ANNUAL JOURNAL OF ELECTRONICS, 2009, ISSN 1313-1842

Design and Simulation of MEMS Vertical Accelerometer

Marin Hristov Hristov, Stiliyan Lyubomirov Filipov, Krassimir Hristov Denishev, Ivan Stefanov Uzunov, Vladimir Emilov Grozdanov and Dobromir Georgiev Gaydazhiev

Abstract - **The MicroElectroMechanicalSystems (MEMS) inertial instruments have seen significant progress over the past decades, because of their advantages of low-cost, low-power, small size, batch fabrication.**

This paper presents design and simulation of four vertical accelerometers, 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 modifying the layout dimensions. Different topologies of the proof mass have different spring constants, due to their geometry parameters like width, length, effective mass and electrostatic force.

Keywords – **MEMS, Vertical Accelerometer, Cantilever Beam, PolyMUMPs, SoftMEMs and ANSYS CAD systems**

I. INTRODUCTION

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 inertial sensor, used to measure acceleration. This MEMS-based accelerometer uses a capacitive-sensing scheme for acceleration detection.

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 two cantilever beams. The mass being displaced is the proof mass. Newton's law simply states that, if a mass m, is undergoing an acceleration a, then there must be a force F, acting on the mass and given by $F = ma$. Hooke's law states that, if a spring, with spring constant k, is stretched (extended) from its equilibrium position for a distance Δx, then there must be a force, acting on the spring, given by $F = k\Delta x$.

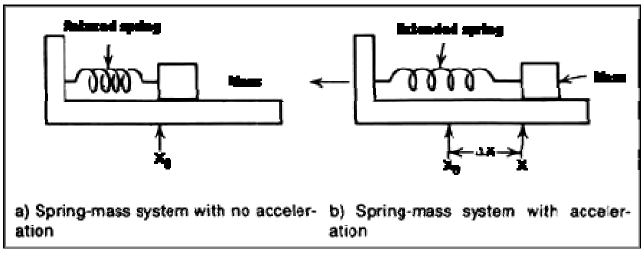

Figure 1. Schematic diagram of spring-mass system in relaxed position (a) and with applied acceleration (b).

The MEMS Vertical Accelerometer measures differential change in capacitance. One of the capacitors is formed between Poly0 and Poly1, with space between the plates of 2 μm. The other capacitor is formed between Poly2 and Poly1, with space between the plates of 0.75 μm, where the spaces (2 μm and 0.75 μm) are the first and second sacrificial oxide layers. The proof mass (Poly1) deflects from its relaxed position, when an external acceleration is applied. That causes change in the differential capacitance. A detailed 3D view of the structure is shown in Fig. 2.

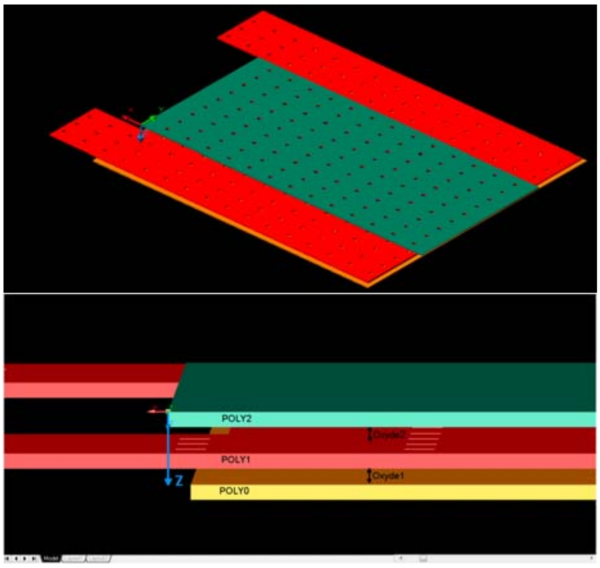

Figure 2. 3D view of the vertical accelerometer; orange – Poly0, red – Poly1, green – Poly2

M. Hristov is with the Department of Microelectronics, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: mhristov@ecad.tu-sofia.bg,

S. Filipov is with the Department of Microelectronics, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: steli.filipov@gmail.com,

K. Denishev is with the Department of Microelectronics, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: khd@tu-sofia.bg,

I. Uzunov is with the Department of Communication Networks, Faculty of Telecommunications, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: iuzunov@tu-sofia.bg,

V. Grozdanov is with Smartcom-Bulgaria, 7th km, Tzarigradsko Chausee Blvd, 1784 Sofia, Bulgaria, e-mail: vladimirgrozdanov@gmail.com,

D. Gaydazhiev is with Smartcom-Bulgaria, 7th km, Tzarigradsko Chausee Blvd, 1784 Sofia, Bulgaria, e-mail: dobromir_gaydajiev@smartcom.bg.

