Light Directs Microfluid Flow

Researchers at the University of Tokyo (Tokyo, Japan) and the Kanagawa Academy of Science and Technology (Kawasaki, Japan) have increased the utility of biochemical lab-on-a-chip designs by creating a new way to control microfluid flows using light.

“Our method takes advantage of changes in surface wettability of substrates coated with spiropyrans [SP] that occur in response to photochromism [a reversible change in a compound’s absorption spectrum induced by excitation of the compound by a specific wavelength or waveband of light],” explains Haeng-Boo Kim, researcher at the University of Tokyo. “We found that the water contact angle of SP-coated glass was 60° after irradiation with ultraviolet light and 75° after irradiation with visible light [VIS], and we assumed it would be possible to photoinduce separations of phase flows in Y-shaped SP-coated microchannels.”

Microfluidics and microarrays are indispensable to the production of lab-on-a-chip microchemical systems, Kim says. Until now, such control has been effected with micro-pumps and microvalves integrated with microfluidics. “It is quite difficult to fabricate tiny physical pumps and valves,” Kim remarks. “And we knew that the fluidic characteristics in microchannels were strongly affected by the surface properties of the channel walls because of the relatively large surface area.”

The research team synthesized an SP derivative containing N-alkyl carboxylic acid, then fabricated microchannels 200-mm wide and 100-mm deep on Pyrex glass with photolithography and wet-etching techniques. They treated the inner surfaces of the channels with (3-aminopropyl) triethoxysilane modified with SP derivatives. “The average density of SP on the channel surfaces, according to the absorption measurement, was one SP unit per 39Å²,” says Kim.

To test the wettability, or microfluid flow tendency, the researchers irradiated the SP derivative on a flat glass substrate with UV light, leading to the absorption of light at 362 nm by the merocyanine form of the spiropyran molecule, resulting in a water contact angle of 60°, and then light absorption of VIS at 562 nm by the neutral-spiro form, which returned the water contact angle to 75° (see figure).

The team prepared two test fluids, one water/air and the other water/n-hexane. Prior to introducing the fluids to the microchannels, the upper leg of the Y-channel was irradiated with UV and the lower leg with VIS, which made the upper channel more hydrophobic than the lower one. The two-phase fluids were then introduced with a syringe. With the initial two-phase fluid, water flowed up the UV-irradiated channel and air flowed down the VIS-irradiated one. And reverse irradiation resulted in a reverse of the flow, water flowing down and air up. The second two-phase fluid performed the same as the first. Water flowed to the channel irradiated with UV and n-hexane to the channel irradiated with VIS.

“Our results clearly show that the wettability difference between channels controls the flow path,” says Kim, “and that means we can use this method as a photocontrolled separation device.”

Eivind Hovig, a senior scientist of the department of tumor biology at the Institute for Cancer Research in The Norwegian Radium Hospital (Oslo, Norway), says there is a definite need for valve-like mechanisms such as those Kim’s team demonstrated for a number of chip applications. While Hovig thinks

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who helped develop the laser system, a 200-cm$^3$ Nd:GGG crystal provides the lasing medium for each laser module. Researchers chose Nd:GGG because at 1 µm the laser operates in a window with minimal absorption in the atmosphere and because of its good thermal/mechanical properties. Nd: YAG crystals, although more common at this wavelength, Yamamoto says, display a spiral formation at the center of the crystal boule during crystal growth, which, if used, would severely limit laser performance and efficiency.

The crystal slab, which measures 10 cm × 10 cm × 2 cm, is pumped by four water-cooled diode arrays from Decade Optical Systems Inc. (Albuquerque, NM). A single diode array consists of 720 laser diode bars—9 rows of 80 diode bars each—and produces upwards of 75 kW peak power at 808 nm wavelength. A pair of pump diode arrays is located on each side of the slab for a total of four arrays per slab module. Microlenses on each diode bar direct the light towards the slab at an incident angle of approximately 55° with the slab face. Currently the laser system consists of four laser modules, which equates to four 10-cm Nd:GGG slabs and 16 diode arrays.

To minimize the footprint, the system does not cool the Nd:GGG crystal during lasing, which limits laser operation to approximately 10 s of cumulative run time—hence the “heat capacity” portion of the laser’s name. To increase the duty cycle of the system, General Atomics (San Diego, CA) provided a gain medium exchange system that swaps the heated crystal for a room temperature crystal slab, and then uses cooling plates “off-line” to reduce the hot crystal from 100°C to approximately 20°C within 1 min. “Critics say the laser does not operate continuously, however, we think it would take longer than 1 minute to acquire, track, and shoot 5 to 10 incoming missiles,” Yamamoto says.

Electricity for the pump lasers was another major hurdle for the proposed mobile laser weapon system. In response, SAFT America (Cockeysville, MD) provided 672 prototype lithium ion batteries with 1.2 kW/kg power density. DRS Technologies (Parsippany, NJ) engineered and integrated a power management system using Buck converters in the power control electronics to provide peak power to the diode arrays at very low ripple. As designed, the power pack can be recharged from the hybrid diesel/electric humvee engine.

The LLNL team continues to scale the solid-state laser, working with Synoptics to produce slabs 13 cm on a side. “Power scales linearly with the cross sectional area of the crystal slab and linearly with the number of slab/diode array modules,” Yamamoto says. “LLNL and the industrial team have plans to build a 40-kW laser system on a mobile demonstrator to verify and validate the missile defense shield concept. We believe we are funds limited, not technology limited.” —Winn Hardin

Optical Sensor Monitors Glucose Levels in Real Time

Traditional methods of blood-glucose monitoring require a blood sample, which can be painful for people with diabetes who may need to take four or five blood samples per day. Researchers at the University of California, Santa Cruz used a fluorescent chemical complex immobilized in a thin-film biocompatible polymer or hydrogel to make a non-invasive glucose optical sensor.

To make the sensor, the team developed the sensor’s two main components: an anionic pyrane sulfonamide monomer fluorescent dye, and a benzyl viologen with attached boronic-acid functional group, which acts as the fluorescent quencher. Glucose modulates the fluorescent signal by binding reversibly to the boronic acid component attached to the quencher molecule.

Researchers say the sensor is capable of operating under typical physiological pH conditions in blood or water, has a fast response time, and utilizes stable compounds that don’t degrade over time. “This is the first system to show reversible optical sensing of glucose with a thin-film hydrogel. We tested the sensor under conditions that are as close as possible to the physiological conditions under which a continuous glucose monitor would have to operate,” explains Bakthan Singaram of the research group.

This technology is expected to find immediate application in a catheter device called GluCath, which will monitor blood glucose levels in hospitalized patients.

—Phillip Espinasse

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The work described could function in a valve-like manner, “it seems that the question of time remains,” he says, “as it seems to take several hundred seconds to make the shift described.”

Hovig says he has not examined the compatibility of SP molecules and other chemicals and biologicals relevant for molecular biology, or the systems’ ability to control precise amounts of fluid. “That may be another hurdle,” he says.

“If the hurdles I have mentioned can be overcome, then I believe the technology could find use in a host of on-chip liquid handling systems, primarily within time-controlled serial reactions.” —Charles Whipple