DESIGN AND INVESTIGATION OF AN ACCELEROMETER

Marin Hristov Hristov[1], Plamena Dimitrova Veleva[1], Krasimir Hristov Denishev[1], Vladimir Emilov Grozdanov[2], Dobromir Georgiev Gaydazhiev[2]

[1]Department of Microelectronics, Technical University of Sofia, 8 Kliment Ohridski Str., 1797 Sofia, Bulgaria, phone: +359 29652220,
e-mail: mhristov@ecad.tu-sofia.bg, pdv@ecad.tu-sofia.bg, khd@tu-sofia.bg,
[2]Smartcom, 7th km, Tzarigradsko Chausee Blvd, 1784 Sofia, Bulgaria, phone: +359 29650650,
e-mail: vladimirgrozdanov@gmail.com, dobromir_gaydajiev@smartcom.bg

The past few years have witnessed an increasing maturity of the MEMS industry and a rapid introduction of new products addressing applications, ranging from biochemical analysis to fiber-optic telecommunications. The market size for MEMS products has doubled in the past 5 years and is projected to grow at this fast rate for the foreseeable future. The corresponding technology has enjoyed a fast pace of development and has rapidly spread to institutions and companies on all inhabited continents.

MEMS accelerometers are one of the simplest but also most applicable micro-electromechanical systems. They became indispensable in automobile industry, computer and audio-video technology. This paper presents the design and simulation of an accelerometer with default and not default tether (two different sets of tethers) and investigates the displacements to x,y,z-axis.

Keywords: MEMS, Accelerometer, PolyMUMPs, Surface Micromachining

1. INTRODUCTION

Accelerometers are sensors or transducers that measure objects acceleration. Acceleration sensors generally measure acceleration forces, applied to a body, by being mounted directly onto a surface of the accelerated body. Accelerometers are useful in detecting motion in objects. An accelerometer measures force exerted by a body, as a result of a change in the velocity of the body. A moving body possesses an inertia, which tends to resist change in velocity. It is this resistance to change in velocity, which is the source of the force, exerted by the moving body. This force is directly proportional to the acceleration component in the direction of movement, when the moving body is accelerated. The motion is detected by the sensitive part of the accelerometer. This motion is indicative for the motion of the larger object or application, to which the accelerometer is mounted. Thus, a sensitive accelerometer can quickly detect motion in the application. Various accelerometers, capable of measuring acceleration are being developed. Mainly, the accelerometers are fabricated by using of the semiconductor process, and classified into piezoelectric, piezoresistive and capacitive accelerometers. The technology, used in this article, is so called PolyMUMPs surface micromachining technology. It is MEMS-only technology, composed of 3 polysilicon and 1 metal layers, deposited on top of an insulating nitride layer, as a part of silicon semiconductor technology.

2. DESCRIPTION OF THE ACCELEROMETER

All accelerometers share a basic structure, consisting of an inertial mass, suspended from a spring (see Fig. 1). They differ in the way of sensing of the relative position of the inertial mass, as it displaces under the effect of an externally applied acceleration. One of the common sensing methods is capacitive, in which the mass forms one side of a two-plate capacitor. Another method uses piezoresistors to sense the internal stress, induced in the spring. In yet a different method, the spring is piezoelectric or contains a piezoelectric thin film, providing a voltage in direct proportion to the displacement.

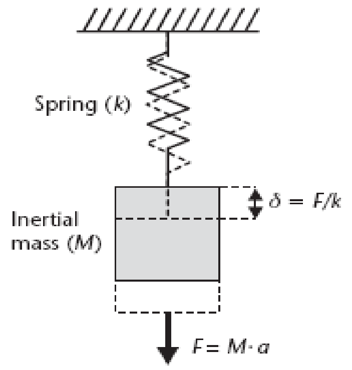


Figure.1 The basic structure of an accelerometer, consisting of an inertial mass, suspended from a spring.

