Localized Microfluidic Actuation and Mixing Using Planar Fresnel Type Gigahertz Ultrasonic Transducer

CNF Project Number: 1121-03

Principal Investigator(s): Amit Lal

User(s): Adarsh Ravi

Affiliation(s): Electrical and Computer Engineering, Cornell University

Primary Source(s) of Research Funding: Intelligence Advanced Research Projects Activity (IARPA) - Trusted Integrated Chips (TIC) program, and National Science Foundation (NSF) - Emerging Frontiers in Research and Innovation (EFRI) program

Contact: amit.lal@cornell.edu, ar2256@cornell.edu

Website: http://sonicmems.ece.cornell.edu/

Primary CNF Tools Used: Heidelberg mask writer - DWL2000, Westbond 7400A ultrasonic wire bonder, ABM contact aligner, SU-8 Hotplates, YES Polyimide Bake Oven, Optical Microscopes, CorSolutions microfluidic probe station, Harrick plasma generator, high-temperature PDMS curing oven, low-temp PDMS vacuum oven, Tencor P7 profilometer

Abstract:

We report on an AlN-based gigahertz (GHz) frequency ultrasonic transducer for microparticle actuation and microfluidic mixing. The device uses focusing transducers placed in a Fresnel lens configuration, which generates bulk acoustic waves through the silicon substrate adding in phase at the focus. The device is planar and is fabricated with a CMOS compatible process, with no thin-film release steps. Peak displacement of 250 pm was achieved at the focus with 5 V_p, 1.06 GHz RF input. Owing to high absorption at gigahertz, vortices with streaming velocities > 2.6 mm/s in water were generated, and localized mixing of blue dye and water with 90% efficiency was observed.

Introduction:

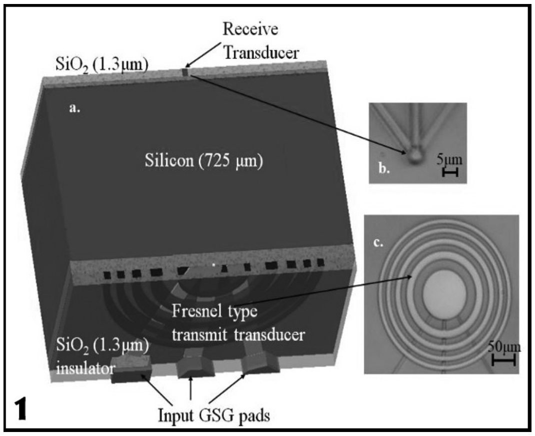
Among the contactless microparticle manipulation mechanisms, optical and acoustic techniques are the most common. The laser based optical technique can produce a few pico-Newton of trapping force, but cannot control larger biological objects and operate in a medium of high optical opacity [1,4]. On the other hand, acoustic devices can be more easily integrated with the microfluidic channel and have been shown to handle biological particles better because of longer wavelengths and higher forces [1-3].

Efficient and rapid mixing of laminar fluid flows is critical for several microfluidic applications such as drug screening, chemical synthesis, genetic analysis, protein folding studies, etc. [3-5]. Traditional macroscopic fluidic mixing strategies employing long channels, mechanical or magnetic stirring elements become impractical for microscale mixing. Furthermore, as microfluidic flow lies in the laminar regime, mixing is dominated by diffusion, which is slow and prevents mixing in channel lengths compatible with microfluidic chip dimensions [2,4].

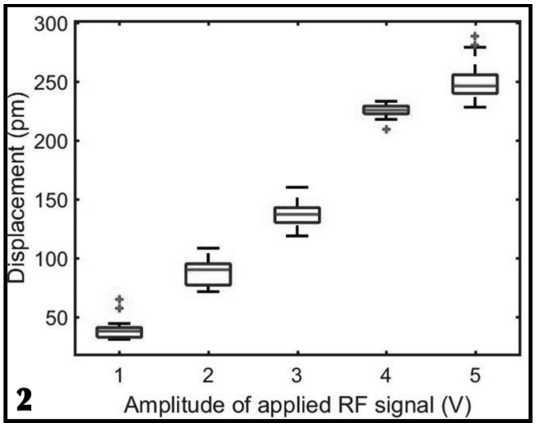
To improve the mixing time and homogeneity, various approaches have been employed. These approaches can be classified into passive and active mixing based on the absence or presence of an external energy source. Active mixers generally outperform the passive counterparts with respect to mixing time, efficiency, and required channel length. Active microfluidic mixers employing external electrical, thermal, magnetic or acoustic energy sources have been reported [5]. However, acoustic mixers are advantageous as they perform contactless fluidic mixing without any restriction on the electrical properties of the fluids.

Acoustic mixers perturb the streamlined flow in the microfluidic channel by employing bulk acoustic wave (BAW), surface acoustic wave (SAW) or membrane transducers. For efficient mixing, strong acoustic streaming forces are required. The body force that generates streaming vortices at the edges of the acoustic fields in fluids scales as $F_B \propto f^4$, where f is the frequency. As a result, much interest is being showed in developing ultra-high frequency SAW and BAW based microfluidic actuators and mixers [4,5]. However, most of these actuators reported thus far require > 10 V_p drive voltage and are fabricated using non-CMOS compatible materials such as ZnO, $LiNbO_3$, $LiTaO_3$ or PZT [4].

