ACOUSTIC STREAMING - ULTRASONIC AGITATION IN MICROCHANNELS
Martin Bengtsson, Thomas Laurell
Department of Electrical Measurements, Lund Institute of Technology
Box 118, SE - 221 00 LUND, Sweden

Abstract
This paper describes an acoustic method to induce rotating vortex flows in microchannels. The method is tested on two different systems, a mixing channel with two parallel flows and a porous silicon microreactor for protein digestion. A significant increase of the mixing ratio is detected in both cases.

Keywords: ultrasound, agitation, microchannels, microreactor

Introduction
In most microfluidic systems one of the major issues is the time required to get the reactants in contact with each other and transport the products away. The problem derives from the often very low Reynolds number in microsystems, due to the small dimensions. This leads to a laminar flow, which makes any transport transversal to the main flow strictly diffusion limited. Various alternatives for mixing the components have been presented utilising multilayer structures, movable parts or ultrasonic mixing chambers. A drawback with these solutions is that the mixing often is separated from the rest of the system, why they require a redesign of the system and may increase the deadvolume of the system.

One possible way to speed up the process could be to induce a vortex flow in the channel to carry reactants from the centreflow to the channelwalls and the products back. Lateral acoustic flow, Rayleigh flow [1], is a method to induce such a flow. Rayleigh flow typically occurs in the presence of a standing acoustic wave field in a channel with a width much smaller than the wavelength of the acoustic wave but much larger than the thickness of the periodic boundary layer. The standing wave form a number of vortex flows, transversal to the acoustic field, spaced λ/4 apart [2]. With the use of high frequency ultrasound it is possible to achieve an acoustic wavelength in the same dimension as most microchannels, and thus the flow should be possible to generate in any high aspect ratio channel system.

In order to study the feasibility of using Rayleigh flow for agitation in microchannels a testchannel was designed for mixing measurements. As an application suitable for this kind of agitation an existing system, a parallel channel enzyme reactor in porous silicon [3], was chosen and tested with ultrasonic agitation.
Materials and methods
All structures were fabricated in (110)-silicon with anisotropic etching in KOH. The testchannel was 30mm long, 300μm deep and 75μm wide with parallel vertical walls, figure 1. The two flowpaths flows parallel with a 5μm wall in between prior to combining in order to let all turbulence from the inlets fade out. The porous silicon enzyme reactor comprised of 32 parallel channels, 10 mm long, 300μm deep and 25μm wide. The reactor was anodised in an HF/DMF solution at 50 mA/cm² for 10 min, to obtain a porous silicon layer on the surfaces, figure 2. The structures were sealed of with an anodic bonded Pyrex lid and the flow was injected via glued capillaries. An ultrasonic crystal was pressed between the silicon chip and a polyurethane wafer, with a gel interface to ensure a good acoustic contact. The standing wave was supposed to form between the channelbottom and the Pyrex lid, figure 3.

Figure 1. Schematic view of the testchannel with the separating wall.

Figure 2. Cross-section of porous silicon enzyme reactor.

Figure 3. Schematic cross-view of the setup with the ultrasonic crystal. The expected vortex-flow is marked with arrows.
The mixing efficiency was tested with a colorimetric assay. In the testchannel liquids with two different pH-values, 2.5 and 6 respectively, was injected one containing a pH-reagent, dinitrophenol. The actuating frequency was swept and the absorbance shift of the output was monitored. In the enzyme reactor trypsin was immobilised onto the porous matrix and the digestion of BAEE was monitored.

Results and discussion

When sweeping the actuating frequency on the testchannel the absorbance show a significant absorbance peak for an frequency of 4.85 MHz, figure 4. The bandwidth of the peak appears to be very narrow and no effect is shown for neighbouring frequencies. The peak frequency corresponds very well to the measured height of the channel, 305 μm.

Figure 5. Absorbance at 251 nm, measured at the outlet of the enzyme reactor. First the flow is directed past the reactor to establish a baseline, then the reactor is connected and the ultrasound turned on and off at the channel resonance frequency.
The measurements on the porous silicon enzyme reactor also show a significant increase in catalytic effect with the ultrasound switched on, figure 5. The measured increase in catalytic effect with agitation is between 15-20%. The resonant peak bandwidth seems larger than for the channel. This may be the cause of the porous matrix, since it might be possible for the wave to reflect at several depths in the matrix. This indicates that the porous surface is a non-perfect reflector of the acoustic wave, which in turn may cause a damping effect. This combined with the larger volume of the reactor, compared to the testchannel, indicates that with higher ultrasonic effect it is possible to get much higher agitation effect.

Conclusion
A method to introduce a lateral vortexflow, Rayleigh flow, in microchannels is demonstrated. The ability to acoustically induce a lateral vortexflow gives a possibility to increase the mixing in microchannels without redesigning an existing system.

References