Modelling and Analysis of a Type of Capacitance Based Accelerometer

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***Abstract*—In this paper, a capacitance based accelerometer is studied. The sensitivity, frequency response, mask layout and finally fabrication process are presented. For the sensitivity of the selected accelerometer, the relative change of capacitance of the selected accelerometer with respect to acceleration a is derived, the frequency response of the accelerometer is investigated, and the value of which is estimated under the specified parameters provided; finally the accelerometer is displayed and it is fabricated by using several steps of deposition, patterning and etching.**

***Index Terms*—capacitance, accelerometer, modelling, sensitivity, frequency response**

I. Introduction

Vibration is very common in the manufacturing areas, and it can be caused by many factors, such as dynamic unbalancing conditions exist. In some manufacturing arenas, vibration can be ignored due to not required precise machining (e.g. rough machining), while some areas requires the machine system to have zero vibration or make the vibration minimize due to the strict machining requirement (e.g. precise machining). Vibration sometimes can severally degrade some performances of the machining system and therefore, how to detect the vibrations and therefore reduce or ideally eliminate the vibration have attracted many researchers and engineers attentions.

Accelerometers can be used to measure vibration. Often machinery that is failing has a characteristic vibration pattern - a motor bearing for example. Smooth and quiet when in good order, gradually getting rougher and noisier as it wears out. An accelerometer can be used to detect the impending failure by measuring the changing vibration signature of that machine.

Accelerometer is a type of sensor that senses the accelerations, and it has been developed and used in numerous areas [1-23]. An accelerometer is shown in Fig. 1 will be the subject of our study. The proof mass is supported by two cantilevers with length L=500um, width w=30um, and thickness t=10um. The comb fingers have overlapped length l_0=100um, thickness t_0=5um, and spacing d=5um. Suppose there is an acceleration a in the z direction. The following sections present the sensitivity analysis, frequency response, and fabrication process.

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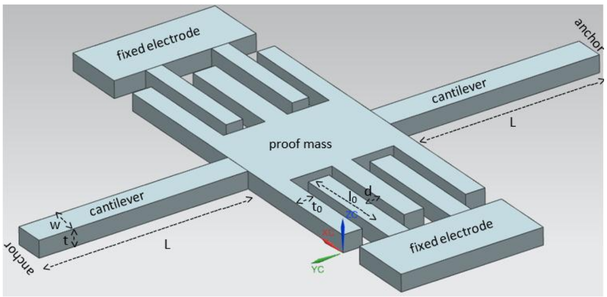

Figure 1. A capacitance based accelerometer

The organization of this paper is as follows, Section II conducts the sensitivity analysis of the capacitance based accelerometer; frequency response of the capacitance based accelerometer is presented in Section III; Section IV presents the fabrication process details for the capacitance based accelerometer; some potential applications are briefly presented in Section V; and finally the conduction is given in Section VI.

II. Sensitivity

There are five fingers on each side, which indicates that 8 capacitors exist for this case and therefore, the total capacitance can be expressed as follows:

$$C = 8\frac{\varepsilon_0 l_0 t}{d} \tag{1}$$

Because there is an acceleration in z direction, and there is a mass, so according to the newton law, there will be a force acting in that direction, which makes the fingers move in the z direction and therefore, the effective thickness t' will change.

Here we set z=5um as an example for the following analysis, and the capacitance is then changed to:

$$C = 8\frac{\varepsilon_0 l_0 (t-z)}{d} \tag{2}$$

The force constant is twice that of cantilever [24]:

$$k = 2\frac{12EI}{L^3} \tag{3}$$

The relationship between the displacement z and the acceleration a can be expressed as follows:

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$$z = \frac{ma}{k} \tag{4}$$

Here the mass m refers to the mass of proof mass. So the relative change of capacitance w.r.t. acceleration a can be expressed as follows:

$$C = 8\frac{\varepsilon_0 l_0 (t - z)}{d}$$

$$= 8\frac{\varepsilon_0 l_0 (t - \frac{ma}{k})}{d} \tag{5}$$

$$= 8\frac{\varepsilon_0 l_0 (t - \frac{maL^3}{24EI})}{d}$$

$$= \frac{8\varepsilon_0 l_0}{d} t - \frac{\varepsilon_0 l_0 maL^3}{3EId}$$

The expression for the acceleration sensitivity is therefore as follows:

$$\frac{\partial C}{\partial a} = -\frac{\varepsilon_0 l_0 mL^3}{3EId} \tag{6}$$

III. Frequency Response

The above accelerometer will be regarded as a both end fixed beam. The resonant frequency is therefore formulated as follows:

$$f_1 = \frac{22.4}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$$= \frac{22.4}{2\pi}\sqrt{\frac{EIg}{w(2\mathrm{L} + 5\mathrm{t}_0 + 4\mathrm{d})^4}} \tag{7}$$

