Micro-Fluidic Channels with Integrated Ultrasonic Transducers

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Abstract - **This paper describes the work done in an attempt to integrate ultrasonic sensors in micro-fluidic channels. We have developed a system with fluidic channels having embedded zinc oxide transducers. A zinc oxide film is deposited on a glass substrate and is sandwiched between two electrodes. The transducers made are found to resonate at 400 MHz in thickness mode. The channels are made both from PDMS using a silicon master and from glass. These channels are aligned on top of the transducer forming a narrow path for fluid flow. The fluid of interest is pumped in the micro-channels by means of a syringe pump and pulse echo measurements are done with the necessary circuitry. This paper will also show the results of the first experiments on mixing induced by the transducer and the measurement of physical dimensions, temperature of fluid in the channel using broad band pulse echo techniques.**

Index Terms - **micro-fluidics, cMUT, ultrasonic transducer, temperature sensing, mixing.**

I. INTRODUCTION

Micro-fluidics involve the analysis and manipulation of fluids made to flow through channels with dimensions in the micron range [1]. The motion of fluids in such micro-channels give rise to a number of interesting applications like particle sensing, measurement of density, flow, viscosity and observation of chemical reactions. Some of the techniques available currently for this purpose include optical methods such as fluorescence microscopy and capacitance measurements. Surprisingly, ultrasound has been used to a very limited extent in micro channels in contrast to their successful applications for measurement of flow, physical properties and pressure in large-scale devices.

The study of fluid flow becomes both interesting and challenging at such miniature channels as the characteristics of flow vary to a great degree when compared to fluid flow in pipes and tubes. The flow is no longer turbulent and mixing of fluids in such a laminar flow becomes an issue.

Ultrasound has traditionally been used in many applications involving macro-fluid flow in tubes and pipes [2]. Its use in micro-fluidics has been rather limited; the main reason for this being the incompatibility of the transducers with the micro-channels. With advancement in technology this limitation has been surpassed and has led to a whole new realm of applications. The biomedical industry is one of the major industries to benefit from the advancement of micro-fluidics. Portable micro-total analysis systems (μTAS) and lab on chips are more close to realization due to current micro-fluidic techniques.

This paper describes the work done in integrating ultrasonic transducers to micro-fluidic channels in an attempt to embed more functionality to the traditional micro-fluidic channels. The transducer used for this purpose is made of zinc oxide (ZnO) though further research is being done on replacing them by capacitive micromachined ultrasonic transducers (cMUTs). The zinc oxide devices are made by depositing a 10 μm film on a glass substrate. This paper will discuss the method adopted and the results obtained in measuring the temperature of fluids in the channels using ultrasound. This paper will also explain the ultrasonic mixing that can be obtained in localized regions of the transducer.

II. THE MICRO-FLUIDIC DEVICE

The micro-fluidic device contains an array of ultrasonic transducers which are in the form of interleaving fingers by depositing 10 μm of zinc oxide [3] which are patterned as shown in Fig. 1.

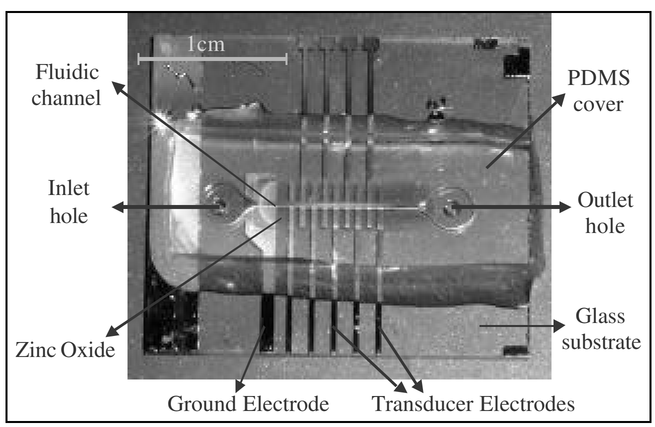

Figure 1. Layout of a microfliudic device.

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The zinc oxide is sandwiched between thin gold electrodes, which are sputtered and patterned using standard lithography tools. The channels are made separately using polydimethylsiloxane (PDMS) or glass and are aligned and bonded to the transducer substrate. The transducers can be on either side of the substrate, i.e., either inside the channel or outside the channel with the glass substrate in between. The typical flow rates used in these channels vary from 1µl/min to 1 ml/min.

