STUDY OF A THREE-AXIS PIEZORESISTIVE ACCELEROMETER WITH UNIFORM AXIAL SENSITIVITIES

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Abstract:

Micro-electro-mechanical systems (MEMS) for automotive industry and biomedical applications (BioMEMS) have the fastest growth rate within the MEMS market. The Microsystems job market imposes to research laboratories and universities to respond by increasing the quality of MEMS engineering and informatics interdisciplinary training programs. In this fact, our work consists to study and develop a three-axis piezoresistive accelerometer having uniform sensitivities along to three axes. This sensor which is made of a heavy proof mass and four long beams, allow us to obtain high sensitivities, by reducing the resonant frequencies. Uniform axial sensitivities, with a transverse sensitivity, could be obtained using a three-axis sensor. The stress analysis of this sensor was performed in order to determine the positions of the piezoresistances, in the four flexure beams.

Key Words: Accelerometer, MEMS, Piezoresistance, Simulation

Introduction

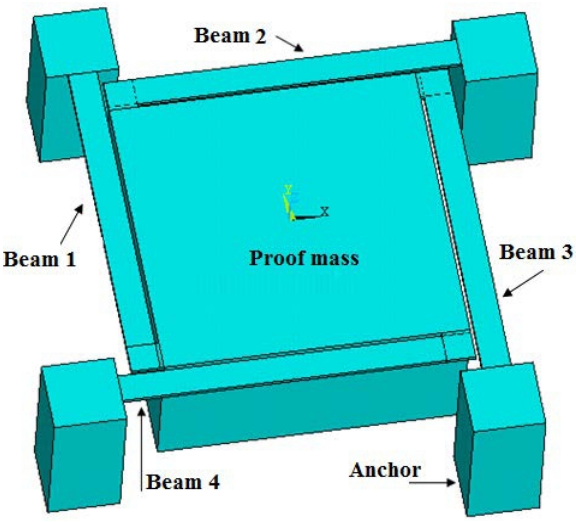
The micro-machined inertial sensors which are composed of accelerometers and gyroscopes have a significant percentage of sensors containing silicon. They can be found mainly in the automotive industry, the biomedical applications, the household electronics, robotics, vibration analysis systems, navigation systems. There are various techniques to transform the action of acceleration on the sensor into electric signal. These techniques are based on principles capacitive, piezoresistive, piezoelectric, and ect… The concept of accelerometer is not new, but its fabrication offers new market opportunities to Microsystems manufacturers, so the MEMS market has motivated continuous researches in this kind of sensors in order to minimize the size and to improve the performance.

As we know, the realistic applications create an enormous motivation for research on sensors MEMS, especially accelerometer. In this modern world, the applications require new sensors with a smaller size and high performances. In practice, rare are research which can provide an effective and complete methodology for the design of accelerometers.

The proposed of three-axis accelerometer

The three-axis accelerometer always requires small cross-axial acceleration, high and linear sensitivity. We proposed a flexure configuration that is show in figure (1) in order to meet these critical characteristics.

The parameters of the structure brought to the FEM process is shown in table (1).



Parameters	Size (Length, Wide, Thickness)
Proof mass	845x845x400 μm^3
Beams	975x80x10 μm^3
Anchors	200x200x200 μm^3
Global structure	1.5x1.5x0.5 mm^3

Figure 1: Structure of three-axis piezoresistive accelerometer. **Table 1:** Parameters of structure.

When an external acceleration is applied to the sensor, the proof mass is deviated. The vertical component (*Az*) of acceleration causes a vertical displacement of the mass. The second type of movement is caused by transverse accelerations (*Ax* and *Ay*). The deviation of the proof mass causes a variation of the stress on four surfaces of the beams. This can be measured by twelve p-type and n-type piezoresistances diffused and assembled by three Wheatstone bridge circuits.

These piezoresistances was aligned with the crystal direction < 110 > and < $1\bar{1}0$ > of silicon (100). In silicon material, there are only three independent piezoresistive coefficients π_{11}, π_{12} and π_{44}.The longitudinal piezoresistive coefficient □ is defined in the case the stress is parallel to the electric field. Similarly, the transverse piezoresistances coefficient π_t is defined in the case the stress is perpendicular to the electric field.

