FREQUENCY TUNABLE LABEL-FREE SURFACE ACOUSTIC WAVE-BASED FLOW SENSOR

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ABSTRACT

We present a label-free surface-acoustic wave (SAW)-based flow sensor with enhanced precision and repeatability. This sensor improves the signal-to-noise ratio by one order of magnitude (dB scale) at an optimized frequency, and lowers the measurable flow rate to 3 µL.min^{-1}, from 250 µL.min^{-1}, when compared to our previous approach using a sine wave generator. The device was designed so that the distance between the transducers is tunable to further increase its sensitivity to 53 mdB.µL^{-1}.min. This easy-to-integrate sensor does not affect the microfluidic network and offers an integrated flow measurement.

KEYWORDS: Flow Metrology, Electroacoustics, SAW Sensor

INTRODUCTION

Sensing capabilities of SAW-based sensors include flow measurements, which have previously been demonstrated in microfluidic systems [1]. Such SAW flow sensors based on thermal, doppler shift or time-of-flight measurements require labeling of the fluid. Our label-free SAW-based flow sensor relies on absorption of the SAW by the liquid as a function of the flow rate and SAW's frequency. This work presents label-free flow measurements over the range of 0 µL.min^{-1} to 1 mL.min^{-1} in a microfluidic channel. The design consists of a microchannel that passes between the transducers, which are placed in air cavities to improve the accuracy of the measured flow.

EXPERIMENTAL

The sensor is fabricated on a 128XY (128º X-Y cut) lithium niobate substrate. It has two pairs of interdigitated transducers (IDT), one emitter and one receiver, placed in air cavities on either side of the microchannel (Figure 1). Each transducer has 85 pairs of fingers made out of titanium (10 nm) and gold (90 nm). All fingers are 0.5 mm long and have a pitch (λ) of 80 µm. A 100 nm thick silicon oxide layer is sputtered as an adhesion layer for the 80 µm deep polydimethylsiloxane (PDMS) microchannel. We fabricated three pairs of IDT, each with a different distance traveled by the SAW in the liquid (*Df*): 0.7 mm, 0.9 mm and 1.1 mm. The deionized water flow is controlled by a syringe pump at rates between 0 µL.min^{-1} to 1 mL.min^{-1}, in steps of 50 µL.min^{-1} (± 0.35 %, as certified by the manufacturer). Each measurement is done in triplicate. The two IDTs are connected to a vector network analyzer (VNA) to measure the transmission coefficient (S12) at each flow rate for frequencies between 45 MHz and 46 MHz, with a sampling frequency of 1.88 kHz. Contrary to the sine wave generator used in our previous work [2], the VNA is a highly-accurate measurement device, with an uncertainty of less than 0.2 dB for an S12 measurement result between -70 dB and -50 dB, and an uncertainty less than 0.04 dB for an S12 measurement result above -50 dB.

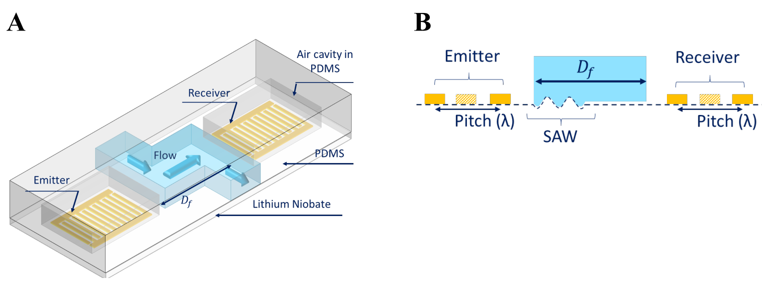

Figure 1: Sensor configuration. A) Sketch of one sensor. Emitter and receiver are placed on a lithium niobate substrate and on opposite sides of the microchannel where the liquid flows. The microchannel wall is in PDMS. B) Cross-section sketch. The SAW travels a distance Df at the liquid-solid interface, from the emitter to the receiver. The IDT's pitch is 80 µm.

RESULTS AND DISCUSSION

The acoustic absorption of a medium is dependent on the frequency of the SAW and *Df* [3]. S12 amplitude depends on *Df* (compare Figure 2A, B, C, or 2G, H, I at no flow) and frequency (Figure 2E, F, G). The maximum amplitude of S12 is reached at the acoustic frequency and decreases with the increase in *Df*, as expected [3]. The highest sensitivity to flow of 53 mdB.µL^{-1}.min is obtained at the low-notch frequency with *Df* = 0.9 mm (Figure 2H). With *Df* = 0.9 mm and a flow range between 0 µL.min^{-1} and 450 µL.min^{-1}, we obtained a precision of 0.2 dB and a theoretical limit of detection of 4 µL/min. As the flow rate increases, S12 amplitude decreases and then increases. Thus, a slip is likely responsible for the non-monotonic response of the S12 to flow rate (Figure 2G, H). In fact, McHale *et al.* [4] have previously reported that the absorption is optimal when the slip can be neglected, and starts decreasing when the liquid slips on the solid. The best precision of 0.04 dB is obtained at the notch frequencies with *Df* = 1.1 mm (Figure 2I), given a theoretical limit of detection of 3 µL.min^{-1} with a sensitivity of 16 mdB.µL^{-1}.min.

