Design and Simulation of MEMS based Capacitive Accelerometers for Crash Detection and Airbag Deployment in Automobile

Name:	**Thouti Ruthik Goud**
Roll No:	20088
Name:	**Vimaleswar A**
Roll No:	20305
Institute/University Name:	IISER Bhopal
Stream:	BS
Department:	EECS

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Abstract

This paper focuses on design and analysis of MEMS based accelerometer to detect accidents and for the deployment of airbags. In the case of a car accident, where there are sudden and strong accelerations, it is necessary to measure as fast as possible their intensity and direction with good accuracy and precision, aiming to reduce the injuries severity to passengers. With the continuous advancements in **Micro Electro Mechanical Systems (MEMS)** fabrication technology, inertial sensors like accelerometers and gyroscopes can be designed and manufactured with smaller footprint and lower power consumption. Capacitive accelerometers are the most popular and highly researched due to several advantages like high sensitivity, low noise, low temperature sensitivity, linearity, and small footprint. When sudden displacement occurs due to impact the comb gets shock loads or forces and that movement is observed by differential capacitance concept with dielectric as air. The simulations will be carried out on COMSOL and the design will be carried out on COMSOL, the actual theoretical calculation and the simulations are compared in order to get accurate results. The capacitance output obtained is carried to the electronic control unit which sends the impulse signal to air bag system and deployment of air bags takes place.

Introduction

Automotive is one of the most emerging area since ages and is constantly under developments. These developments in technology and these advancements are not without responsibilities to assure that the end user is safe and satisfied. The industries' primary concerns are improving the performance, safety, and comfort aspects which have become evident over the years with introduction of highly improved standards with every iteration. Passenger safety is a field highly researched on to ensure the survival of a passenger in a car crash. This brings us to the crash detection and air bag deployment systems in the automotive industry. At the instant of a crash, sensors start to measure severance of the impact. When the crash occurs beyond a set intensity, the sensors signal control unit to inflate the bags with gas within fractions of a second. The reference work analyzes a capacitive accelerometer capable of identifying positive and negative levels of acceleration along three perpendicular directions. To understand this type of sensor the technological process with which modern semiconductor integrated circuits are manufactured is extensively used, thanks to which MEMS sensors are able to have dimensions in the order of nano meters. In case of a car accident, it is of utmost requirement that the airbag system reacts as fast as possible from the moment of the impact, in order to avoid fatal injuries. For this reason, it is necessary that the system analyses and give a response within the shortest possible time. The capacitive sensors are basically based on a moving solid body with a certain mass that will move when subjected to acceleration. The movement of the mass is the most important factor, because the small displacements of the structure leads (fingers and proof mass) to a variation of a capacity, as there are parts, called ”fingers” that move closer or farther away depending on the direction of acceleration. These displacements are a direct effect of the acceleration on the system. When the capacity produced reaches a certain threshold value, it means that we are in a limit condition in the case under consideration; therefore, the system will react appropriately. e.g., Figure 1

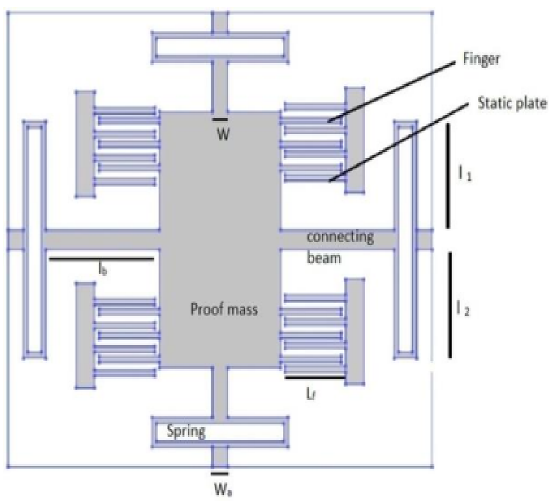

Figure 1: Overview and parts of capacitive accelerometer

Motivation

The project’s motivation stems from the pressing need to enhance and improve automotive safety by leveraging computer technology to accurately detect and respond to crashes, and ultimately reduce the severity of injuries in vehicular accidents.

Objectives

The objective of our project is to design a 2-axis MEMS accelerometer and analyze the displacement and stress along the x and y axis. Certain alterations with respect to the design of the accelerometer are done to study the difference in performance.

System Details

Proof mass: A proof mass or test mass is a known quantity of mass used in a measuring instrument as a reference for the measurement of an unknown quantity. A proof mass that deforms a spring in an accelerometer is sometimes called the seismic mass. This proof mass will have fingers attached to it on either side.

Spring: Thin beams placed in rectangular manner act as springs in the system. It facilitates movement to the proof mass, which in turn moves the fingers. The stiffness of these springs is the key parameter for displacement.

Fingers: Attached to the proof mass, these components are responsible to obtain differential capacitance. They are placed in between di-electric plates, such that a finger-gap and an anti- finger gap exists between them.

