DESIGN AND SIMULATION OF ACCELEROMETER SPRINGS

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With the development of MicroElectroMechanicalSystems (MEMS), inertial instruments have seen significant progress over the past decades. The advantages of low-cost, low-power, small size, batch fabrication, makes MEMS-based inertial sensors have a wide range of applications in automotive, consumer, computer, and navigation markets. An accelerometer is internal sensor used to measure acceleration. This MEMS-based accelerometer uses a capacitive-sensing scheme for acceleration detection.

This paper presents the design and simulation of two kinds of springs, built on the same principles, with different geometry parameters. The main aim of the work is to find, how the accelerometer parameters are changed, by using of different springs to attach the proof mass. Different spring types have different spring constants, depending on their geometry parameters like width, length, effective mass etc. We are going to find out, how the range of measured acceleration changes, if we use modified spring parameters.

Keywords: MEMS, Accelerometer, Spring, PolyMUMPs, SoftMEMs and ANSYS CAD systems

1. INTRODUCTION

The MEMS accelerometer operates under the same principles of a spring-mass system, shown schematically in Fig. 1. However, instead of springs, the accelerometer employs a double folded beam flexure system. The mass being displaced is the proof mass. To measure displacement, one capacitive sensor exists on each side of the proof mass. The sensitivity of these sensors is proportional to the size length of the mass. These sensors send back a voltage signal, proportional to the displacement measured. By equating Hooke's Law to Newton's second law, $kx = ma$, the acceleration, experienced by the mass, can easily be determined.

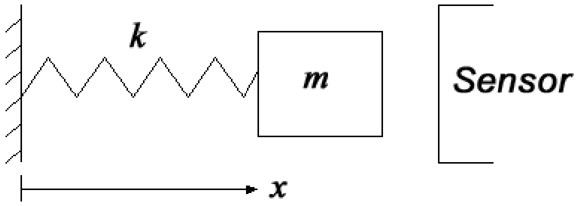

Figure 1. Schematic Diagram of Spring-Mass System, with sensor measuring displacement.

There are two basic techniques that are used to build MEMS – these are surface and bulk micromachining technologies. Using the first technique (surface micromachining), we can build a Surface-Micromachined Variable Capacitors. They provide lower cost and noise reduction, as well as lowering both parasitic capacitance and resistance. Their disadvantage is that the capacitance per unit area in a standard process is relatively small, large capacitances (more than a few picofarads) occupy too great part of the chip area and it is not cost effective. The bulk technique is used to build Bulk-Micromachined Variable Capacitors. In these devices, a spring supports a set of movable fingers that mesh with a set of stationary fingers. The capacitance scales linearly with the number of fingers and the finger thickness and is inversely proportional to the gap. The technology, used in this article, is called PolyMUMPs (Poly Multi-User MEMS Processes). PolyMUMPs is a three-layer polysilicon surface and bulk micromachining process, with 2 sacrificial layers and one metal layer. Eight mask levels create 7 physical layers. The minimum feature size in PolyMUMPs is 2 μm. [6].

2. ACCELEROMETER SPRING BASICS

Two types of springs are used, to attach the proof mass. The first one is shown in Fig. 2. The disadvantage here is that this spring has no consistent spring constants.

