Assessing Level of MEMS Process Variation on Fabricated Micro Resonator Sensor Structure

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Summary: The micro resonator sensor structures fabrication used bulk micromachining processes which rely on a lithography process to transfer the structure pattern on Silicon-on-Insulator (SOI) wafer. The structures were dry etched and released using Hydrofluoric (HF) vapour process. The research assessed criticality of the level of process variation by measuring and comparing frequency response patterns of single comb-drive resonators fabricated on randomly selected single chips. Further analysis was done by analysing the frequency response of designed and fabricated coupled comb-drive resonator array for mass sensor. This paper highlights steps to fabricate the resonators, changes of fabricated geometrical dimension of the resonators which measured using scanning electron microscopy (SEM) and measurement process of the resonator frequency response. From the measured frequency response of the single fabricated resonators, the assessed level of the process tolerance and part-to-part variation were from 1.03% to maximum of 9.48% and 0.35% to maximum of 3.91% respectively.

Keywords: MEMS Process Variation, Bulk Micromachining, Frequency Response Pattern, Micro Comb-Drive Resonator.

1. Introduction

With the present micro fabrication techniques, process variation is inevitable [1, 2] which leads to change in geometrical dimensions of the MEMS product and causes variability in the product performance [3]. For the case of coupled micro resonator array sensor structure, it is important to reduce the effect of variation for measurability of the sensor readout [4]. It had been revealed that identical micromechanical resonators always have variations in resonant frequency even when fabricated on the same die [5]. Many researchers studied related to the process variation in MEMS [3, 6-23]. Reducing the performance variability at a design stage is an alternative to reduce the impact of process variation [3, 6, 7-12]. Other researches focused on introducing coupling to minimize the effect of process variations [13-18]. For any approaches, it is very important to examine the level of variation for particular processes, so that the worst impact scenario on the fabricated micro structure is accurately integrated at the design stages. The research on performance variation estimation and approaches to quantify process variation emphasized on the performance and variability of the fabricated MEMS when compared to its design value [19-23]. This paper presents two level of process variations based on structure tolerance of micro resonators (comparison between fabricated and nominal designed value) and part to part variation [24] (variation between the fabricated resonators) focussed on the measured resonant frequency. The resonant frequency of the structure,

Resonant Frequency, $\omega = \sqrt{k/m}$ (1)

Therefore, $$\frac{\Delta\omega}{\omega} = \frac{1}{2}\left[\frac{\Delta k}{k} - \frac{\Delta m}{m}\right] \quad (2)$$

Any change of the structure stiffness (Δk) or mass (Δm) due to the change of the nominal designed dimension causes part to part variation. The variation may cause difficulty in driving many single resonators on one substrate with shared connections. It may affect the response pattern of the coupled resonator, due to the change of the structure geometrical dimension.

2. Fabrication Process

Figure 1 illustrates schematic diagrams of the cross section of the silicon (Si) device layer on the Si insulator layer and flow of processes (a) – (f), to fabricate micro comb-drive resonator. .

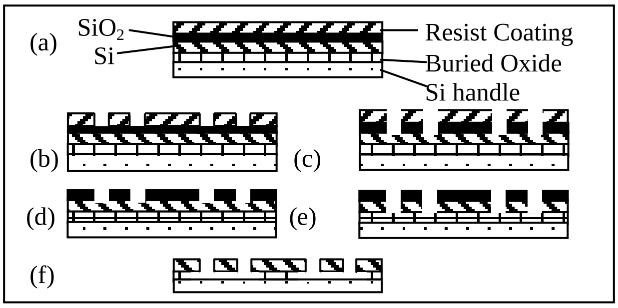

Figure 1. Schematic diagram of structure device layers and flow of the fabrication processes; (a) Resist Coating, (b) Photolithography and Development, (c) Reactive Ion Etching (RIE), (d) Stripping off resist, (e) RIE, (f) HF Release process.

The process used S1805 resist and MF319 developer. For 20µm Si device layer, the wafer was exposed and developed for 3.6 and 20seconds respectively. A thin film of silicon dioxide

(SiO_2) was used as a secondary mask layer during the second stage of RIE. The 160nm oxide mask layer was etched at 6nm per minute and at 5µm Si layer the wafer was etched for 2 minutes and 40seconds. Figure 2 shows SEM image of a single resonator after aluminium metallization

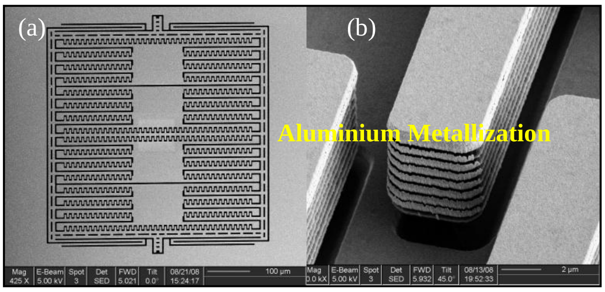

Figure 2. (a) SEM image of a single resonator; (b) Aluminium metallization.

3. Frequency Response Measurement

Figure 3 portrays a schematic diagram of the frequency response measurement system for the resonator sensor. The system consists of a vacuum chamber system (to control the air pressure level), a signal processing unit, power supply unit (to supply voltage to amplifiers on the signal processing board), DAQ, personal computer and the connector block to interface the input line, output line and the DAQ.

