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Integrated thin film resistive sensors for in situ temperature measurements in an acoustic trap

Gabriel Werr¹, Zahra Khaji¹, Mathias Ohlin^{1,2}, Martin Andersson¹, Lena Klintberg¹, Sean S. Searle^{1,3}, Klas Hjort¹, and Maria Tenje^{1,4}

¹ Department of Engineering Sciences, Uppsala University, 721 29 Uppsala, Sweden

² Now at Aimpoint AB, 213 75 Malmö, Sweden

³ Department of Biomedical Engineering, National University of Singapore, Singapore 117583, Singapore

⁴ Science for Life Laboratory, Sweden

E-Mail: maria.tenje@angstrom.uu.se URL: <https://www.teknik.uu.se/mikrosystemteknik/embla/>

Introduction

Microfluidic devices offer a precise and rapid assay platform with fully controlled microenvironment conditions with regards to pH and chemical composition. Some assays require particle manipulation for sorting, incubation or perfusion and here acoustophoresis offers a non-contact and label-free method to achieve this. Acoustic trapping is a method to retain microparticles in a microfluidic channel against a flow and its use has already been demonstrated for sample enrichment [1], and multistep bead-based assays [2]. One challenge when using acoustic trapping for biological samples is the heating effects from the piezoelectric transducers (PZT) used to actuate the system. The common method to control and measure the temperature is by measuring the external temperature of the PZT in the assumption the internal temperatures of the chip will be lower than that of the heat source [3]. Here, we present an acoustic trap with integrated temperature sensors, measuring the *in situ* temperature of the trap comparing it to five external measuring points. With the system we were able to measure temperature variations in the range of ± 0.01 °C. Our goal was to test the hypothesis, whether the PZT would always be the hottest position during operation. Our results confirmed this assumption for the system without external cooling, but refuted it with applied external convective cooling. This demonstrates the need for integrated temperature sensors to monitor all microenvironmental aspects in an acoustic trap.

Methods

Figure 1 shows the design of the acoustic trap with two integrated thin film resistive sensors (RTD). The chip consists of two glass layers, where the channel and the trap were etched in the bottom glass, while the RTDs were sputtered onto the top glass. The top glass was then bonded to the bottom glass with RTD1 positioned to form the ceiling of the trap and RTD2 placed underneath the external PZT. The PZT was glued on top of the glass chip and the fluidic connection was achieved by gluing a capillary sheathed with metal tubing to the chip [4], [5].

For the temperature measurements the RTDs and a Thermocouple (TC2), to compensate for room temperature variations, were calibrated to a reference Thermocouple (TC1), which was placed on the five external measurement positions. The trap was tested for influences by different bead sizes, conductance of the liquid, and cell suspensions, with no negative effects observed. For the main temperature measurements DI-water was used. The measurement cycles consisted of 20 min with the PZT actuated followed by 20 min where the PZT was switched off. For each position the cycle was repeated $n=20$ times at stop-flow with the PZT at 20 V_{pp} and 1.83 MHz. Additionally, a parametric study was conducted with flow rates from 0.2 μ l/min to 20 μ l/min and PZT voltages from 10 V_{pp} to 20 V_{pp}, with $n=5$.

Figure 1: To the left the design of the acoustic trap with integrated thin film sensors and the relevant dimensions. To the right the assembled system with connected tubing, sensors and piezo, and the five external measurement spots.

The results were pooled to calculate average values and standard uncertainties at a confidence level of 95 %.

Results

The integrated RTDs performed without disturbance both when beads and cells were trapped. We observed no

Figure 2: External temperature of the chip relative to room temperature at five different positions with standard uncertainty ($n=20$). Black line shows internal trap temperatures of RTD1 ($n=100$). The arrow indicates the distance of the sensor to the trap. In the left graph temperatures without external cooling are shown, while the right graph shows temperatures with external cooling. A change in the order can be seen for Position 5 and Trap

differences in the measured temperatures when using DI water or conducting liquids. Upon actuation, the temperature increased at all measurement positions. With no external cooling applied, Position 5 (on top of the PZT) measuring the highest temperature increase of 1.67 ± 0.01 °C. When external convective cooling was applied on the chip the hottest reported temperature was observed inside the trap, at 0.52 ± 0.01 °C. Position 5, only reported an increase of 0.4 ± 0.01 °C. The same trends were observed with fluid flow in the channel.

Conclusion

We present an acoustic trap with integrated thin film sensors, that for the first time allows *in situ* temperature measurements during operation. From our results we find the temperature increase inside the acoustic trap to be a result of the dissipative actuation of the PZT. The most important finding is that the temperature inside the acoustic trap can be higher than the temperature measured directly on top of the PZT.

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