Utilization of Surface Acoustic Waves for On-Chip Manipulation of Micro/Nano Particles

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Abstract

The on-chip integration of microfluidic and surface acoustic wave (SAW) systems provides a promising platform for potential applications such as cell patterning, cell sorting and separation, high throughput screening in drug development and testing, and ultrafast mixing. In this study, we integrated polydimethylsiloxane (PDMS) microchannels with inter-digitated transducers (IDTs) on a piezoelectric substrate to enable the on-chip manipulation of micro/nano particles. Photolithography techniques were utilized to define the micropattern for both the microchannels and IDTs. The mold for the PDMS microchannels was fabricated via deep reactive ion etching (DRIE) on a photoresist-patterned silicon (Si) wafer. Precision control of polystyrene (PS) micro/nano particles is achieved by generating standing SAW within the microchannel using IDTs. Through careful arrangement of microchannels and IDTs, one-dimensional and two-dimensional patterning of micro/nano particles in the microchannel can be achieved.

Introduction

In recent years, much interest has been expressed in the development of robust, integrated lab-on-a-chip systems which serve a multitude of purposes in engineering, medicine, and biochemistry. In this study, our goal was to design, fabricate, and test an on-chip integrated microelectromechanical systems (MEMS) device that would enable aggregation of micro/nano particles within a microchannel at the pressure anti-pressure nodes of standing SAW.

Microfluidic channels provide a controlled region for study, taking advantage of laminar flow, low Reynolds numbers, and high surface area to volume ratios [1]. The underlying mechanism for particle patterning stems from wave theory, where two approaching waves converge and undergo positive interference to form standing waves. In this project, a piezoelectric substrate was used due to the fact that it functions as an energy interface, converting between electrical and mechanical forms of energy. Thus, when a form of electrical energy, voltage, is applied across an electrode on a piezoelectric substrate, mechanical vibrations of the substrate result, and SAW propagate across the medium, perpendicular to the IDT. Arranging two IDTs in either parallel or angled patterns enables precise 1D or 2D patterning, respectively, at the pressure nodes of the standing SAW.

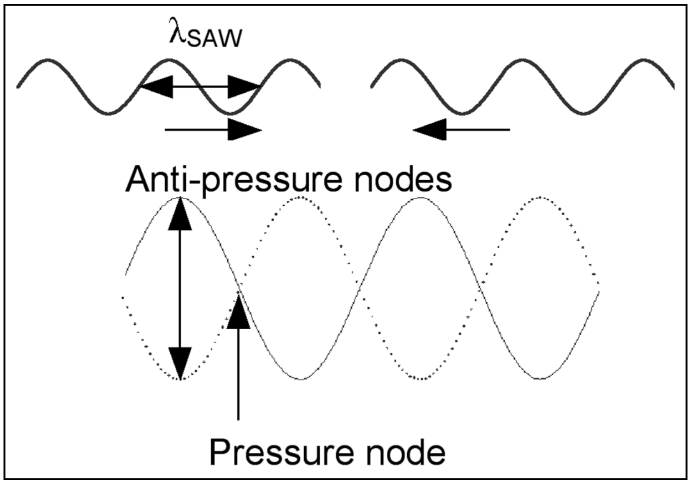

Figure 1: The underlying mechanism for particle manipulation: the combination of two converging SAWs into one standing SAW.

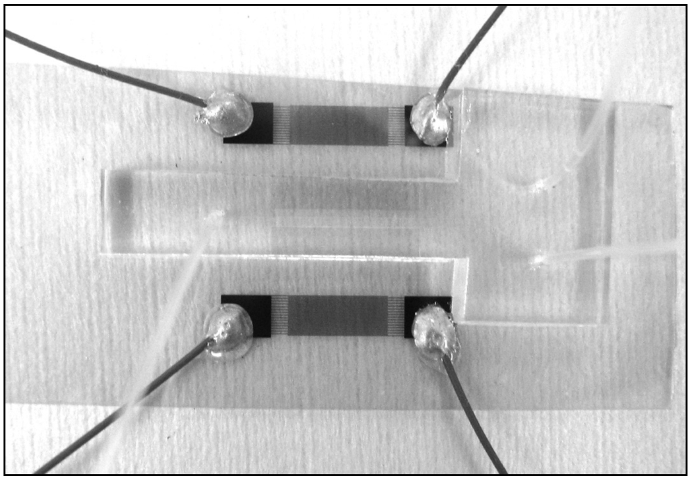

Figure 2: On-chip combined acoustic and microfluidic systems: titanium/gold IDTs with wires bonded and PDMS microchannel with polyethylene tubing, ready for testing.

Experimental Procedure

Photolithography techniques were implemented in both the fabrication of the IDTs and microchannels. First, IDT and microchannel masks considering a variety of parameters were designed on AutoCAD. Based on the orientation of the IDTs and microchannels, both 1D and 2D patterning systems were designed.

