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# Design of Two Beam Capacitive Micromachined Acceleration Sensor and Its Displacement and Stress Analysis

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**Abstract :** Micro Electro Mechanical Systems (MEMS) is an emerging technology that may fundamentally affect every aspect of our lives. The sensor consists of bulk micromachined capacitive transducer. This capacitive transducer converts acceleration into signal of capacitance variation, and a microprocessor control unit for signal conditioning. In this paper, the structure of micro electromechanical acceleration sensor was developed with a relative simplified structure, static analysis were carried out by using FEM simulation software COVENTORWARE. The effects of stress, displacement and reaction forces on two beam bulk micro-machined acceleration sensor using FEM simulations were also observed.

**Key words :** MEMS, Capacitive transducer, FEM

## Introduction

Micro Electro Mechanical Systems (MEMS) consists of mechanical devices and machine components ranging in size from a few microns to a few hundred microns. These devices generally integrate signals from one physical domain to another, such as mechanical to electrical, electrical to mechanical, electrical to chemical. It is officially coined over two decades ago. It has since generated a great deal of interest as well as expectations in the scientific and engineering communities (Bernstein *et al*,1999) MEMS Sensors are devices such a pressure sensors, acceleration sensors, and gyroscopes that perceive an aspect of their environment and produce a corresponding output signal. The core elements in MEMS generally consist of two principal components: a sensing element and a signal transduction unit (Hsu, 2002).

### Design of acceleration sensor

### *A. Sensor Design*

An acceleration sensor is an instrument that senses the external acceleration. To extract the acceleration values, the sensor has a movable proof mass which is connected to a fixed frame via spring structures. When there is an external acceleration, the proof is displaced from its rest position. The magnitude of the displacement is proportional to the magnitude of the acceleration. Hence, the acceleration input that is applied to the sensor is converted to the proof mass displacement in the sensor. The sensor then extracts the magnitude of this displacement using its sensing scheme (Li and Tseng, 2001). Capacitive sensors have important advantages compared to other types (Boser, 1996). They have simple structure and hence low fabrication cost. In addition, they provide low power consumption, high sensitivity, high reliability as well as low non-linearity, low temperature dependency, low noise, low drift. Using etching process of fabrication and high performance capacitive readout circuits 0.05 g/sqrt hz resolution is achieved. Capacitive MEMS sensors are widely preferred in consumer applications due

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to their high performance and low cost. ADXL series (Analog Devices Inc.) accelerometers available in the market with different resolution.

As shown in Fig-1, The accelerometer is modeled as a simple spring-mass system with an effective spring stiffness of $K_e$, mass m, damping coefficient c, and is forced by a harmonic forcing function F=ma. The situation is expressed as a second order differential equation.

$$m\ddot{x} + c\dot{x} + kx = F_0 \sin \omega t$$

The solution for the equation consists of both transient terms and steady state terms. The transient vibration dies out within a short time leaving only the steady state vibration.

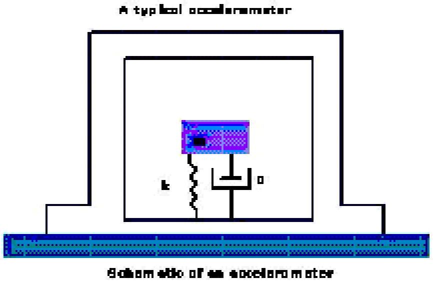

Fig.1.Basic accelerometer design

The mass used in accelerometer is called 'Proof mass' or 'Seismic mass'. In most cases the system also includes a dashpot to provide a desirable damping effect. A dashpot with damping coefficient 'C' is normally attached to the mass in parallel with the spring. For acceleration sensors built in miniature, the coil spring and dashpot occupy more space. The basic configuration of micro acceleration sensor includes a casing that contains a cantilever beam and attached mass or a hanging mass from a thin beam or diaphragm (Judy, 2001). In the casing of acceleration sensor is attached to a vibrating machine, when such a machine or device is subjected to dynamic or impact loads, the mass will vibrate. The theoretical correlation of the amplitude of vibration of the mass and the acceleration of the casing can be found.

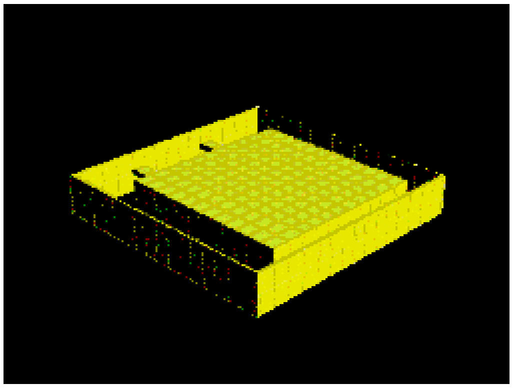

Fig.2. Meshed model of an Acceleration sensor

Single-crystal silicon is the most widely used substrate material for MEMS (Perterson, 1982). It is mechanically stable and it can be integrated into electronics on the same substrate. Silicon is almost an ideal structural material. It has about the same Young's modulus as steel (about 2E5 MPa), but is as light as aluminum, with a mass density of about 2.3 g/cm$^3$. Materials with a high Young's modulus can better maintain a linear relationship between applied load and the induced deformations. In Microsystems or MEMS, silicon needs to withstand severe mechanical and thermal loads. It is thus important to have a good understanding of the mechanical characteristics of silicon as a structural material

