouse Electric assigned a young physicist named James Fergason to explore ways of using thermal imaging in making vacuum tubes for televisions. He observed the optical properties of liquid crystals for the first time in November 1957 and made them the subject of his thermal-imaging research. He would become one of the foremost pioneers in the field of liquid-crystal optics, and today, at 68, he is among the nation's most prolific living inventors.

At Westinghouse, Fergason had to fight to form the first nonacademic scientific group anywhere whose primary focus was liquid crystals. "First off," he says, "I had to get people to believe there was such a thing as liquid crystal, even though it's colorful and all that sort of thing, and get them to believe that it was more than just a lab curiosity. And it took a lot of measurements and a lot of work. Then I had to show them not only that liquid crystal was important but also that what you did with liquid crystal was important."

A snapshot records RCA's first successful use of color in a liquid-crystal display, 1965.

FOR A WHILE IT LOOKED AS IF BIOLOGY WOULD BE THE MAIN FOCUS OF LIQUID-CRYSTAL RESEARCH, EVEN CURING CANCER.

Studying the physics, chemistry, and electronics of the phenomenon, Fergason's group soon had results they could publish and patent. In 1958 he invented the first important application, cholesteric liquid crystals that turned colors dramatically as the temperature changed. Two years later his group started to develop an optical-display system. Since liquid crystals don't produce light but only reflect or transmit it, they can create patterns or change color using very little energy. Right away, he started to see many uses, but he didn't have the support to move forward with product development at Westinghouse. "In fact," he says, "it took from 1957 until really 1964 for the potential of liquid crystal in products to be recognized enough to get real interest and funding. That was when I published the article in *Scientific American*. It was a big leap forward."

In that piece, titled simply "Liquid Crystals," Fergason suggested that thermal mapping could locate anatomical features beneath the skin, pinpoint structural flaws in metals, and make possible a variety of temperature-sensitive warning devices. He followed up the article by teaching classes on the subject at the University of California, Penn State, and other colleges. "The word started to spread," he says.

By the mid-1960s liquid crystals were accounting for at least one of every 200 new organic compounds synthesized in a lab. In 1960 Glenn Brown had moved to Kent State University, in Ohio, and five years later he had raised enough interest there to form the Liquid Crystal Institute, which is still the nation's largest academic center for basic and applied research in the substances. (The center was renamed the Glenn H. Brown Liquid Crystal Institute in 1986.) He also put together a conference on the chemicals. It continues every two years to this day.

Fergason and Brown joined forces at Kent State from 1966 to 1970, bringing together Brown's expertise in X-ray diffraction and probing techniques with Fergason's focus on practical uses. Together they went forward with the medical applications Fergason had first experimented with at Westinghouse. They found they could use liquid crystals for thermal mapping to screen for breast cancer and other medical conditions. *Life* magazine showed this to the public in 1968 with a full-length photograph of a woman's bare back, her skin a swirl of dramatic blue, green, brown, and black according to her body temperature. Liquid crystals had been painted onto her, over a black background for enhanced color, and were mapping the variations in body heat that correlated with changes in blood flow. This simple procedure could reveal circulatory effects of diseases, including hemophilia, arthritis, and diabetes. A medical journal responded to liquid-crystal mapping by calling the procedure a "kaleidoscopic window on disease." The *Life* article also showed a test illustrating how just a few puffs of nicotine restricted blood and heat to the body's extremities. It ran not far from a full-page Marlboro ad.

