MICRO CORIOLIS MASS FLOW SENSOR DRIVEN BY EXTERNAL PIEZO CERAMIC

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ABSTRACT

We have realized a micro Coriolis mass flow meter driven with an external piezo ceramic. The piezoelectric ceramic is glued on top of sensor chip with a inetrial weight on top of the piezo ceramic. Its ability to measure mass flow is characterized by a laser Doppler vibrometer. Our measurement with water from 0 to 10 ml/h confirms that the sensor response is linear .

KEYWORDS

Micro Coriolis mass flow meter, piezoelectric actuation, Microfluidics, Resonator

INTRODUCTION

Micro fluidic systems have gained interest in lots of fields e.g. medical instrumentations [1], micro reactors [2] and chemical analysis systems [3]. Flow control and flow measurement are critical components for micro fluidic systems.

A Coriolis mass flow meter is a preferred option for flow measurements because of its ability to measure flow rate regardless of fluidic property. Conventional Coriolis flow meters are taking an ever increasing share of the flow meter market. However, there is currently no commercially available Coriolis flow sensor that occupy small space and measure very low flow. Micro Coriolis flow meters in research are driven by either electrostatic force [4] or Lorentz force [5]. However, electrostatic actuation requires high voltage while Lorentz actuation results in Joule heating. Using piezoelectric actuation evades these drawbacks.

THEORY AND DESIGN

A Coriolis mass flow sensor consist of a vibrating flow channel, as shown in Figure 1. In this work, the piezo ceramic actuate the flow channel to vibrate in swing mode as shown by the red arrows in Figure 1. When a mass flow through the channel as indicated by the blue arrow, the induced Coriolis force F_c can be written as:

$$F_c = -2L(\omega \times \phi_m) \tag{1}$$

where L represent the height of the triangle as indicated in Figure 1. ω is the angular velocity of the swing motion. According to the equation, the direction of the Coriolis force at the left side of the channel is antiparallel to the direction of the swing motion, while direction of Coriolis force at the right side of the channel is parallel to the the direction of the swing motion. The Coriolis force will generate a twist motion that has the same frequency as the swing motion.

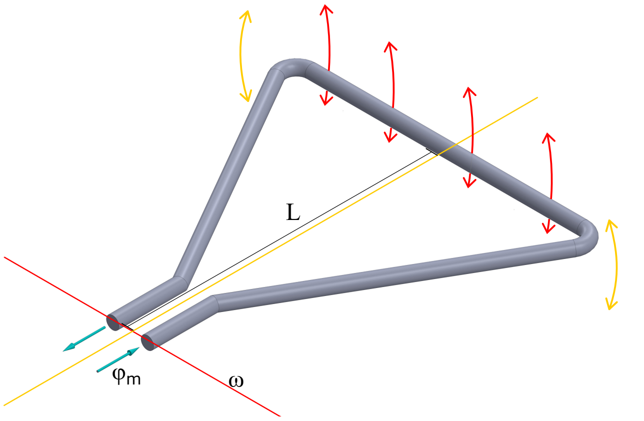

Figure 1: Schematic operating principle of a Coriolis flow meter. The fluidic channel is actuated in the swing mode indicated by the red arrows. The twist mode caused by Coriolis force is indicated by the yellow arrows. The rotation axis of swing and twist motion is showen in rad and yellow line respectively. The blue arrows indicate the liquid flow. The channel is fixed on its two ends.

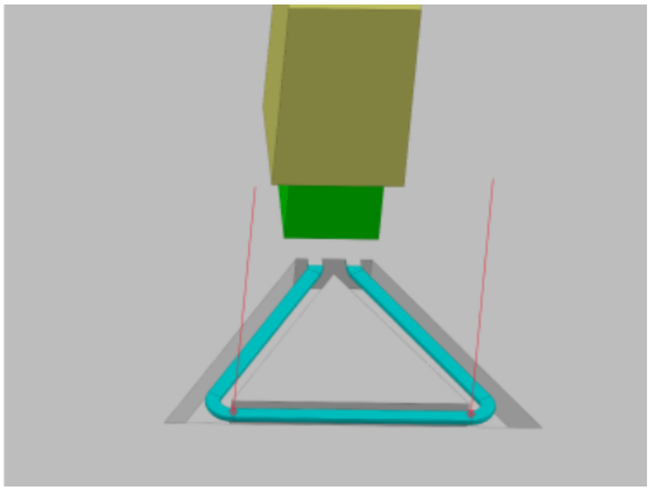

Figure 2: Schematic of the chip with sensor and inetrial weight. The inetrial weight is shown in yellow. The piezo ceramic is shown in green. The microfluidic channel is shown in blue. The red lines indicate the laser from laser Doppler vibrometer when measure the flow versus twist relation

Figure 2 shows the setup of the sensor chip and piezo actuator with inertial (counter) weight on top. Piezo actuator, shown in green, drive the chip. This configuration can excite different resonant modes of the microfluidic channel depending on the frequency of the signal applied to the piezo actuator. This configuration also generate a lot of noise when working. Figure 3 shows a photo of the device.