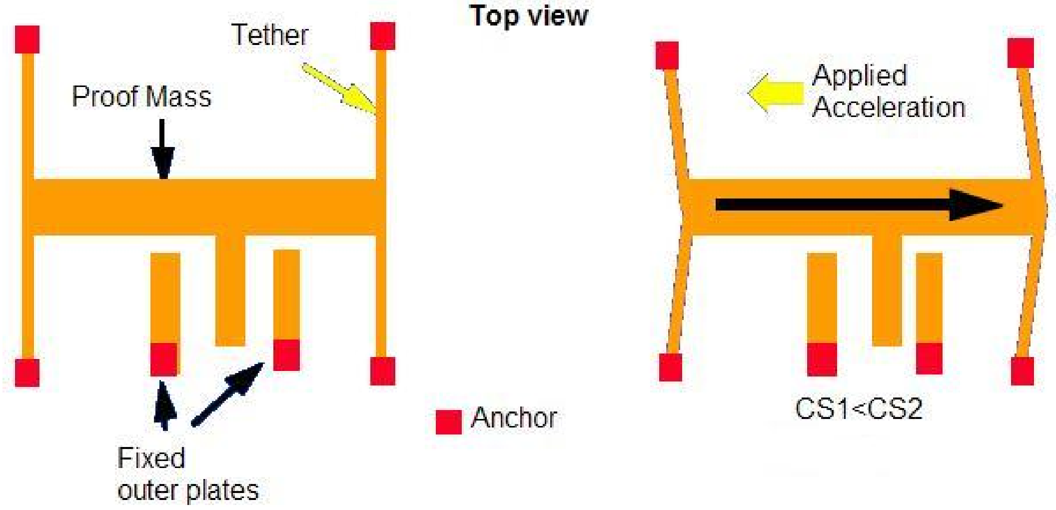

Figure 2. Single beam spring

The second one is called Folded Tether and has more consistent spring constant, leading to better part to part consistency. Folded Tether is shown in Fig. 3.

The technology used in the production of the spring is called MESCAP PolyMUMPs. The PolyMUMPs process is a three-layer polysilicon surface micromachining process, derived from the work, performed at the Berkeley Sensors and Actuators Center (BSAC) at the University of California, in the late 80's and early 90's. Several modifications and enhancements have been made to increase the flexibility and versatility of the process for the multi-user environment. Fig. 4 is a cross section of the three-layer polysilicon surface micromachining PolyMUMPs process. The difference of this process, comparing with the most customized surface micromachining processes, is in the fact that it has to be capable of supporting many different designs on a single silicon wafer. After all steps, the final structure is graphically presented in Fig. 5 [3].

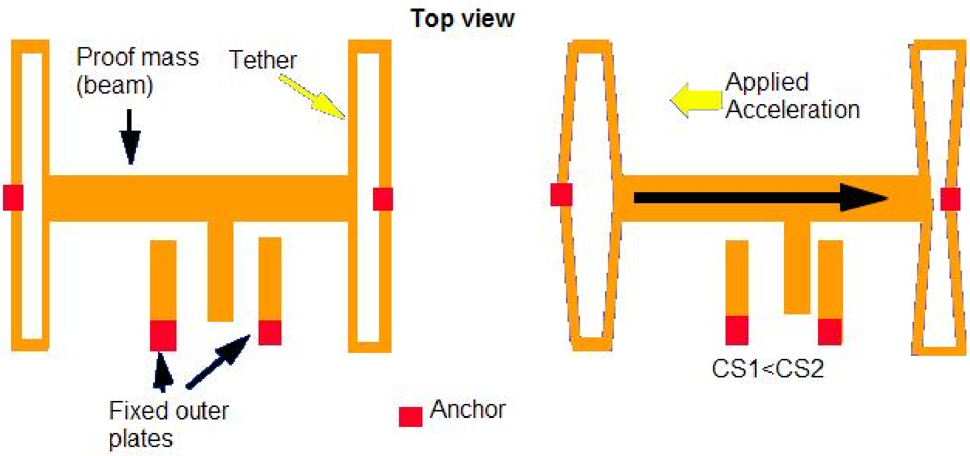

Figure 3. Double Folded Beam Flexure System

All simulations are made with SoftMEMs and ANSYS CAD systems. The SoftMEMs CAD Design Environment is a customizable set of CAD tools for the development and test of MEMS-based products. SoftMEMs CAD tools are products that support leading electronic design automation environments, used for integrated circuit development. The applied tool suites enable designers to develop new MEMS designs and integrate existing designs into systems [4].

ANSYS Multiphysics software is a comprehensive coupled physics tool, combining structural, thermal, computational fluid dynamics (CFD), acoustic and electromagnetic simulation capabilities in a single engineering software solution. Multiphysics simulation allows engineers and designers to evaluate their designs, operating under real-world conditions. The ANSYS Multiphysics solution allows engineers and designers to simulate the interaction between structural mechanics, heat transfer, fluid flow, acoustics and electromagnetics, all within a single software product [5].

