Brilliant Displays

A new technology that mimics the way nature gives bright color to butterfly wings can make cell phone displays clearly legible, even in the sun's glare

By M. Mitchell Waldrop

KEY CONCEPTS

- Interferometric modulator (IMOD) displays can produce brilliant colors by exploiting the physical effect of interference while using little of the limited battery power in mobile devices such as cell phones. They are also readily seen in bright daylight.
- The basic unit of an IMOD display is a tiny mechanism that consists of two mirrored surfaces with a gap between them. The gap determines the color that reflects back when light strikes the display.
- Qualcomm, a large wireless electronics firm, hopes that IMOD technology can make inroads in a mobile electronics market dominated by liquid-crystal displays (LCDs). *—The Editors*

The next time you buy a cell phone, take a close look at the display panel. If things go the way Qualcomm hopes, that colorful little rectangle could give a whole new meaning to the expression "butterfly effect." True, the interferometric modulator (IMOD) displays recently introduced by the San Diego–based firm have nothing to do with the unexpectedly strong effect a wing beat can theoretically have on the weather. But the devices do use an array of artificial microstructures to produce the same kind of iridescent colors as are seen on the wings of tropical butterflies. And Qualcomm is betting that its approach will give IMODs several advantages over today's dominant liquid-crystal-display (LCD) technology.

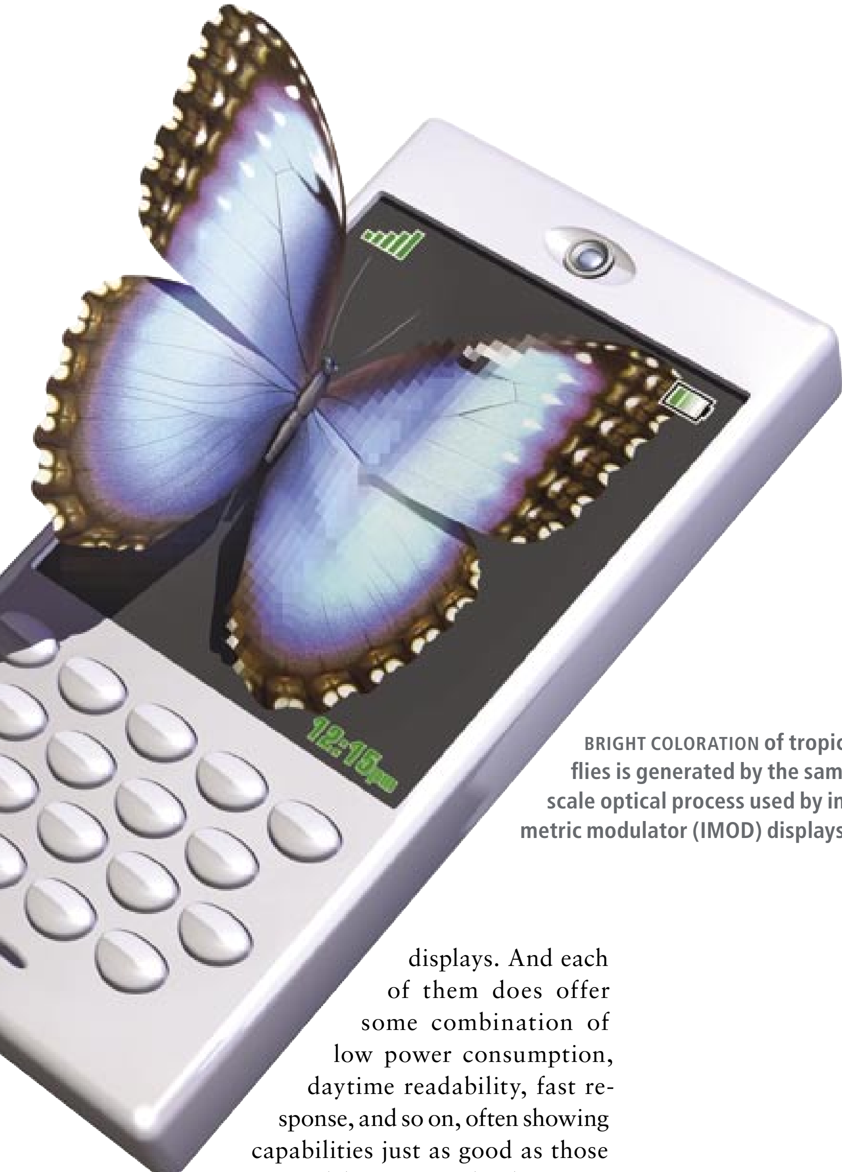
Most important is that an IMOD display is much easier on a handset's battery—a characteristic that will matter more and more as people increasingly use cell phones for Web browsing, text messaging, and playing games, videos and music. Such intensified use poses a severe power-management challenge for LCDs, most of which cannot be read at all unless they have a backlight shining up through them. But an IMOD display simply reflects ambient light the way paper (or a butterfly wing) does.