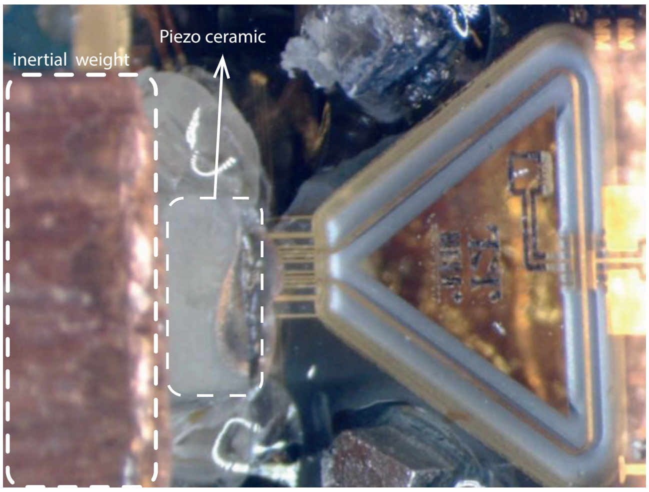

Figure 3: Photograph of chip with piezo actuator and inetrial weight

FABRICATION

The device fabrication process has been reported in [6]. The schematic of the fabrication process is shown in Figure 4. The first process step consist of depositing a 500 nm thick layer of silicon rich silicon nitride (SiRN) on the wafer. Then a layer of chromium is sputtered on top of the SiRN layer. The chromium and SiRN layers are patterned with a slit pattern that defines the channel outline. Then we use isotropic plasma etching to remove silicon through the slits to form microfluidic channel. Then both the the chromium and photo resist are removed. This results in a cross section shown in Figure 4(a). Then a silicon-dioxide layer is deposited using LPCVD. The wafer is then etched from the back side with deep reactive ion etching. These two processes are shown in Figure 4(b) and (c) respectively. After this, silicon dioxide layer is removed and a 1.8 μm SiRN layer is deposited. Then a 10/200nm Cr/Au layer is deposited and patterned. The cross section after this step is shown in Figure 4 (d). The last step is to release the channel. This is done by etching openings in the SiRN and then isotropically etching the exposed silicon. The cross section of the chip after fabrication is shown in Figure 4 (e).

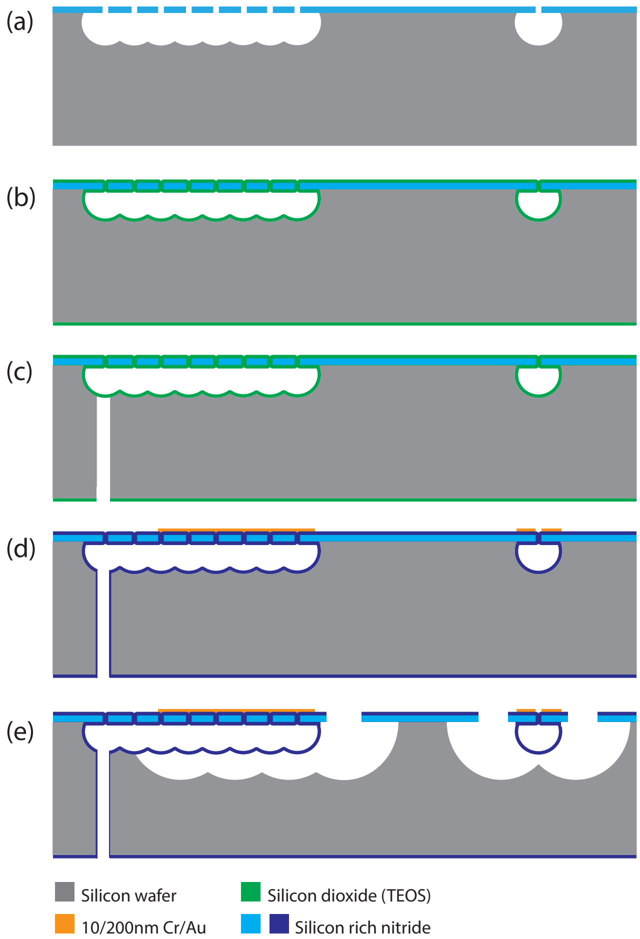

Figure 4: Schematic cross section of the fabrication process. The left side shows a cross-section along the length of a channel while the right side shows a cross-section perpenticular the the channel

After mounting the chip and a fluidic connector on a printed circuit board, a piece of Noliac NAC2001 piezo ceramic was glued on the top of the chip, close to the microfluidic channel, as shown in Figure 2. The piezo ceramic is a piezo stack. Electric connection is made using silver paste. A piece of $5 \times 4 \times 19$ mm copper inertial weight was glued on the top of piezo ceramic.

MEASUREMENT SETUP

A Polytec MSA-400 laser Doppler vibrometer was used to characterize the device. All measurements was down when the micro channel is filled with water. A sinusoidal or chirp signal with 4V bias and 2V amplitude was used to drive the piezo ceramic. The bias is applied to avoid shifting of the pooling direction of the piezo ceramic. The referenece beam is placed at a fixed reference point druing normal measurement in order to measure the vibration of micro fluidic channel. In the flow measurement, we use 1390Hz sinusoidal signal to actuate the mode shown in Figure 6. When measuring the twist mode induced by Coriolis force, the measurement and reference beam of the laser Doppler vibrometer is placed as shown in Figure 2. In this setup, only the relative displacement between the two measurement points are detected.

