

Control of Micro-Fluidic Flow Using 3D Features

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ABSTRACT

Lab-on-a-Chip sensors require precise control and mixing of samples, reagents and buffers. New techniques are presented for using Excimer Laser, micro-machined, three-dimensional (3D) channel and well features, to pump and control nanoliter volumes of fluids in micro-fluidic devices. The goal is to enable the development of micro-fluidic sensor devices that are small, portable, and economic, yet have capabilities that exceed those of current laboratory bench instruments.

Advanced confocal microscopy is used to make precise, 3D measurements of micrometer scale features of the channels, valves, micro-pumps, and mixers used in these micro-fluidic devices.

Keywords: micro-fluidic, micro-machining, confocal, micro-pumps, lab-on-a-chip.

1 MICRO-FLUIDIC INSTRUMENTS

One important application of micro-fluidics is to make small, automatic measurement instruments, to replace the function of large laboratory instruments that require highly trained and skilled operators. The micro-instrument must precisely meter the sample and reagents required for the analysis, and then thoroughly mix them in preparation for analysis of a very small quantity of material. One significant advantage of the small sample is that the both dispersion times and chemical reaction times are much shorter.

Many researchers have developed techniques to control the flow in micro-circuits. Some related mechanical methods use shape memory metal alloys as actuators [1], or piezoelectric actuation [2] or voice coils [3]. We will describe a different valve construction, which could use these or other mechanical techniques to activate the valves and pumps. Another less related flow control technique involved the movement of a gas bubble in the channels [4].

Figure 1. shows a micro-fluidic circuit to be used for a Nitrate analyzer. This was chosen as a typical project because nutrient pollution of the environment is a critical problem and nitrate is the principle pollutant. Nitrate detection is important in ponds, lakes, reservoirs, ground water, coastal estuaries, waste water and drinking water. All of these sources can be measured with the same basic

micro-fluidic analyzer but the sample collection and preparation will vary considerably for the various applications.

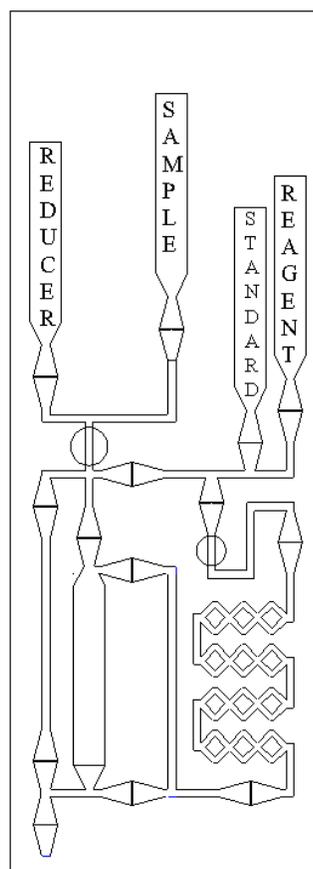


Figure 1: Layout of Micro-Fluidic Nitrate Sensor

The micro-fluidic sensor planned has about 1000 times less volume than the laboratory model it is based on. Standard chemical engineering practice is to limit scale factors to 100 times to minimize problems with unknown scaling effects. We have made two models; one (mini-scale), which uses conventional machining with close to the minimum size features possible. The scale of the fluidic elements is about 1/100. The second model (micro-scale), is made with laser micro-machining, using channel

dimensions in the range of 50 microns, which results in a scale factor of about 1/1000.

2 DESIGN OF VALVES AND PUMPS

Many micro-fluidic devices are constructed using glass or plastic plates for the fluidic channels, and PDMS for the cover plate that creates closed channels. Our design utilizes the elastic property of the PDMS in a unique manner to control the flow of fluids. The Micro-fluidic Prototyping and Commercialization (MPAC) group at the Advanced Technology & Manufacturing Center has publicized [5,6] the capability to produce 3D features in a variety of materials used for micro-fluidic devices. By machining spherical segments as part of the flow channels mechanical valves and positive displacement pumps can be constructed. The matching spherical surfaces provide optimal sealing of the valves, with minimum displacement of the PDMS. The quantity of fluid displaced with each cycle of the pump is determined by the machined spherical segment, which is fully displaced on each cycle. The spherical displacement of the PDMS, is accomplished by the mechanical depression of steel balls imbedded in the PDMS, directly above the spherically machined surfaces in the channel plate. This design uses a linear cam bar to depress the balls. Figure 2. illustrates a complete cycle of valves and pump for one pump cycle.