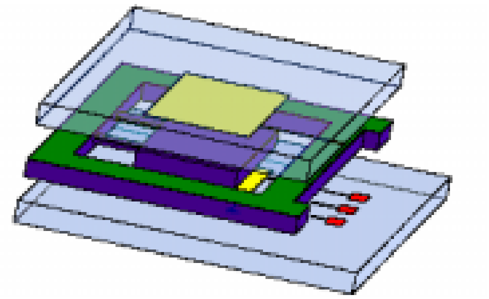

Fig.3. Designed Two beam capacitive principle based acceleration sensor.

### *B. Fabrication Technique*

MEMS fabrication or micromachining refers to fabrication of devices with at least one of their dimensions in micrometer range with the help of etching techniques to remove part of the substrate or deposit thin films. There are basically two micromachining techniques involved. 1. Bulk Micromachining (BMM) and Surface Micromachining (SMM). In bulk micromachining, the wafer is etched deeply from either front side or backside. However, the surface micromachining tries to buildup structures on to the wafer with depositing techniques. It is not easy to say whether a process is surface or bulk micromachining due to the fact that the process can use proper steps from both surface and bulk micromachining (Kovacs, 1998).

### *C. Signal Conversion*

The differential capacitance accelerometer works on the principle of complementary changes of two capacitors with acceleration. These changes are above and below the nominal capacitance whose typical value is 3 pF. The maximum capacitance change with full-scale excitation is about 1.6 pF. These small values of capacitance are critical for capacitance to voltage conversion schemes as the parasitics are introduced while integration with signal conversion electronics and packaging.

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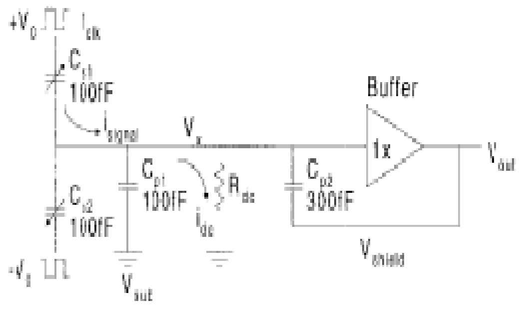

**Fig.4. Signal Conditioning Circuitry**

A high input impedance inverting operational amplifier with feedback capacitor configured as charge amplifier can be used for capacitance to voltage conversion. The circuit is as shown in Fig.4. The output voltage is made proportional to the total change in the differential capacitance. The common plate/ electrode connected to inverting input of the Op-amp and the other two terminals of the sensor are applied with square wave out of phase with each other. The feedback capacitor value determines the sensitivity of the unit.

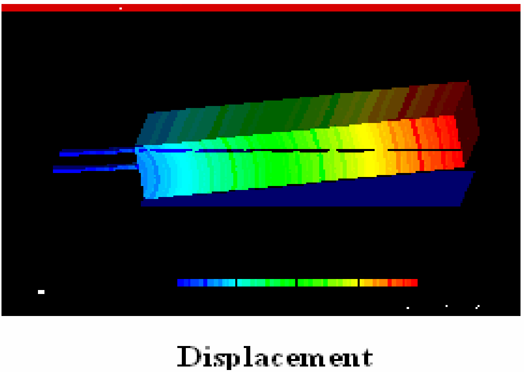

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**Fig.5. Displacement result when 10 g in Z-direction**