The inlet and outlet for the fluid is made possible through holes that are drilled in the glass substrate. A cross-section of the device used is shown in Fig. 2.

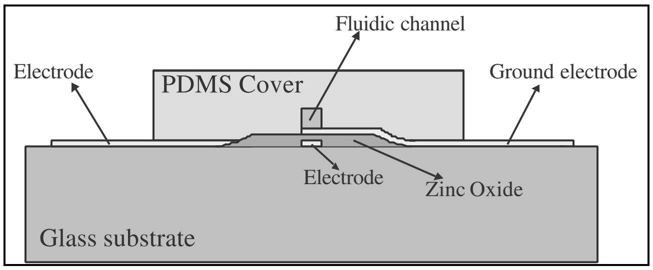

Figure 2. A cross-section of the micro-fluidic device.

The impedance response for the devices built is shown in Fig. 3. It is seen that these devices resonate with a center frequency at around 400 MHz.

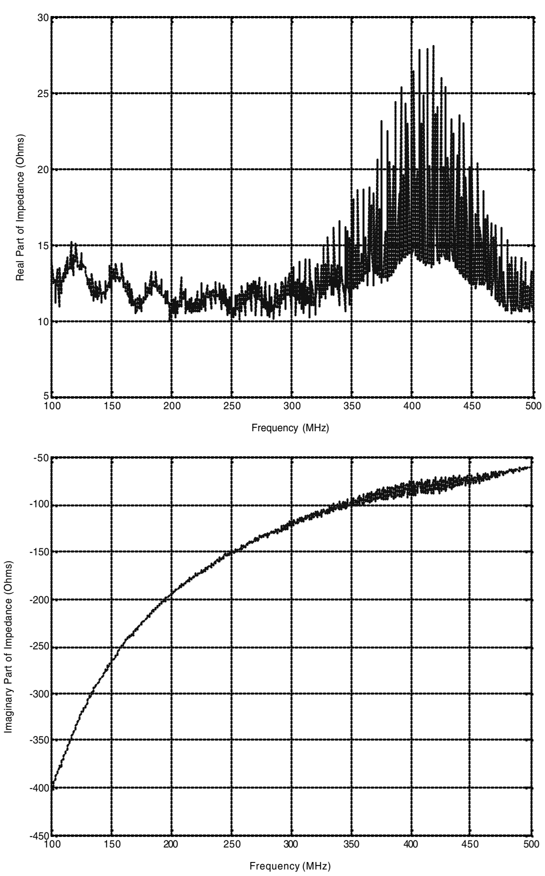

Figure 3. Impedance of ZnO transducer.

The multiple peaks seen in the impedance response in Fig. 3 are due to the thickness mode resonance of the 1.27 mm thick glass substrate. The sound velocity inside quartz is 5600 m/sec. The peaks appear to be separated by 2.2 MHz. The experimental setup for operating the micro-fluidic device is show below in Fig. 4.

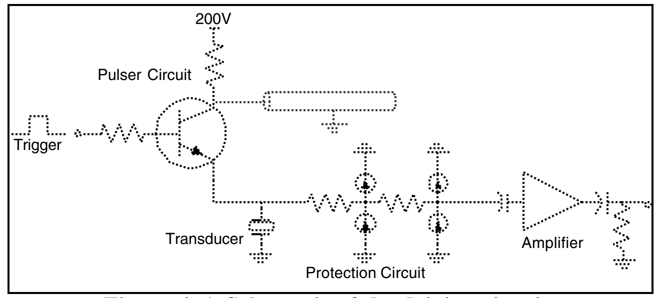

Figure 4. A Schematic of the driving circuit.

A trigger input is given to a pulser circuit which generates pulse 70 V in amplitude and 2 nsec wide. These pulses when applied on the piezoelectric film generate longitudinal waves both in the liquid and the substrate. The reflections obtained are then passed through the protection and amplification circuitry and are analyzed on the oscilloscope. The devices used for the pulse echo measurements have the transducer on one side of the substrate and the channel on the other side. The channel was made of glass with SU-8 walls. The response obtained in the absence of fluid in the channel is shown in Fig. 5.