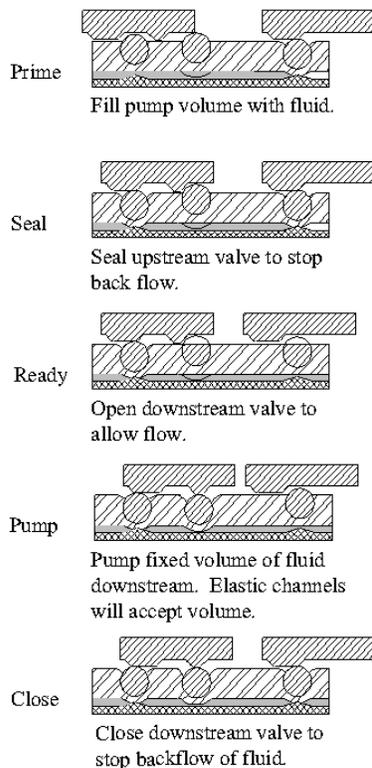


Figure 2. Pump sequencing.

3 FEATURE MEASUREMENTS

Accurate measurements of the flow channels are key to understanding the function of fluidic devices. The Hyphenated Systems Advanced Confocal Microscope (ACM) is a next-generation analytical tool, allowing the engineer rapid 3D visualization of manufactured structures and accurate measurements of the machined surfaces. The ACM uses a parallel array of apertures in a spinning "Nipkow" disc assembly, at the conjugate focus of the objective, to create a live confocal image. Precise vertical movement of the sample allows acquisition of a set of bitmap images, essentially representing surface contours of the sample.

Reconstruction of the 3D structure of the surface is achieved using advanced surface detection algorithms to manipulate the image stack. The resultant 3D surface model can be rendered and displayed in a variety of ways to illustrate important surface features, or even to probe below transparent surfaces.

Accurate dimensional measurements, down to the nanometer scale, can be made on the 3D images. Figure 3. is a composite, confocal microscope picture of a laser-ablated, 3-D channel that is approximately the same width and depth, which transitions to a wide and shallow spherical channel that can be sealed with a small deflection of a ball actuator. The surface finish of the laser micro-machined material, which must seal against the PDMS, is rough; process parameters will have to be optimized to control the surface conditions. Multiple designs, process specifications, materials, and measurements will be studied to select the best conditions for each application. The rapid analysis of the ACM allows machining parameters to be adjusted and iterated quickly, reducing the time required for set-up of the equipment and providing immediate feedback on the quality of the resulting parts.

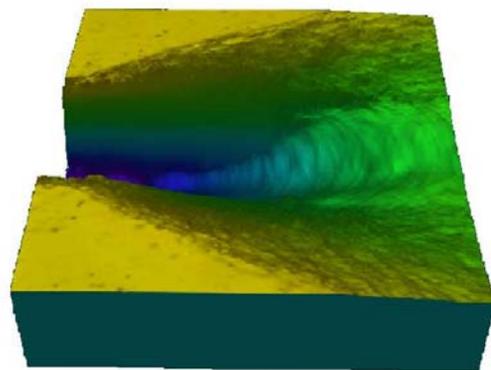


Figure 3. Confocal Micrograph of Laser Micro-Machined Valve Seat

A mini-scale test circuit (Figure 4.) was machined to test the operation of the valves and pumps. This device was designed so that each section of the circuit can be flushed to clean the channels, a reagent can be added to the sample and the fluids can be circulated to mix and fully react the chemicals.