"So an IMOD consumes as little as 6 percent of the handset's battery power, versus nearly 50 percent for an LCD," says James Cathey, Qualcomm's vice president of business development. And that means that an IMOD-equipped handset should run a lot longer on a single charge—even allowing for the supplementary illumination it would need for low-light situations. "In a typical usage scenario, we estimate that an IMOD-equipped phone would give you 140-plus minutes of video time, versus 50-plus minutes with an LCD display," he notes.

Being reflective, IMOD displays are also far easier to read in bright daylight: rather than turning black, as most LCD displays effectively do, they actually get clearer and more vivid. "If you're using your phone for video, text, pictures, you want the same viewing quality in many environments," Cathey says.

IMOD displays can also switch their basic unit cells on and off within about 10 microseconds, roughly 1,000 times faster than LCD displays can, a feature that makes them considerably better suited to video. And IMOD displays are at least as rugged as LCDs. Qualcomm has tested the IMOD unit cells through at least 12 billion on-off cycles, the equivalent of more than seven years of continuous operation, without a failure.

Of course, there are many other alternatives to LCDs, ranging from OLEDs (organic light-emitting-diode) displays to electrophoretic "e-paper"



BRIGHT COLORATION of tropical butterflies is generated by the same nanoscale optical process used by interferometric modulator (IMOD) displays.

displays. And each of them does offer some combination of low power consumption, daytime readability, fast response, and so on, often showing capabilities just as good as those possessed by IMOD displays. But none of them can deliver all such features at once, which is why Qualcomm is so hopeful.

A Multidecade Odyssey

The idea that became IMOD first occurred to Mark Miles, then a Massachusetts Institute of Technology electrical engineering major, in 1984, when he was working at a summer job with Hughes Aircraft in Los Angeles.

"I happened to read an article that discussed how you might use arrays of submicroscopic antennas to convert sunlight directly into electricity," Miles recalls, "and I was fascinated." He was familiar with the large-scale antennas used for radar, television and broadcast radio. And he had learned that radio waves are basically the same as ordinary visible light waves: both are intertwining electric and magnetic fields, rippling through space at 300,000 kilometers a second. The only difference is that radio waves are measured from crest to crest in centimeters, meters or even kilometers, whereas light waves are roughly a million times as short. The visible range extends from about 700 nanometers (red) to about 400 nanometers (violet) from crest to crest, with all the other colors of the rainbow in between.

Despite knowing all that, Miles had never put those two concepts together to imagine a microscopic device able to manipulate light waves. "Then it occurred to me," he recalls. "If you could somehow control the characteristics of these microstructures—change their absorption and reflection as needed—you could make an incredible display." It would be just a flat panel, far more compact than the bulky cathode-ray tubes (CRTs) that were standard in televisions in those days.

True, Miles did not have the slightest idea how to build such a display, but no matter. After he finished his studies, he worked as a programmer in the computer printer industry and, in his spare time, researched the problem and discussed it with professors at M.I.T.

From one of those professors he learned about an optical device that would do exactly what he wanted. The Fabry-Pérot interferometer, or etalon, is basically a cavity formed by two reflective surfaces aligned in parallel. When light passes into the cavity through the top surface, which is translucent, it reflects from the bottom surface—and then bounces back and forth between the surfaces ad infinitum, with a little bit leaking out of the top each time. Thanks to a phenomenon called interference, all this bouncing causes most wavelengths of light to cancel themselves out. But the rebounding waves actually reinforce the reflection of wavelengths that just happen to fit precisely in the gap between the surfaces [*see box on next page*]. So, in effect, the etalon as a whole functions as a mirror that reflects only one specific color, which you can choose simply by changing the spacing between the surfaces.

The technique was perfect for Miles's purpose—except for one thing. Etalons were certainly an invaluable laboratory tool for measuring and controlling light, but for a high-resolution display, he needed to shrink them down to a microscopic scale and then array them across a screen surface by the millions, with small groups of them forming a single pixel (picture element). As it turned out, nature had already accomplished that feat: the iridescent colors on the wings of tropical butterflies, such as the blue morpho, are caused by nanoscale structures that function very much like tiny etalons. But how

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GEORGE RETSECK (*PDA*); BEN ZWEIG (*Waldrop*) was Miles going to make such minute structures? And, not incidentally, how was he going to turn the pixels on and off?

The question stymied him until he learned of microelectromechanical systems (MEMS)—tiny silicon-based machines. The basic idea of MEMS, which date back to the 1970s, is to carve microscopic mechanical structures into the surface of a silicon wafer by applying the same techniques used to create microprocessors. MEMS researchers had already learned to produce all manner of gears, springs, cantilevers, channels and the like, some of which were starting to reach the market.