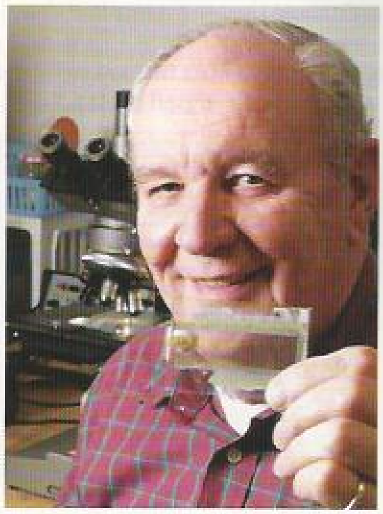
A few doctors, finding liquid crystals safer than X-rays, began painting them on patients to outline tumors, precisely locate the placenta in a pregnant woman, measure varicose veins, see allergic reactions, and monitor the temperatures and sensory reactions of newborn babies undergoing treatment. To avoid applying liquid crystals directly to a patient's skin, the Bayer Corporation developed equipment that used a plastic-enclosed liquid-crystal plate for breast exams. The apparatus rode on wheels and supported the liquid-crystal plate on a metal arm connected to a photographic recording system. It had a fan to cool a patient's breast before the plate was placed against it. In retrospect, it's no wonder that such thermal mapping was hard to sell.

"People had already invested a lot in electronic thermal imaging, cameras that sense infrared light, showing thermal patterns," says Fergason. "They saw how to make money with it. They didn't see how to make money with liquid-crystal thermal mapping, so we didn't do very well there. But we tried. Starting in 1970, it got pretty popular in France, Spain, and a few other places, but it never caught on in the United States, and I think that was a mistake. Companies had margin goals and didn't think they could make the margins."

Thermographic techniques also began to be used in industry to analyze stress in car springs, test for faulty circuits and bonding defects in electronic components, and detect escaping gases. They, too, were successful for a short time. But liquid-crystal thermal imaging was eventually replaced with high-resolution digital infrared imaging, in which cameras and computers could do the same work with no need to paint the body or object black. Moreover, doctors found that liquid-crystal mapping couldn't replace X-rays, though it could enhance the analysis. Also, there was a built-in inaccuracy to much of the medical imaging. Panels like those in the Bayer system affected the temperature of the skin when they pressed against it. Today's cameras record heat patterns remotely.

Life had reported that "biologists trying to understand the sensory processes have found that the body contains some substances that act like liquid crystals. This discovery may in time help explain how we see and touch and think." Fergason and Brown co-wrote papers and lectured about the role of liquid crystals in the human body, for it turned out that cell membranes are liquid-crystalline in nature. They embody a type of system called lyotropic, in which the liquid crystal's behavior responds, often dramatically, to the presence and concentration of a solvent. The discovery that liquid crystals were a part of human cell structure was extremely important to the basic study of how cells work, and for a while it seemed that biology would become the main focus of liquid-crystal research, leading to important applications for human health and even to cures for diseases like cancer. But as industrial and consumer development came to the forefront, this field came to be scantily funded and all but forgotten.

John Janning holds the first display using his process that obviated rubbing.



Xerox was among the first businesses to begin experimenting with liquid-crystal displays, in the mid-1960s. The company devised a copying process in which a liquid-crystal film, activated electronically, created a sharp temporary image. *Life* predicted that this might "one day make it possible to produce signs and billboards with liquid crystals that can display moving words and pictures. Conceivably, a similar screen could be built into a telephone of the future on which a caller could leave not only an erasable message and number but also an erasable picture of himself." This was prescient. Nowadays in Tokyo at least, businessmen staring down at a talking face on their cellular videophones are a common sight.

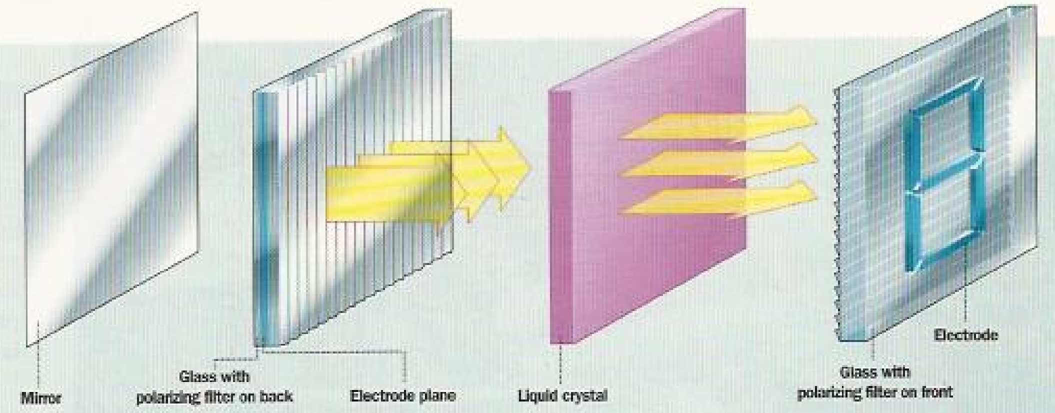
JANNING'S BOSS REACTED TO HIS IDEA "LIKE I WAS NUTS.... SO I JUST WENT UP TO MY LAB AND DID IT MYSELF."

