ELECTROCHEMICALLY ACTUATED SU8 PUMP FOR ULTRASONIC BLOOD CELL SEPARATION

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This paper presents an electrochemical pump utilizing electrolysis of water to create pressure driven flow through a previously developed blood cell separator [1]. A fabrication process is developed using thick layers of biocompatible SU8 resist and interdigitated platinum electrodes. The pump is capable of meeting the specific requirements of the cell separator including a 2-3 µl/min flow rate, 10 kPa of pressure, displacing 5-10 µl, biocompatibility, and low power consumption. Stepping toward a complete lab-on-a-chip device, this pump is designed to be integrated with an ultrasonic blood cell separator developed in [1] (Fig. 1).

The requirements eliminate many micropump options such as reciprocating membrane pumps and electroosmotic pumps [2]. Similar electrochemical micropumps to the one described have been developed for drug dosing and lab-on-a-chip applications [3-5]. However, these pumps are limited to small volumes due to fabrication with silicon or have excessive sizes due to polymer fabrication [4]. Using thick layers of SU8 resist, this pump is able to maintain a similar footprint as the cell separator (~1cm^2) and supply the required volumes of blood.

Electrochemical pumping relies on increased pressure from gas produced when current flows through an electrolytic fluid. Using the geometry in Figure 2, this pressure can be used to drive fluid flow. Separation between the electrolytic fluid and the blood sample is achieved using the interface between two liquids in microchannel meanders.

Approximate flow rates are governed by Faraday's Law of Electrolysis and the Ideal Gas Law [5]:

Farady's Law of Electrolysis: $N = \frac{It}{zF}$ Ideal Gas Law: $PV = NR_uT$

where N is moles of gas produced, I is current, z is number of "excess" electrons, F is Faraday's constant (96500 C/mol), and R_u is the universal gas constant (8.314 J/mol*K). Assuming constant pressure, temperature, and fluid contact, the volume of gas produced is proportional to the supplied current (Fig. 6). However, bubble formation causes changing resistivity of the electrolytic fluid resulting in varied flow rates. Controlling the input potential can produce a predicable and steady flow rate [6].

Pump fabrication includes spinning, exposing, and developing thick layers (>500µm) of SU8 100 on glass wafers. A process was developed optimizing the exposure times and bake times to reduce the total internal stress in the SU8. The complete process is shown in Figure 3. The electrolysis reservoir has a depth of ~750 µm with an area of 2.5 x 8.4 mm^2 (15.75 µL). There are 13 microchannels in the meander that are ~150 µm deep with widths of 600 µm and lengths of 5.5 mm (6.5 µL). The actual device is shown in Figure 4.

A test setup was designed to measure the current applied through the electrolytic fluid, the flow rate, and pump pressure (Fig. 5). A rigid, sealed tube using air compression as fluid flows changes the outlet pump pressure. Particle image velocimetry (PIV) using fluorescent polystyrene beads is used to measure flow rates. Preliminary results (Fig. 6 and 7) show variable flow rates of 2-5 µl/min at applied currents of 0.9-2.7mA are achieved. Deviation from predicted flow rates results from electrode drying as bubbles form. Pressure results show that smaller electrode spacing can greater pressures for similar flow rates. Qualitative results using sodium chloride solution electrolytic fluid show greater flow rates and pressures as ions increase. Future work will include optimizing the sizing and spacing of the electrodes, charactering the interface between the electrolytic fluid and the blood solution in the microchannels, and integrating the pump with a working ultrasonic blood cell separator.

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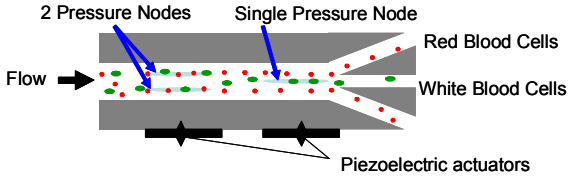

Figure 1. Schematic of ultrasonic cell separation using acoustic standing waves to create varying pressure nodes in a microchannel. Rates of cells moving from 2 pressure nodes to 1 pressure node is used to separate cells [1].

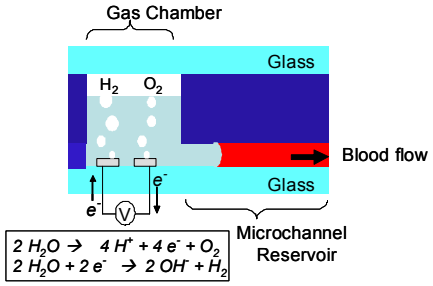

Figure 2. Schematic of using electrolysis to drive fluid flow. The increased volume of gas produced from the electrolytic fluid provides increased pressure forcing fluid to flow through the microchannel meander.