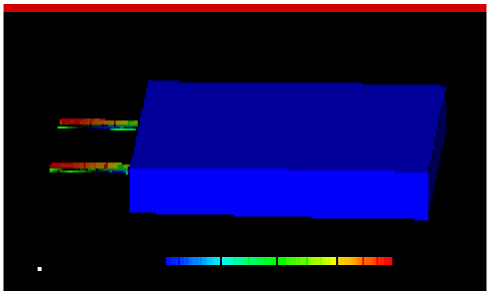


Fig.6. Stresses on sensor when 10 g is applied in Z-direction

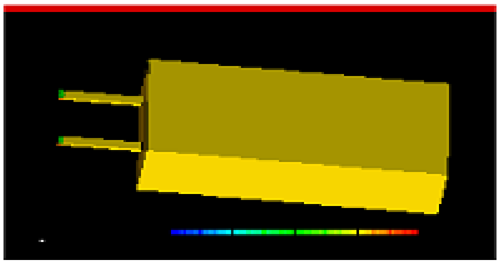


Fig.7. Reaction Forces on sensor when 10 g is applied in Z-direction

## Maximum Displacement Result when ‘g’ is applied along Z axis

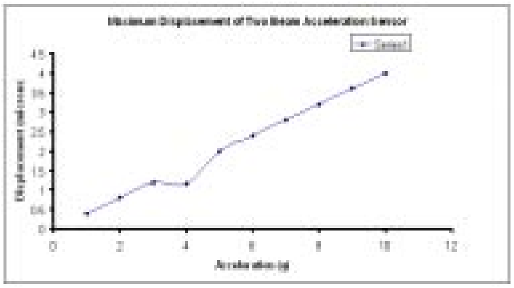
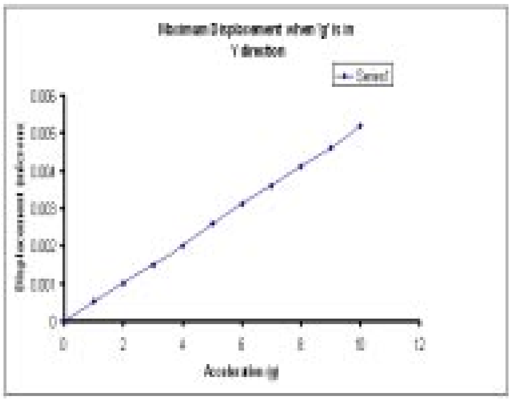


Fig.8. Acceleration Vs Displacement results.

The above figure indicates the displacement of the sensor when the acceleration is applied along its z direction. The displacement is going on increasing with increasing acceleration in z direction. The maximum acceleration can applied to this designed acceleration sensor is 10’g’. The maximum displacement will be around 4 microns



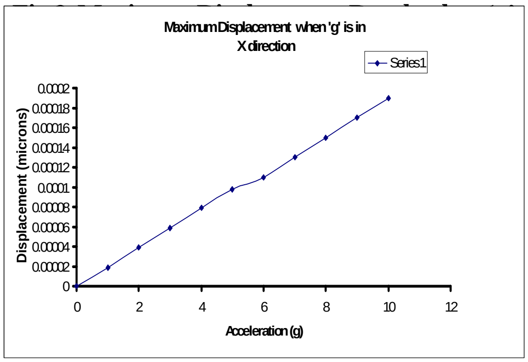


Fig.10. Maximum Displacement Result when ‘g’ is applied along x- axis.

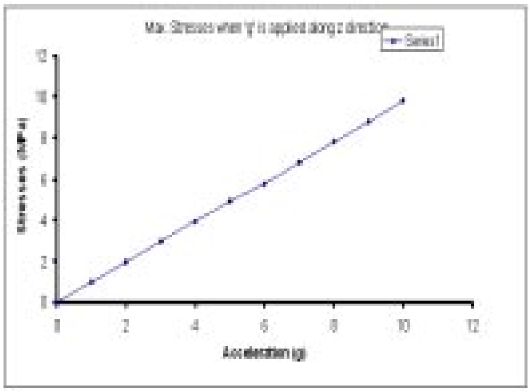


**Fig.11. Maximum Stress Result when 'g' is applied along Z – axis.**

Change in Capacitance due to the movement of proof mass in both directions can be shown in figure below.

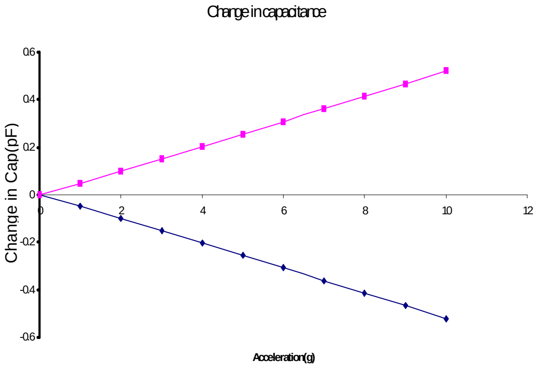


**Fig.12. Change in capacitance with change in acceleration.**

## Conclusion

A capacitive micromachined acceleration sensor is designed using the simulation software Coventerware and the process is defined. The initial test results are encouraging. This work would be a stepping stone to design four beam acceleration sensors to increase the performance and range of operation.

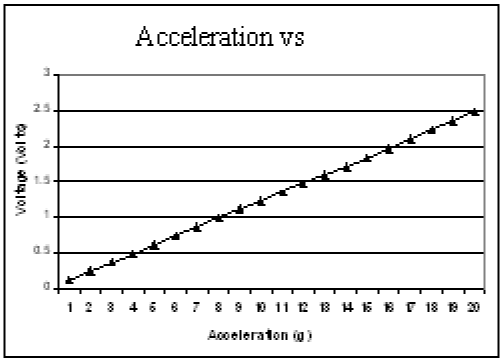


**Fig.13. Voltage at different 'g's.**

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