DUAL CHANNEL MICROFLUIDIC RESONATORS FOR SIMULTANEOUS MEASUREMENTS OF LIQUID ANALYTES

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ABSTRACT

This paper reports microfluidic resonators with two independent channels integrated for simultaneous measurements of different or same liquid analytes, for the first time. Such a unique design intrinsically enables independent access of each integrated fluidic channel. Therefore, fast sample exchange and simultaneous loading of two different liquids can be guaranteed. Dual channel microfluidic resonators mounted on the custom vacuum clamp are thoroughly characterized with a laser Doppler vibrometer. One of the two channels would be loaded with functional materials to measure liquid properties at modulated conditions.

KEYWORDS

Simultaneous sample loading, Sacrificial process, High quality factor.

INTRODUCTION

Microfluidic resonators including suspended microchannel resonators (SMRs) and hollow microtube resonators (HMRs) have been employed for measurements of liquids [1, 2], synthetic particles [3], and biological matters [4, 5] including cells, bacteria, virus, and exosomes with the unprecedented performance. However, fabrication of such microfluidic resonators are yet laborious thus expensive since the major research effort is focused on further improvement of device performance, mostly resolution, by making resonators smaller or achieving high quality factor via wafer-level vacuum packaging. In addition, only a single channel or bifurcated channels are integrated within resonators which limit the loading and characterization of multiple samples simultaneously. Therefore, multiple samples of interest must be tested sequentially and this, in turn, increases the overall analysis time, risk of contamination, and inconvenience in calibration thus higher costs. Here, we propose relatively simple fabrication of fluidic resonators with multiple channels and demonstrate simultaneous loading of liquid samples.

SYSTEM DESCRIPTION

Fabrication

Figure 1 shows fabrication processes of the proposed dual channel microfluidic resonators. The fluidic resonators are batch fabricated with a set of 4-inch silicon wafers by deposition, etching, and sacrificial process [6]. Silicon nitride and polycrystalline silicon are deposited by chemical vapor deposition. Next, the internal channel of fluidic resonator is patterned by photolithography and reactive ion etching on polysilicon layer. Then, silicon nitride is deposited on the polysilicon and pre-deposited silicon nitride layers. The secondly deposited silicon nitride layers define channel walls of microfluidic resonators. Finally, the resonator is released and polysilicon is sacrificially removed by potassium hydroxide etching process. The fabricated microfluidic resonator is a mechanical structure which acts as a doubly clamped beam of which theoretically calculated fundamental flexural mode resonance frequency is 227.18 kHz. The large sample delivery channels are connected with the dual channel microfluidic resonator and four liquid access holes that are configured during the polysilicon sacrificial step. Figure 2(a) and 2(b) show optical and scanning electron micrographs of a fabricated dual channel microfluidic resonator. The scanning electron micrograph on the right of Figure 2(b) represents an intentionally broken resonator near its anchor that confirms well-defined dual channel structures. Each channel is 12 µm wide and 3 µm tall.

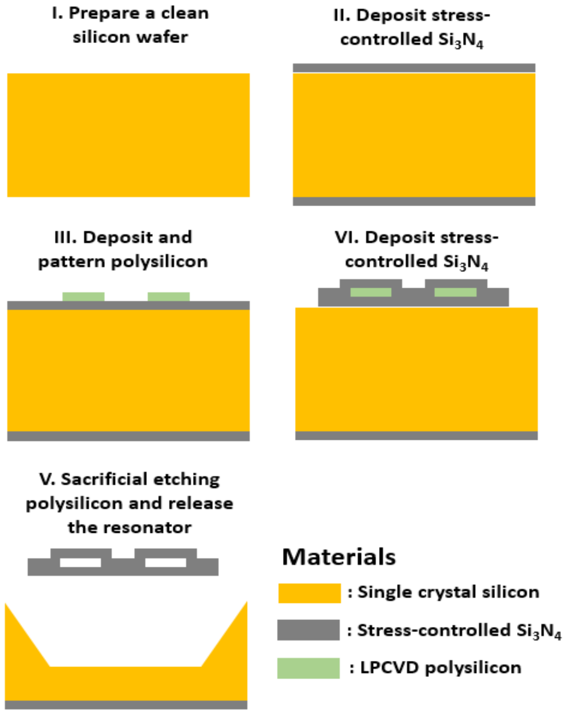

Figure 1: Fabrication of the dual channel microfluidic resonators.