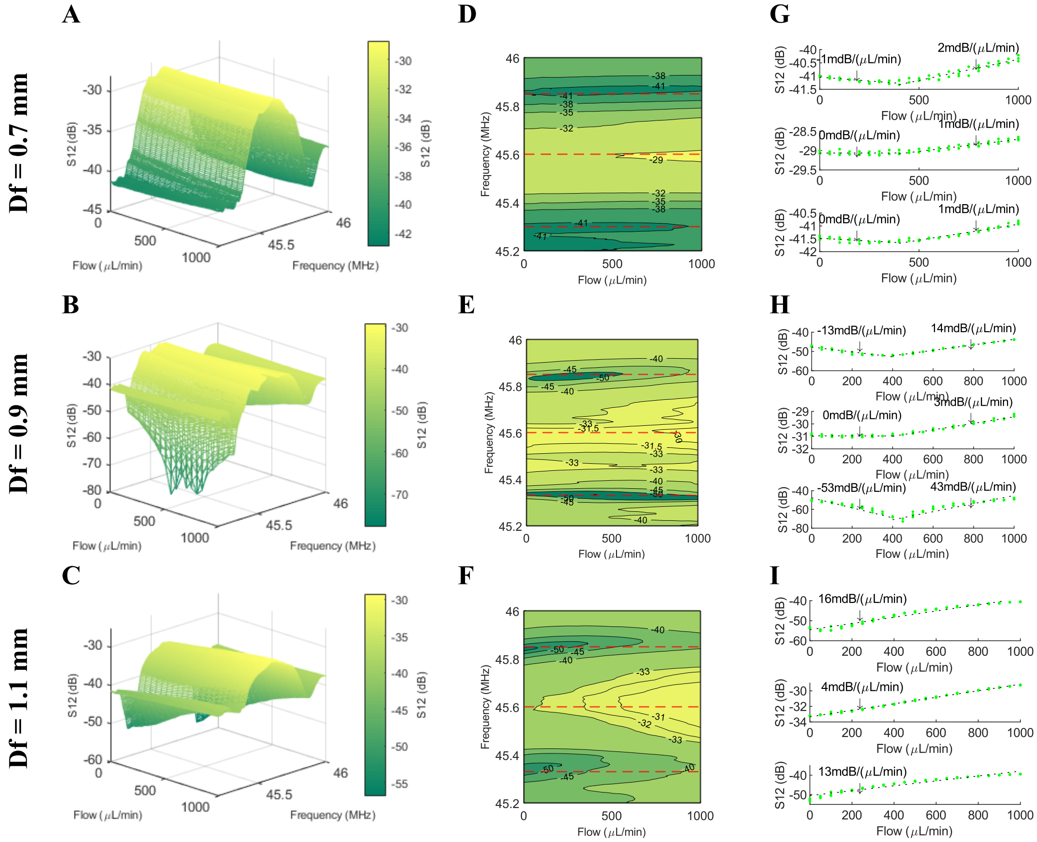

Figure 2: Sensors' responses to flow for Df of 0.7 mm, 0.9 mm and 1.1 mm. A-B-C) 3D plot of S12 as a function of the frequency and the flow rate. D-E-F) Colormap of S12 as a function of the frequency and the flow rate. Three horizontal dashed red lines are plotted at the low-notch frequency, the acoustic frequency and the high-notch frequency, from bottom to top respectively. S12 is the most sensitive to flow rate at these three frequencies. G-H-I) S12 of three measurements (green) and their fit (dashed line) as a function of the flow rate and at the low-notch frequency, the acoustic frequency and the high-notch frequency (from bottom to top). Df and frequency can be tuned to increase the sensitivity to the flow rate. The sensitivity is the highest at the low-notch frequency for Df = 0.9 mm. A wider range of flow rate is measurable, using Df = 1.1 mm.

CONCLUSIONS

This work presents a label-free SAW-based flow sensor with greatly improved accuracy that can be integrated in a microfluidic chip to provide local flow data. This sensor could be integrated, in the future, in drug encapsulation droplet and in diffusion-based reaction microfluidic systems where localized flow measurements are critical to produce high yield results.

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