Rapid Electrokinetic Mixing:

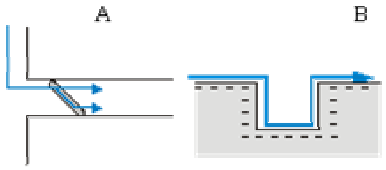

Figure 1. A. Imprinted microchannel with laser-ablated wells. B. Electroosmotic flow into laser ablated wells.

Microfluidic Passive Mixing Structures

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Approaches to passive mixing in microfluidic systems have been limited by the fact that microflow is strictly laminar. Currently, diffusive mixing is the most common approach used in microfluidics to initiate chemical reaction. With diffusive mixing, two or more fluid streams are brought into contact, and reaction occurs when the streams are allowed enough time to diffuse into one another. To encourage more rapid diffusive mixing, inlet streams are generally subdivided into streams of smaller diameter then recombined at the outlet1. Ultimately, however, the process remains diffusion limited and species with slow diffusion coefficients, including cells, proteins and other biopolymers, will mix and react slowly under these conditions.

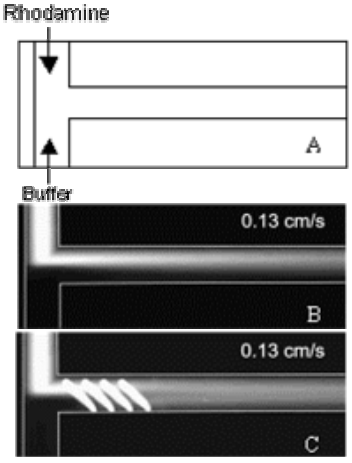

Figure 2. A. Schematic of experiment showing flow of dye and buffer into T-microchannel system. B. Fluorescence image of flow in T without wells (diffusive mixing). C. Fluorescence image of flow in T with wells (transverse mixing).

In order to speed up the mixing process in fluidic systems, designs are required that can either encourage turbulent flow or transverse flow across the channels. Turbulent flow is almost impossible to achieve in microfluidic systems because of the low Reynolds numbers associated with flow in a channel of micrometer-sized dimensions. To date, few researchers have attempted to induce transverse flow in microfluidic systems2. Transverse flow, or flow in the lateral direction across the microchannel, is a good approach to mixing since it should enhance the diffusive mixing process, yet if done properly should not result in significant sample dilution. We have focused our efforts on developing passive mixing structures in microfluidic systems that encourage lateral transport across microchannels3.

Recently, our group has reported on the development of hybrid techniques- using imprinting in combination with laser ablation- to fabricate microchannels. Using this approach, channels are first imprinted in a polymer substrate material, then post-modified by exposure to a UV-laser (248 nm) using a direct write process. Areas in the microchannel that have been exposed to the UV-laser may have a different surface charge and/or a different geometry than the surrounding surface of the imprinted channel. We have recently used this approach to create patterned regions of high charge in plastic microchannels to correct for band broadening around 90^{o} turns4.

In this work, we use the hybrid fabrication method to create wells or trenches in a preformed polymer microchannel. The wells are laser ablated in an imprinted polymer microchannel at a 45^{o} angle relative to the channel length as shown in Figure 1A. We then use electroosmotic flow to drive the fluid through the microchannels. Because electroosmotic flow is a wall driven phenomenon, as the fluid approaches the well, it is pulled down into the well as depicted in Figure 1B.

We have demonstrated that this microchannel design can be incredibly effective at generating flow in the transverse direction across the microchannel. Shown in Figure 2 is a comparison of flow in microchannels with and without wells at flow rates of 0.13 cm/s. Rhodamine dye is mixed in this system with buffer as the two flow solutions flow into the microchannel in a T format (Figure 2A).

As shown in Figure 2B, diffusive mixing, even at relatively lower flow rates, is slow and the solution exiting the channel at a distance of approximately 0.5 mm is not completely mixed. Conversely, the two solutions are completely mixed as they exit the 4-well mixer indicating that the altered channel geometry (and possibly the altered channel charge imposed by the ablation process) induces lateral transport across the microchannel.

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(4) Johnson,T.J.; Ross, D.; Gaitan, M.; Locascio, L.E., *Laser Modification of Preformed PolymerMicrochannels: Application To Reduce Band Broadening around Turns Subject to Electrokinetic Flow, Anal. Chem.* **2001**, *73(15)*, 3656-3661.