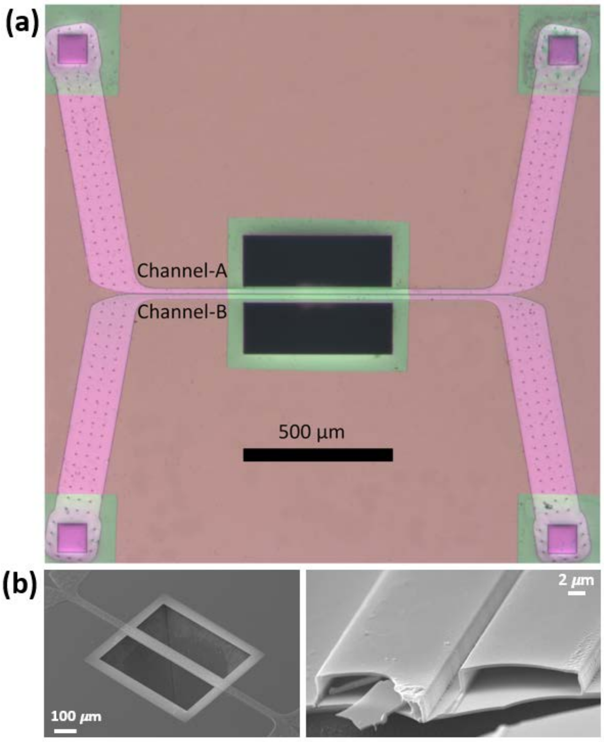

Figure 2: (a) Optical and (b) Scanning electron micrographs of the fabricated dual channel microfluidic resonator.

Experimental setup

We measured dual channel microfluidic resonators with a custom off-chip vacuum clamp that eliminates viscous damping thus provides high quality factors. Figure 3 displays the 3D CAD of the custom off-chip vacuum clamp composed of two (top and bottom) parts. The top part exhibits a transparent glass window for optical transduction and an air vent hole connected to a standard KF16 vacuum flange. The bottom part exhibits four fluid microfluidic ports, machined spaces for four O-rings, the resonator chip, and the piezo actuator.

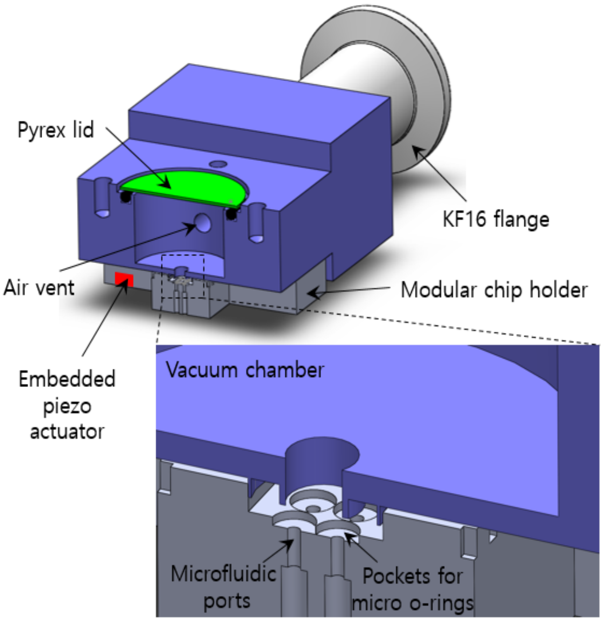

Figure 3: Design of the off-chip vacuum clamp.

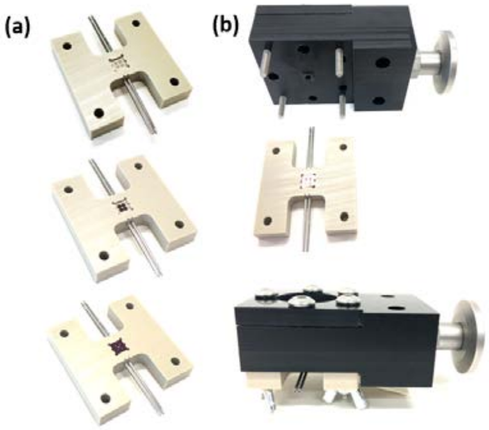

Figure 4: (a) Removable chip holder (top), with 4 O-rings (middle), and with the chip mounted (bottom). (b) Aligned off-chip clamp.

Figure 4(a) shows the bottom part without four O-rings and resonator chip (top), with four O-rings only (middle), and with four O-rings and resonator chip (bottom), respectively. Once four O-rings and resonator chip is placed in the bottom part, it can be tightly assembled with the top part with a larger O-ring inserted by using four screws and wing nuts as shown in Figure 4(b). The resonator chip firmly fixed between one larger O-rings on top and four small O-rings at bottom guarantees no leakage during the operation of a turbo pump attached to the vacuum flange.