Both masks were written on a laser writer, and contact lithography was used for the patterning of the Si wafer for the microchannel mold and the piezoelectric IDT substrate. Following, the photoresist-patterned Si wafer underwent DRIE, which etched into the exposed areas of the wafer, creating a Si mold for microchannels. PDMS was mixed and poured over the mold and cured, and the microchannels were released. To complete the IDT fabrication, an adhesive layer of titanium (Ti) was deposited, followed by a layer of gold (Au), by metal evaporation onto the photoresist patterned piezoelectric substrate. Finally, the Ti/Au electrodes were revealed by a chemical liftoff process, removing any remaining photoresist/Ti/Au.

Device integration challenges were overcome by relying on reactive ion etching (RIE) to pre-treat bonding surfaces of both the PDMS microchannel and piezoelectric substrate. Immediately following low-power oxygen RIE, microchannels were aligned with the IDTs under a microscope. Wires were bonded to the IDT electrodes, and polyethylene tubing was inserted into the microchannel inlets and outlets.

The device testing experimental setup consisted of an radio frequency (RF) signal generator first connected to a power amplifier, which was then connected to both IDTs. An oscilloscope recorded the signal voltage and frequency. The integrated MEMS device was placed on the stage of an inverted optical microscope for testing. Specified flow rates of micro/nano particle containing fluid were delivered to the polyethylene tubing by a syringe pump.

Results and Conclusions

In conclusion, we have developed an effective method for the on-chip manipulation of micro/nano particles. When an alternating current (AC) signal was applied across the surface of both IDTs, aggregation of micro/nano particles within the microchannels did occur successfully at the pressure nodes of the standing SAW. Both 1D and 2D patterning of micro/nano particles was achieved, resulting in an aggregated line or grid of dots, respectively. Patterned particles ranged in size from 460 nm to 10 μm in diameter.

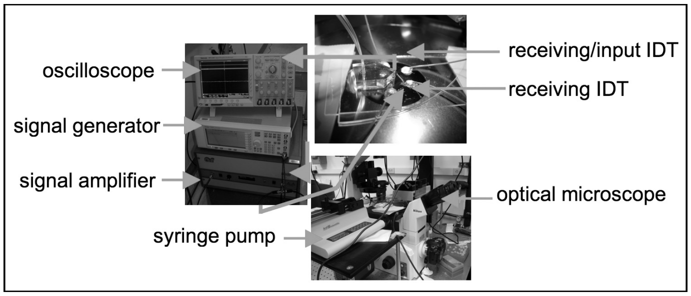

Figure 3: Experimental setup consisting of signal generator, power amplifier, MEMS device, syringe pump, inverted optical microscope, and oscilloscope.

Future Work

This work boasts a multitude of applications, particularly in pharmaceuticals, biology, and biochemistry. Future work involving the patterning of cells would be applicable to drug discovery, development, and testing. This technique could potentially be used to affix the positions of cells and provide a uniform environment for monitorable testing during high throughput screening. Cell responses to variations in dosage amount, frequency, and other factors could be observed. Secondly, functionalizing molecules with polystyrene micro or nano particles could lead to improvements in molecular sorting and deoxyribonucleic acid (DNA) analysis techniques. Finally, microfluidic in-channel mixing, which is often difficult to attain in laminar microfluidic systems, could be achieved efficiently by selective functionalization and patterning of molecules.

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References

[1] Squires, T. M., Quake, S.R.; "Microfluidics: Fluid physics at the nanoliter scale; Revs of Modern Physics, 77, 977-1026 (2005).

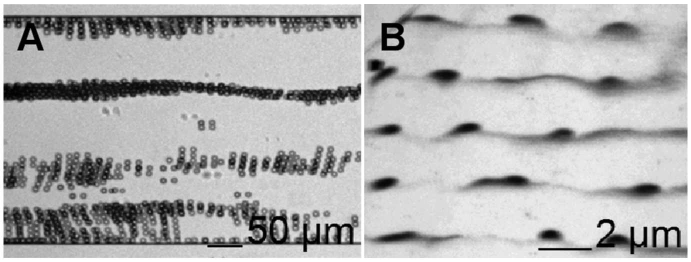

Figure 4: 1D patterning of 10 µm (A) and 2D patterning of 1 µm (B) polystyrene microparticles at pressure nodes of standing SAW.

(Note new publication; "Focusing Microparticles in a Microfluidic Channel with Standing Surface Acoustic Waves"; J. Shi, X. Mao, D. Ahmed, A. Colletti, and T.J. Huang. Received 1st January 2007, Accepted 1st January 2007, First published on the web, 1st January 2007, www.rsc.org/loc | Lab on a Chip.