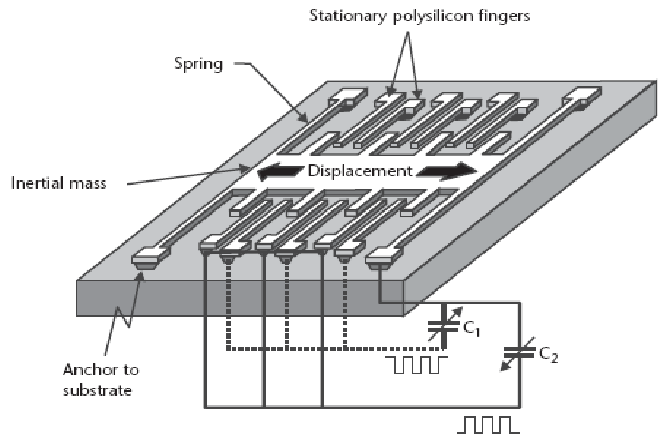


Figure.2 Basic structure of the ADXL family of surface micromachined accelerometers. A comb-like structure, suspended on springs.

The element of investigation in this paper is capacitive micromachined accelerometer. This device consists of three sets of 2-μm-thick polysilicon finger-like electrodes (Fig. 2). Two sets are anchored to the substrate and are stationary. They form the upper and lower electrode plates of a differential capacitance system, respectively. The third set has the appearance of a two-sided comb, whose fingers are interlaced with the fingers of the first two sets. It is suspended approximately 1 μm over the surface, by means of two long, folded polysilicon beams, acting as suspension springs. It also forms the common middle and displaceable electrode for the two capacitors. The inertial mass consists of the comb fingers and the central backbone element to which these suspended fingers are attached. In case of absence of externally applied acceleration, the two capacitances are identical. The output signal, proportional to the difference in capacitance, is null. An applied acceleration displaces the suspended structure, resulting in an imbalance in the capacitive half bridge. The differential structure is such that one of the capacitances increases, and the other decreases.

The technology, used in the production of the accelerometer is PolyMUMPs. It is a MEMS-only technology, composed of 3 polysilicon and 1 metal layers, created on top of insulating nitride layer. Eight mask levels create 7 physical layers. The minimum feature size in PolyMUMPs is 2 µm. Fig. 3 shows the cross section of the layers.

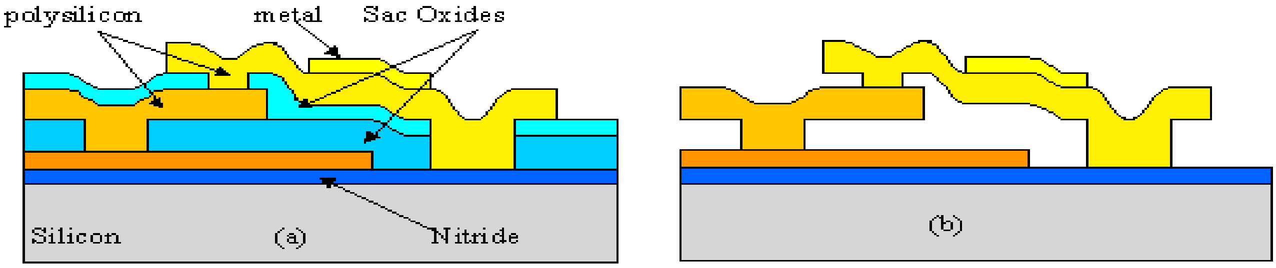


Figure 3. Cross section view of the PolyMUMPS surface micromachining technology, before (a) and after (b) HF etching of sacrificial (Sac) oxides.

All analyses are done by using of SoftMEMs. It is a CAD system, which is used for design and analysis of MEMS. Software functionalities encompass mixed MEMS/IC schematic capture, simulation, design optimization, statistical analysis, and full custom mask layout, supporting popular mask formats. Also included are manufacturing and design rule verification, 3D model generation and visualization from manufacturing process descriptions, behavioral model creation and links to 3D analysis packages. A variety of foundry-specific modules are fully integrated with SoftMEMS' tool suites to ensure process compatibility and manufacturability with the world's leading MEMS foundries.