For the orientations < 110 > and < $1\bar{1}0$ > of silicon (100), these coefficients can be expressed as follows:

$$\pi_l = \frac{1}{2}(\pi_{11} + \pi_{12} + \pi_{44}) \quad (1) \qquad \pi_t = \frac{1}{2}(\pi_{11} + \pi_{12} - \pi_{44}) \quad (2)$$

Design and simulation using ANSYS

The finite element method (FEM) is applied to perform analyses of the stress distribution in the flexure beams. Considering the stress distribution, the piezoresistances are placed in order to eliminate the transverse sensitivities and to obtain maximum sensitivities for the three components of acceleration. The finite elements model of the sensing structure was analyzed by using software ANSYS. The boundary condition, by considering the fixed anchor, and the free proof mass charged in the medium by acceleration in the form of a force was applied.

Figure (2) shows the generation of mesh for the analysis by the finite element method.

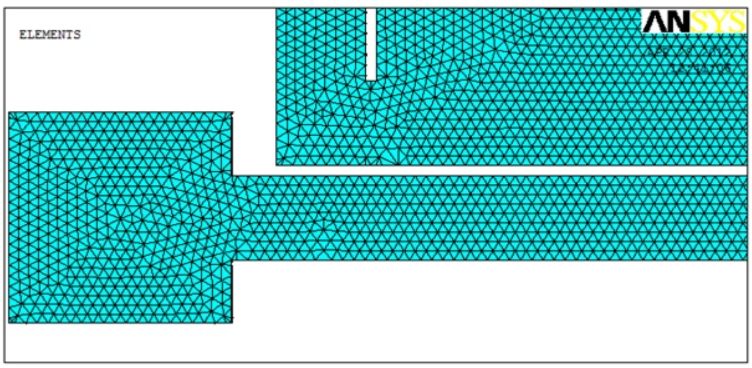


Figure 2: The mesh generation of the FEM model.

The stress distribution on the surface of the beams, caused by the *Az* component of acceleration, is shown in figure (3). The principle of detection of the sensor is based on the characteristic of the p-type and n-type piezoresistances. The n-type piezoresistances decreases when the sensor is exerted by a tensile stress and contrary in the case of a p-type piezoresistances.

The figures (4.a) and (4.b) shows the stress analysis results along 1st and the 3rd beams when the sensor is exerted to a force caused by acceleration along axis z. From these figures, we can find the optimal locations for the piezoresistances Wheatstone bridge of component *Az*.

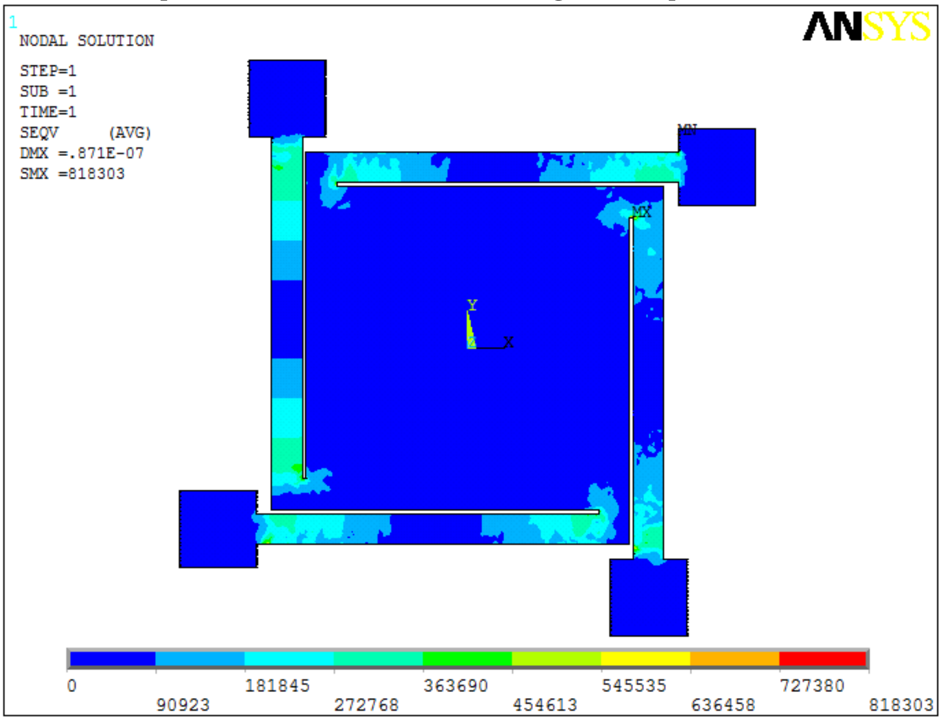


Figure 3: The stress distribution on the beams caused by the 1g acceleration *Az*.