Connecting beams: These are used to connect the proof mass to the springs. 4 connecting beams are used with 2 for each spring.

Di-electric medium: Air is taken as the di-electric medium.

Anchors: A 100nm square cross section fixed joint, to which the springs are attached. Density: 2320 Kg/m^3.

Material of component: Polysilicon is chosen as the material of design.

The Top view and lateral view of our designed model from COMSOL is shown in Figure 2 and Figure 3

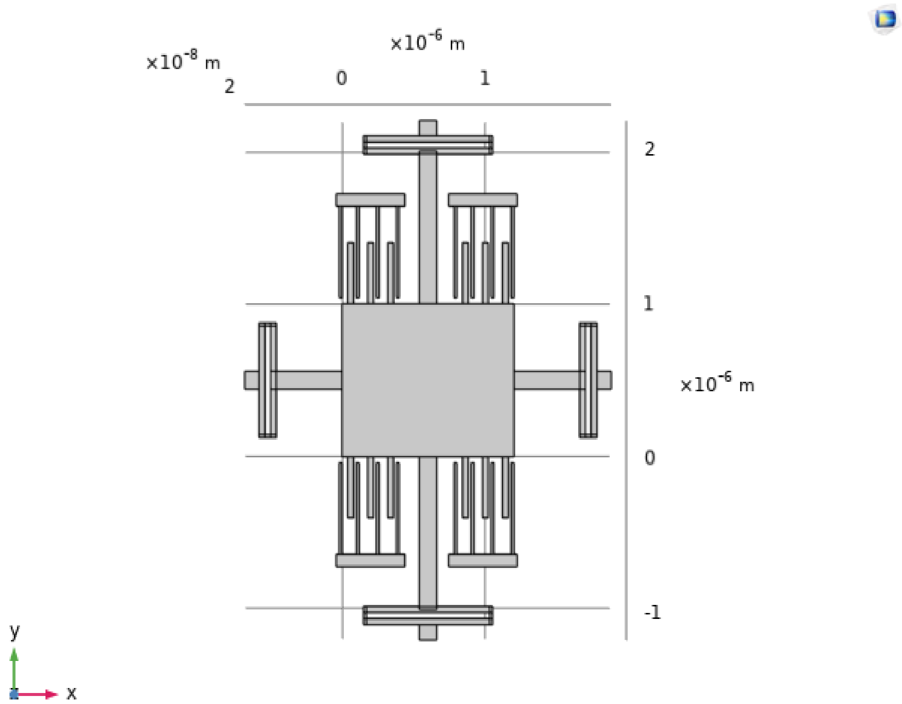

Figure 2: Top view of capacitive accelerometer model from COMSOL

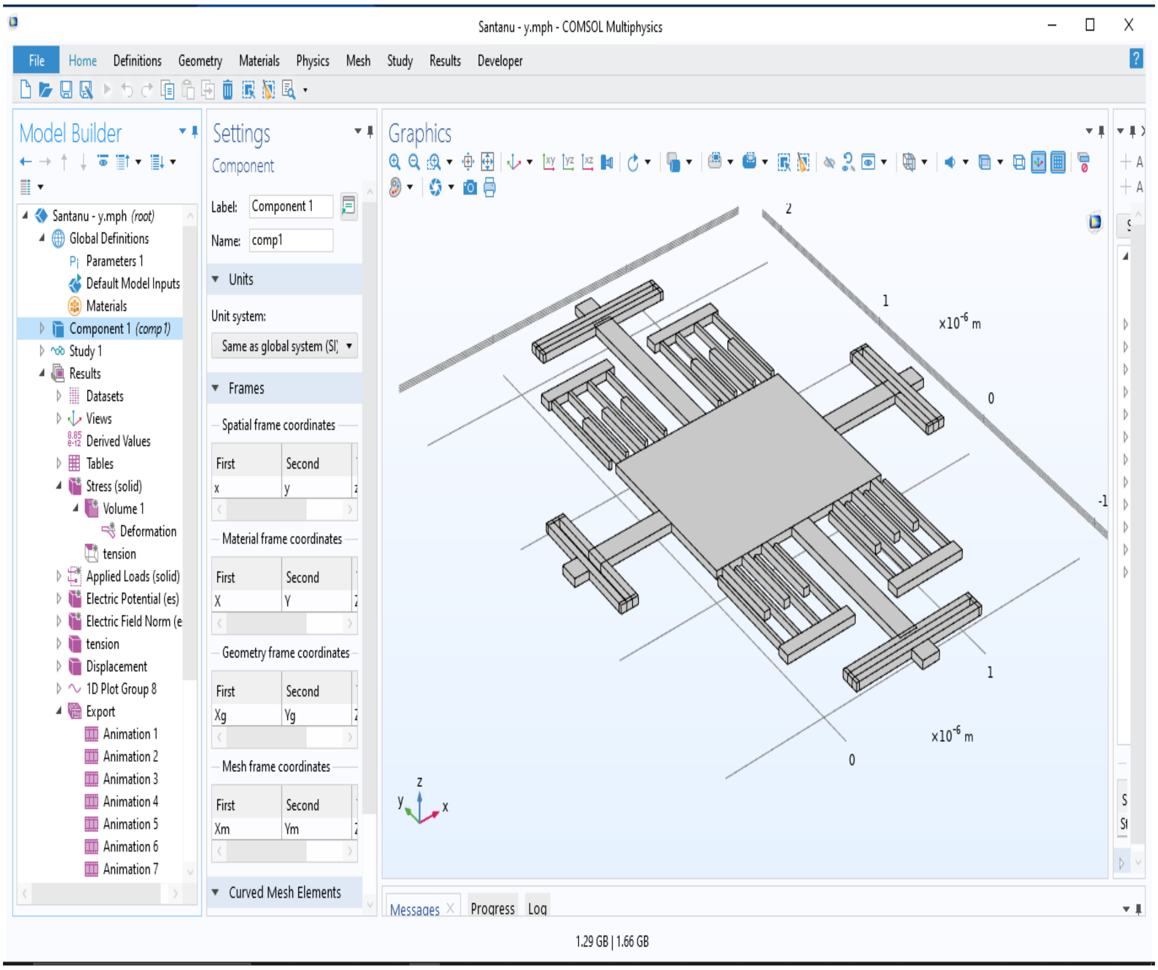

Figure 3: Another view of capacitive accelerometer model from COMSOL

Working of the System with Key Parameters

It is based on the movement of a proof mass to which are attached mobile fingers whose movement makes a change in capacity, that is calculated between them and the fixed fingers. From the displacement it can be traced back the acceleration value and the capacitive system is used to calculate it.The instantaneous change in velocity (acceleration) on impact is converted into force on the system by Newtons laws of motion. This force is then responsible for the proof mass to move, which results in the movement of the fingers. A differential capacitance is set up at the gaps between the fingers and the di-electric plates. This capacitance produces a voltage which is transferred to the electronic control unit of the vehicle and if it is within the acceptable range causes the airbag to deploy. A force F, generated by external acceleration acting on the mass, m, causes a displacement x. The differential equation describing the system response is given by equation:

$$F(t) = m\frac{\partial^2 x}{\partial t^2} + b\frac{\partial x}{\partial t} + Kx \tag{1}$$

b is the damping coefficient and K is the spring coefficient, the stiffness.

Displacement: F is both the force that will be induced to the mass of the system by the external acceleration, both the force given by Hooke's law that could be Comparing the equations, displacement x can be given as:

$$x = ma/k \tag{2}$$

This is the displacement obtained in x-direction for x-axis analysis. The same equation will hold good for y-direction:

$$y = ma/k \tag{3}$$

Capacitance: Capacitance of the system at a single finger between two dielectric plates (electrodes) n is given as:

$$C = \varepsilon_0 \times \varepsilon_r \times A/d \tag{4}$$