3. Design of the Accelerometer

The first step is to investigate the displacement only to x-axis of a default accelerometer with Verilog model S_HACCEL_1_M_X_1.1 and with two different tethers. The maximum possible displacement in the x direction is 1 µm, because, the minimum distance between shapes on POLY1 should be less than 2 µm and the gap between the fingers is 3 µm. To find the acceleration that causes the maximum displacement of 1 µm, first we should find the mass of the accelerometer and the spring constant of the "tether 1":

We use the relation between Hooke's Law and Newton's second law: $kx = ma$(1),

where k – constant of the tether; x – displacement; m – body mass of the accelerometer; a – acceleration

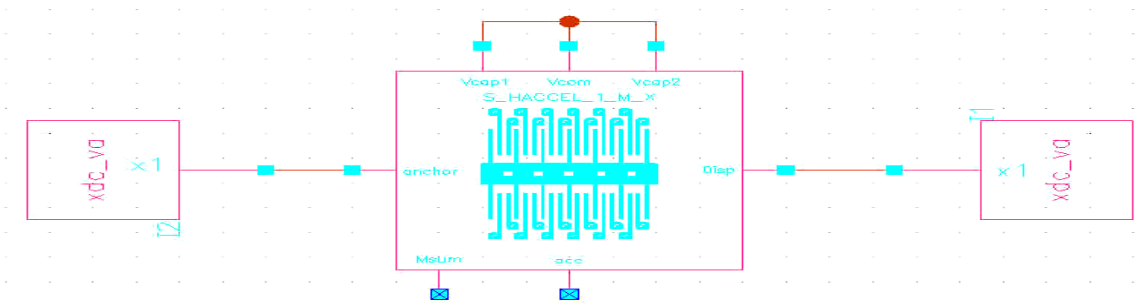


Figure 4. Schematic view of the tested scheme and the result of DC analysis

Using the schematic, shown on Fig.4, we run DC analysis. The Verilog-A model of the accelerometer calculates the mass 'm' of the suspended part: m = $3{,}734.10^{-10}$ kg.

By similar analysis we find the tether constant (Fig. 5): k_1= 3,087 N/m

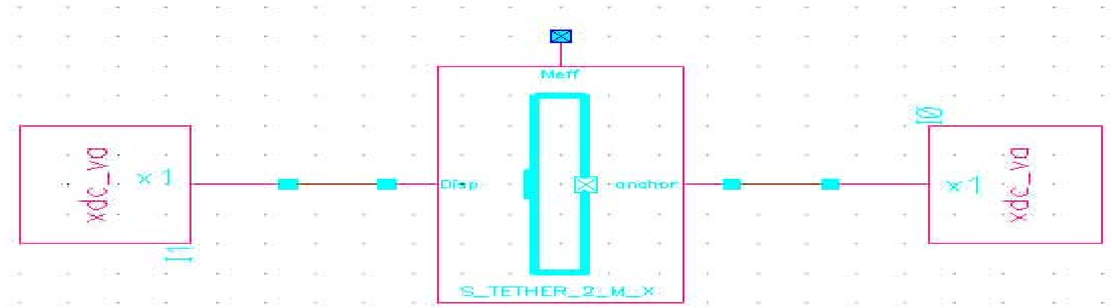


Figure 5. Schematic view of the tested "tether 1" and the result of DC analysis

By (1) and the analyses' results we find $a = \frac{k_1 x}{m} = \frac{3{,}087.1.10^{-6}}{3{,}734.10^{-10}} = 825 m/s^2$.

With simulation we show the results graphically. We use two tethers, and thus the maximum range of the acceleration is doubled. (Fig. 6).