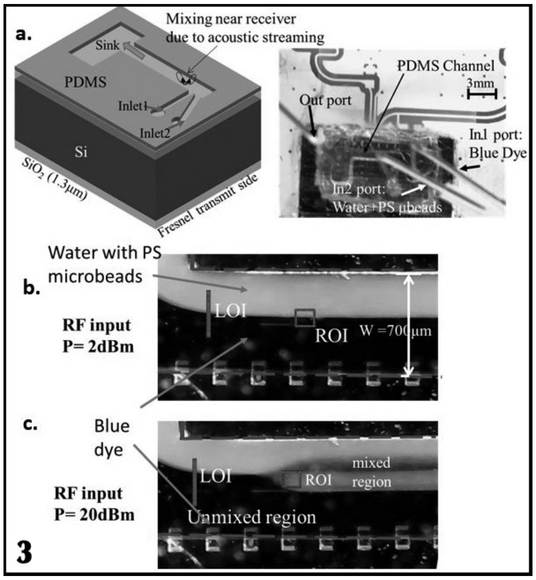
Furthermore, in most of these devices, the fluid is placed on the same side of these transducers. This then forces considerable chip area dedicated to isolate electrical



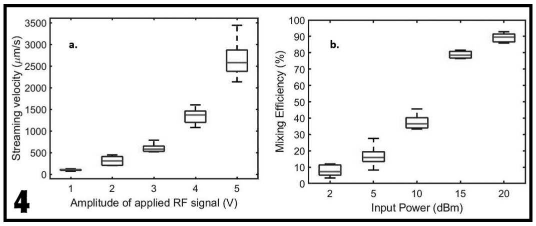
1



2



3



4

interconnects from the fluidic sample. These factors can result in increased device area, expense of fabrication, and electronics complexity in the generation and amplification of high voltages at ultra-high frequencies.

Summary of Research:

The acoustofluidic micro-mixer and actuator presented here uses gigahertz focused ultrasonic beam to create localized streaming vortices in the microchannel. The device is fabricated without any thin-film release steps, using CMOS compatible materials like aluminum nitride solidly mounted to silicon substrate. Further, the placement of the transducers on the opposite side of fluidics enable easier integration of distributed CMOS electronics with AlN transducers on one side, and the fluidic system on the opposite side. The cross-sectional sketch of the simplified GHz transducer stack with planar FZP shaped AlN transducer on the transmit side and a small circular AlN transducer on the receive side is shown in Figure 1. AlN in the regions without transduction are not shown here for simplicity. Figure 2 shows the peak displacements at the point of focus for different RF drive voltages.

A PDMS microfluidic channel with two inlet ports and an outlet port was fabricated using standard soft lithography process. The molds for the PDMS channel were made using 325 µm thick SU-8-100 photoresist spun onto a clean silicon wafer. The photo resist was patterned using UV contact lithography to make a 700 µm wide channel. PDMS resulting by mixing Sylgard-184 elastomer base and curing agent in the mass ratio 10:1 was poured onto the silicon wafer with SU-8 master. The cured PDMS stamp was then peeled off from the silicon wafer to make a microfluidic channel. The surfaces of the PDMS channel and the AlN-Si transducer stack were modified using a room temperature plasma cleaner before bonding. The image of the PDMS channel bonded onto the AlN-Si transducer substrate is shown in Figure 3. Figure 4 shows the results from the mixing activity and the streaming velocities for different drive voltages.

References:

[1] C. Lee, et al., "Single microparticle manipulation by an ultrasound beam," IEEE International Ultrasonics Symposium, 849-852, 2010.

[2] B. W. Drinkwater, "Dynamic-field devices for the ultrasonic manipulation of microparticles," Lab Chip, 16, 2360, 2016.

[3] A. Sarvazyan, et al., "Stirring and mixing of liquids using acoustic radiation force," The Journal of the Acoustic Society of America 125, 3548, 2009.

[4] A. Ravi, et al., "CMOS compatible GHz ultrasonic Fresnel microfluidic actuator," Technical Digest of the 2018 Solid-State Sensor and Actuator Workshop, Hilton Head Isl., SC, 2018.

[5] A. Ravi, et al., "Localized Microfluidic mixer using planar Fresnel type GHz ultrasonic transducer," IEEE International Ultrasonic Symposium, Japan, 2018.

Figure 1: *Cross sectional schematic of the AlN-Si stack (a) and images of the Fresnel lens transmit (c) and circular receive (b) transducers post fabrication.* **Figure 2:** *Plot of surface displacement at the point of focus against different applied voltages.* **Figure 3:** *a. image of the GHz acoustofluidic micro-mixer after bonding. Image captures showing: negligible mixing activity near the receive transducer when RF input power is 2 dBm (a) and localized mixing when RF input power is 20 dBm (c) (LOI - Line of interest; ROI - region of interest for mixing efficiency calculation).* **Figure 4:** *a. Box plot of streaming velocity versus applied voltage. b. Box plot of mixing efficiency vs. applied RF input.*