"Today LC technology is a big deal," Fergason says. "In the sixties few saw the potential of it, but by 1970 people started coming into the field in a major rush, because at that point there had been 14 years of education." Xerox, National Cash Register, Donnelly Mirror Company, Hoffman–La Roche, Boeing, Westinghouse, and RCA were among the many firms investing in it by the mid-seventies. Suddenly corporate scientists were racing to see who could get a display to market first.

Jim Fergason left Kent State in 1970 and set up shop above

LEFT: RAY MCCOY/*DAYTON BUSINESS JOURNAL*; RIGHT: STEVEN STANKIEWICZ

HOW IT WORKS



A LIQUID-CRYSTAL DISPLAY (LCD) is a sandwich containing two plates of glass with polarizing filters that are perpendicular to each other. Under normal circumstances, no light could pass through. In an LCD, however, the area between the glass plates is filled with liquid crystals, and the inner side of each plate is grooved in the direction of polarization. Under these conditions, the liquid-crystal molecules form spirals that rotate the polarization of the light, allowing it to be transmitted.

In addition, the bottom plate is covered with a layer of a transparent conducting substance. Areas meant to be blacked out (the 8 in our illustration) are covered with the same substance on the top plate. When a current is applied between one or more segments of the 8 and the bottom plate, the liquid-crystal spirals in between untwist and stop rotating the light. This makes the corresponding areas of the display appear dark. In a laptop computer screen, the same principle is used on a much finer level, allowing the display to be controlled pixel by pixel.

a real-estate office nearby, gathering some fellow scientists in a small firm called International Liquid Xtal Company, or Ilixco, to create a marketable display. By the following year they had developed an effect called the twisted nematic, which has since been cited in hundreds of liquid-crystal patents. The twisted nematic became the foundation of the multibillion-dollar liquid-crystal display industry.

The breakthrough was an LCD consisting of two plates of glass with liquid crystal sandwiched between them. The plates were equipped with polarizing filters on their outer sides. These were arranged perpendicular to each other, but Fergason's breakthrough allowed light to pass through the sandwich nonetheless. The inner side of each plate had been rubbed about 100 times with a cotton cloth in the direction of polarization. When the liquid-crystal film was in place, the molecules immediately next to each rubbed surface lined up with the direction of rubbing. The molecules in between the two surfaces formed spirals that rotated the polarization of the light by 90 degrees. This twisting behavior gives the technology its name.

Fergason knew that an electric current would cancel the tendency to spiral, making the sandwich opaque. So he covered one of the glass plates completely with a transparent conducting material and applied it to certain areas of the other. These areas were connected with wires to a power source, and when a current was applied, they were blacked out. By turning the current through the various sections on and off, Fergason could display letters and numbers.

Ilixco sent out prototypes to companies working with liquid crystals, and scientists gathered in labs to watch the digits come and go. The big problem was that the displays lasted only a couple of weeks before moisture got in and ruined them. John L. Janning, at National Cash Register in Dayton, watched his colleagues prepare a Fergason display and grew so intrigued that he immediately went to work to make an LCD that would last. Before long he found a way to align the crystals without rubbing. Instead he evaporated a layer of silicon monoxide 18 molecules thick on the glass. By tilting the glass at an angle to the vertical during evaporation, he could make the silicon monoxide condense in microscopic parallel lines.