Here, ε_0 is the dielectric permeability of vacuum and has a value of $8.854 \times 10^{-12}\,\mathrm{F/m}$, ε_r is the dielectric permeability of the material separating the armatures (in this case, taken as 1 for air), A is the total overlap surface between the electrodes, and d is the gap from the finger. The finger gap d_1 and anti-finger gap d_2 are taken in the ratio 1:2, respectively. This is done to discriminate the displacements in the x and y axes. Thus, capacitance will be:

$$C = \varepsilon_0 \varepsilon_r HL \left(\frac{1}{d_1} + \frac{1}{d_2} \right) \tag{5}$$

X-axis: When acceleration along the x-axis occurs, the capacity between the mobile and fixed fingers varies, because on the right the surface will increase by a factor x, the displacement, which will be added to the overlap length L and on the other side it will decrease, by the same amount. So, for the two capacities their magnitude is given by:

$$C_1 = \varepsilon_0 \varepsilon_r H \left(\frac{1}{d_1} + \frac{1}{d_2} \right) (L + x) \times F \tag{6}$$

$$C_2 = \varepsilon_0 \varepsilon_r H \left(\frac{1}{d_1} + \frac{1}{d_2} \right) (L - x) \times F \tag{7}$$

Y-axis: When acceleration on the y-axis happens, the variation in capacity depends on the displacement that makes the distances d from the fingers vary. The change in capacity will depend on the displacement along the y-axis and further simplified substituting d1=2×d2

$$C_1 = \varepsilon_0 \varepsilon_r LH \left(\frac{1}{d_1 - y} + \frac{1}{d_2 + y} \right) \times F = \varepsilon_0 \varepsilon_r LH \left(\frac{3d_1}{2d_1^2 + d_1 y - y^2} \right) \times F \tag{8}$$

$$C_2 = \varepsilon_0 \varepsilon_r LH \left(\frac{1}{d_1 + y} + \frac{1}{d_2 - y} \right) \times F = \varepsilon_0 \varepsilon_r LH \left(\frac{3d_1}{2d_1^2 - d_1 y - y^2} \right) \times F \tag{9}$$

Voltage: The system is initially given a fixed amount of supply voltage, and once the differential capacitance is obtained, an output voltage signal will be sent to the control unit of the vehicle.

$$V_{\text{out}} = \frac{C_1 - C_2}{C_1 + C_2} \times V_s \tag{10}$$

Result

Acceleration along X-axis

Significant findings and plots for **X-axis** direction is shown in Figure 4, Figure 5 and Figure 6. Figure 4 and Figure 5 gives the displacement plot along the X-axis direction and the plot for the same. Here we can see that the displacement is linearly varying with the acceleration along the X-axis.