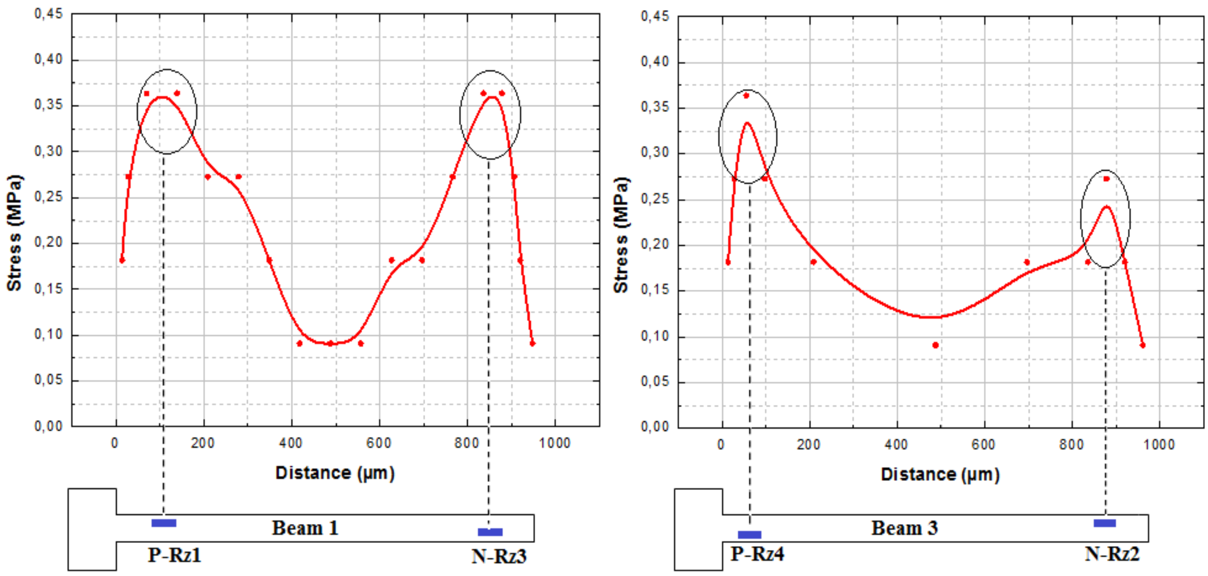


Figure 4.a Figure 4.b

Figure 4: Longitudinal stresses on the surface of the 1st and 3rd beams due to 1g acceleration *Az*.

By the same method, the acceleration components *Ax* and *Ay* can be detected by using four piezoresistances on 2nd and 4th beams of the Wheatstone bridge of component *Ax*, and four piezoresistances on 1st and 3rd beams of the Wheatstone bridge of component *Ay*. The positions of the piezoresistances are also indicated on the figures (5.a) and (5.b).

