Ultrasonic Temperature Control and Measurement in Micro-Fluidic Channels

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ABSTRACT

This paper describes the design and operation of a system used for the accurate control and measurement of temperature in micro-fluidic channels. Ultrasonic transducers are used for both heating and measuring the temperature of fluids inside the channel. Heating is performed by exciting the transducer with a tone burst at a single frequency. The temperature measurement is done through non-invasive means by monitoring the velocity of a sound propagating through the channel. The whole system is automated for data collection using Labview. The system developed has the advantages of easy integration, simple operation and design along with a wide application domain. The same ultrasonic transducer can be used for both heating and temperature measurement leading to possibilities of closed loop temperature control in micro-channels. The system requires milli-watts of power for heating and has a nano-second response time for temperature measurement with an accuracy of 0.1 degrees.

Keywords: Ultrasound, piezoelectric, CMUT, micro-fluidics, temperature measurement, heating

1. INTRODUCTION

The growth in the field of micro-fluidics has underscored the need for improved measurement and actuation techniques of fluids in micro-channels. Current techniques of sensing fluids in micro-channels include the use of lasers, fluorescence microscopy, and image processing by the use of cameras. These techniques involve bulky instruments which result in problems during system integration. The actuation of fluids is done through mechanical pumping or by the moving of micro-machined components such as switches or valves. Heating is commonly done by using polysilicon resistors fabricated inside the channel.

While ultrasound theory is commonly used to study fluid flow in large pipes and tubes, it is rarely applied in the field of micro-fluidics. Our work emphasizes the use of ultrasound to achieve useful operations in micro-channels [1]. Both piezoelectric transducers and Capacitive Micromachined Ultrasonic Transducers (CMUTs) are used for this purpose. The piezoelectric devices operate at a center frequency of 400 MHz in air and have been used in our experiments. Capacitive Micromachined Ultrasonic Transducers have also been fabricated operating at a center frequency of 50 MHz. The channels are made of either PDMS (polymethylsiloxane) or glass.

The control and monitoring of temperature in micro-channels is a very important task. The ability to measure and control temperature precisely will result in the monitoring of reaction rates between two or more chemicals, the measurement of flow rate or even the state of the fluid or sample. Many bio-medical procedures, Polymerase Chain Reaction (PCR) among others involve cycling of temperatures. The ability to control and monitor the temperature in micro-channels would enable the same procedures to be carried out in small and portable devices.

2. THE ULTRASONIC TRANSDUCERS

Traditional ultrasonic transducers are made using piezoelectric materials that possess a property of producing charge proportional to the applied stress or vice versa. Today, a large variety of ultrasonic transducers are available. Some of these are made from new technologies that were not available in the past. Each type of transducer has particular advantages depending on its field of application. For example, the frequency of operation of transducers is generally a strong function of the thickness of the material deposited. This is generally the main reason for piezoelectric ceramics like PZT to be used for relatively low frequency applications. Whereas the

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ability to deposit thin films of Zinc oxide makes it a very attractive option for conventional high frequency ultrasound. A number of devices have been made in the past by using this concept operating in the Giga hertz range [2]. With the increasing developments in fabrication technologies, better methods of fabrication and deposition of these materials have been found. The development in MEMS has also resulted in modern ultrasonic transducers that do not have any piezoelectric films deposited and that have significantly different characteristics [5]. Both conventional piezoelectric and modern micromachined ultrasonic transducers were fabricated though most of the experiments were done using the piezoelectric transducers.

3. THE FLUIDIC CHANNEL

With the field of microfluidics gaining popularity on a daily basis, a number of methods exist in fabricating micro-channels. We investigated three such methods during our experimentation. The first method involves the fabrication of PDMS channels. Here a blank silicon wafer is etched to the dimensions required for the micro channel. Using the patterned wafer as a mould, liquid PDMS is cast on the wafer and then subsequently used after solidification. The second method adopted is by spinning and patterning SU8 walls over a glass wafer by standard lithography techniques. The desired wall height was obtained by successive spinning of SU8. The final method used channels made completely from glass. This is done by machining the glass to the required dimensions. The channels fabricated in the final method were used in the temperature measurement experiments.