Since

$$w = \frac{m_{proofmass} + m_{cantilever}}{2L + 5t_0 + 4d} \tag{8}$$

And

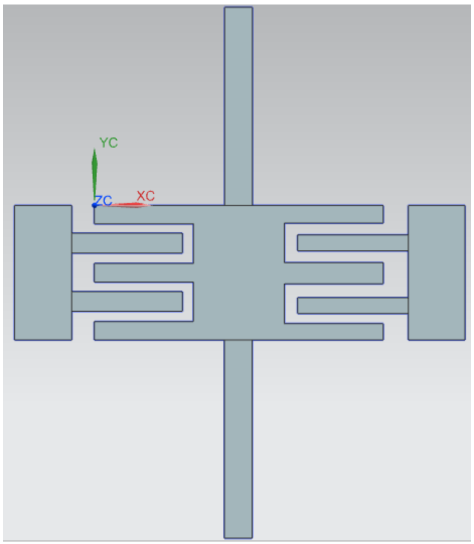
$$I = \frac{\mathrm{wt}^3}{12} \tag{9}$$

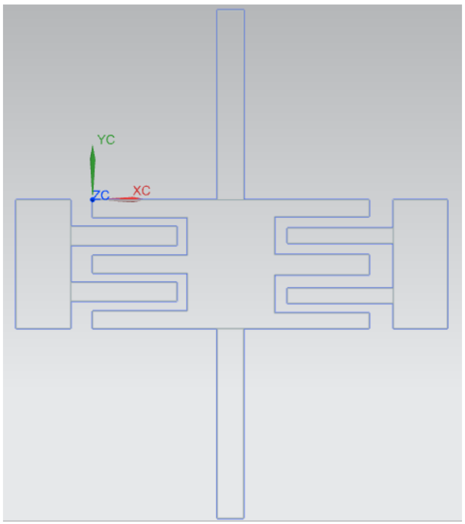
(note: this w is cantilevers width w=30um)

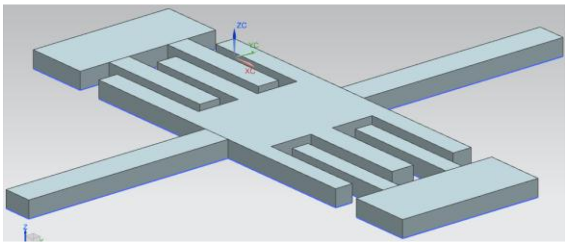
Therefore,

$$f_1 = 545.5958 \text{ Hz}$$

where w is the beam weight per unit length, l is the overall length. E presents the Young's modulus. Here it is assumed that the value of Young's modulus is 120Gpa, the mass of the proof mass is 0.0001kg, and the mass of cantilever is 0.00001kg. The resonant frequency depends on the above mentioned parameters, and different parameters can result in different resonant frequencies. The mask layer is demonstrated in Fig. 2.







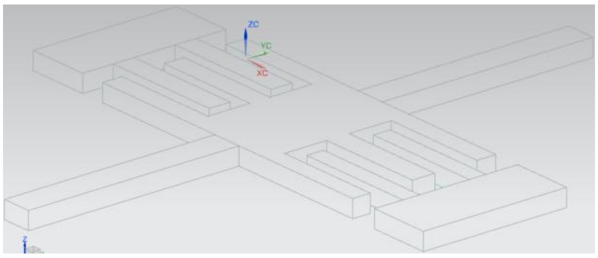


Figure 2. Mask layer

IV. Fabrication Process

A prototyping process is demonstrated as follows in Fig. 3. Please note that this demonstration shows the cross section. For brevity, only two fingers are illustrated, which can be seen from the final step of the prototyping process.

