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Simulations of MEMS based Piezoresistive Accelerometer Design in COMSOL

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Abstract: The investigation in this paper involves simulations of piezoresistive accelerometer system. The piezoresistive accelerometer is made up of square shaped proof mass with flexures supporting it. The piezoresistors are placed near the proof mass and frame ends of the flexure. There is an elongation or shortening of suspension beam when the support frame moves relative to proof mass. The simulations show the von Mises stress, displacement, Eigen frequency plot, voltage distribution and conductivity change in the piezoresistors using COMSOL 3.5a.

Keywords: Piezoresistor, von Mises stress

1. Introduction

The accelerometer in this work is designed to measure acceleration up to 10,000g. The fact that the accelerometer can measure very high acceleration is because it has a very large proof mass. Large number of accelerometers has been designed until now based on Capacitive, Piezoelectric, Thermal and Piezoresistive type transduction. Initially the accelerometers designed were based on the principle of electro magnetism which were large bulky and costly. MEMS technology has been able to optimize the size and cost issues involved in the design of accelerometers [1,2].

In Capacitive based accelerometer proof mass acts as one of the plates of the movable plate capacitor, therefore any change in the position of the proof mass will change the capacitance hence acceleration detection [4]. Differential capacitive sensing is also common these days where a integrating read out circuitry becomes mandatory but has high sensitivity when an array capacitors is used. Despite of having low temperature sensitivity, good dc response, noise performance, low drift, high sensitivity and low power consumption they are highly prone to Electromagnetic Interference and involves considerable amount of parasitic components. The main advantage of piezoresistive type accelerometer is that they are simple in structure, simple in fabrication and it is easy to make a read out circuitry for it [3,4]. The only drawback that is observed is that they have large temperature sensitivity and low resolution.

2. System Overview

The block diagram of the system is shown in figure 1. It involves 4 blocks, which can be fabricated on a single chip with integrated with external components including analog to digital convertor, display unit and signal conditioning circuitry. The proof mass acts as inertial sensing unit. Due to change in inertia of the proof mass there compressive and tensile stress is observed on the flexures of the proof mass. The piezoresistors embedded on the flexures change their resistivity due to stress. This change is sensed by a Wheatstone bridge configuration of the resistors, which is indeed connected to an operational amplifier. The use of Wheatstone bridge cancels the cross talk and hence the accelerometer has a very low off axis sensitivity.

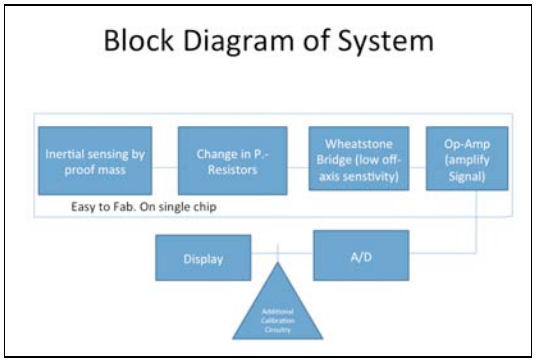

Figure 1. Block Diagram of the System

3. Simulations in COMSOL 3.5a

Figure 2 show the top view of the accelerometer designed using structural mechanics application mode of MEMS module of COMSOL 3.5a. The structure consists of silicon (100) substrate. The p-type single crystal silicon piezoresistors are placed along [110] plane on the substrate.

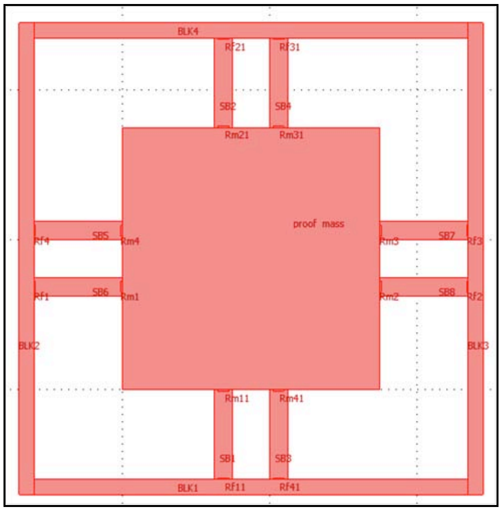

Figure 2. Top view of the design

The proof mass has size of (3500×3500×300) μm and the flexures have a dimension of (1200×250×50) μm. There are four frames each along one side with (6300×200×280) μ m. The piezoresistors have a volume of (150×20×2.5) μm.

This structure has been modeled as a beam fixed at both ends with a point load in the center for stress analysis 10,000g acceleration is applied on the top surface of proof mass, the force has be normalized by volume of the proof mass to consider it as a point.

Figure 3 shows the deformation of in the piezoresistive accelerometer along z-axis. The stress is stress is seen on flexures. The stress on the fixed ends of the flexures is opposite in nature. One side the stress is tensile in nature (red color figure 3) as compared to the compressive (blue color figure 3) on the opposite side.

