

Tech Notes

Micropumps: Innovations to transport fluids in microchips

Microfluidics, the science of systems that can manipulate extremely small volumes of liquids, has been named by MIT Technology Review as one of the ten technologies that will change the world. However, while microfluidic systems have enabled familiar systems such as inkjet printers and not-so-familiar systems such as microchips used for analysis of biological samples (often dubbed “labs-on-a-chip”), microfluidics has not yet lived up to its predicted potential.

Because microscopic quantities of liquids do not behave as bulk fluids do, basic fluidic operations—transporting, mixing, filtering—for microfluids pose new and unique challenges. Researchers at Lincoln Laboratory are working on an innovative technique to solve the problem of moving fluids through microfluidic devices.

Currently, the most widely used approach to controlling the flow of liquids in microfluidic systems is to employ pumps that are external to the microfluidic chip. The size of a system using such pumps is determined by the size of the pumping components, which are usually large in comparison to the microfluidic device itself. A truly miniaturized system would have a self-contained pumping and fluid transport system.

Some scientists have worked on miniaturizing the pumping components. Others have experimented with systems that capitalize on the forces affecting fluids at these small volumes, for example, using electric stimulation to influence the behavior of fluids or altering the surface tension to change the pressure on and cause motion in fluids. Most of these solutions, while restraining the size of the microfluidic device, either require peripheral equipment to supply the energy needed to influence the fluid or add complexity to the system.

The ideal microfluidic transport system, besides being small, would also consume little power, be applicable to a wide range of applications, and be easy to fabricate and integrate into larger systems. Lincoln Laboratory scientists have developed micropumping systems with all these attributes.

Solution: electrowetting

Lincoln Laboratory researchers investigated electrowetting technology as a method for fluid transport. Electrowetting is a microfluidic phenomenon in which the surface energy between a conductive

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liquid and a dielectric-coated electrode can be controlled with a voltage potential (see Figure 1). This technique gives a direct way to control the surface tension of a liquid in a predictable, repeatable way. The unique feature of electrowetting is that it is a reversible process; when voltage is removed, the system returns to its original configuration.

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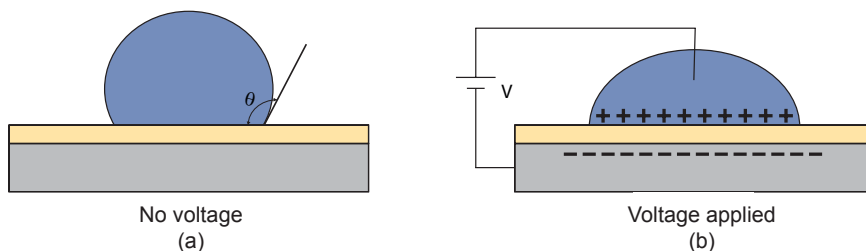


Figure 1. The electrowetting phenomenon is that in which the surface energy between a conductive liquid and a dielectric-coated electrode is controlled by an electric potential. (a) An aqueous drop in equilibrium sits on a dielectric-coated electrode with no potential applied. (b) Drop flattens and wets the surface when an electrical potential is applied. This behavior is a direct response to a reduction in surface energy at the solid–liquid interface. When the potential is removed, the drop returns to its original configuration (a).

By actively controlling the deformation of a water droplet's surface, Lincoln Laboratory researchers seek to do pressure work in a microchannel. This use of electrowetting allows for basic fluidic components such as pistons and valves to be implemented and integrated into a variety of pump designs, drop generators, and other fluid transport systems.

Fabrication

The Laboratory built experimental chips employing the electrowetting technique described above. Fully enclosed microchannels were created by thermally bonding two etched wafers together. The bottom wafer, or substrate, was made of silicon; the top of borosilicate glass (Pyrex®), whose transparency allowed the researchers to see the action within the chip. Aluminum electrodes and contact pads were patterned only on the bottom wafer. Each chip contained multiple microfluidic devices that could be operated, and tested, independently.

Because the most attractive feature of the electrowetting approach is its manipulation of discrete volumes of liquid, the ability to create drops of finite volume within the microdevice is key. To generate a discrete drop of a liquid, water for example, Laboratory researchers devised a "drop generator" in which dual electrodes extrude water from a reservoir into a microchannel. With voltage maintained on the farthest-most electrode, the voltage on the electrode adjacent to the reservoir is removed, thus leaving a droplet of water over the activated electrode.