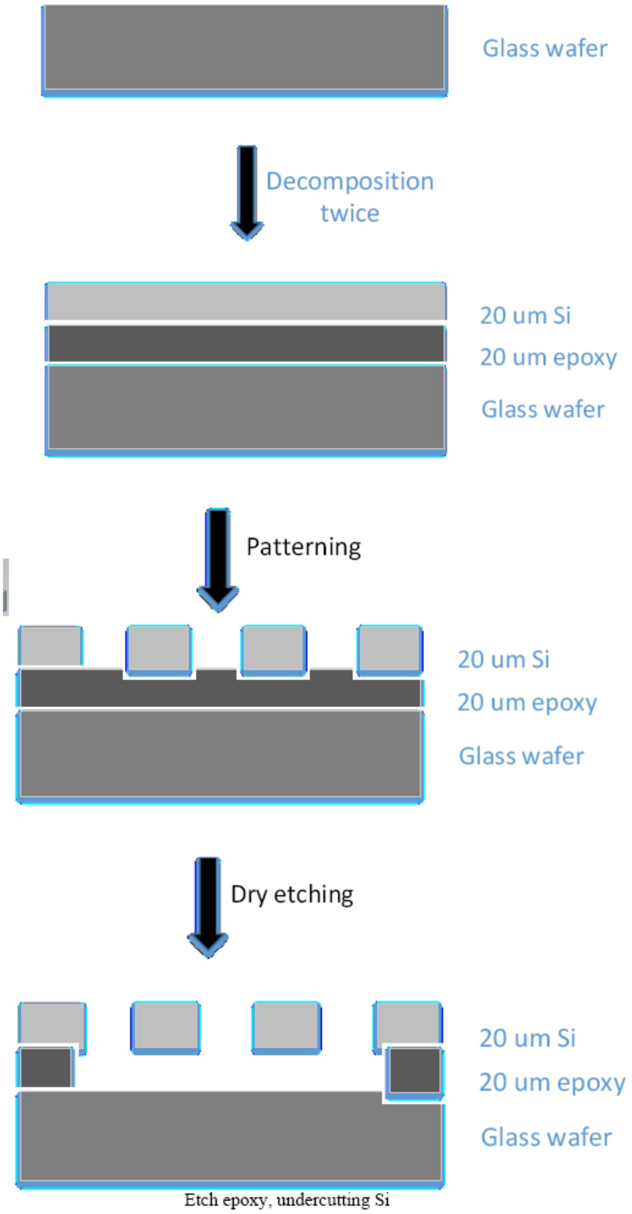
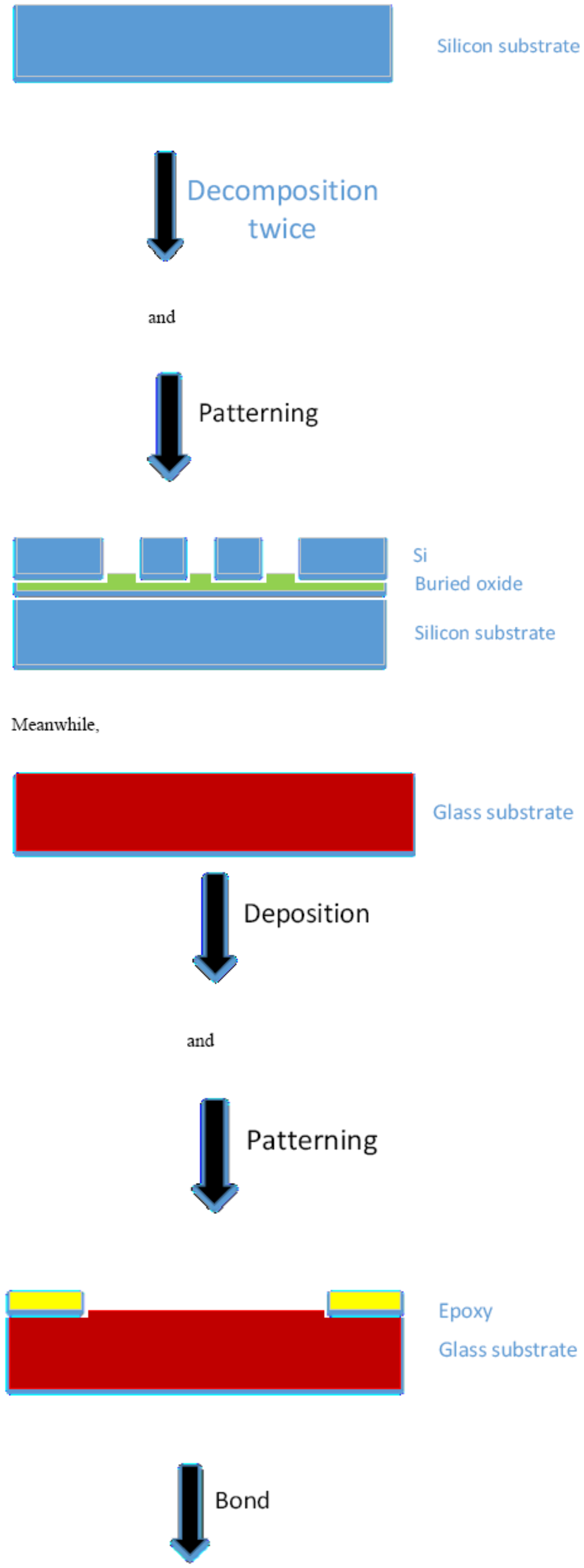


Figure 3. Fabrication process

One can also use a second method [3] as follows to conduct the fabrication.