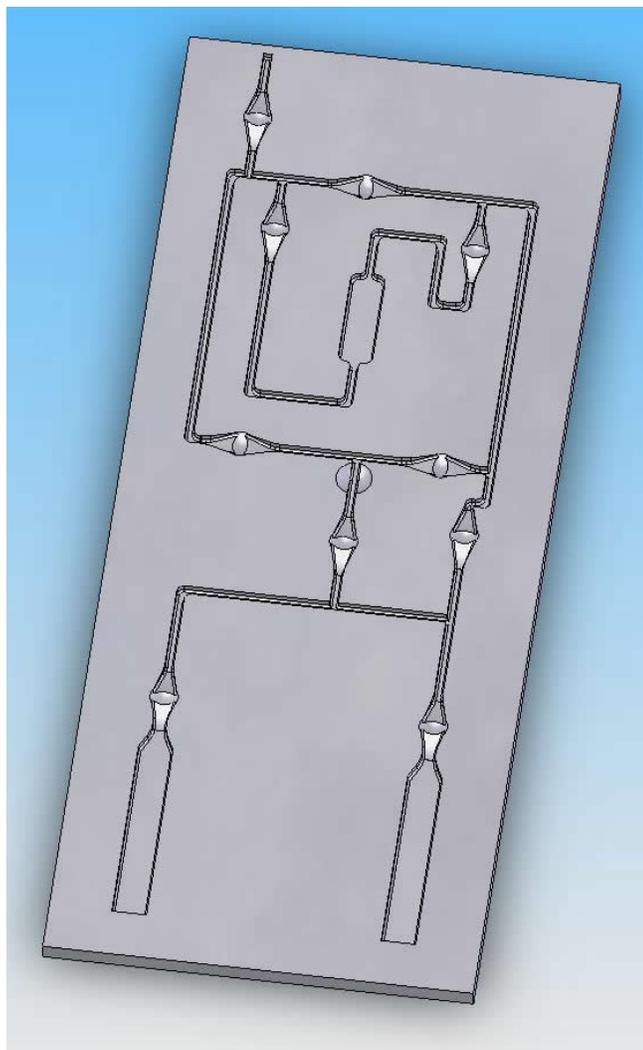


Figure 4. Solid Works Drawing of Micro-Fluidic Test Circuit

Figure 5. illustrates the PDMS cover surface of the micro-fluidic device, with the imbedded balls used to seal the valves and pump the fluids. Various techniques can be used to depress the balls against the valve seat and pump chamber. The complete seal created by the matched contours of the valve seat and compressed PDMS, combined with the consistent volume of fluid displaced by the pump, assures accurate metering of fluids into the micro-fluidic device.

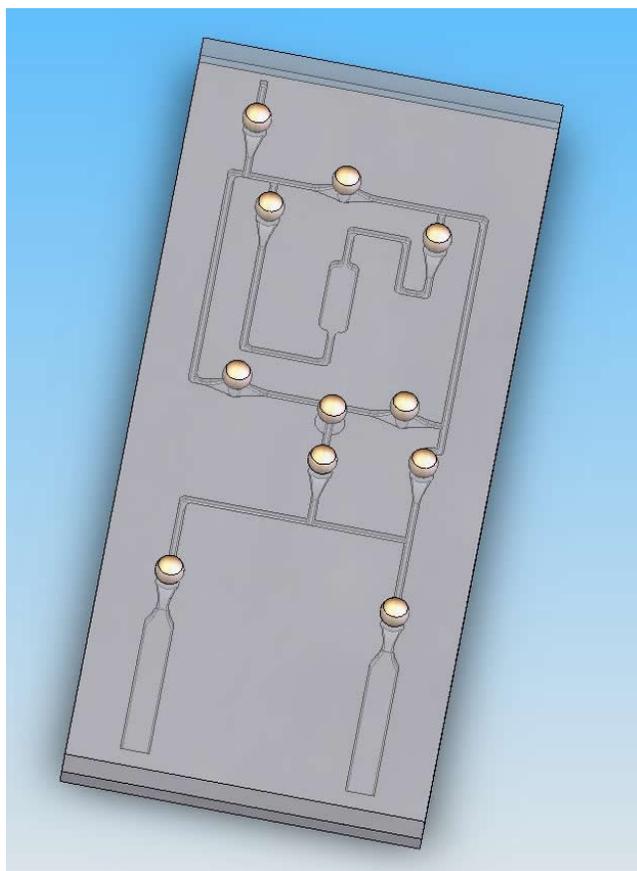


Figure 5. PDMS Cover Over Test Circuit with Embedded Ball Actuators

The management of flow in, Lab-on-a-Chip, Micro-Fluidic Devices is often a limiting factor in the design to meet a specific application. Using the ball actuator technique, and linear cam bar to activate the balls, will allow the designer to meet the requirements of a wide variety of applications. As long as the outside dimensions of the chip are fixed, changing the cam bar design to match the valve and pump requirements of the circuit can accommodate various flow control requirements.

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