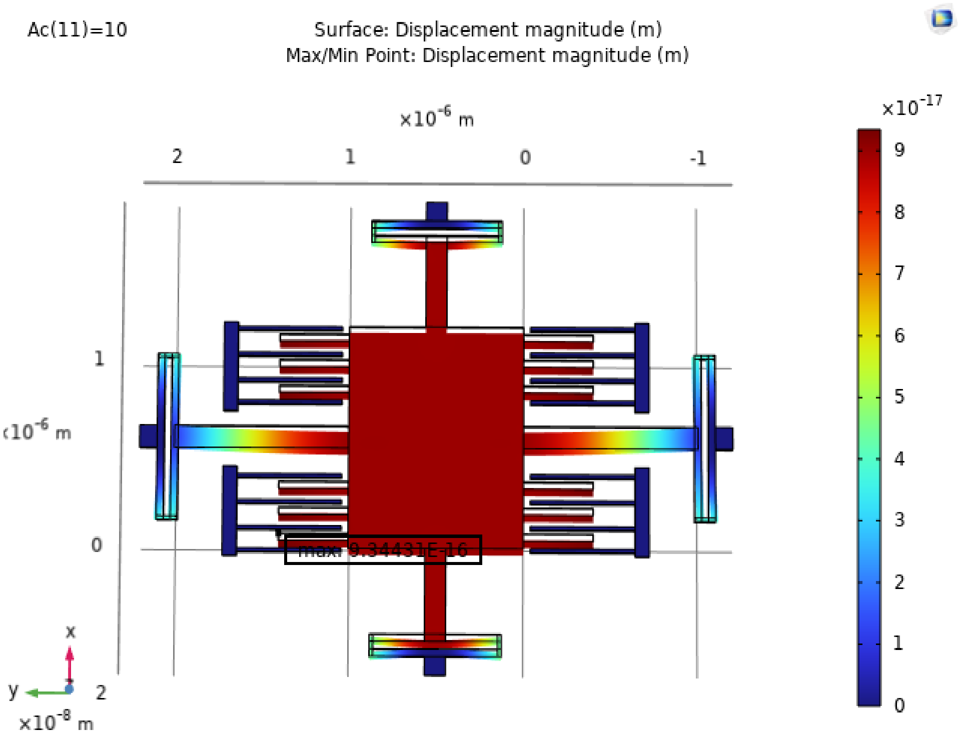

Figure 4: Displacement plot along X-axis

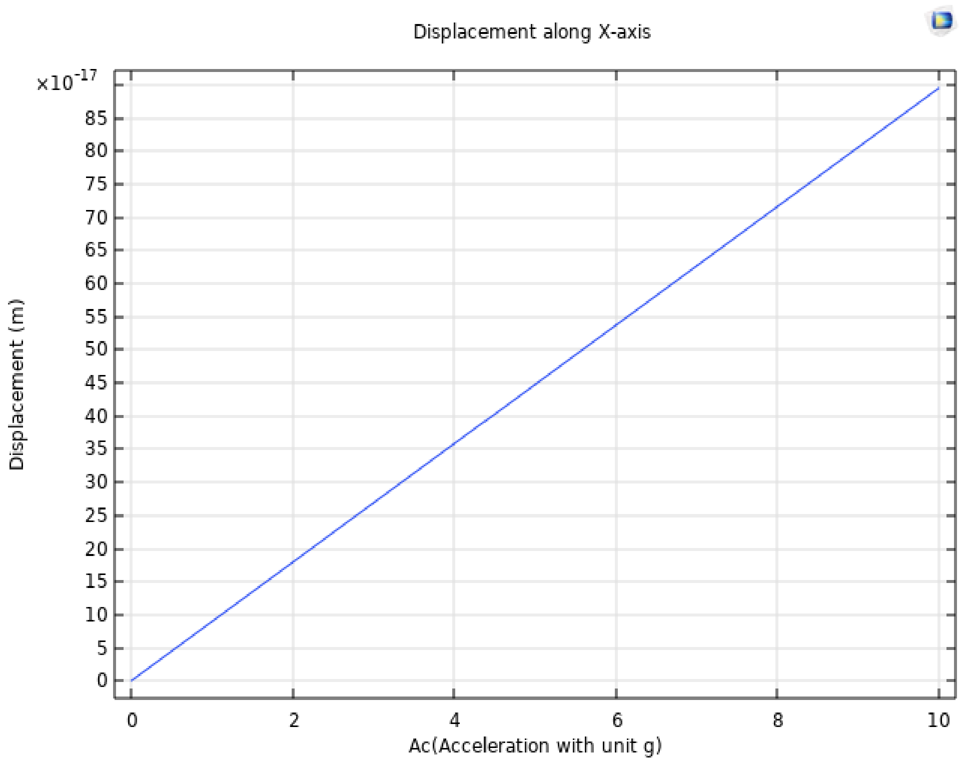

Figure 5: Result for acceleration in X-direction for the standard design

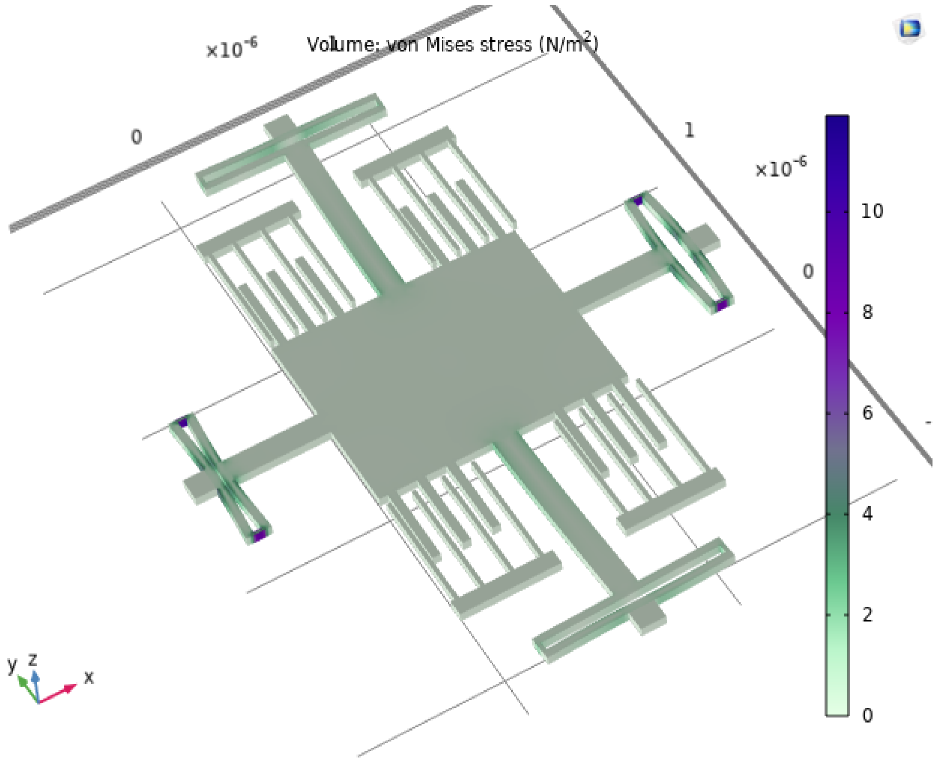

Figure 6: Stress stimulation along X-axis

Acceleration along Y-axis

Significant findings and plots for **Y-axis** is shown in Figure 7, Figure 8 and Figure 9. Figure 7 and Figure 8 gives the displacement plot along the Y-axis direction and the plot for the same. Here we can see that the displacement is linearly varying with the acceleration along the Y-axis. We are almost getting the similar result as done in the research paper.