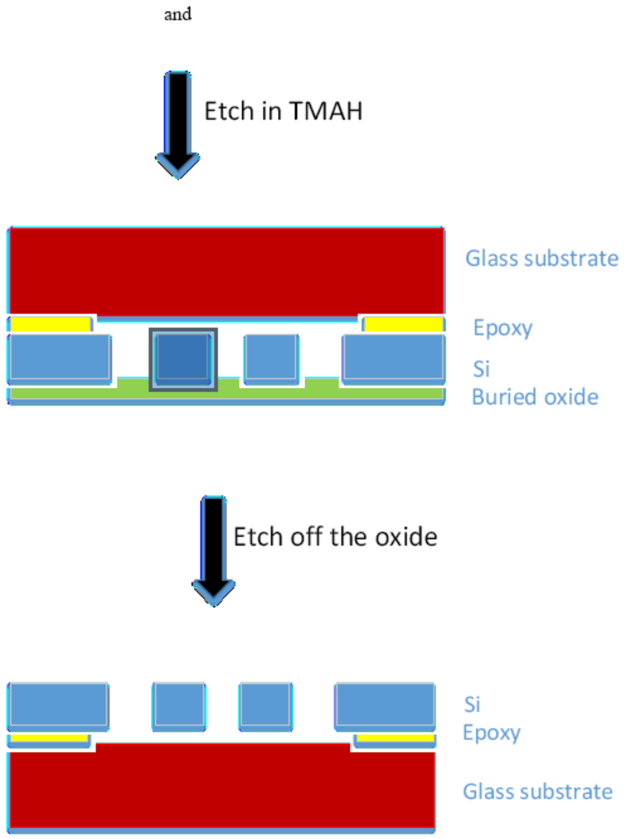


Figure 4. Alternative fabrication process

V. Potential Applications

One of the potential applications of the capacitance based accelerometer is that it can be used as the vibration sensor in the parallel robotic machine tools, as shown in Fig. 5. The capacitance based accelerometer can be placed between the tool head and the parallel robotic structure, which will be investigated in the future. Another application is that it can be used as an earthquake simulation device.

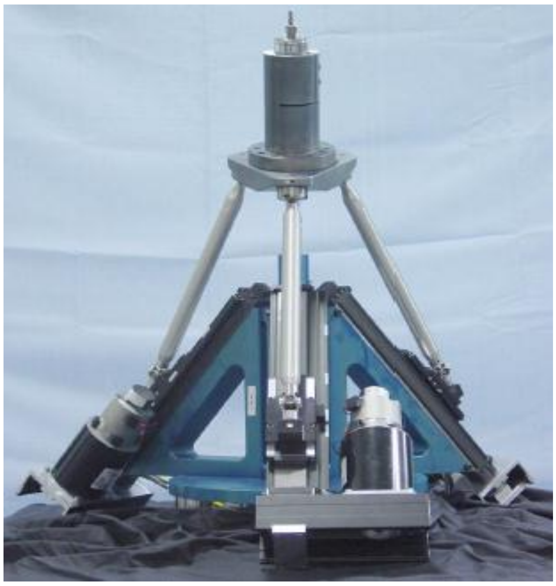


Figure 5. Parallel robotic machine tools and its tool head

Furthermore, the authors believe that by incorporating robotics with the capacitance based accelerometer, the result of which has great potential in the precise manufacturing, medical, agriculture, aerospace, and military areas where they require vibration detections. For example, one of the products by combining robotics and the capacitance based accelerometer is the micro-robot, where in some cases the vibration needs to be detected when micro-robot is conducting operations. Another interesting application is that the capacitance based accelerometer may also combine with the micro mechatronics devices where in some cases vibration needs to be detected and this topic is worth exploring in the future.

VI. Conclusion

A capacitance based accelerometer is analyzed in this study. The sensitivity, frequency response, mask layout and finally fabrication process are presented. For the sensitivity of the selected accelerometer, the relative change of capacitance with respect to acceleration a is derived as $\frac{\partial C}{\partial a} = -\frac{\varepsilon_0 l_0 m L^3}{3EId}$, the frequency response of the accelerometer is derived as $\frac{22.4}{2\pi}\sqrt{\frac{EIg}{w(2L+5t_0+4d)^4}}$, the value that the author derived is 545.5958Hz under the specified parameters, and the resonant frequency value is depending on the above parameters, different parameter will result different values. Finally the accelerometer is fabricated by using several steps of deposition, patterning and etching. The potential application of the capacitance based accelerometer is to be used as a collision detector in CNC machine tools.

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