RESULT AND DISCUSSION

Figure 5 and 6 shows two modes we measured using a laser Doppler vibrometer when device was driven with sinusoidal signal. The frequency of signals were 8716Hz and 1390Hz respectively. The piezo ceramic can actuate different modes depending on the frequency of the signal.

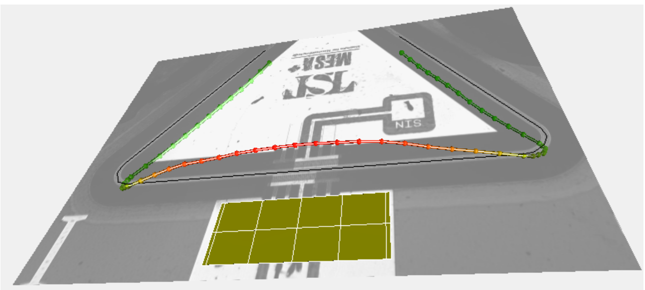

Figure 5: Measured resonance at 8716Hz, the microfluidic channel bend from the middle. there are two static points in resonence process

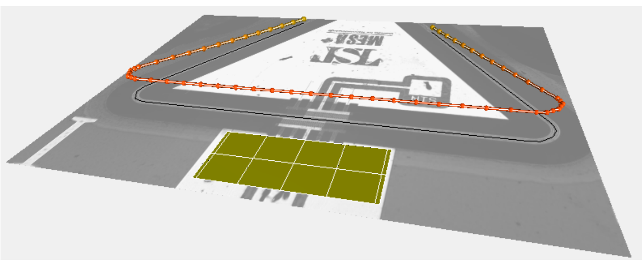

Figure 6: Measured resonance at 1390Hz, there is no static point on channel

Figure 7 show an averaged resonance amplitude between 1000 and 10000 Hz when the chip is driven using chirp signal. First and second highest peak in this figure shows the resonance modes in figure 5 and 6. The mode at 8716Hz has a higher resonance amplitude. This can be explained by the fact that we use an inertial weight to fix the top surface of the piezo ceramic. Thus the frequency of signal influences the force that the piezo ceramic applies on the silicon chip.

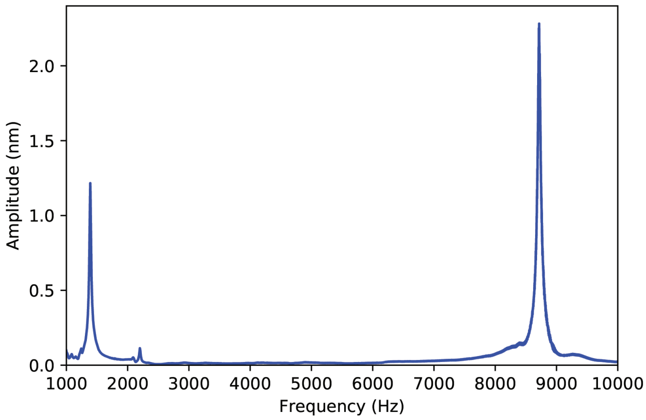

Figure 7: Average spectrum of all the measurement point when the chip is driven using chirp signal

Figure 8 shows a measured twist amplitude as a function of water flow for a range of 0 to 10 mL/h. The resonence amplitude of micro fluidic channel is 2.6 µm. The flow is generated with a syringe pump. A linear relationship between the flow rate and the twist resonence amplitude can be observed.

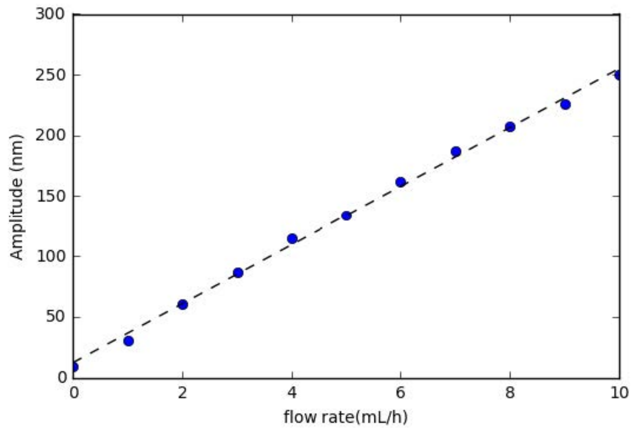

Figure 8: Measured twist amplitude as a function of water flow

CONCLUSIONS AND OUTLOOK

A micro Coriolis flow sensor driven with an external piezo ceramic was presented. The sensor showed a linear response to flow between 0 and 10mL/h. Current device generates a lot of noise when working. Furthermore, the external piezo ceramic and inertial weight will possibly cause difficulties in chip packaging. The next development will focus on integrated piezo actuation and capacitive readout.

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