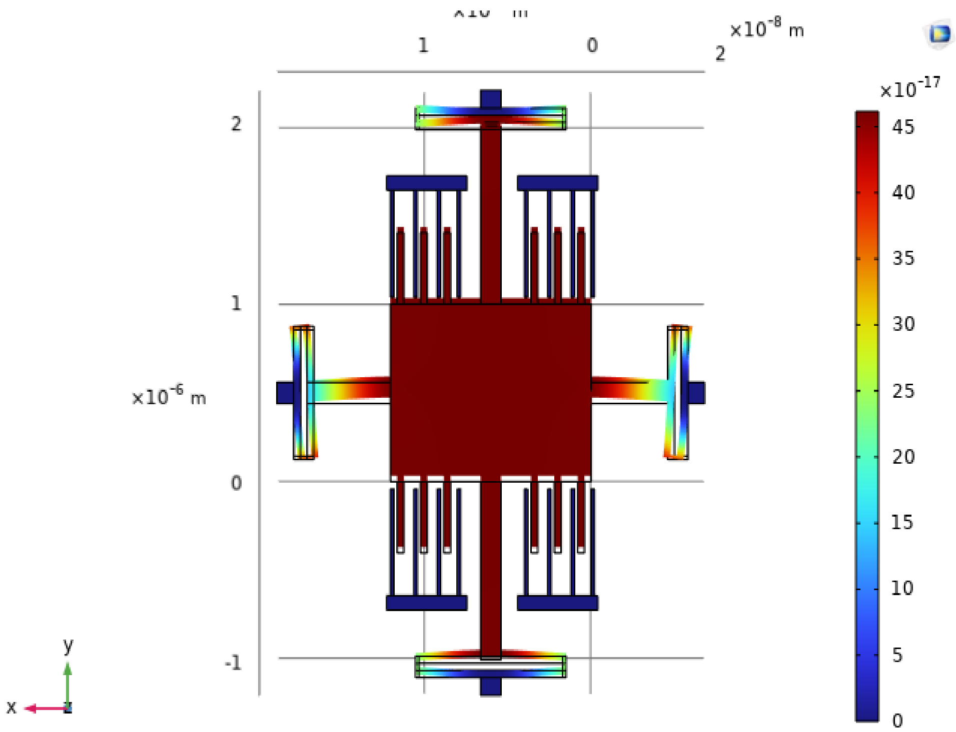

Figure 7: Displacement plot along Y-axis

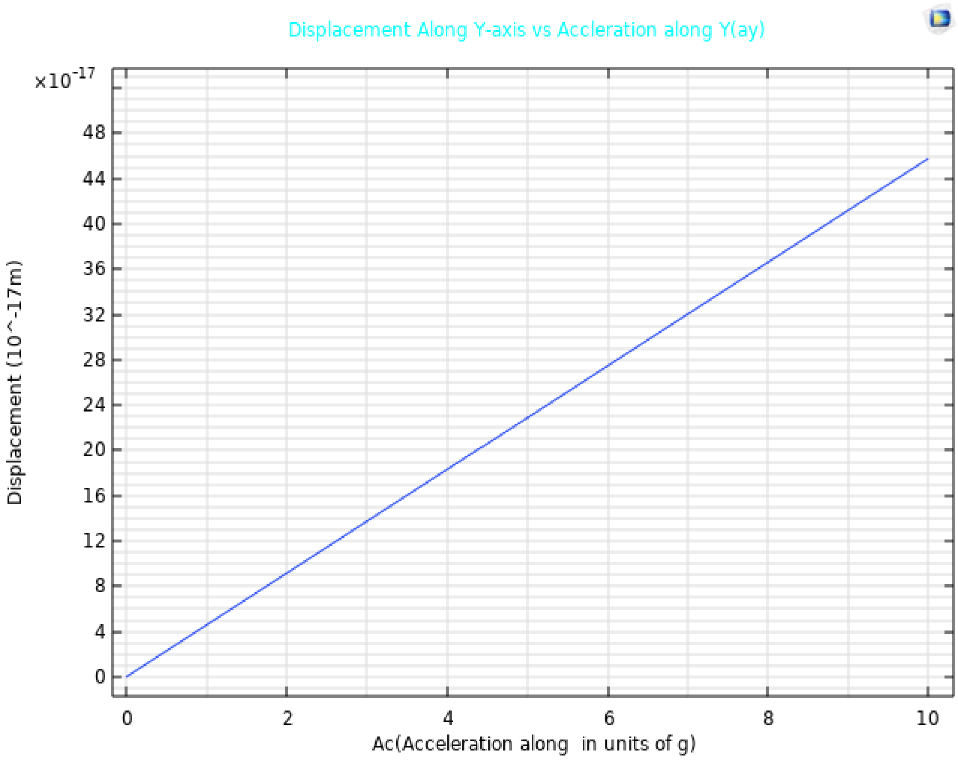

Figure 8: Result for acceleration in Y-direction for the standard design

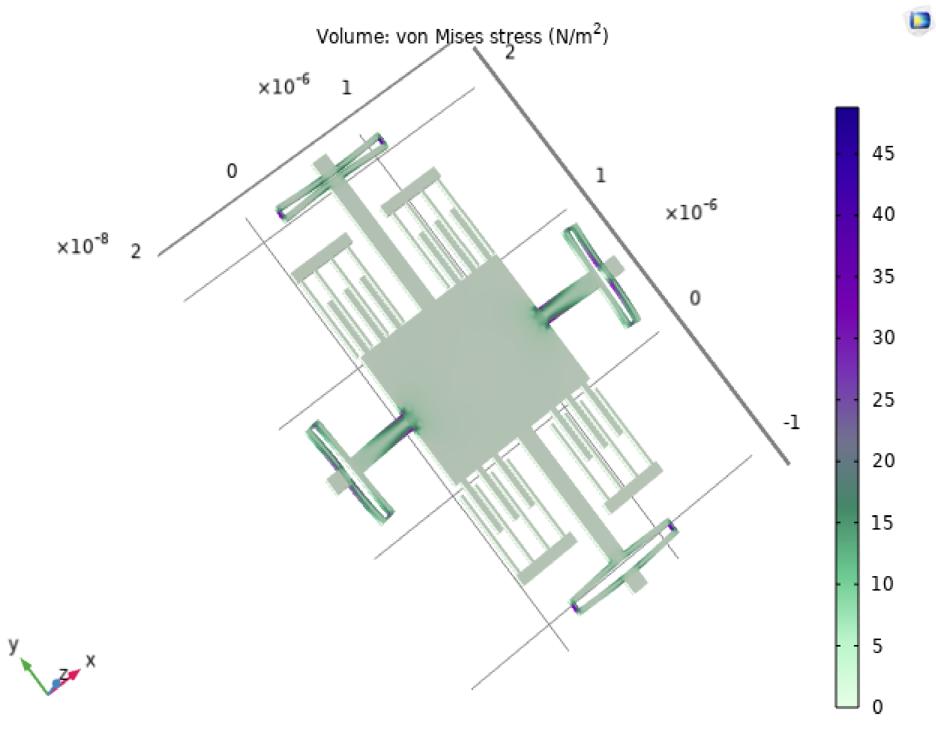

Figure 9: Stress stimulation along Y-axis

Novalty

In the research paper we refer they had only done the displacement and stress analysis for 2-axis i.e., for **(X and Y axis)** MEMS capacitor accelerometer. But we tried the displacement and stress analysis for the same design with some adjustments in the thickness i.e., increase from 40 to 160 nm in **z-axis**. Significant findings and plots for **Z-axis** is shown in Figure 10,

Figure 11 and Figure 12. Figure 10 and Figure 11 gives the displacement plot along the Z-axis direction and the plot for the same. Here we can see that the displacement is linearly varying with the acceleration same as in case like X-axis and y-axis direction.