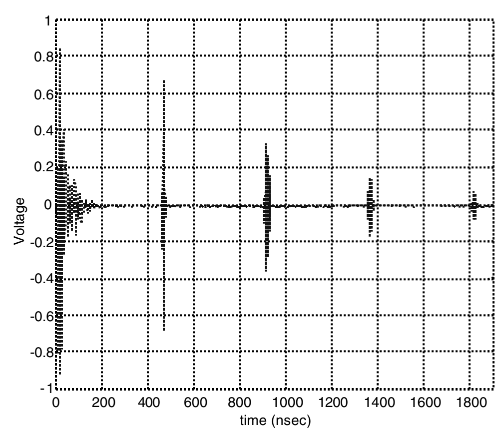

Figure 5. Reflections from the glass substrate.

The pulses in Fig. 5 are separated periodically by 452 nsec that correspond to twice the substrate thickness. It is clearly seen in Fig. 6 that by introducing a fluid inside the channel an additional pulse is obtained which corresponds to the sound waves that propagate through the liquid and reflect from the top of the channel. The amplitude of this refection enables the estimation of the attenuation in that particular fluid. The distance between the pulses due to the top and bottom of the channel was found to be 298 nsec corresponding to a channel height of 223 μm.

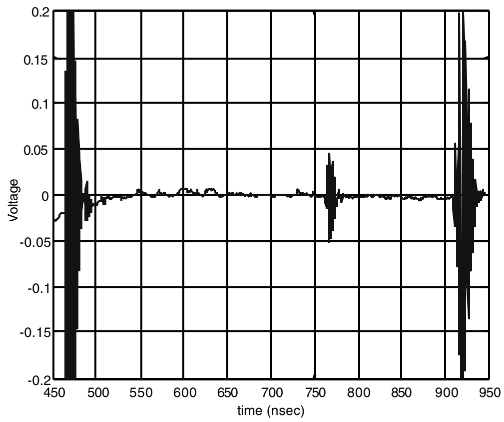

Figure 6. Reflections from the top of the channel filled with DI water.

III. TEMPERATURE MEASUREMENT

Accurate and precise monitoring of the temperature of fluids in micro-fluidic channels is a very important requirement in many modern applications. Channels that handle biological samples like protein and DNA require stringent temperature control and thereby need accurate means of temperature measurement. Operations such as DNA amplification involving cycles of temperature can be made possible only with good temperature detection capabilities. We have adopted an acoustic method of determining the temperature of fluids in the micro-fluidic channels by measuring the change in velocity of propagation of sound in the fluid with the change in temperature. This observed change in velocity is referenced to a calibration curve for that fluid. Fig. 7 shows one such calibration curve for DI water [4].

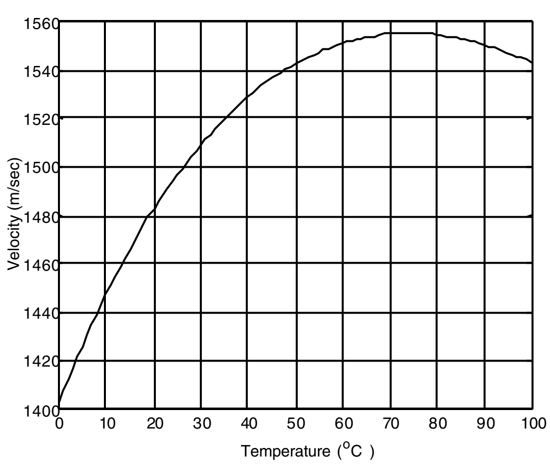

Figure 7. Velocity of sound in DI water as a function of temperature.

Fig. 8 shows the experimental arrangement used for the measurement of the temperature of the fluid inside a micro-fluidic channel.

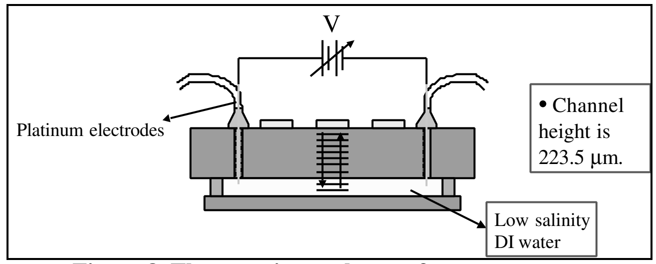

Figure 8. The experimental setup for temperature measurement.