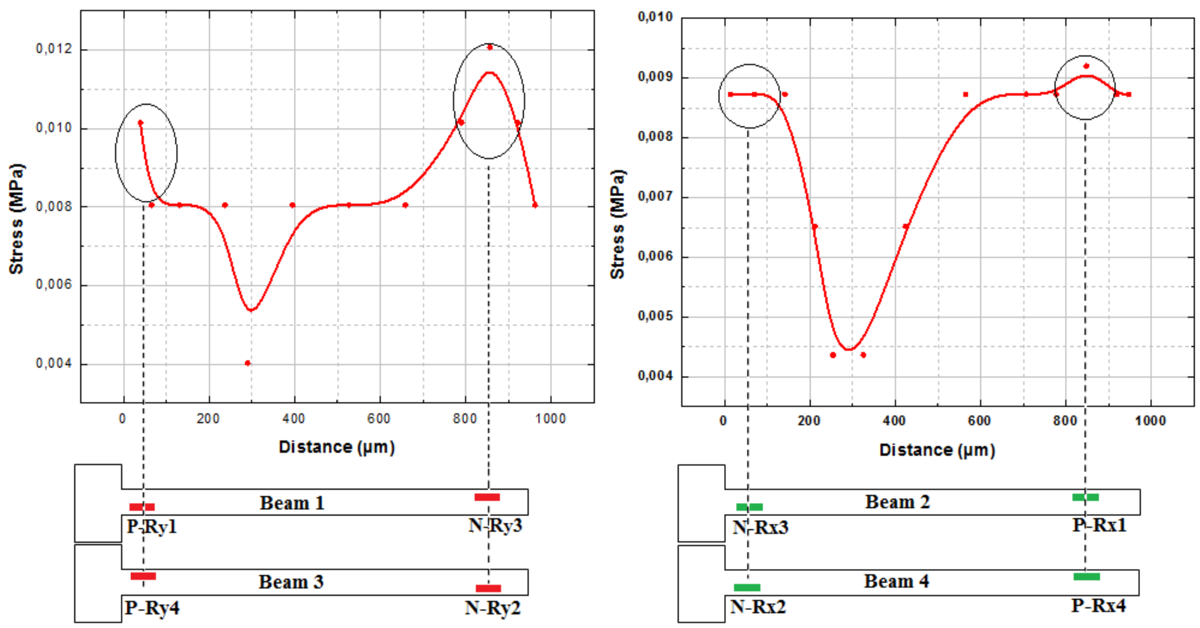


Figure 5.a Figure 5.b

Figure 5: Longitudinal stresses on the surface of the 2nd and 4th beams due to 1g acceleration *Ax* and *Ay*.

From simulation results, we would found that two normal stresses are rather smaller when comparing to the longitudinal stress σ_l. The total resistance change is given by the following equation:

$$\frac{\Delta R_i}{R_i} = G_l.\varepsilon = G_l.\frac{\sigma_l^i}{E} \qquad i = x, y, z \qquad (3)$$

Where G_l is a longitudinal gauge factor: $G_l = \pi_l.E + 1 + 2.\upsilon$ (4)

E is a Young's modulus; υ is a Poisson ratio and ε is the tensile strain.

In the equation (4), we have: $\pi_l.E >> 1 + 2.\upsilon$

Thus the equation (3) becomes:

$$\frac{\Delta R_i}{R_i} \approx \pi_l.\sigma_l^i \qquad (5)$$

The electronics sensitivity can be given by: $S_i = \frac{V_{out}}{a_i} = \frac{\Delta R_i}{R_i}.V_{in} = \pi_l.\sigma_l^i.V_{in}$ (6)

Where S_i is the sensitivity to the i^{th} acceleration component, V_{in} and V_{out} are the input and output voltage, respectively.

The following figure gives the Wheatstone bridge circuits for the three acceleration components.

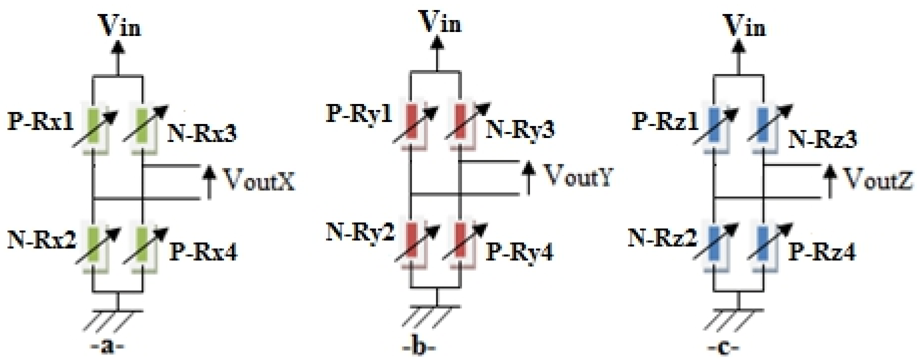


Figure 6: Wheatstone bridge circuits of three acceleration components.

Table (2) gives the increase (+), the decrease (-), or the invariance (0) of the piezoresistances by the application of the *Ax*, *Ay* and *Az* components of acceleration.

	P-R_{Z1}	N-R_{Z2}	N-R_{Z3}	P-R_{Z4}	P-R_{Y1}	N-R_{Y2}	N-R_{Y3}	P-R_{Y4}	P-R_{X1}	N-R_{X2}	N-R_{X3}	P-R_{X4}
Az	+	-	-	+	+	-	-	+	+	-	-	+
Ay	0	0	0	0	+	-	-	+	0	0	0	0
Ax	0	0	0	0	0	0	0	0	+	-	-	+

Table 2: Piezoresistance values changes of three acceleration components.

Conclusion

This work presents a design and simulation of three-axis piezoresistive accelerometer using MEMS technology. The sensing principle of the sensor is the piezoresistive effect. The most important aspect of Finite Element Analysis (FEA) in our design process is the analysis of the stress distribution in the four flexure beams. The stress analysis was performed in order to determine the positions of the piezoresistances on these beams, and consequently to eliminate the transverse sensitivities for obtaining optimal three acceleration components. This model of three-axis accelerometer is used in the field of biomedical applications (BioMEMS).

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