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Enhanced particle focusing in microfluidic channels with standing surface acoustic waves

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ABSTRACT

We demonstrated an enhanced particle focusing in microfluidic channels by using standing surface acoustic waves (SAWs) generated on a piezoelectric substrate. Interdigitized microelectrode arrays patterned by standard photolithography and lift-off techniques are used for both excitation and detection of SAWs. Bragg reflectors (BR) are also integrated to enhance the standing SAW formation. Furthermore, air cavities are introduced in both sides of microfluidic channels made of polydimethylsiloxane (PDMS). Whereas the system without PDMS cover layer showed a loss less than 2 db, the absorption loss after adding PDMS structures was also limited to a few db. Consequently, enhanced particle focusing could be easily observed, showing clear advantages of the use of BR and minimized PDMS wall thicknesses.

1. Introduction

Surface acoustic waves (SAWs) can be used for solution mixing, particles manipulation and other engineering purposes in microfluidic devices [1–5]. Typically, SAWs are generated by using patterned microelectrode arrays or interdigitized transducers (IDTs) on an acoustic piezoelectric substrate. The wavelength of SAWs can vary in the range from several to a few hundreds micrometers, which is comparable to the channel width of commonly used microfluidic devices. Moreover, the energy of SAW propagating on the wafer surface is confined within a layer of one wavelength thickness, which makes SAWs devices also interesting for label free detection and analyses.

Standing SAWs can be obtained in the area between two IDTs and then enhanced by adding Bragg reflectors (BR) inside or outside of the IDTs. Such a SAW resonator has already important applications in telecommunication and sensor manufacturing [6]. Integration of SAW resonator into microfluidic devices should also be relevant for manipulation and analyses of biological and biochemical samples. Comparing to the other acoustic device configurations [7–9], the SAW resonators have unique advantage of monolithic integration, easy and flexible signal analyses.

In practice, the propagation of standing SAW is largely affected by the material absorption inside the resonator. It is therefore important to optimize the device design to have a minimum absorption loss due to the integration of microfluidic channels. The purpose of this work is to propose a device configuration with integrated SAW resonator and microfluidic channels with minimum absorption loss. This has been achieved by introducing air cavities inside the resonator, i.e., by reducing the microfluidic channel walls. The absorption loss of the device has been studied as a function of the BR grating period and the wall thickness. We show examples of SAW induced particle focusing inside the microfluidic channels and the channel geometry dependence under optimal conditions.

2. Experimental

Fig. 1 shows a schematic drawing of a microfluidic device used in this work. The upper part is a polydimethylsiloxane (PDMS) layer fabricated with a microfluidic channel and inlet and outlet reservoir as well as two air cavities in both side of the channel. The lower part includes a part of IDT and BR gratings. The fabrication process is as follows. A Y + 128° X-propagation lithium niobate crystal ($LiNbO_3$) was used as substrate because of its high coupling coefficient in SAW generation (K^2 = 5.5%). IDT and BR were designed to operate at a resonance frequency of 32.2 MHz, corresponding a wavelength of $\lambda_R = 120\ \mu m$. Thus, the period of the IDT electrodes and the BR grating lines was 120 μm and 60 μm, respectively. Both IDT electrodes and the BR grating lines have a line-width of 30 μm and a length of 4 mm. They were fabricated by standard photolithography and electron beam evaporation of Cr (5 nm, adhesive layer) and Au (100 nm), followed by a lift-off.

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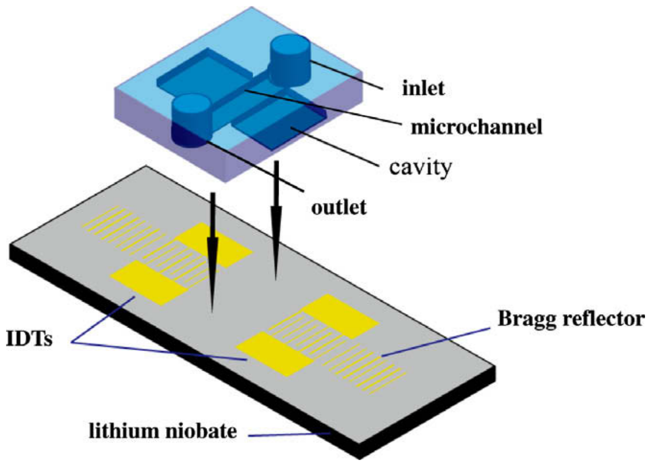

Fig. 1. Schematic of the SAW microfluidic device before assembling. Interdigitized transducers and Bragg reflectors are both patterned on a plate of lithium niobate crystal, whereas a micro-channel with two side air cavities are molded into a PDMS layer.