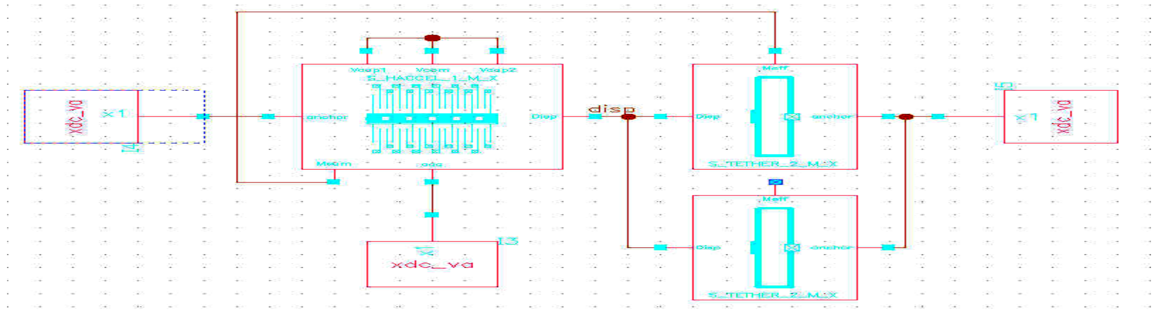


Figure 6. Schematic view of the tested scheme - the accelerometer with the tethers and DC analysis

We do the same steps but with "tether 2"

By (1) and the analysis' results: $a = \frac{k_2 x}{m} = \frac{0{,}349.1.10^{-6}}{3{,}734.10^{-10}} = 93 m/s^2$, k_2= 0,349 N/m.

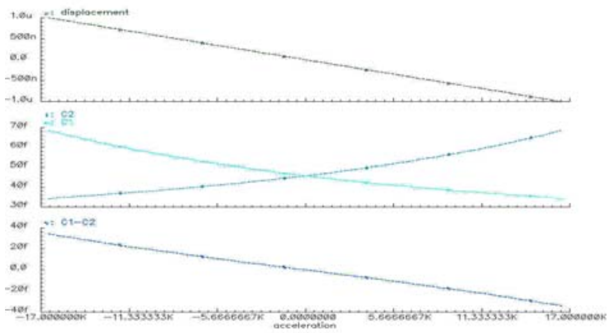


Figure 7. Results of the DC analysis with "tether 1"

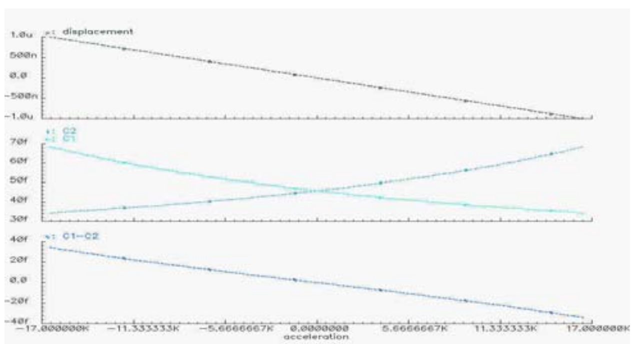


Figure 8. Results of the DC analysis with "tether 2"

Parameter	"tether 1"	"tether 2"
tether length	200µm	645 µm
tether width	20 µm	20 µm
flexure width	2 µm	3 µm
yoke length	25 µm	70 µm

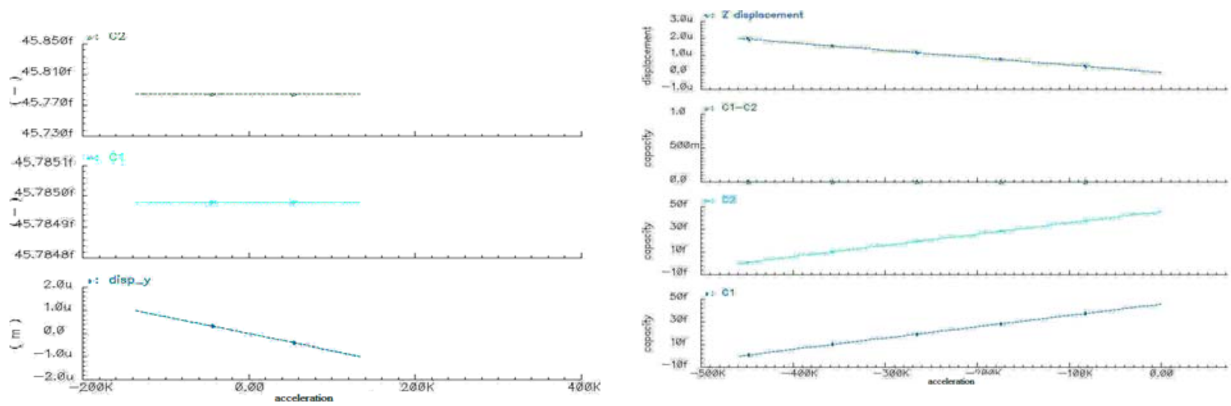
Table.1. The table shows the differences between the tethers

On Fig. 7 and Fig. 8 we see, how the capacitance changes as a function of the acceleration. The difference between C_1 and C_2 is nearly linear function. The difference between the two graphics is that "tether 2" has narrower range of acceleration than "tether 1", but has higher sensitivity.