"When I first suggested this at NCR, my boss looked at me like I was nuts," he remembers. "He looked at me like, Well, if that would have worked, I would have done it. So I just went up to my lab and did it myself. Success first shot." It turned out that Janning's calculations had created the optimum position for a deposited film, and his standard is still used today. His resulting patent made it possible to seal displays hermetically, a major step toward the large-scale manufacture of LCDs.

Five developments now came together to produce the displays that made the first LCD watches available in the early 1970s: semiconductor technology, twisted nematics, the identification of liquid-crystal materials that worked at room temperature and low voltage, Janning's silicon monoxide method, and good conductive thin glass, which was supplied by Optical Coating Laboratory, Inc. "It was an evolutionary kind of thing," Fergason says, "where we took a base of knowledge and brought it into the mainstream with our applications. I'd worked on electronic displays before, as far back as 1962, but we hadn't built a successful display, and nobody had built a successful display for commercialization before we built the twisted nematic."

He says about his patent for it, "You start out by discovering the basic principles of liquid crystals, and once you understand them, they represent a scientific base. Your understanding puts you ahead of everybody else, and maybe you understand them in a different way from other people. We had developed a body of knowledge: what they do when you put an electric field on them, how you can use that change in properties. Most of these changes had been recorded even in the earliest days, but not understood. So you have this body of knowledge that is both yours and other people's, and you go look at it and you look at what needs to be done. There was a lot of talk about watches that needed

A prototype watch at RCA's labs is dwarfed by the electronics needed to run it.

displays. We knew there was a need for new displays, and we acted on it."

Existing display technologies were floundering at the time. Most of them relied on red light-emitting diodes, which were power-hungry yet offered poor resolution. You generally had to push a button to light the display, and even so, they'd quickly run through batteries. The new LCDs were at once far more efficient and relatively cheap and easy to mass-produce.

Fergason's prototype, an eight-digit display commissioned by Donnelly Mirror, was unveiled at an electronics show in Cleveland in 1971, and it was an instant hit. The world had seen its first twisted-nematic digital clock and wanted more. The first liquid-crystal watches soon followed (see "Time's New Face," page 27), and in a few more years consumers all over the world owned them.

Competition grew fierce, and many companies decided that the slow evolution of the technology meant they didn't have to honor Fergason's patent. "I would tell them they were infringing, and they'd say, 'Sue us.' But I couldn't sue anybody." His little company, Ilixco, employed only 100 people, and he didn't have the resources for legal battles. The Swiss company Hoffmann–La Roche, then the world's largest pharmaceutical firm, filed for a patent on the same technology based on work done by Martin Schadt and Wolfgang Helfrich. But when Fergason adduced his earlier work, his patent was upheld. "There are still some arguments about who invented the liquid-crystal display phenomenon and all that sort of thing," he says today, "but there are no arguments about who built the first ones and who invented the display itself. I invented the display and thus the phenomenon."

Since he didn't feel he could go to court, he sold his patent rights to Hoffmann–La Roche in 1972. The company promised him a million dollars in cash and half of all U.S. royalties, plus a smaller amount for foreign sales. Hoffmann–La Roche licensed the technology mainly to Pacific Rim and European firms, and by the 1980s Japan was dominating the market with an annual production of 500 million display units, representing about three-quarters of the market.

The display industry took off, and digital watches and calculators filled stores overnight. Before long the displays appeared on coffee machines, microwaves, VCRs, and other appliances. But they had limited use. They were slow and dull by today's standards, lacked definition and color, and worked poorly in outdoor light. However, with thousands of scientists racing to create new liquid-crystal materials and applications, improvements and changes came rapidly.

In 1977 new liquid crystals were made that resisted moisture, so manufacturers dropped hermetic sealing and went back to rubbing (or aligning the cells with epoxy stamped with tiny grooves). "That's where we are today," Janning says. "Rubbing is simpler and cheaper to manufacture, but not better. When high-quality, high-contrast displays are necessary, they still use my alignment method." Evaporation avoids the dust particles and surface charges that rubbing can introduce.

