3-D Microfluidic devices using ion beam lithography

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Microfluidic devices have attracted a great deal of attention during the past several years because of their applications in biology and biotechnology. These devices offer several advantages over macroscale laboratory operations, e.g., small reaction volume, automation, and integration. Their design often requires unusual geometries and the interplay of multiple physical effects such as pressure gradients, electrokinetics, and capillarity [1]. These circumstances lead to interesting variants of well-studied fluid dynamical problems and some new fluid responses. The small scale of these systems, however, precludes the use of turbulent flow for fast mixing in these systems. Still, complete and thorough mixing is necessary for many applications. Devices that enhance mixing at the microscale include active mixers and passive mixers based on convective transport [2–4].

We use the unique ion beam lithography (IBL) fabrication capabilities of the CNM and Raith, Dortmund, to make novel fluidic devices with the purpose of being able to compress the size of current state of the art microfluidics [5]. As described above, efficient mixing with short length scales is a problem. To solve this problem we take advantage of the ability of IBL to dial-in a specific depth profile into the pattern design file, and make 3-D mixer channels that are much easier to fabricate than other 3-D mixers [2] which require alignment of multiple substrates to form a 3-D fluid flow networks.

The 3-D cascade mixer device shown in Figure 1 has a T-shaped focusing inlet and the outlet mixing section is partitioned in segments that vary in width and depth. The relationship between width and depth is fixed for a constant pressure drop for each segment. This novel device delivers 100% mixing within just a few tens of microns from the inlet as observed from COMSOL microfluidic simulations. The color bar in the simulation indicates concentration of the component liquids to be mixed. There is one inlet liquid flowing through the center channel and a focusing liquid flowing from the two outer channels. The bottom of the color bar indicates 100 % concentration of the focusing liquid and the top of the color bar indicates 100% concentration of the inlet liquid. The outlet shows a 50-50 mixture. In Figure 2 we show a more elaborate design that was patterned using an ionLiNE ™ FIB at Raith, Dortmund.

The 3-D effect is achieved by assigning different ion beam dose to each segment of the design. The dose is delivered by multiple exposure scans (~1000) with a dose sufficient to just skim off about 1 nm of material for each exposure. In this manner, re-deposition effects commonly found in ion beam milling can be prevented. Fabrication details and characterization results will be discussed.

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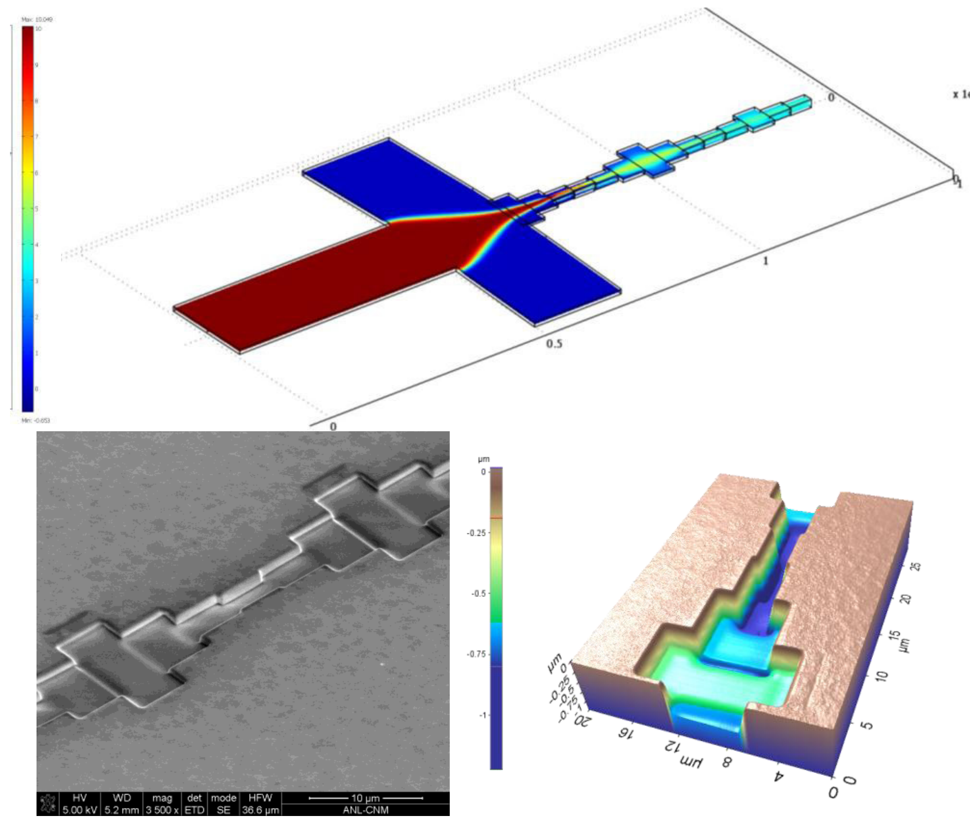

Figure 1. COMSOL simulation of two different fluids (colored red and blue) entering a 3-D microfluidic mixer geometry, and SEM and AFM micrographs of the device fabricated by FIB direct-write lithography.

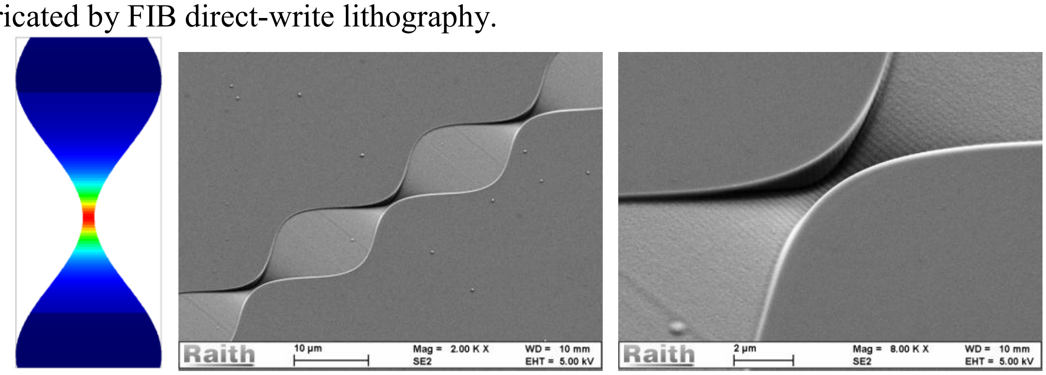

Figure 2. Ion dose distribution and SEM micrograph of a smoother version 3-D mixer. (Wider areas have lower dose than narrow)

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