4. THE EXPERIMENTAL SETUP

The acoustic transducer is aligned with the microfluidic channel under the microscope and is bonded in place. The chip consisting of the transducer and the micro-channel are then mounted on a printed circuit board and are connected to the electronics by means of wire bonds. The printed circuit board contains surface mounted components that make up the pulse generator, protection and amplification circuitry and the switching circuitry. The same transducer is used for both heating and pulse echo measurements. The pulse generator made by operating the transistor in the avalanche mode is used to feed in pulses 2.5 ns in width and 60 V in amplitude for the pulse echo measurements. The protection and amplifying circuitry are used to clip the high voltage signals and increase the amplitude of the pulses under interest for better signal processing. A mechanical relay is utilized in the switching circuitry. The circuit performs the operation of switching between the pulser electronics and the circuitry for ultrasonic heating. Due to the inherent delay of the mechanical switch, an 8 ms delay is present between the application of the heating signal and the application of the pulse for pulse echo measurements. Work is currently under progress for replacing the mechanical switch with a solid state switch which is intended to reduce the delay from 8 ms to a few hundred microseconds.

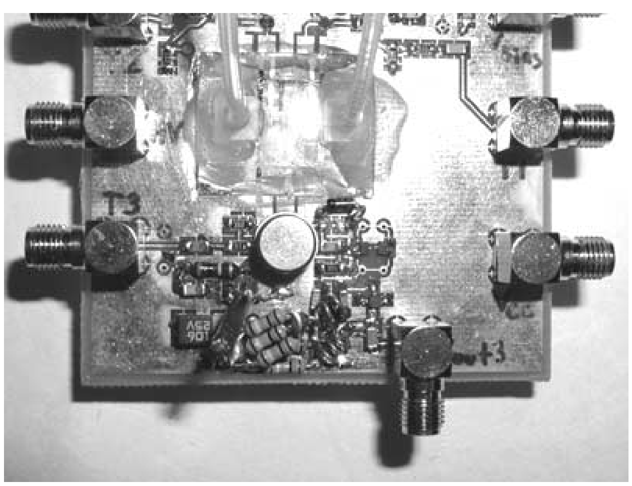

Figure 1. Picture of a printed circuit showing the assembled micro-channel and transducer along with the necessary electronics

Figure 1 shows the picture of one such printed circuit board housing the ultrasonic transducer, the micro-fluidic channel and the necessary electronics.

5. ULTRASONIC HEATING

Ultrasonic heating has been used for quite some time in physiotherapy for treating injuries, pain and inflammation in physiotherapy. This method of treatment is termed as ultrasonic diathermy which involves the application of a strong beam of ultrasound on the skin surface to obtain internal heating of tissues. Modern nebulizers and humidifiers too make use of high intensity ultrasonic transducers for breaking up water and other liquids into fine droplets.

The heating of fluids in the micro-channels is done by the same method. To obtain heating using ultrasound, a tone burst of a single frequency is applied to the transducer. It has been seen from the experiments that maximum heating is obtained when the frequency of the tone bursts matches one of the multiples in the central resonant frequency of the transducer- electronics system. This is expected because when the frequencies of the applied tone bursts and that of the system match, maximum electrical energy applied to the transducer is converted into mechanical energy. This mechanical energy in turn results in maximum heating of the fluid in the channel. Acoustic heating is done by sending an acoustic wave through the fluid to be heated. The heating is obtained due to the frictional damping of the fluid.

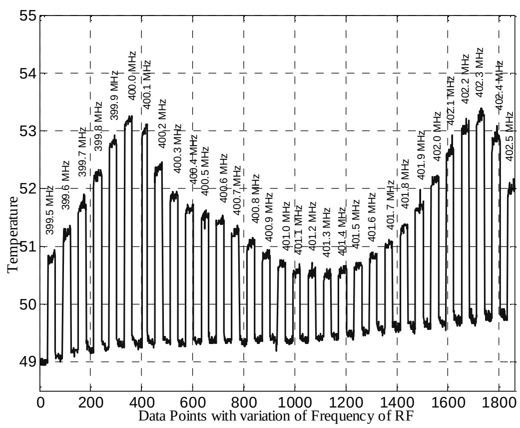

Figure 2. Variation of heating with frequency of applied tone bursts

Fig 2 shows the heating obtained when a tone burst signal maintained at constant amplitude of 20 dBm is applied to the transducer while sweeping its frequency. It can be seen that maximum heating is obtained at 400 MHz and 402.3 MHz. Hence these values of frequency are chosen when operating the transducer as a heater. Our experiments typically needed around 100 mW of power for heating the water by 4 degrees.