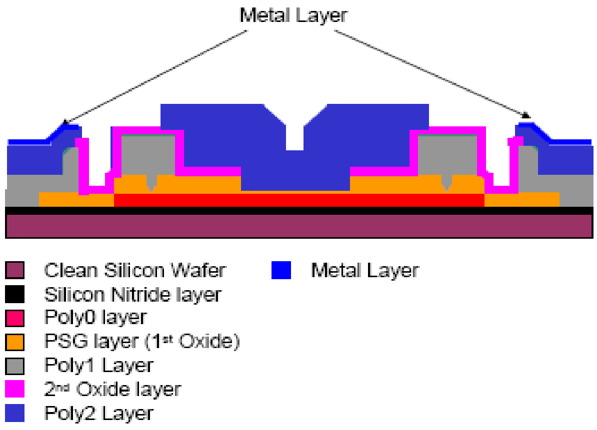

Figure 4. Cross sectional view showing all 7 layers of the PolyMUMPs process

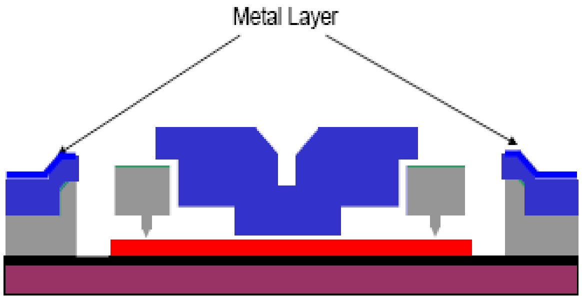

Figure 5. Final structure

3. DESIGN AND SIMULATION OF THE SPRINGS

The spring dimensions are shown respectively in Table 1. The performance of the designed springs is simulated with ANSYS tool. First of all, the spring has to be import from SoftMEMS to ANSYS. Second: material property values for polysilicon have to be defined. They are shown in Table 2. On the next step, the model is meshed to thousand of tetrahedral shape pieces to help easier the analysis of the model.

Table 1. Springs parameters

Parameter	default spring	no default spring
tether length	200 µm	645 µm
tether width	20 µm	20 µm
yoke length	25 µm	70 µm
flexure beam width	2 µm	3 µm
spring constant	3.087 N/m	0.3489 N/m

Table 2. Material properties:

Young's modulus	169 GPa
Poisson's ratio	0.22
Thermal Expansion Coefficient	$2.9e^{-6}$/ºK
Thermal Conductivity	$150e^{6}$ W/µmºK
Resistivity	$2.3e^{-11}$ Ω-µm

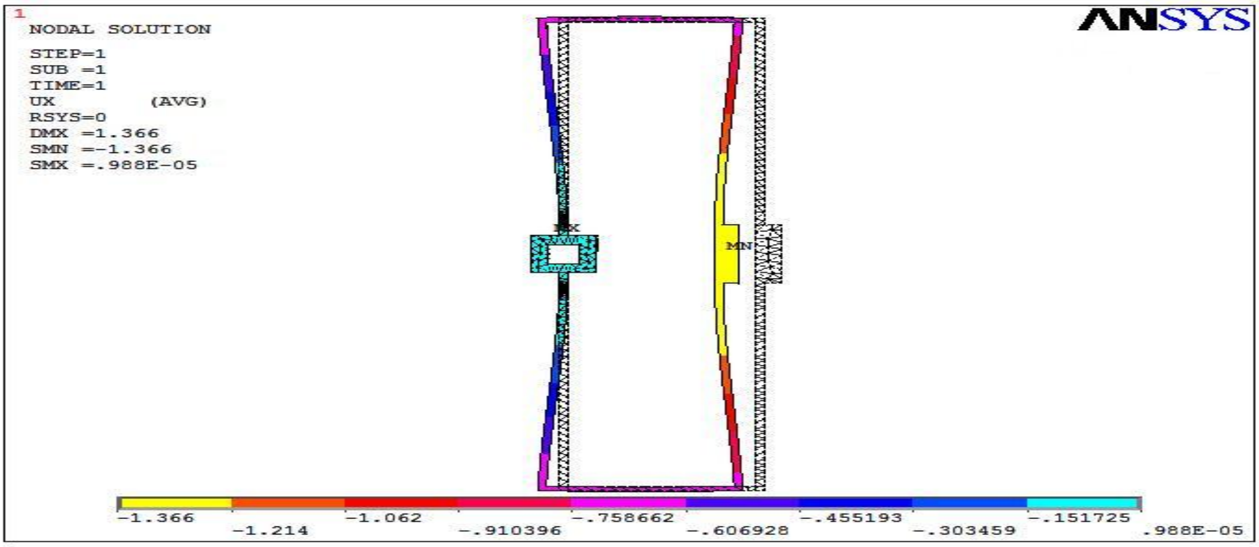

Figure 6. X-Component of displacement of default spring "tether 1"

The deformation of the springs depends on their spring constant. The simulations will show, if the springs constants, estimated by SoftMEMS, is true, and if not – the error in percentage. First, we have to determine the pressure, which we need to apply to displace the default spring, "tether 1", to 1 µm. Pressure value is estimated, using the formula: F = k.x. The spring constant is estimated by SoftMEMs and for default spring it is k = 3.087 N/m. So, the force is $F = 3.087 * 1.10^{6} = 3.087 * 10^{6} N$.