Many calculators worked with a separate wire connected to each element on the display that lit up. This was very fast, but a larger unit would have required a tangle of wires too cumbersome to be practical. So scientists came up with a multiplex system of rows and columns, which allowed an element to be controlled wherever a horizontal and a vertical wire came together. This permitted the display of small, simple graphs and the use of short-term memory. The next step was color and added speed. Fergason made a major improvement on the twisted-nematic LCD with his surface-mode liquid-crystal shutter, patented in 1974, in which a switch for each pixel turned clear or opaque in less than 50 microseconds. In 1983 the Oregon-based Tektronix Inc. announced an invention that was quite similar to Fergason's and started selling products based on it, including a three-dimensional graphic display and a monochrome computer monitor that could display color with liquid-crystal shut-

LEFT: COLLECTION OF LOUIS A. ZANONI, COURTESY OF DAVID SARNOFF LABORATORY; RIGHT: ERIC LONG, SMITHSONIAN INSTITUTION

TIME'S NEW FACE: LIQUID CRYSTALS IN YOUR WRISTWATCH

Manufacturing them seemed nearly impossible—and then much too easy BY CARLENE STEPHENS AND MAGGIE DENNIS

In 1970 two small start-up companies—Optel, near Princeton, New Jersey, and James Fergason's Ilixco, in Kent, Ohio—decided to gamble on making liquid-crystal displays a reality. Two years later both were ready for something completely new: the digital wristwatch. False starts and missteps had bedeviled them, but they had paved the way not just for watch displays but for LCDs of all sorts.

Optel began in early 1970, after a restless RCA employee named Zoltan Kiss had made his way through the company's labs the previous year looking for potential colleagues for his own business. He didn't even have a particular product in mind, but he recruited a staff and put almost everyone to work on his own research project. Only a couple of technicians worked on liquid crystals, but that effort flourished by drawing on fundamental research that had been done at RCA.

There a physicist named George Heilmeier had demonstrated the potential for liquid-crystal displays back in 1964. RCA's management had supported his work for a while, hoping it might be the answer to the dream the company's chairman, David Sarnoff, had of a flat-panel TV that could hang on a wall. Heilmeier put together a team that made new discoveries almost daily, synthesizing a material that worked at room temperature and observing the dynamic scattering effect, in which liquid crystals scattered and reflected ambient light to show up as milky gray characters over a dark, mirrored background.

But Heilmeier and his team had faced numerous obstacles. Although management was supportive, some product-development people saw liquid crystals as easily concocted by any competitor, while others predicted insurmountable sealing and packaging problems or the lack of a market. So in 1970 Heilmeier left RCA in frustration and took a job in the government.

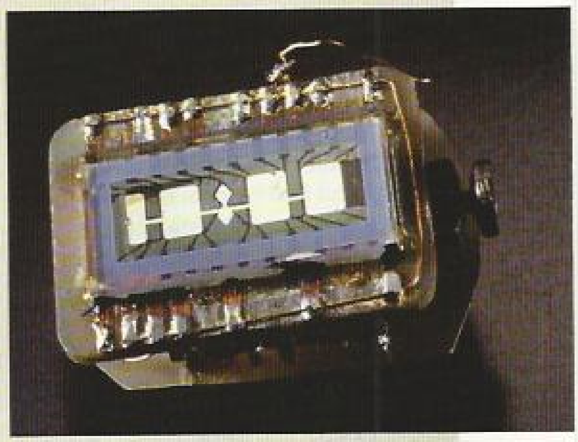
Optel's liquid-crystal group presented the dynamic scattering effect at an electronics trade show in Houston in the summer of 1970 and met with a spectacular reception. Then they put together a digital-display prototype small enough for a wristwatch, to demonstrate that it could be easily manufactured. The liquid crystals were contained in cells to form the seven-segment digits familiar today, indicating hours and minutes, with a flashing colon for the seconds. Kiss immediately sought backing from watch manufacturers, and he got it from both Bulova in the United States and SSIH in Switzerland, the company that made Omega and Tissot watches.