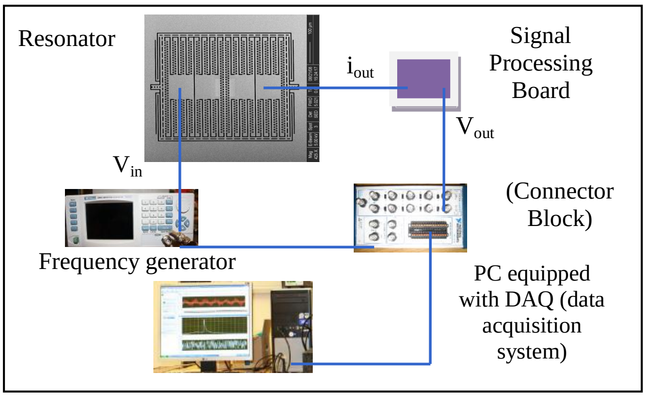

Figure 3. Schematic diagram of frequency response measurement system.

4. Result and Discussion

Figure 4 exemplifies the frequency response measurement results of three similar single resonators from a single chip. As can be observed the measured three resonators display different resonant frequency. All the measured frequencies were larger than the designed structure (12857.3Hz).

Table 1 tabulates the data analysis on the process tolerance and part to part variation based on the measured frequency response of the 3 single resonators for 3 separate chips randomly selected from the SOI wafer. When compared between the measured frequency and the nominal designed value of 12857.3Hz, the maximum structure tolerance for Chip1, 2, and 3 were 9.48%, 7.09% and 8.11% respectively. While the maximum frequency difference between 3 resonators on a single chip (part to part variation) for Chip 1, 2, and 3 were 1.3%, 3.91% and 0.36%.

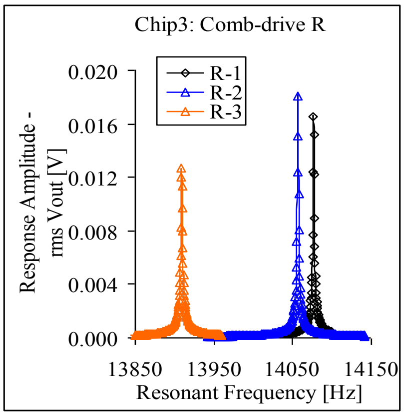

Figure 4. Example of Resonant frequency measurement result for three similar single comb-drive resonators on a single chip.

Figure 5 illustrates initial comparison between the measured resonant frequency and the designed value for 5 constant mass coupled micro resonators. The variation has significantly changed the frequency response pattern of the coupled structure. When compared between the designed and measured frequency for the 5 modes of the coupled structure, the differences were 1.51%, 1.47%, 1.19%, 1.21%and 1.14% for mode 1,2, 3, 4, and 5 respectively.

Table 1. Summary and analysis result of single micro resonators.

*Structure tolerance; ** Part to part variation			
Chip	R1	R2	R3
Chip1	* 9.48% ** 1.3%	* 9.33% ** 1.15%	* 8.18% **Reference
Chip2	* 7.09% ** 3.91%	* 6.25% ** 3.07%	* 3.18% **Reference
Chip3	* 8.10% ** 0.35%	* 8.11% ** 0.36%	* 7.75% **Reference

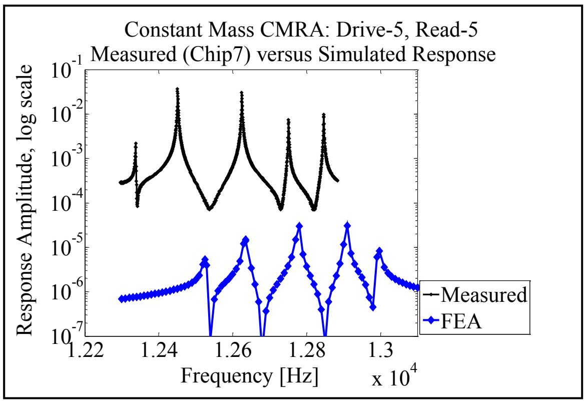

Figure 5. Comparison between resonant frequencies of fabricated Constant Mass 5 coupled micro resonator and the designed value (FEA, Finite element analysis).

5. Conclusions

One of the sources of the process variation of the fabricated micro resonator was originated from the photo resist preparation and the process to transfer the pattern onto the wafer (photolithography and development process). The variation of the thickness of the SOI layer supplied by the manufacturer caused the processing time to etch the Si device layer varies from one chip to another chip, which also affected the micro resonator profile. Frequency response measurement of the three similar resonators which were fabricated on a single chip significantly shows the level of process variation. The assessed level of process tolerance and part-to-part variation were from 1.03% to maximum of 9.48% and 0.35% minimum to maximum of 3.91% respectively. While, for the coupled structure, the maximum frequency difference between the designed and measured response was 1.51%. In order to use the structure as a sensor, it is important to exactly quantify the change of the resonator mass of the fabricated structure, so that any absorbed mass onto each resonator could be determined accurately. More chips are required to be quantified across the whole wafer in order to confirm the level of the variation for particular facilities and different techniques to fabricate the MEMS structure. It is important for a further research to include the worst impact scenario or level of process variation at the design stage of the micro resonator structure so that the performance of the resonator is insensitive to the effect of process variation.

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