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. The vertical view of the structure is shown in Fig. 3. Eight mask levels create 7 physical layers. The minimum feature size in PolyMUMPs is 2 μm and the resolution is 0.25 μm. [1]

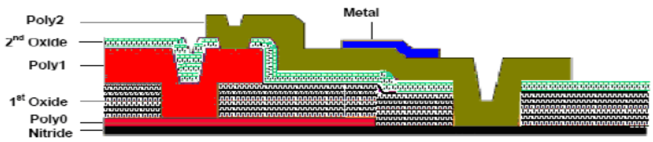

Figure 3. Vertical cut of a structure made by PolyMUMPs process

II. Accelerometer Spring Coefficient Basics

The springs, used for supporting the proof mass, are so called cantilever beams. They are anchored from one side and the mass is attached to the opposite side. If an external acceleration with direction on the *Z* axis is applied, then the beams and the proof mass deflect in the opposite direction (Fig. 4).

Using these relationships, four different vertical acceleration structures were designed and investigated. The difference is in their maximum admissible acceleration, having as a result, different geometry dimensions (Fig. 5).

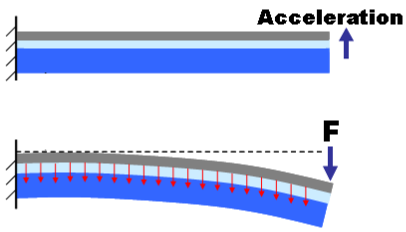

Figure 4. Deflection of the cantilever beam

The spring coefficient (in *Z* direction) of each structure is measured in N.m and is a sum of two parts. The first one is the mechanical spring coefficient (k_{mech}), which depends on the dimensions of the cantilever beam. The second one is the electrostatic spring coefficient (k_{elec}), which depends on the electrostatic force, after supply voltage is being applied. The formulas for these coefficients are [3]:

$$k_{mech} = \frac{E.h^3.w}{2l^3}$$

$$k_{elec} = \frac{-F_{elec}}{d},$$

where *E* is the Young`s modulus, *h* is the thickness of the beam, *w* and *l* are respectively the width and the length of the beam, F_{elec} is the electrostatic force and *d* is the distance between the electrodes.

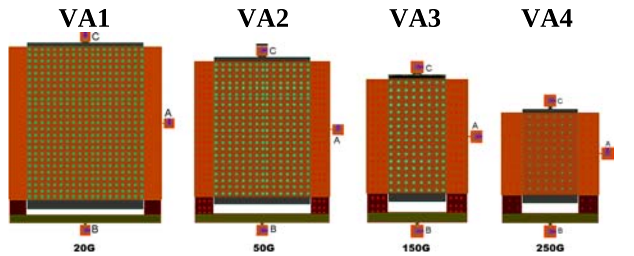

Figure 5. Layout view of the different G structures [2]

In Table 1, different parameters of these vertical accelerometers are shown.

TABLE 1. SPRING COEFFICIENTS FOR 4 DIFFERENT STRUCTURES

Name	k_{mech} N/m	k_{elec} N/m	k N/m	MAX G
VA1	105,6	55,6	50	20
VA2	105,6	35	70,6	50
VA3	105,6	15,1	90,5	150
VA4	105,6	10,5	95,1	250

The parameter k_{mech} is the same for all the accelerometers, due to equal dimensions of the cantilever beams. On the other hand, k_{elec} is different for each structure, because the proof masses are different. From the equation

$$a = \frac{k\Delta x}{m}$$

we can determine the maximum acceleration for each accelerometer. This is shown in the MAX G section ($1G=9.8m/s^2$).

III. Design and Simulation of the Accelerometers

Some specific capacitances, giving information for the deviations, during the normal acceleration loading of the accelerators, were calculated. These calculations were made in SoftMEMS, using the parameterized cell S_VACELL_1. The software model of this cell is written in Verilog-A. The results are given in Fig. 6.

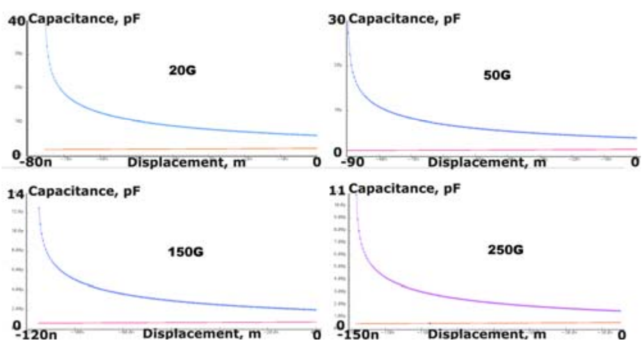

Figure 6. C1 (formed between Poly1 and Poly2) and C2 (between Poly0 and Poly1) capacitances

The other simulated parameters, such as change in differential capacitance, applied force and displacement of the cantilever beam`s free end, are shown in Fig. 7.

