FLUID ON A SMALL SCALE

Labs fit microchips, and liquid lenses come into focus

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The inability of some fluids to mix makes for a fine focus in a tight space. By Paul Sharke, Associate Editor

Scientists and engineers at Royal Philips Electronics of the Netherlands are developing a fluid lens that loosely duplicates the way in which they see with their own eyes. Called the Fluid-Focus lens, it focuses by adjusting the shape of the lens itself. In much the same manner, the human eye varies the shape of its own lens to bring nearby and far-off objects into view.

The Philips lens produces an optical curve along the meniscus formed where two immiscible fluids meet. The lens curves change from concave to flat to convex, and back, through the manipulation of an electrical charge.

According to the company, the lens may eventually find application in digital photography, endoscopy, home security, optical storage—almost any low-cost imaging system where high-volume manufacturability can differentiate a finished product's price.

Yet, the future may not be as easily into view. Another company, Varioptic in Lyon, France, holds two patents on electrowetting technology from the late 1990s and plans to enforce its claim to the invention of the variable-focus fluid lens. According to Varioptic's CEO, Etienne Paillard, the company has already begun producing 100 lens units a day and will ramp up to full manufacturing capability by summer. It recently signed a deal with Samsung.

Electrowetting, a term more familiar to physicists and chemists than to mechanical engineers, describes the way that an electrical charge on a material can alter the material's attraction to a conductive fluid.

The lenses from both companies consist of hollow cylinders capped at the ends with transparent plastic or glass. Each uses the principle of electrowetting over a dielectric to vary its focus. An electric charge changes the hydrophobic property of an insulating coating that lines part of the lens's inside wall. The lens,
filled with one part insulating oil and one part conductive aqueous solution, forms a hemispheric bubble in the unenergized state as the hydrophobic sides repel the water and oil fills the void.

Through electrowetting, a voltage applied to electrodes changes the insulating coating from hydrophobic to hydrophilic. The material loses its repulsion for water in varying degrees according to the charge that’s applied. The amount of charge governs how much water sticks to the wall and so controls meniscus curvature.

The Philips lens, demonstrated this year at a computer trade show in Hannover, Germany, can focus from 5 cm to infinity in 10 milliseconds and measures 3 mm across by 2.2 mm long, according to a company press release. Aperture diameter of the Varioptic lens measures 4.5 mm, according to that company’s Web site.

Small system size ensures that interfacial forces between the two fluids exceed gravitational forces, said Benno Hendriks, a principal scientist at Philips. The lens remains stable in any orientation, he said, because densities of the two liquids are closely matched. The lens works properly when its diameter remains less than a centimeter, he added.

Power consumption is low, too, since the lens presents a capacitive load to the dc voltage source in the Philips case, and an ac source in the Varioptic case. The Philips lens remains fixed in its last shape after power loss. The Varioptic design requires power to maintain any but its inert shape.

Philips says that it has tested the lens through one million operations without any degradation in optical performance.

Compared with mechanical lenses, which can be made very small and quite capable of fast focusing, smaller is a decided advantage for fluid lenses, which can be much less costly.

“[In the FluidFocus] lens we make use of surface tension,” Hendriks said. For mechanical focusing systems, “surface tension is their enemy because it causes friction,” he added.

**ONGOING RESEARCH**

Electrowetting is nothing new, according to mechanical engineering professor C.J. Kim, who applies the principle in developing digital microfluidic devices at the University of California, Los Angeles. During the late 19th century, Gabriel Lippmann discovered electrocapillarity, and it has been a staple in the field of electrochemistry ever since.

In an inert state, the fluid lens forms a hemisphere as the aqueous solution moves as far as it can from the hydrophobic sidewalls. A charge on the electrodes lowers the level of hydrophobias.

What is new is the discovery that dielectric materials—insulators—that thinly overlay conductive metal can be made to change from hydrophobic to hydrophilic states under an applied charge to the conductor. This discovery came in the 1990s, when engineers trying to protect electrical cable from weather covered it with a hydrophobic dielectric and found that the covering’s water shedding properties diminished as they energized the conductor.

In his own work, under a National Science Foundation
grant, Kim had been experimenting with moving droplets on metal grids by electrowetting. He found that after only one or two trials, repeatability fell off, owing to the ion exchange taking place between the water and the metal. When he heard about the discovery of the electrowetting in dielectrics, he knew he'd found an answer to his problem.

At the Duke University microfluidics lab in Durham, N.C., researchers are also applying electrowetting on dielectrics to move fluids around the so-called lab-on-a-chip (as discussed elsewhere in this issue). There, in the microrealm, surface tension dominates, according to Vamsi K. Pamula, a research associate in Duke's Department of Electrical and Computer Engineering.

To understand one case—a droplet resting on a surface surrounded by air—imagine that the three materials form a three-phase line of contact. Voltage applied to the underlying electrode develops a charge in the droplet. Researchers think this charge may modify the interfacial energy, Pamula said. Or, an electrical force develops that possibly acts on the three-phase contact line. Just what produces the phenomenon of electrowetting on dielectrics is still being studied, he said.

Where oil surrounds the drop, as in the case of the fluid lens or the lab-on-a-chip experiments at Duke, the phenomenon seems to grow even more complicated. Pamula's group has demonstrated electrowetting actuation of liquid droplets for a microfluidic lab-on-a-chip. The group has conducted complex clinical diagnostics on the chip as well. It is also using droplet transport to carry heat away from microprocessor chips. Still, "the fluid transport of the droplets is very complex," he said—a fertile ground for study by mechanical engineers. For lab-on-a-chip procedures, the motion of drops by electrowetting is further complicated by the tendency of proteins in blood and other body fluids to stick to the hydrophobic surface, Pamula said.

TOWARD PAPERLESS LIVES

Electrowetting on dielectric has other applications as well. Last fall, Philips scientists wrote in the journal Nature of an electronic paper they developed that used the principle to control the movement of "ink" in tiny wells. The ink—actually a layer of colored oil overlaid by a layer of water—covered a white substrate in the absence of any applied voltage. An electrical charge carried by a transparent electrode sitting over the substrate shifted the ink to a corner of the well. As the voltage increased, more of the background came into view.

The resulting display changes fast enough to show video, the authors said. It also has high reflectivity and high contrast, two important attributes for any display technology seeking to overthrow paper's ubiquity.

It's not Philips's first venture into electronic paper. But this latest development promises high switching speed and color displays.

Time will tell if fluid paper or fluid lenses will make it to market. Already, Samsung and Varioptic have jointly demonstrated an autofocus camera module that uses liquid lenses and an integrated circuit for controlling its electrowetting. According to a press release, Samsung will be targeting its camera module marketing at mobile phone and PDA makers.