RESULTS

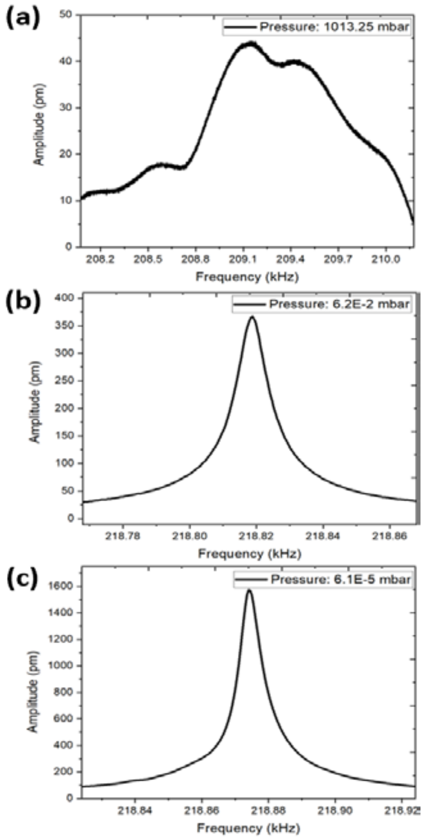

Figure 5: Amplitude spectra for a dual channel microfluidic resonator measured at (a) 1 atm, (b) 6.2×10^{-2} mbar and (c) 6.1×10^{-5} mbar.

Figure 5 shows amplitude spectra for a dual channel microfluidic resonator with both channels empty measured at 1 atm, low vacuum of 6.2×10^{-2} mbar and high vacuum of 6.1×10^{-5} mbar. Resonance frequencies are 209.2, 218.8, and 218.9 kHz at 1 atm, 6.2×10^{-2} mbar, and 6.1×10^{-5} mbar, respectively and quality factors are 186, 10,940, and 15,094, respectively. Quality factors are remarkably improved under vacuum condition.

Figure 6 shows fluctuation in the resonance frequency of the microfluidic resonator with both channels empty which were measured for 450 seconds at 1 atm (black line), 6.2×10^{-2} mbar (red line) and 6.1×10^{-5} mbar (blue line). While the frequency measurement at atmospheric pressure exhibits significant drift and its exact origin is not clear at the moment and needs further investigation, measurements at vacuum are relatively uniform.

Figure 7 shows the resonance frequency of the microfluidic resonator as a function of liquid mass density when channels are filled with water and/or ethanol (Channel A - Channel B; ethanol-ethanol, ethanol-water, and water-water). It is reasonable to assume that each channel has a same volume, so that the change of resonance frequency with two different liquids depends on the average value of their mass densities.

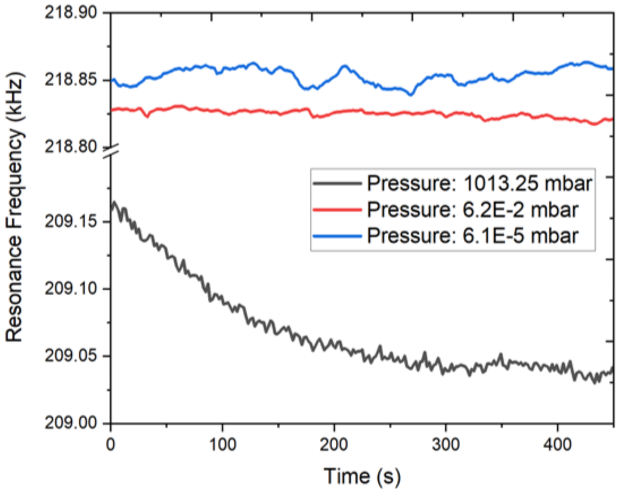

Figure 6: Fluctuation in resonance frequency measured for 450 seconds at 1 atm (black line), 6.2×10^{-2} mbar (red line) and 6.1×10^{-5} mbar (blue line).

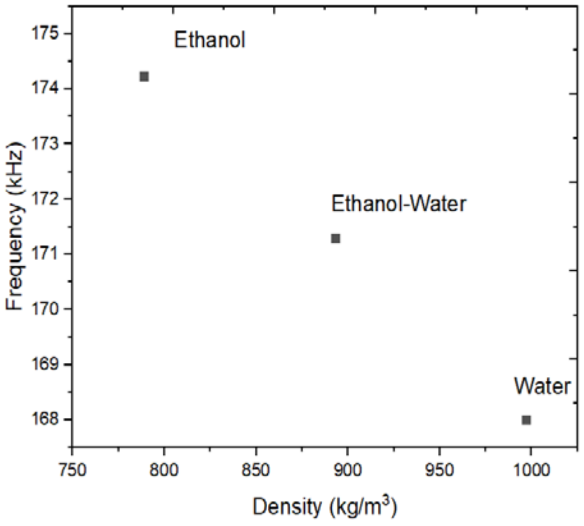

Figure 7: Resonance frequency as a function of liquid sample density when both channels are filled with water or ethanol.

CONCLUSIONS

This paper reports simple fabrication of dual channel microfluidic resonators and demonstrates loading and measurements of multiple liquid analytes. By minimizing the intermediate washing step with a reference, dual channel can accelerate calibration and measurement of multiple liquids. Dual channel microfluidic resonators reported herein can also be applied for particle measurements. In addition, one of dual channels can be loaded with electrically conductive or optothermally modulated materials towards on-chip local heating and magnetic materials towards excitation.

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