Lincoln Laboratory researchers built three prototype micropumps based on their concepts. One micropump design transports individual drops of water in a channel; two other designs pump liquid continuously.

Design 1: individual drop pump

This design is referred to as a "push-pull" pump. It consists of a drop generator device as described above and a series of electrodes positioned to act as valves and pistons when electrically sequenced (see Figure 2). When a valve is electrically energized, water in the channel advances, closing the line that feeds the other liquid (e.g., oil) into the drop channel. A piston

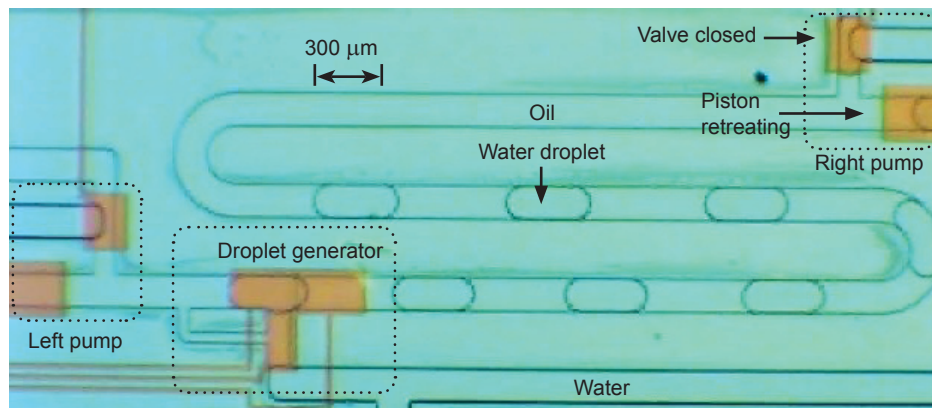


Figure 2. Top-down photograph of an integrated microfluidic system consisting of a drop generator and two piston/valve pumps. Nine water drops were created and move left to right with the right-side pump working in "pull" mode.

electrode is then activated, and the water spreads along the channel forcing a drop along the channel. Then, the valve electrode is de-energized, opening the valve and allowing the water to recede when the piston electrode is de-energized. The oil can then flow from the feed line, filling in behind the receding water. Repeating this process causes the drop, or multiple drops, to advance along the channel.

Designs 2 and 3: oil pump and water pump

For many applications, a continuous flow of fluid is desirable. Design 2 modifies the single-drop design by using the oil as the working fluid and energizing dual valves in an alternating open-close fashion and piston electrodes in a push-release sequence so that oil is allowed to fill the pump chamber and then compelled to flow out of the chamber. The cycle, which takes just 0.3 sec, is repeated for continuous pumping.

Since most of the interest in microfluidic systems has come from biotechnology, it is important to build systems that can handle the aqueous liquids used in this field. This third design addresses the need to continuously pump water instead of a nonconductive liquid. This design works much as design 2, but the design was modified to create a pump chamber at a channel height different from that of the valves and piston. When the valve has a potential applied, water fills the valve region and the water valve is open. When the potential is removed, water retracts from the valve region blocking the flow

of water with oil. The water piston draws water in during actuation, and dispenses it when the potential is removed. By properly timing the sequence of the valves and piston actuations, water can be pumped in a continuous manner.

These designs demonstrated the viability of the electrowetting technique. The next step is to find applications for the technology. One possibility is a glucose monitor; a microfluidic monitor would need only a very tiny blood sample and it would not require a continual supply of test strips. Another potential application may be in sensors that detect and identify biological pathogens. The chip's small size would enable handheld detection and identification systems, and the tiny volume of sample needed is advantageous for emergency responders who could be processing trace samples right in the field. ■

Additional Reading

Berry, S., J. Kedzierski, and B. Abedian, "Irreversible Electrowetting on Thin Fluoropolymer Films," *Langmuir*, vol. 23, pp. 12429–12435, 2007.

Berry, S., J. Kedzierski, and B. Abedian, "Low Voltage Electrowetting Using Thin Fluoropolymer Films," *Journal of Colloid and Interface Science*, vol. 303, pp. 517–524, 2006.

Kedzierski, J. and S. Berry, "Engineering the Electrocapillary Behavior of Electrolyte Droplets on Thin Fluoropolymer Films," *Langmuir*, vol. 22, pp. 5690–5696, 2006.