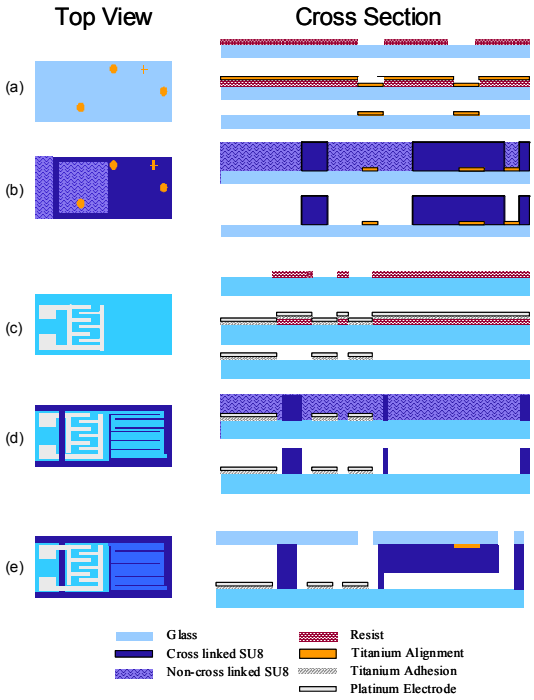

Figure 3. Fabrication process. (a) Alignment marks and thru hole locations patterned on glass wafer using Ti lift off process. (b) 500µm layer of SU8 100 spun, exposed, and developed to give the electrolysis chamber. (c) Pt electrodes with Ti adhesion layer patterned on glass wafer using lift off process. (d) 150µm SU8 100 layer spun, exposed, and developed to define the microchannel meander blood reservoir. (e) The two wafers are bonded using UV adhesive. Inlet and outlet holes (.75mm) are drilled using a diamond tip drill bit.

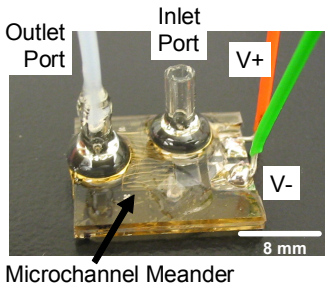

Figure 4. Image of actual pump showing inlet port to the electrolysis chamber and the outlet port from the microchannel meander. Voltage is applied the two leads to pass current through the electrolytic fluid.

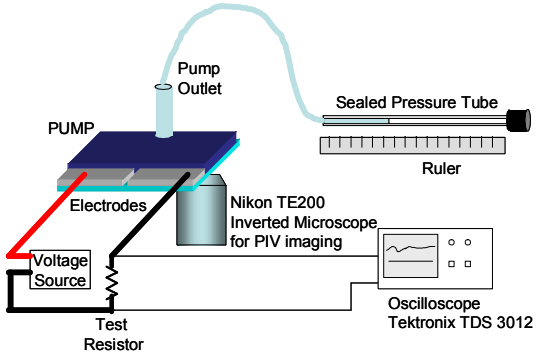

Figure 5. Schematic of test setup. A sealed pressure tube is used to increase the outlet pressure with flow. Voltage and current are measured using an oscilloscope.

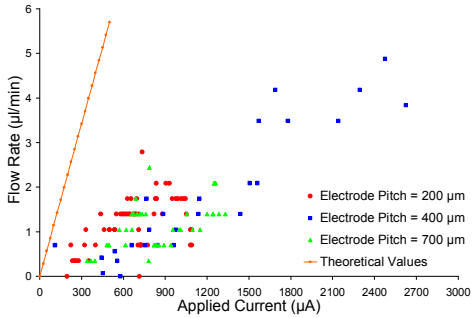

Figure 6. Flow rate vs. current results plotted with predicted values from Faraday's Law of Electrolysis. 3 devices were tested at various input voltages. Although a large deviation from predicted values, the flow rate is proportional to the applied current.

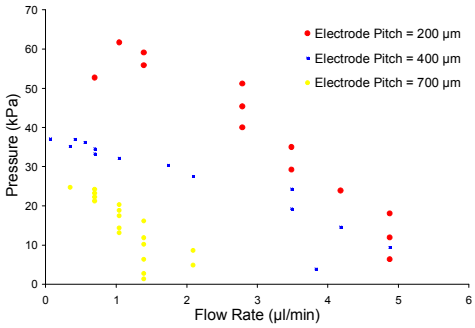

Figure 7. Pump pressure vs. flow rate results. The pressure and flow rate are linearly proportional. 3 different electrode configurations are shown where the smaller pitch of the electrodes is capable of producing higher pressures.