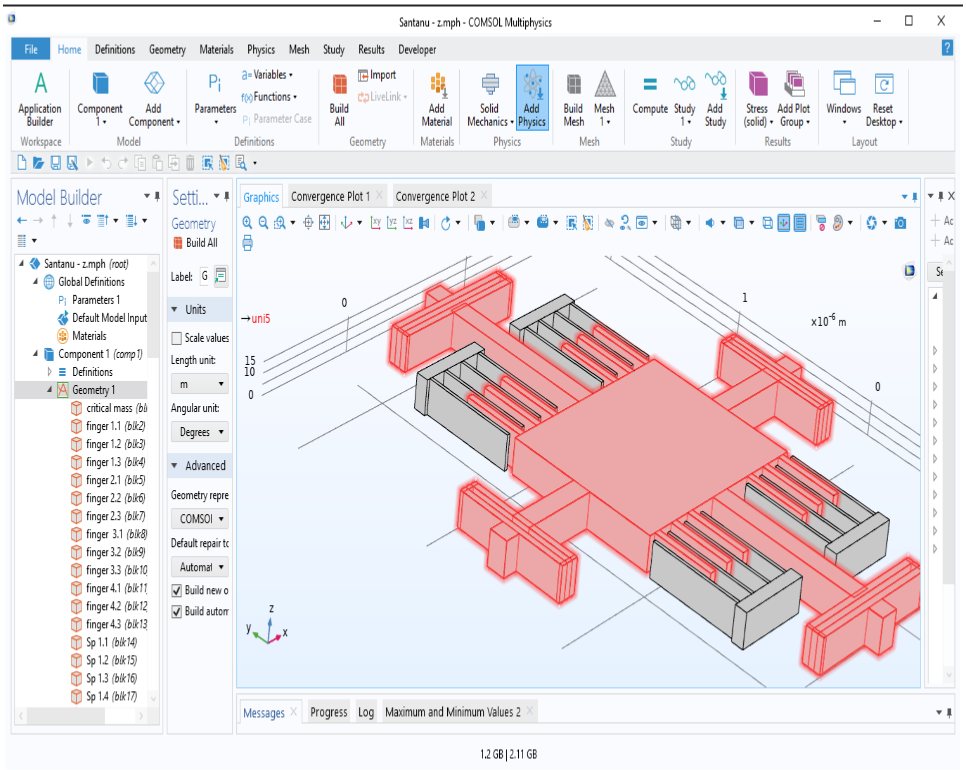

Figure 10: Thickness Increased to 160nm

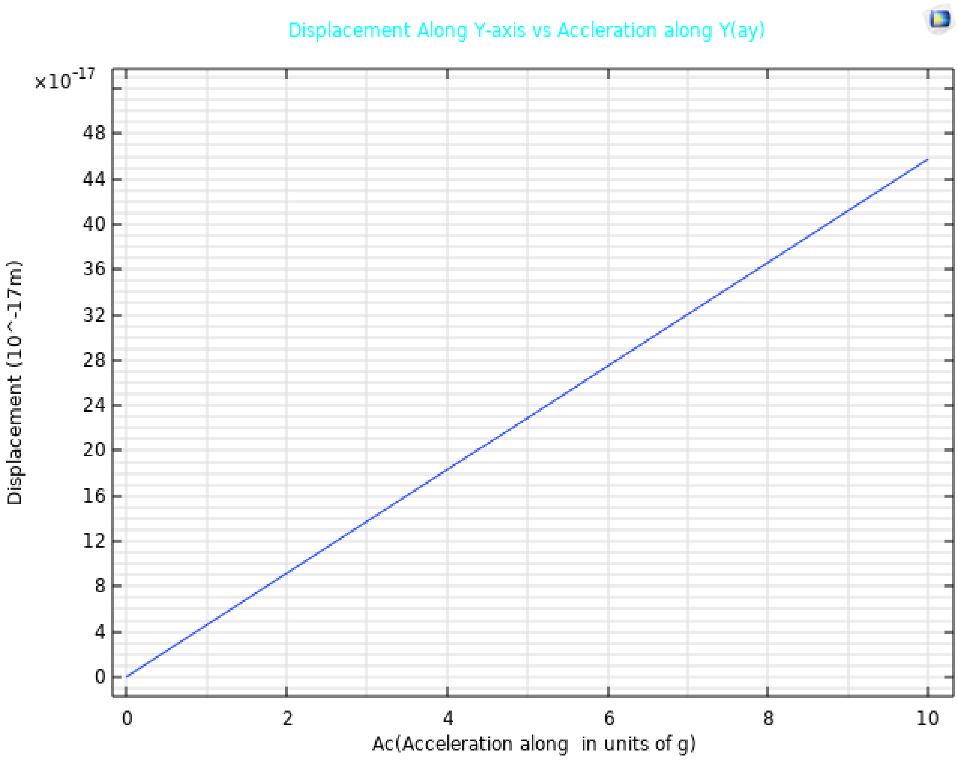

Figure 11: Result for acceleration in Z-direction for thickness increased to 160

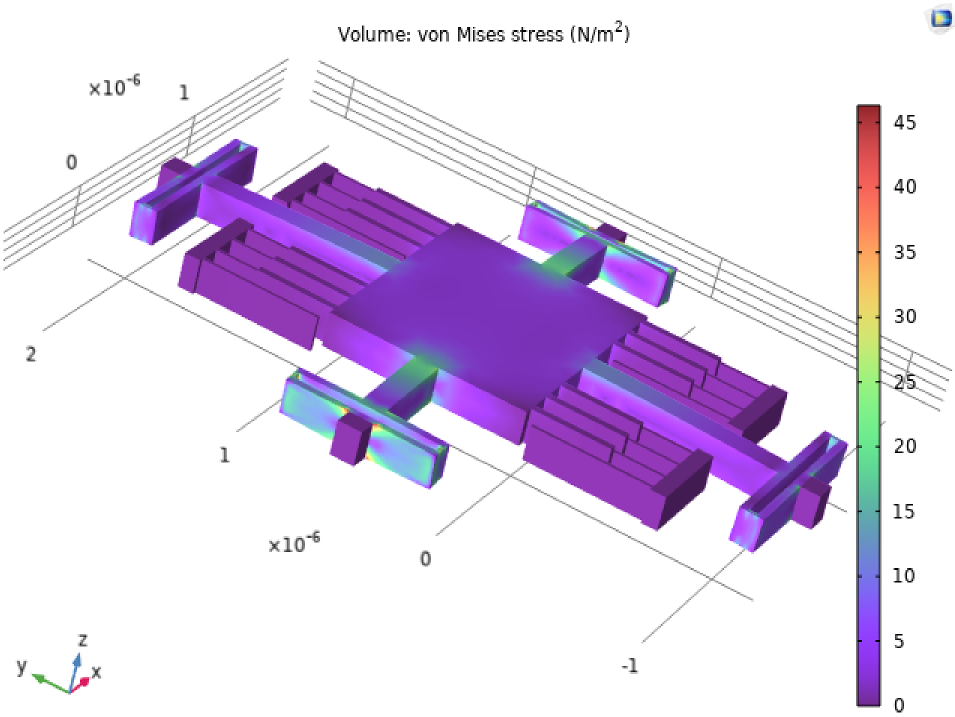

Figure 12: Stress stimulation along Z-axis

Conculsion

The result obtained in the research paper and that which are simulated by us are similar (are of same order femtometer, fm) for X-axis and Y-axis acceleration. From the graph, we can see that the displacement linearly varies with acceleration. Acceleration is measured based on the change in overlapping between capacitive plates, and the thickness mentioned in the design is 40 nm, which is small compared to the Z-axis displacements observed for a small range of accelerations. Due to the low thickness, just after a small range of accelerations, we observe that the displacements of the system (proof mass) are so large that there is no overlapping between the capacitive plates. As a result, the range of accelerations along the Z-axis that is measured is low compared to the ranges of accelerations along the X-axis and Y-axis. To increase the range of accelerations that can be measured along the Z-axis, we increased the thickness from 40 nm to 160 nm. After doing this, the range of acceleration is observed to be comparable with that of X-axis and Y-axis acceleration ranges.

Contribution

Design and stimulation analysis of displacement and stress along x-axis and z-axis is done by Thouti Ruthik Goud - 20288.
Design and stimulation analysis of displacement and stress along y-axis and latex report is done by Vimaleswar - 20305.
Powerpoint presentation is done by both.

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