"MEMS opened another path for me," he says. "Creating actual devices." Having no experience in MEMS fabrication, Miles continued to write software by day to support himself and spent his evenings taking an M.I.T. extension course on MEMS. Once that was completed, he wrangled permission to use the university's MEMS fabrication facilities. Eventually he arrived at a workable concept: the first version of IMOD. In essence, it was a microscopic etalon in which the parallel reflecting surfaces were thin-film layers created using MEMS techniques. During the fabrication process, the spacing between the films could be set to reflect a specific wavelength, or color. In this configuration the etalon would correspond to a unit cell in the on state.

Because the bottom layer was flexible, however, changing the unit cell to off was easy: one just had to apply a very brief voltage between the surfaces. The resulting electrostatic attraction would make the bottom layer bulge upward, thus narrowing the gap and shifting the reflected wavelength down into the invisible ultraviolet part of the spectrum, which appears black. Moreover, the unit cell would *stay* black, without consuming any further power, until the time came to flip it back to colored. And that was simple, too: one just had to apply another voltage pulse.

These first IMOD devices were crude and ugly, Miles admits. But they worked well enough that he could begin to see a path toward commercialization. By the mid-1990s he had quit his job and joined with his former M.I.T. classmate Erik J. Larson to found Iridigm in Cambridge. Cash was very hard to come by as they slowly refined the technology, but within a few years one of the firm's investors—Qualcomm—decided that it was time to acquire the company outright. Iridigm became the Qualcomm MEMS Technologies unit in October 2004.

A Tough Market

To succeed, IMOD is going to need all the help it can get. Competition in the handheld-display market is fierce, says Chris Chinnock, managing director of Insight Media, which specializes in news and analysis about the display industry. "LCDs are the gorilla here," he says. With a multidecade head start on technological develop-

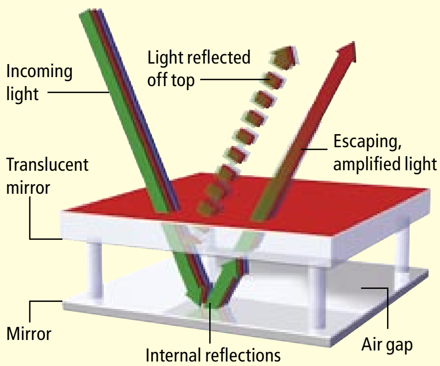
[THE BASICS]

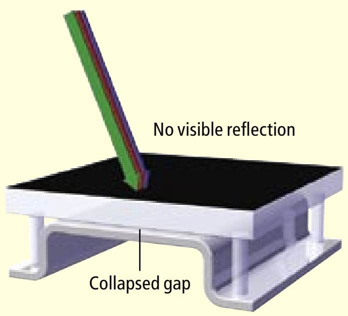
HOW IMOD WORKS

Interferometric modulator (IMOD) displays use interfering light waves to create bright colors on demand. Each basic unit cell produces either a single color (*top*) or black (*middle*). Placing many unit cells into arrays forms pixels, or picture elements (*bottom*). Qualcomm currently produces bichrome displays composed of single-color cells, but it says full-color displays, as depicted, are on the way.

COLORED UNIT CELL

The IMOD unit cell consists of two parallel, mirrored surfaces. When light hits the structure, some reflects off the top and some passes through the translucent top mirror into the gap, where it reflects internally. A little light, however, leaks out with each upward bounce. Many of the escaping light waves (*green and blue in this example*) will be slightly out of phase with those rebounding off the top as well as with other escaping waves. These waves will cancel one another out via destructive interference. But other reflecting light waves that are in phase (*here, red*) will add (constructively interfere) and so will be visible to the eye.



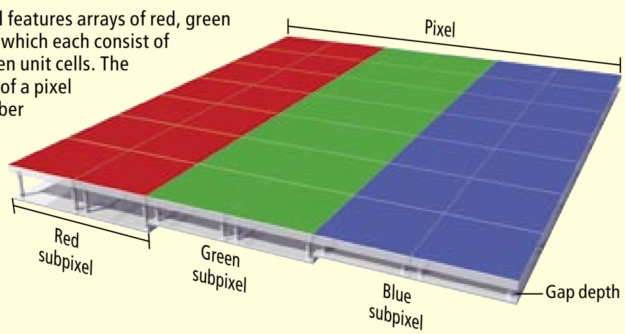


UNIT CELL IN BLACK STATE

A colored unit cell turns black when an applied voltage produces an electrostatic attraction between the mirrors, thereby collapsing the air gap. The black color appears because the shrunken gap shifts the reflected light into the invisible, ultraviolet range. Another voltage pulse reverses the cell back to color.

FULL-COLOR PIXEL

An IMOD color pixel features arrays of red, green and blue subpixels, which each consist of two columns of seven unit cells. The hue and brightness of a pixel depend on the number and color of activated cells. Gap depth determines if the cells are colored red, green or blue.