The pressure is $P = \frac{F}{S}$, where S is the area of the yoke (place, where the proof mass is attached to the tether). It could be found, multiplying the yoke length by layer thickness.

$$P = \frac{3.087 * 10^{6}}{25.10^{-6} * 2.10^{-6}} = 0.0617.10^{6} Pa = 61.7 kPa\ .$$

Fig. 6 shows, how the default spring deforms under pressure of 61.7 kPa/m^2, or 61.7 mPa/µm^2. We can see that the maximum displacement is where the pressure is applied – at the yoke, where the proof mass has to be attached. The value of this maximum is 1.366 µm. It is with 0.366 µm more than we estimated. That value shows that, the spring constant, estimated by SoftMEMs, is not so accurate.

Fig. 7 displays the strain of the structure. Even in the areas, where there is maximum strain, it doesn't goes higher than the silicon breaking point (7000 MPa [7]).

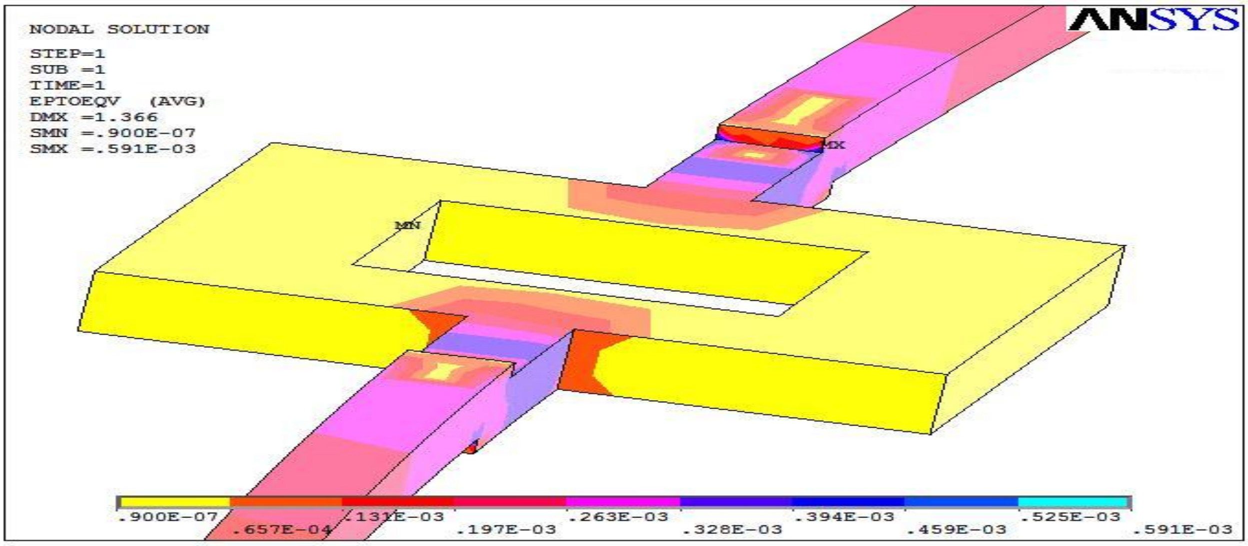

Figure 7. Total mechanical strain of default spring "tether 1".

The pressure of the spring, which is not default, "tether 2", is estimated, using the same formula F = k.x, and P = F/S. In this case, the spring constant is k=0.3489 N/m.