The watch industry was in turmoil at the time. Electronic components and vibrating quartz crystals were beginning to replace gears and balance wheels, and in 1970 Hamilton announced the world's first electronic digital watch, the Pulsar, with no hands or dial but rather a bright-red light-emitting-diode display. It went on sale in 1972. But it was so power-hungry it couldn't shine continuously; the user had to push a button to see the time. And it cost $2,100, as much as a small car.

James Fergason first saw the Pulsar not long after he founded Ilixco (see main text). He realized that the energy efficiency of his twisted-nematic technology (which was superior to that of Optel's dynamic-scattering method) would make it especially suitable for watches, and he performed his attention-getting demonstration in Cleveland in 1971. Soon Ilixco had contracts for watch displays too.

Both start-ups had a hard time. Bulova signed development contracts with both Ilixco and Optel but failed to pursue the projects past the prototype stage. Ilixco and Optel both accepted huge orders only to find that they couldn't meet their deadlines as they faced problems with moisture contaminating the liquid crystals and with the suppliers of other components for the watches.

Nonetheless, LCD watches soon hit the stores. Optel promised its biggest customer, Waltham, displays for 25,000 watches for the 1972 Christmas season but could deliver only 2,000. Ilixco filled its first orders for Gruen in 1973 and went on to produce others for Timex and Seiko.

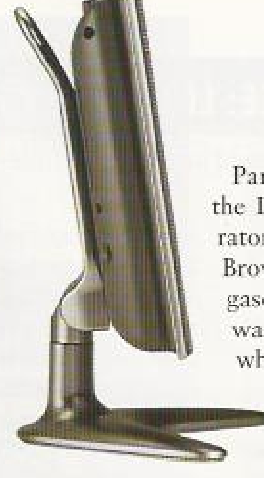


Optel began its effort with prototypes like this unhandsome one.

Then companies like Fairchild and Motorola moved in, and within a few years nearly 50 other outfits flooded the market with digital watches. Quality suffered while prices plunged, and consumers returned faulty watches in record numbers. To get decent contrast, you had to hold a watch at just the right angle; you couldn't tell time in the dark; many of the watches were plain ugly. The glut forced new companies to pull out almost as quickly as they had gotten in. Most went out of business entirely.

As American manufacturers retrenched, Japanese firms stepped in. They sent representatives to learn from American companies. Foreseeing a future full of portable electronic devices needing low-power displays, businesses including Seiko, Sharp, Hitachi, and NEC committed to improving LCDs and producing a host of new products. Their success was sealed in 1983 when Seiko introduced the world's first LCD television wristwatch (with a receiver in the user's pocket). Its tiny screen was a giant step toward Sarnoff's dream of a TV on the wall.

__Carlene Stephens__ is the curator in charge of the time collections at the National Museum of American History. __Maggie Dennis__ is a historian with the Lemelson Center for the Study of Invention and Innovation at the museum.



A contemporary LCD television offers sharp colors in bright light and at wide angles.

ters. Involved in other projects and still short on cash, Fergason didn't sue until 1988, and after a jury decided in his favor, he and Tektronix settled out of court in 1993.

The first laptop monitors, in the late 1980s, were made with a refinement to the twisted-nematic display called super-twisted-nematic, which rotated light as much as 270 degrees instead of 90. It wasn't adequate for long, so active-matrix technology, today's standard, followed. In an active-matrix display, the light is provided by a fluorescent source behind the screen, and each pixel is controlled by a liquid-crystal shutter that turns different colors on and off.

Inventors found more and more other applications. Janning went on to invent the thermal printing wafer, which is used in thermal fax machines, and the plasma display, whose orange numbers you can see at supermarket checkouts. In the early 1980s new polymer-stabilized liquid crystals made possible coated windows for buildings that could be turned electronically from clear to dark to opaque. Many hospitals, hotels, and institutions have them. In the early 1990s Fergason's company Optical Shields, Inc., began selling LCD goggles to the military to protect soldiers' eyes from laser weapons and flashes from nuclear explosions. They respond to radiation by triggering a phase that reflects back the light. The welding industry now uses that technology in most of its masks.