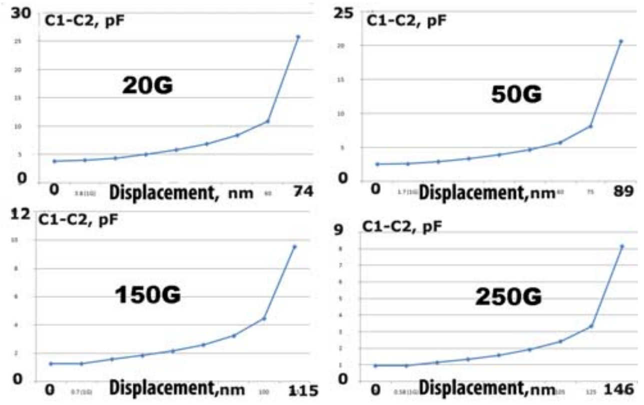

Figure 7. Change in differential capacitance C1-C2

According to the formula *F=k.x*, where *k* is a constant, there should be a linear relationship between applied force and displacement. The simulated results are shown in Fig. 8.

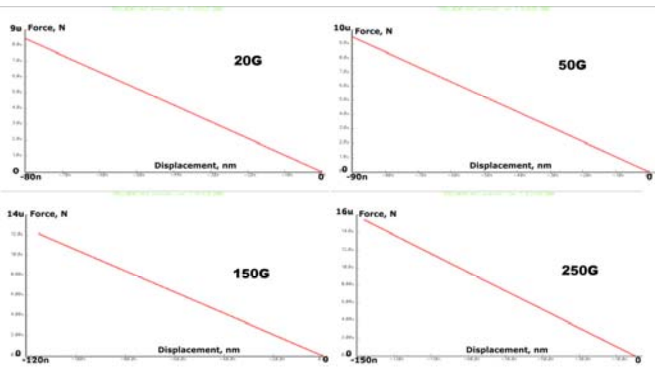

Figure 8. Displacement versus applied force

For running an analysis in ANSYS we have to know the mechanical properties of the structure material (Polysilicon in this case) [4]. The parameters are shown in Table 2.

TABLE 2. MECHANICAL PROPERTIES OF POLYSILICON

Young's modulus	169 GPa
Poisson's ratio	0.22
Thermal Expansion Coefficient	$4.7e^{-6}$/ºK
Thermal Conductivity	$150e^{6}$ W/µmºK
Resistivity	$2.3e^{-11}$ Ω-µm

ANSYS was used for simulating the displacement of the proof mass, when an external acceleration is being applied. That is shown in Fig. 9, where, the blue region represents the most displaced area.

All simulations were made in the ECAD Laboratory of TU-Sofia, 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 [5].

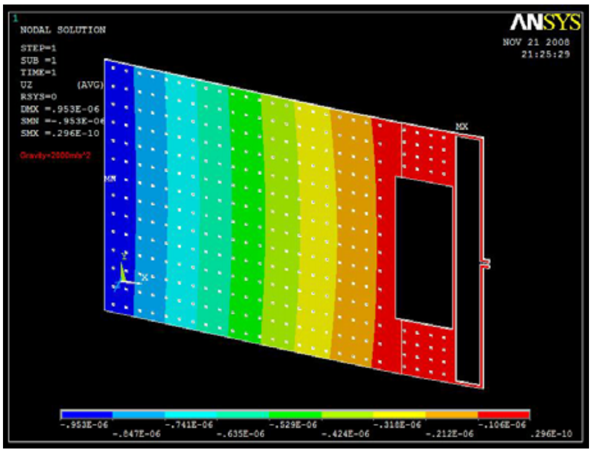

Figure 9. Displacement simulation in ANSYS

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 [6].

IV. CONCLUSION

This work demonstrates a design of MEMS vertical accelerometers, which are widely used in the automotive and navigation systems. The simulations are performed using ANSYS and SoftMEMs CAD systems. The default Verilog-A model, describing the S_VACELL_1 was modified, due to errors in it. This model is useful for design of customized accelerometers for specific applications.

ACKNOWLEDGEMENT

The research, described in this paper, was carried out within the framework of the contracts № 091ni034-03/2009 D002-106/15.12.2008 and D002-126/15.12.2008.

REFERENCES

[1] www.memscap.com/mumps/nc-mumps.poly.html
[2] Carter J., A. Cowen, B. Hardy, R. Mahadevan, M. Stonefield, S. Wilcenski, *PolyMUMPs Design Handbook*, MEMSCAP Inc, 2005.
[3] MEHMET AKİF ERİŞMİŞ "*MEMS ACCELEROMETERS AND GYROSCOPES FOR INERTIAL MEASUREMENT UNITS", 2004*
[4] www.design.caltech.edu/Research/MEMS/siliconprop.html
[5] www.softmems.com/products.html
[6] www.ansys.com/products/default.asp