GEORGE RETSECK

ment and manufacturing infrastructure, LCDs have been systematically conquering every segment of the flat-screen market, from handhelds to computer monitors to wall-mounted TVs. “So going up against them head-to-head is like a death wish,” Chinnock warns. And then there are all those other LCD alternatives—OLEDs, e-paper and the like, not to mention the many variations on basic LCD technology itself.

Still, the market is huge. “The leading cell phone manufacturer, Nokia, makes 350 million handsets a year—almost a million per day,” Chinnock says. The annual worldwide output is in the billions. And that is not even counting all the digital music players, personal digital assistants, GPS receivers and other handheld electronics. “So it doesn’t take much market penetration to have significant sales,” he concludes.

Qualcomm’s challenge has been to get the company’s IMOD devices out there. It is one thing to make a display work in the laboratory, Qualcomm’s Cathey says, but quite something else to create a robust consumer product. He asks, for example, “Can you adapt it for mass production?” The answer to that question turns out to be yes: the individual IMOD unit cells are much simpler than their LCD counterparts but similar enough that IMOD displays can be made in existing flat-panel fabrication facilities. That is a huge advantage, Cathey says, because building a completely new fab facility is a billion-dollar proposition. But then you have to work on manufacturing yields: What fraction of the displays coming off the assembly line actually work? Likewise, quality control: “A display is right out there in front,” he says. “If there are dead pixels, or areas of nonuniformity, people see them.” And cost control is paramount, Cathey adds. “In this market we *have* to be price-competitive.”

Finally, there is the issue of color. Just as in any other display, LCDs included, a color display requires that each of its pixels actually consist of three subpixels: one for each of the three primary colors. And each of those subpixels has to have several unit cells, or sub-subpixels, that can be turned on or off independently, so as to produce a range of color and brightness. In this case, Cathey says, individual IMOD unit cells will need to be less than 100 microns across to produce a good-quality display.

Given this steep learning curve, Cathey says, the company’s strategy has been to start small and build, gaining experience and working out the production bugs as it goes. Qualcomm’s initial products are only bichrome—black lettering on a background of, say, gold. But full-color IMOD displays are on the way, he reports. “We haven’t released the upper-end resolution. But we will be able to compete with other technologies on that score—and maybe even exceed them.”

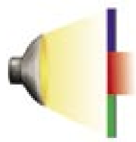
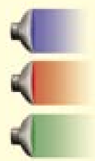
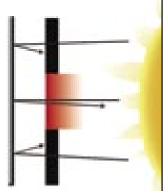
Qualcomm’s first publicly announced licensing agreement, this past May, was with the Korean electronics firm Ubixon, which will market a line of IMOD-equipped Bluetooth headsets that provide the user with a wireless connection to cell phones and digital music players. The bichrome IMOD screens will display text messages and song titles.

Obviously, Qualcomm is hoping that IMOD technology will catch on quickly. Although Cathey cannot discuss the research in detail, he says the company is in the meantime investigating a variety of nondisplay applications. As Miles points out, “IMOD is a very powerful photonic device and can be integrated with many other kinds of devices that are involved in manipulation of light.” Still, Cathey says, displays are where IMOD should ultimately shine the brightest—from handsets and camcorders to electronic books, computer monitors, wall-mounted TVs and beyond. “We can scale to that,” he says, “but give us some time!” ■

[THE BIGGER PICTURE]

COMPETING TECHNOLOGIES

IMOD technology is entering the tough, multibillion-dollar mobile-display market, which already includes several other approaches. Liquid-crystal displays (LCDs) currently dominate, but organic light-emitting-diode displays (OLEDs) are finding application niches.

DISPLAY TECHNOLOGY	ADVANTAGES	DISADVANTAGES
LCD Optically active material modulates an artificial light source, such as a backlight 	Inexpensive, widely available, technically simple	High power consumption, poor legibility in sunlight, low resistance to temperature extremes, limited viewing angles, thick mechanism
OLED Organic substances generate light when exposed to electric current 	Should be inexpensive after fabrication plants are built, rapid electrical response	High power consumption, poor legibility in sunlight, relatively short life span, susceptible to water and oxygen contamination, technically complex
IMOD Reflective materials modulate ambient light and bounce it back off a mirrorlike surface 	Inexpensive, low power usage, always on, rapid electrical response, good readability in bright sunlight, wide viewing angle, technically simple	New, unfamiliar technology, not yet available as full-color displays

➥ MORE TO EXPLORE

Description of a Fabry-Pérot interferometer: **hyperphysics.phy-astr.gsu.edu/hbase/phyopt/fabry.html**

Qualcomm’s IMOD Web site: **www.qualcomm.com/technology/imod/**

ANN SANDERSON