Back in 1964 George Heilmeier, a liquid-crystal pioneer at RCA, had predicted that wall-size flat-panel color televisions were just around the corner. That application is still in its infancy and is being developed around the world. The largest commercially successful screen so far measures about 20 inches across.

Some researchers in the 1970s headed in other directions, especially ones using thermochromics, the subject of Fergason's first patent (1963) and articles, in which liquid crystals react to temperature changes with color changes. Snow, wax, and mercury salts are all thermochromic; snow, for instance, goes from opaque white to clear as it starts to melt. One of those researchers was this author's father, Robert Parker. Parker, a young engineer at the Livermore Radiation Laboratory in California, read both Brown's paper in 1956 and Fergason's article in 1964, so he was ready in the late 1960s when, amid his work on nuclear warheads, he was given some cholesteric liquid crystal to see if he could use it to trace electron beams and map the heat of lasers. He began experimenting with liquid crystals on his own time and constructed a prototype of a digital thermometer, with hand-painted numbers that changed color as the temperatures they indicated were reached.

The material he used for the numbers faded and cracked quickly. "Cholesteric LCs would oxidize, chemically degrade in air," he explains. "I had the idea for the thermometer, but the materials hadn't matured enough." That was solved when a team of scientists at National Cash Register invented a way to encapsulate tiny spheres of liquid crystal in a gelatin base, which insulated them from the air. Parker's next problem was that cholesteric, or chiral nematic, liquid crystals were degraded by ultraviolet energy. "So I started making the thermometers with large transparent pieces of plastic to block out the ultraviolet, and used ultraviolet coatings for longer life."

In spring of 1972 he put his digital thermometer into mass production and started his own company, Robert Parker Research. "Before I even started RPR," he says, "I gave a phone interview to *The Wall Street Journal*. It was on Leap Day 1972. I told them the thermometers were going to be a big business, and as a result of the story I had an order for 100,000 units before I even started. It turned out pretty much like I told them."

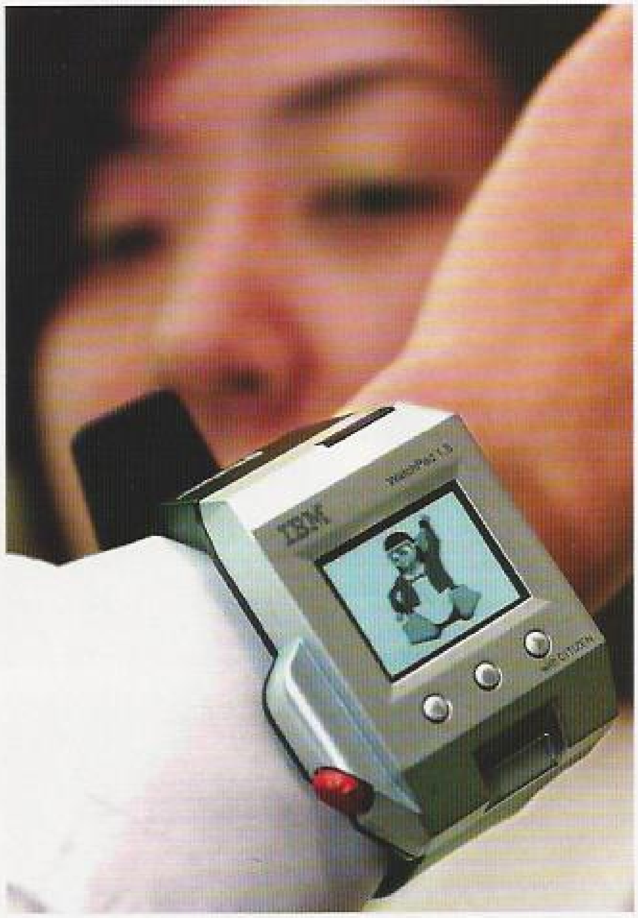
In 1975 Josh Reynolds, a New York City businessman and marketer who would later bring the ThighMaster to the world, approached Parker with an idea for a piece of jewelry containing a film of liquid crystal inside a clear drop of glass or plastic. In the following months Parker's company produced millions of what Reynolds named the Mood Ring. For a moment it captured the world's attention. The rings made their debut at 30 dollars apiece; the cost almost immediately dropped as low as 30 cents, and imitations were

FERGASON BELIEVES HE HAS ALREADY COME PRETTY CLOSE TO SEEING THE DICK TRACY TV WATCH HE LOVED AS A BOY.

