Autonomous lenses may bring microworld into focus

August 2 2006

Developed by University of Wisconsin-Madison Electrical and Computer Engineering Assistant Professor Hongrui Jiang, Biomedical Engineering Professor David Beebe, postdoctoral researcher Liang Dong and doctoral student Abhiskek Agarwal, and inspired by the natural compound eye, "smart" variable focal length liquid microlenses incorporate hydrogels that respond to physical, chemical or biological stimuli and actuate lens function. In this artist's rendering of a smart liquid microlens, environmental stimuli (shown as yellow rays and tiny spheres) trigger a hydrogel (shown as a yellow ring edged in black) to swell or contract. As a result, water below the lens (center) either bulges or bows and the lens becomes divergent or convergent. Such smart microlenses could advance lab-on-a-chip technologies, optical imaging, medical diagnostics and bio-optical microfluidic systems. Credit: Ryan Martinson, Silverline Studio

When Hongrui Jiang looked into a fly's eye, he saw a way to make a tiny lens so "smart" that it can adapt its focal length from minus infinity to plus infinity-without external control.

Incorporating hydrogels that respond to physical, chemical or biological stimuli and actuate lens function, these liquid microlenses could advance lab-on-a-chip technologies, optical imaging, medical diagnostics and bio-optical microfluidic systems.

Jiang, a University of Wisconsin-Madison assistant professor of electrical and computer engineering; David Beebe, a professor of biomedical engineering, postdoctoral researcher Liang Dong, and doctoral student Abhiskek Agarwal describe the technology in the Aug. 3 issue of the journal *Nature*.

At this size-hundreds of microns up to about a millimeter-variable focal length lenses aren't new; however, existing microlenses require external control systems to function, says Beebe. "The ability to respond in autonomous fashion to the local environment is new and unique," he says.

In a lab-on-a-chip environment, for example, a researcher might want to detect a potentially hazardous chemical or biological agent in a tiny fluid sample. Using traditional sensors on microchips is an option for this kind of work-but liquid environments often aren't kind to the electronics, says Jiang.

That's where hydrogels - thick, jellylike polymers - are important. Researchers can tune a hydrogel to be responsive to just about any stimulus parameter, including temperature and pH, says Jiang. So as the hydrogel "senses" the substance of interest, it responds with the programmed reaction. "We use the hydrogel to provide actuation force," he says.

A water-oil interface forms his group's lens, which resides atop a water-filled tube with hydrogel walls. The tube's open top, or aperture, is thin polymer. The researchers applied one surface treatment to the aperture walls and underside, rendering them hydrophilic, or water-attracting. They applied another surface treatment to the top side of the aperture, making them hydrophobic, or water-repelling. Where the hydrophilic and hydrophobic edges meet, the water-oil lens is secured, or pinned, in place.

When the hydrogel swells in response to a substance, the water in the tube bulges up and the lens becomes divergent; when the hydrogel contracts, the water in the tube bows down and the lens becomes convergent. "The smaller the focal length, the closer you can look," says Jiang.

Because they enable researchers to receive optical signals, the lenses may lead to new sensing methods, he says. Researchers could measure light intensity, like fluorescence, or place the lenses at various points along a microfluidic channel to monitor environmental changes. "We've also thought about coupling them to electronics-that is, using electrodes to control the hydrogel," says Beebe. "Then you can think about lots of imaging applications, like locating the lenses at the ends of catheters."

Clustered in an array, the lenses also could enable researchers to take advantage of combinatorial patterns and provide them with more data, he says.

The array format improves upon the natural compound eye, found in most insects and some crustaceans. This eye essentially is a sphere comprised of thousands of smaller lenses, each of which has a fixed focal length. "Since the lenses are fixed, an object has to be a certain distance away for it to be clearly seen," says Jiang. "In some sense, our work is actually better than nature, because we can tune the focal length now so we can scan through a larger range of view field."

Fabricating lenses is a straightforward, inexpensive process that takes just a couple of hours. The real advantage, however, is their autonomous function, says Jiang. "That forms a universal platform," he says. "We have a single structure and we can put different kinds of hydrogels in and they can be responsive to different parameters. By looking at the outputs of these lenses, I know what's going on in that location."

Source: University of Wisconsin-Madison