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An electrolysis-based bubble-actuated micropump

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A novel microdevice promises both compactness and versatility.

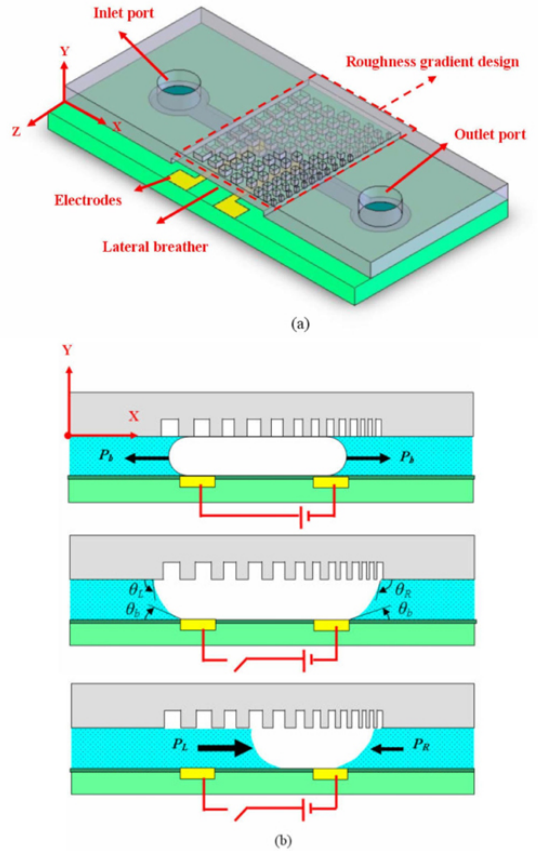

***Figure 1.** Schematic illustration of the design concept and pumping principle. (a) A three-dimensional view of the micropump. (b) A side view showing net pumping flow along the x direction in the three phases of a single pumping cycle. Here, P_L and P_R represent pressure. θ_L, θ_R, and θ_b are contact angles.*

Micropumps come in a variety of designs that use different actuation mechanisms. Diaphragm micropumps,[1] for example, achieve high volume through a large chamber using a membrane: however, most techniques for fabricating such diaphragm-based pumps are complicated and involve many photolithographic steps. Another technique[2,3] drives fluid by applying a high voltage to it. Among such approaches, bubble-actuated valveless micropumps are attractive for their simple operation, miniaturized size, large actuation force, and the ability to conform physically to different types of microchannels with a wide range of cross-sections. Unfortunately, although these valveless pumps have been successfully demonstrated,[4–6] they involve complicated time-sequence power control on many pairs of electrodes, large or long nozzle-diffuser structures, and have the further disadvantage of a sealed reservoir inside the fluidic chip.

To overcome these problems, we propose a compact micropump with a simple pattern of changing surface roughness (i.e., gradient) to propel the liquid forward. Like other valveless micropumps, our device has a large actuation force. But it has the additional benefits of low power consumption and room temperature operation. It also gets around the sticking or choking of electrolytic bubbles that happens with sealed reservoirs.

Figure 1(a) illustrates the design concept. The device consists of platinum electrodes, a hydrophilic microchannel, and a hydrophobic lateral breather connected to air for removing bubbles. The pumping principle—shown schematically from the side in Figure 1(b)—relies on surface tension and multiple bubble-actuation cycles. The actuation mechanism is divided into three phases: bubble generation, degassing, and liquid movement. First, the bubble is generated by electrolysis to push the liquid in whichever direction is required. Next, the bubble is vented out through the lateral breather. At the sides of the microchannel, surface tension exerts a pull on the liquid that creates a characteristic concave shape called a meniscus. Owing to the design of the roughness gradient, the apparent contact angle of the leading meniscus (right) is larger than that of the trailing meniscus (left): $\theta_R > \theta_L > 90°$. Thus, the pressure on the left is larger than that on the right: $P_L > P_R$. As a result, both menisci respond with different velocities so that a net pumping

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flow along the *x* direction is achieved. Displacement of the liquid occurs through repetition of these cycles.

Figure 2(a) shows the prototype device, which has two micropumps of different roughness gradient design on a chip (to demonstrate the robustness of the pumping feature). Figure 2(b) presents time-sequence images captured from the top view of the device. Experimental results prove the function of a variety of micropumps.

A maximum pressure head of 1.9kPa and maximum pump rate of 114nl/min are measured in a device with a microchannel cross-section of 100 × 20μm. Compared with other pumps, this one has the potential to be used in closed-loop microfluidic systems, such as those used for counting cells or measuring concentrations of chemicals. Precise control of the potential of the working electrode enables low operating voltage and power consumption on the order of microwatts. For an applied voltage of 7V with an average current of 26μA, that would come to 182μW.

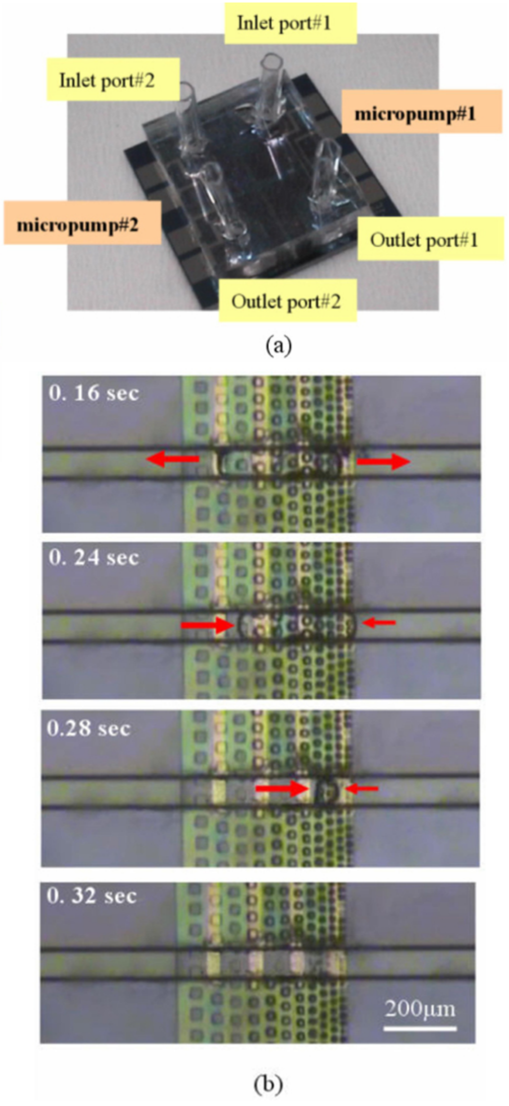

Figure 2. (a) The prototype device with two micropumps on a chip. (b) Time-sequence images captured from the top view of the pump.

This combination of features makes our micropumps suited for integration with other multiple components to form micro- and biomicrofluidic systems for various applications. As a next step, we are modifying and optimizing the pumps for use in a micro direct methanol fuel cell.

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