LEFT: COURTESY OF SHARP ELECTRONICS CORPORATION; RIGHT: AFP/CORBIS made around the world. "It turned out to be a fun kind of thing," Parker says, "and I have fond memories of it, not only for all the money we made but also because it was fascinating. The total market lasted three months. It wasn't a long life, but it was a good one. Of course, I did the follow-up product, which was Mood Panties." Since then Parker has devised a sterilization indicator that sells in Third World countries, the Eggrite, which shows when eggs are boiled, the Pasta Per'fect, which does the same for noodles, and the Grill-Per'fect, for meats.

In the 1980s he developed the tester strip for Duracell batteries, which took 10 years to reach store shelves but helped Duracell build its lead in the battery market. Liquid Crystal Resources, of Northbrook, Illinois, which manufactures many of these products, also sells vials with thermometers for urine testing ("to insure urine submitted in drug testing is the correct temperature and therefore fresh," according to the company). Other companies sell baby bottles with temperature indicators and a host of novelty items, including liquid-crystal mouse pads. John L. Janning invented a doll that, when hugged, gets rosy cheeks.

Much undoubtedly lies ahead. With the popularity of handheld organizers, touchscreen technology is a growing field. Flat screens for home televisions, pocket televisions, and computer monitors remain in their infancy. The push for marketable electronic books has generated a search for a screen that looks like paper. But Jim Fergason believes he has already come pretty close, with the Sony Watchman, to seeing in life the Dick Tracy TV watch he loved as a boy growing up on a Missouri farm. "I like to just sit on a plane and count how many LCD products there are in the in-flight magazines," he told a reporter in 1993. He has received more than 125 patents and was inducted into the National Inventors Hall of Fame in 1998.



IBM and Citizen are developing an LCD computer watch with wireless capability to handle e-mail and other electronic communications.

"Field-emission displays, that's what you'll be seeing next," John Janning says. "Light-emitting just like the picture tube on a television, except that they're flat and maybe a quarter inch thick and give off light. Today's liquid crystals act like a light valve, blocking it or letting it through. Field emission creates light, so it's a radical departure. It'll be in televisions, monitors, everywhere. That's what you'll be seeing all over the place in 2006 or '07." Like Fergason, Janning, at 74, is still inventing, though his career has taken him away from liquid crystals.

John West, the current director of the Liquid Crystal Institute at Kent State, believes that the most important new direction is a return to biological uses, in which Kent State is leading the way. Recent advances include using liquid crystals to encapsulate drugs and in viral-detection devices. "Basically, you dissolve an antibody in the liquid crystal phase," West explains, "and it doesn't disturb the phase. But when a bacterium or virus binds with the antibody, it becomes large enough to disturb it. You can actually see it. Being both immediate and cost-effective, it has moved very quickly from the laboratory to the marketplace. New companies have started to commercialize this technology."

Glenn Brown's widow, Jessie, recently funded an endowment to support graduate research into biological liquid crystals. The potential appears great, as West puts it, "once you have a conceptualization that cell membranes are liquid-crystalline and therefore in an ordered system, and of why they're ordered and how this phase behavior works."

"Liquid crystals will always be around," Janning says. "Some people may say, 'This new technology or that one is going to take over.' Well, hey, Edison created the electric light bulb, and then when inventors came out with other lights, fluorescents and stuff like that, people said that they were going to take over. No. The incandescent light burns on. There will always be liquid crystal."

John West agrees. "Biologically speaking," he says, "life is liquid-crystalline." ★

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