Next analysis we do with *xyz-accelerometer*. The steps are the same. We investigate the displacement to *x, y and z-axis* with "tether 1". The maximum displacement to *y-axis* is 1 µm. Because of the technology, the thickness of the oxide between layers Poly 1 and Poly 2 is 2 µm. So the maximum displacement to *z–axis* is 2 µm. By (1) and the analysis' results:

$$a_y = \frac{k_y y}{m} = 6794 m/s^2, \qquad a_z = \frac{k_z z}{m} = 22881 m/s^2,$$

where $k_y = 25,37$ N/m, $k_z = 42,72$ N/m



(a) (b)

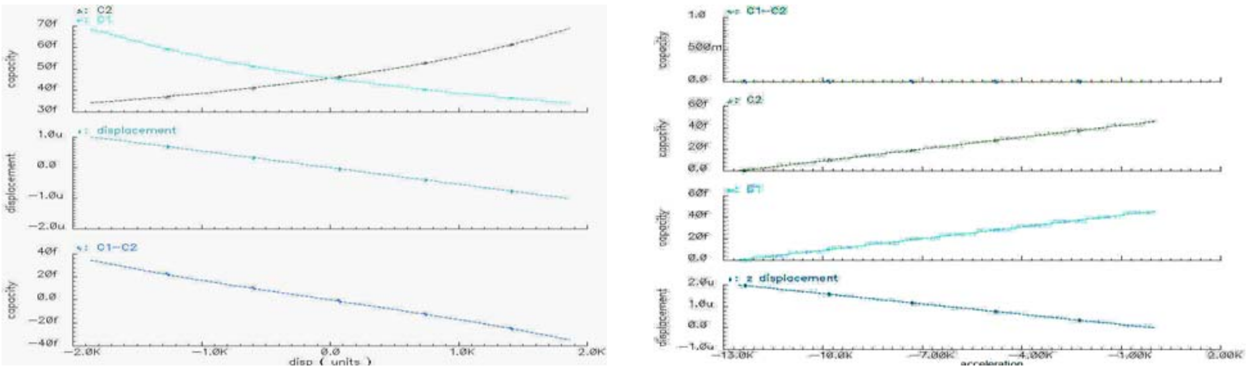
Figure 9. Results of the DC analysis with "tether 1", where (a) and (b) are results of displacement to y and z – axis respectively.

The displacement to x-axis is the same like on Fig. 7 and Fig. 8. There are no changes in capacitances, when the displacement is to y-axis. When the displacement to z-axis increases, the capacitances decreases, because the area of the two capacitors becomes smaller. We can make the same conclusion from Fig. 9 and Fig. 10, which show the same differences between the two tethers.

We do the same steps with "tether 2". By (1) and the analysis' results:

$$a_x = \frac{k_x x}{m} = 96,3 m/s^2 \qquad a_y = \frac{k_y y}{m} = 7080 m/s^2 \qquad a_z = \frac{k_z z}{m} = 629 m/s,$$

where $k_x = 0,36$ N/m $k_y = 26,42$ N/m $k_z = 1,17$ N/m



(a) (b)

Figure.10. Results of the DC analysis with "tether 2", where (a) and (b) are results of displacement to y and z – axis respectively.

4. CONCLUSION

This work demonstrates a design of a default accelerometer. The simulations are performed using Cadence and SoftMEMs CAD systems. The simulations show how the maximum detectable acceleration and the sensitivity of a horizontal accelerometer vary, depending on the spring constant of its tether and the mass of the suspended structure.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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