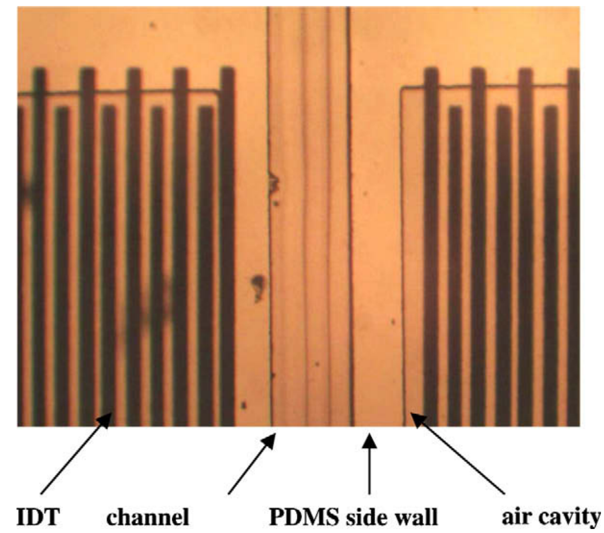

Fig. 2. Microphotograph of a SAW microfluidic device in operation, where a micro-channel, two sidewall cavities and BR grating lines as well as three focused particle lines inside the channel can be clearly seen.

The distance between the two IDTs was fixed to have 32 λ_R and the number of period of each IDT was also fixed to be 32, whereas the number of period of BR grating can be changed from 0 to 175. Soft lithography was used to fabricate the PDMS microfluidic channels of 200 μm width. First, a mold was prepared by photolithography with a negative photoresist (SU-8 2050) coated on a silicon wafer (thickness 50 μm). After anti-sticking surface treatment by trimethylchlorosilane (TMSC) in vapor phase, PDMS (GE RTV615, France) with a 5:1 ratio (A:B) was spin-coated onto the SU-8 mold and then placed in an 80 °C oven for 3 h. Afterward, the PDMS layer with inverse structures was bonded to the $LiNbO_3$ substrate between the two IDTs. Air cavities could be introduced on both sides of the PDMS channel with a wall thickness of 50 μm in the working area of the SAW generator.

To characterize the performance of the fabricated device, the bonded device was mounted on the stage of an inverted fluorescence microscope (Zeiss Axiovert 200, France). The stimulation AC signal produced by a RF signal generator (Agilent 33250A) at a frequency of 32.2 MHz (resonance frequency) was applied to the two IDTs to generate standing SAW. We first obtained an absorption loss less than −2 db for the device without PDMS structures. Here, RF power (input: 23 dbm) was applied to one IDT, the output signal was measured from another IDT with a spectrum analyzer (Agilent N9320A).

3. Results and discussion

We examined the device performance by injecting an aqueous suspension of fluorescent (red) polystyrene particles (diameter 2 μm) into the microfluidic channel. As particles entered the standing SAW area enclosed by the two side cavities, acoustic force exerted on the particles drove them toward the pressure nodes. We then observed several narrow streams in the channel because of the standing SAW induced mechanical pressure. Fig. 2 shows a microphotograph of a device in operation, in which a microfluidic channel, two air cavities and some of the IDT electrodes can be clearly seen. One can also observe three focused particle lines inside the channel.