6. ULTRASONIC TEMPERATURE MEASUREMENT

The determination of temperature in micro-channels is a very important function in micro-fluidics. The knowledge of the temperature of the fluid can be used to get an idea of the rate of certain reaction. Current methods of temperature measurement use thermocouples placed inside or in thermal contact with the channel. These methods pose significant problems for packaging and integration. Due to the small volumes of the fluids used in micro-channels, the need to make measurements without disturbing the temperature is imperative.

The ultrasonic measurement of temperature in micro channels is done by measuring the velocity of sound propagating in a liquid [3,4]. This is done by measuring the time of flight of sound waves along the height of the channel. A well defined relationship between the velocity of sound in a fluid and the temperature of that fluid is used to find the temperature at that instant of time. Figure 3 shows the relationship between the velocity of sound in DI Water and temperature. It should be noted that the attenuation of sound can also be used as a secondary reference for the temperature measurement.

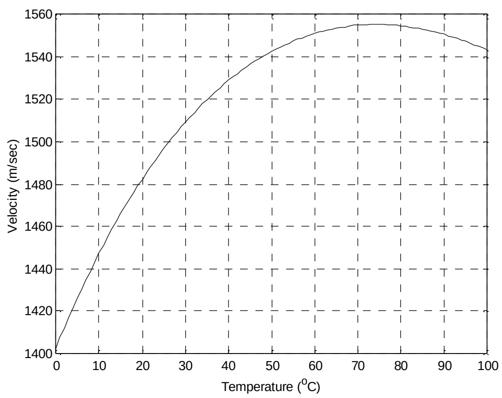

Figure 3. Velocity of sound in DI water versus temperature

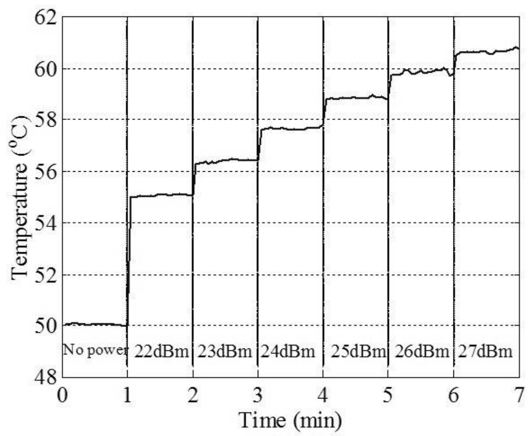

Figure 4. Temperature measurements by varying power applied for heating

The pulse echo measurements are made using the automated Labview program. A one point calibration is done initially knowing the room temperature of the liquid which is water in our case. Upon this calibration the consecutive data are run through a data extraction routine to get the temperature for each data point.

Fig 4 shows the temperature plot achieved using the above mentioned procedure. The tone burst is maintained at a constant length of 100 ms and at a frequency of 400 MHz. The temperature measurements are then carried out by varying the amount of power applied at the transducer. It can be seen that increased heating is obtained for increase in the applied power to the transducer. A temperature resolution of 0.1 degrees has been achieved.

7. CONCLUSION

Ultrasonic transducers have been successfully integrated with micro-channels. The temperature control and measurement of fluids the channels have been demonstrated successfully. The heating is performed using a few hundred milli-watts of power and the temperature is measured with an accuracy of 0.1 degrees. Work is currently in progress in using the system for the measurement of fluid flows in micro-channels. These results show promising prospects for the application of ultrasound in micro-fluidics. Future work includes the improvement of the switching speeds of the switching circuitry, replacing piezoelectric transducers with CMUTS and performing flow measurement in channels.

8. ACKNOWLEDGEMENT

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9. REFERENCES

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