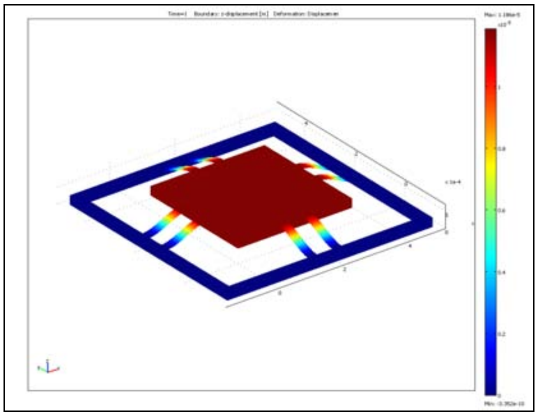

Figure 3. Stress distribution along flexures

The figure 4, shown below, highlights the elongation of piezoresistors when the proof mass is subjected to acceleration. In addition the voltage distribution is also seen along the piezoresistor. It is seen that when a voltage of 3.3 Volts is applied on 2 sides of the resistor the voltage is uniformly distributed along piezoresistors.

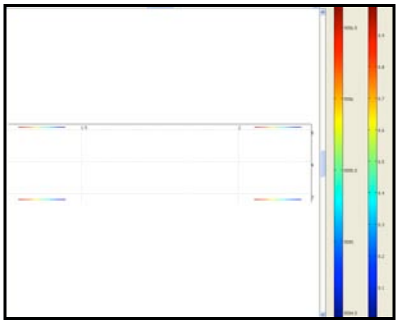

Figure 4. Stress and Voltage distribution in the embedded Piezoresistors

Stress indeed changes the mobility hence change in the voltage is observed along the piezoresistors [3]. This change is responsible for changing the conductivity of the piezoresistors, which in turns changes resistivity. This change in resistivity is the measure of the acceleration. Stress induced mobility change is given by the equation 1.

$$\sigma = K.\mu.q \qquad (1)$$

In above eqaution σ is the stress, μ is the mobility, q is the charge and K is the proportionality constant.

Figure 5 shows the conductivity distribution of the piezoresistors.

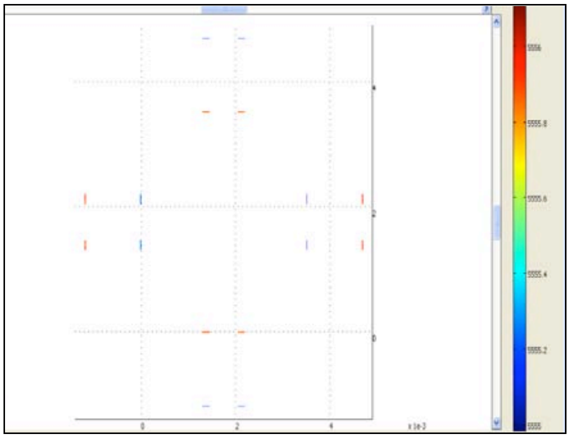

Figure 5. Conductivity change in Piezoresistors

On the basis of the simulations ΔR/R i.e. change in the resistivity with w.r.t. Nominal resistance was calculated and plotted against acceleration. The results show that the curve is linear. This indicated that change in resistance of piezoresistor is linear with change in acceleration of the device.

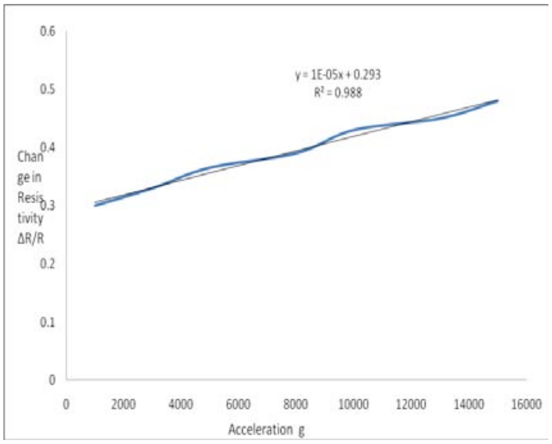

Figure 6. ΔR/R vs. acceleration

The figure 5 shows that the regression coefficient of the line is 0.988 which shows which supports the linearity of design.

4. Sensitivity Analysis

The sensor is designed to measure acceleration along one axis. Connecting Piezoresistors in Wheatstone bridge configuration can reduce crosstalk effectively. The table given below shows three modes of operation with two modes producing acceleration along x, y axis and third mode along z-axis which is the desired axis. In the table R denotes the piezoresistor suffix f denotes the piezoresistor at the flexure end and m denotes the piezoresistor at the proof mass end.

Piezoresistors	ΔR	ΔR	ΔR
	Mode-1 (Desired Axis)	Mode-2	Mode-3
R1f	⇩	⇧	⇧
R1m	⇧	⇩	⇩
R2f	⇩	⇩	⇧
R2m	⇧	⇧	⇩
R3f	⇩	⇩	⇩
R3m	⇧	⇧	⇧
R4f	⇩	⇧	⇩
R4m	⇧	⇩	⇧
R11f	⇩	⇧	⇧
R11m	⇧	⇩	⇩
R21f	⇩	⇧	⇩
R21m	⇧	⇩	⇧
R31f	⇩	⇩	⇩
R31m	⇧	⇧	⇧
R41f	⇩	⇩	⇧
R41m	⇧	⇧	⇩

Table 1 Change in resistance

The Eigen frequency called for mode-1 was 2.2KHz, which give a dc bandwidth of 440 Hz.

5. Conclusions

These structures would be fabricated using bulk micromachining [4,5]. Figure 7 summarizes basic steps in fabrication of this device. The unique anisotropic wet etching of silicon would be carried out fabrication process in the this MEMS device.


STEP 1: Die made by MEMS Process


STEP 2: Oxidation


STEP 3: Patterning


STEP 4: Releasing Structure

6. References

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