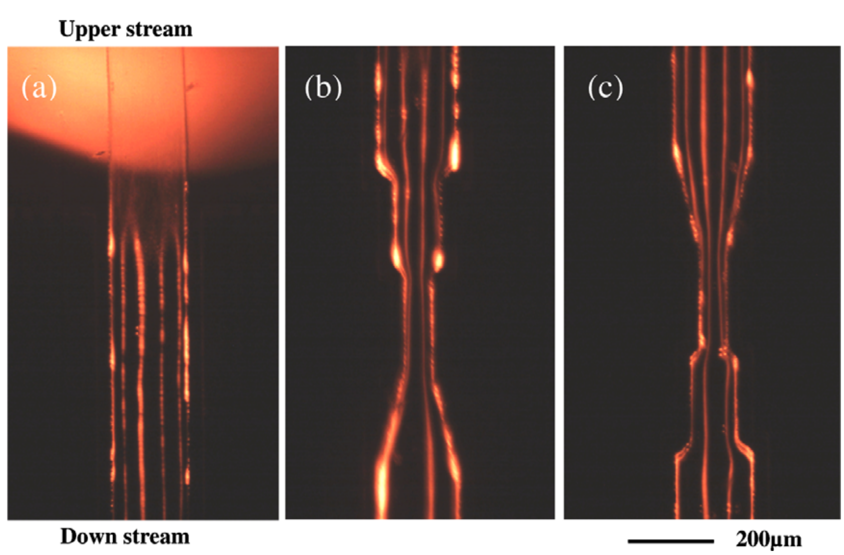

Fig. 3. Fluorescence images taken at the entrance of the SAW working area with 200 μm wide channel (a) and the two narrowed segments with a minimum channel width of 50 μm (b and c).

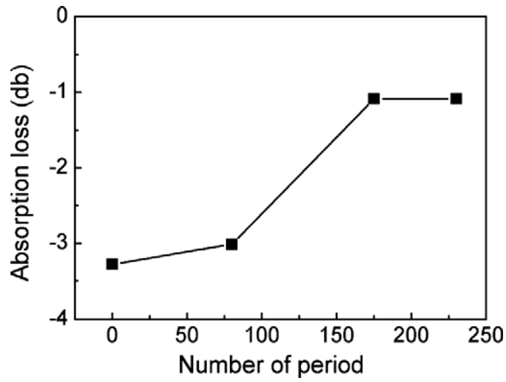

Fig. 4. Variation of the absorption loss as a function of the number of BR grating periods, showing a rapid decrease with the increase of the number of period until saturation.

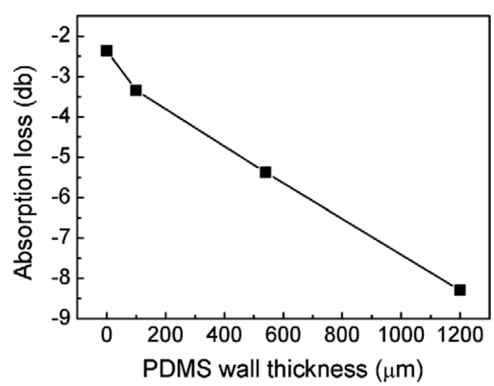

Fig. 5. Variation of the absorption loss as a function PDMS wall thickness, showing a linear dependence with a loss coefficient of about −5 db/mm.

Fig. 3 shows fluorescence images taken at the entrance of the SAW working area with 200 μm wide channel (a) and two narrowed segments with a minimum channel width of 50 μm (b and c). As expected, several particle lines are observed at the entrance with a distance of separation comparable to half of the working wavelength (λ_R). When particles streams went into the area without standing SAW, the width of the focusing streams remained constant because of the laminar nature of the flow (not shown here). However, if the SAW is switched off, no more particle lines could be formed. When the flow passed into the 50 μm wide channel, the particles lines are forced to merge totally or partially, depending on the shape of the entrance (Fig. 3b and c). In such a case, the competition between the SAW induced pressure and the viscous force, together with the geometric constrain will determine the exact trajectory of the particle movements.

Quantitative measurements of the transmission efficiency have been performed with different device configurations. Fig. 4 shows the variation of the absorption loss as a function of the number of the BR grating period with PDMS but without liquid filling. Note that since the recorded spectrum is sample dependent, only the maximum value of each transmission spectrum has been taken and presented in Fig. 4. As expected, the absorption loss decreases rapidly with the increase of the number of period until saturation. Our results also showed that the BR gratings patterned outside the IDTs are more efficient than that patterned inside. Finally, we show in Fig. 5 the variation of the absorption loss as a function PDMS wall thickness. From the observed linear dependence, we obtained an absorption loss coefficient of about −5 db/mm.

4. Conclusion

In summary, we have successfully integrated a SAW resonator into microfluidic devices made by soft lithography techniques. To reduce the PMDS absorption of SAW, air cavities have been introduced on both sides of a micro-channel and in the working area of standing SAW propagation. The performance of the device has been tested, showing micro-particle focusing inside the channel with the expected efficiency and physical phenomena. Quantitative measurement of PDMS induced SAW absorption has also been performed, giving a linear lost coefficient of −5 db/mm. We believe that our approach will be useful not only for enhanced particle handling but also for SAW based analyses.

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