The experimental setup consists of a heating mechanism consisting of platinum electrodes that are in contact with the fluid in the channel. The heating is done by passing current through the fluid. This method of heating therefore requires a small amount of salinity for conduction. The velocity vs. temperature curve for low salinity water was found to be very similar to that shown in Fig. 7 and was used for calibration. The corresponding elevation in temperature is calculated by observing the temporal shift in the reflection from the top of the channel corresponding to a change in the time of flight of the sound waves propagating in the channel.

Voltage (Volts)	Δt (nsec)	Velocity (m/sec)	Temperature (^{o}C)
0	298.0	1500.0	25.0
20	297.8	1501.2	26.7
40	297.0	1505.0	28.3
60	294.4	1518.1	34.1
80	292.2	1529.9	40.1
100	290.8	1537.3	45.4

Table 1. Variation of velocity of sound with temperature of fluid.

Table 1 shows the various velocities of sound measured on heating saline water. This method of temperature detection is independent of the substrate type, which in conventional temperature sensors is a major limiting factor due to need for accounting for the thermal losses of the substrate. Moreover the temperature measurement is very localized enabling the measurement of temperature gradient in micro-fluidic channels by having an array of these transducers along the channel.

IV. MIXING

The characteristic laminar flows that are obtained in micro-fluidic channels make mixing of fluids a very challenging operation. Fluids can flow side by side for long distances with almost no mixing. This property is due to the low Reynolds's number in micro-channels and the absence of turbulence. The mixing if any is only due to diffusion of the fluids across their interface. Figure 9 shows the characteristic laminar flow obtained in micro-fluidic channels.

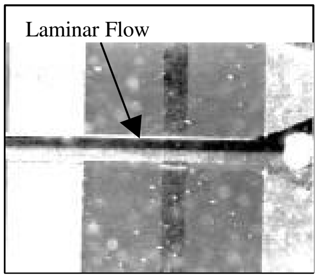

Figure 9. Laminar flow of two fluids in a micro-fluidic channel.

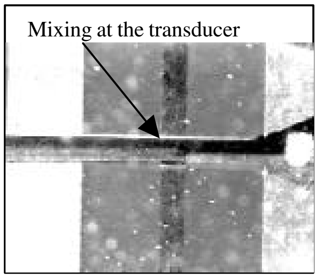

Figure 10. Mixing of the two fluids at location of the transducer.

An RF source is used to drive the transducer that in turn transmits ultrasonic waves into the channel. The acoustic field inside the liquid creates radiation pressure pushing the fluid directly above the transducer up and down causing mixing at that region. Figure 10 shows a picture of the mixing occurring at the localized region defined by the ultrasonic transducer.

This method of mixing possesses many inherent advantages with respect to conventional mixing methods. First and foremost the mixing is limited to localized regions and is instantaneous. The device is not very large when compared to passive mixers and does not need any direct contact to the fluid unlike active mixing methods like electrophoresis. This mixer configuration is relatively simple and can easily be realized in arrays for mixing at various positions in the channel.

V. FUTURE WORK

Our future work will be focussed on replacing the piezoelectric material that we have used as ultrasonic transducers with capacitive micromachined ultrasonic transducers (cMUTs) [5]. The advantages of the change in the transducer are multifold. First and foremost cMUTs have broader band operation. They are CMOS compatible allowing for future integration with electronics. cMUTs also have lesser mechanical impedance when compared to piezoelectric materials eliminating the need for matching layers.

Figure 11 shows a picture of a cMUT device fabricated for micro-fluidic applications. The device was found to operate at a center frequency of around 50 to 60 MHz.

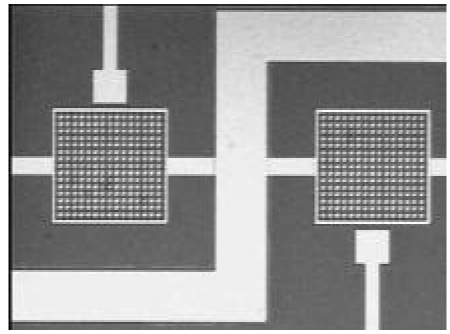

Figure 11. A picture of a cMUT device for micro-fluidic applications.

VI. CONCLUSION

This paper has presented the work done in an effort to integrate ultrasonic transducers to micro-fluidic channels. These transducers have been successful applied in the measurement of fluid temperature in micro-fluidic channels. In addition the same device has been realized as a very good active mixer. Further research is in progress to improve the device and to make the transition from using piezoelectric materials to cMUTs.

ACKNOWLEDGMENT

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