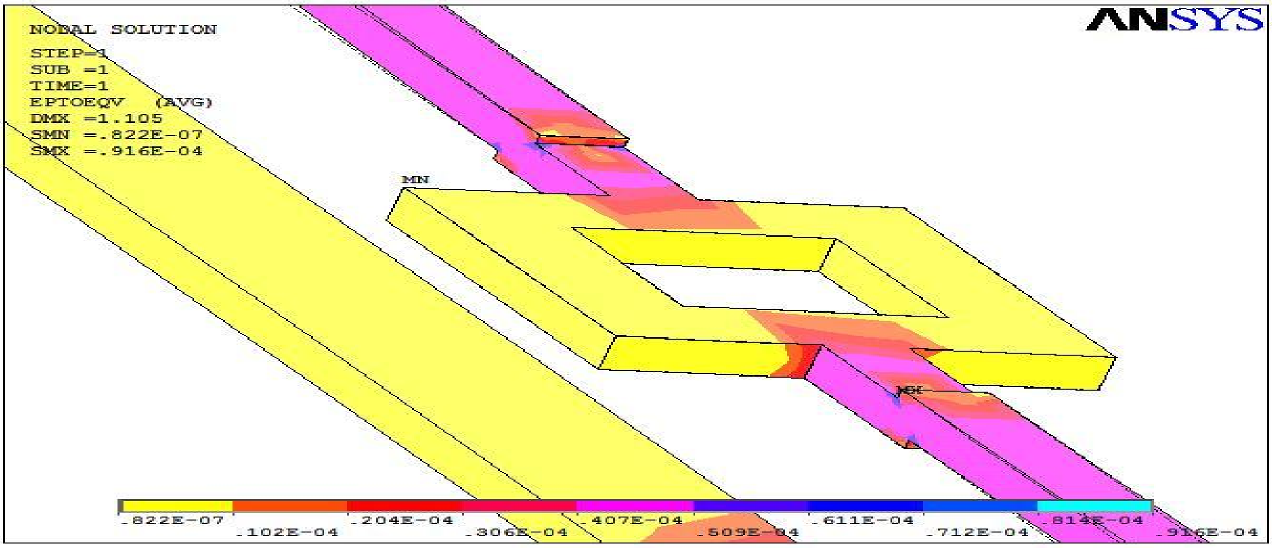

Figure 8. X-Component of displacement of no default spring "tether 2"

It is nearly ten times smaller than the constant of the default spring. The pressure value is $P = \frac{0.3489}{140} * 10^6 = 2.49 kPa$. The simulation of "tether 2" is shown in Fig. 8. As we can see, the no default spring is more flexible than default. Fig. 9 displays the strain of the no default spring "tether 2".

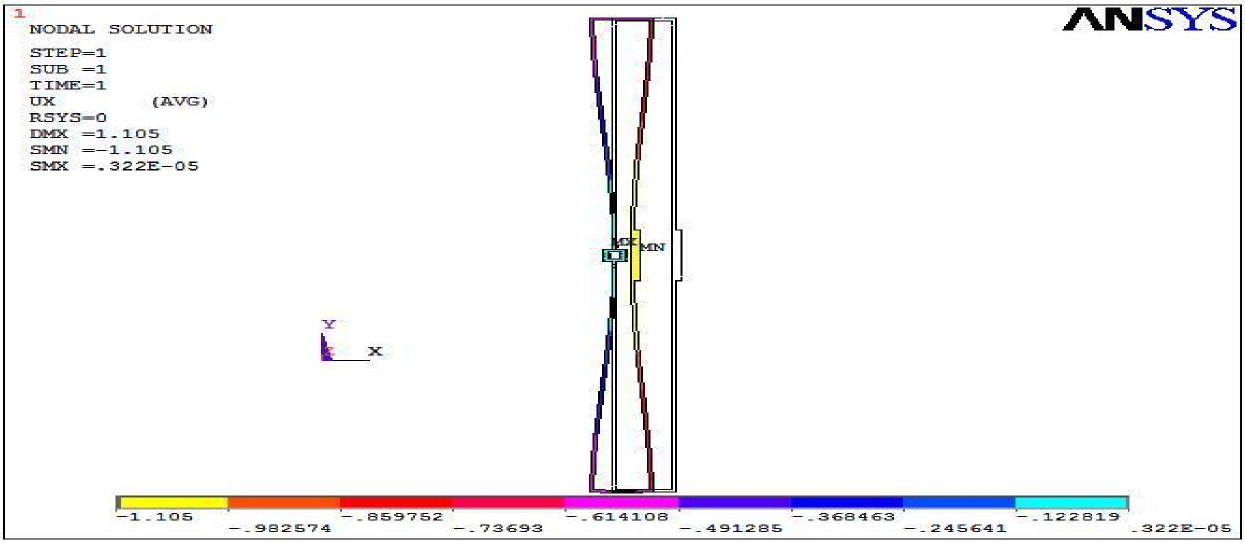

Figure 9. Total mechanical strain of no default spring "tether 2"

4. CONCLUSION

This work demonstrates a design of springs, which are necessary for creation of MEMS accelerators. The simulations are performed using ANSYS and SoftMEMs CAD systems. A parametric coupled physics model has been developed and validated for predicting the performance of springs, as parts of surface micromachined MEMS accelerators. This model is useful in the design of customized actuators for specific applications.

5. ACKNOWLEDGEMENT

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