Group - I
MSA Project Report

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Problem Statement: -

Design of MEMS based capacitive accelerometer and its implementation in 3-axis using COMSOL Multiphysics.

Motivation: -

We are using capacitive accelerometers because of the following factors: -

- Higher sensitivity
- Less prone to noise
- Low power consumption
- Excellent Stability

Introduction: -

Accelerometer is an electromechanical device that measures change in velocity or force of acceleration caused by gravity or movement over time.

Most of them are Micro-Electro-Mechanical-Sensors (MEMS) devices.

Most commonly used capacitive sensing accelerometers have an edge over the piezoresistive accelerometers in terms of less power, less temperature sensitivity and lower fundamental noise.

This model performs an analysis of a hypothetical sensor design using the electromechanical interface of COMSOL.

We'll be using COMSOL Multiphysics tool.

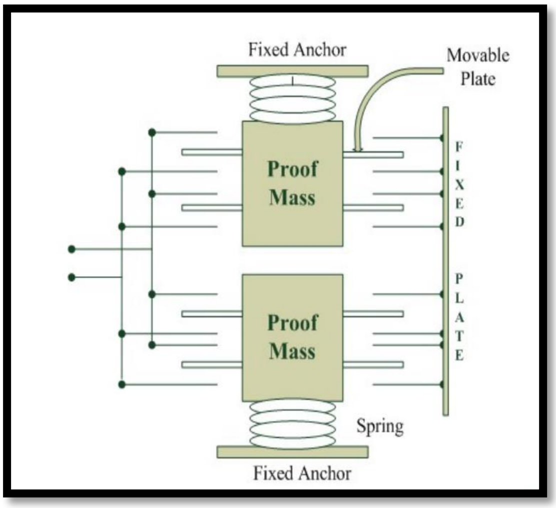
Working Principle: -

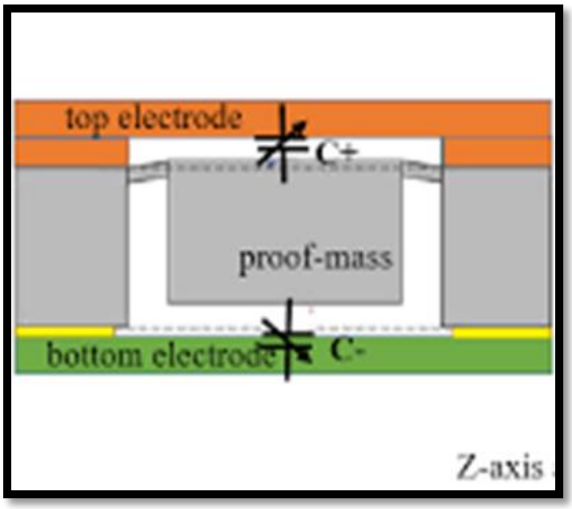
The main principle behind the project is that external acceleration displaces the Proof Mass to support frame which increases the stress in the suspension springs.

Measure of the external acceleration: -

- Relative displacement - change in capacitance between the electrodes.
- Suspension beam stress

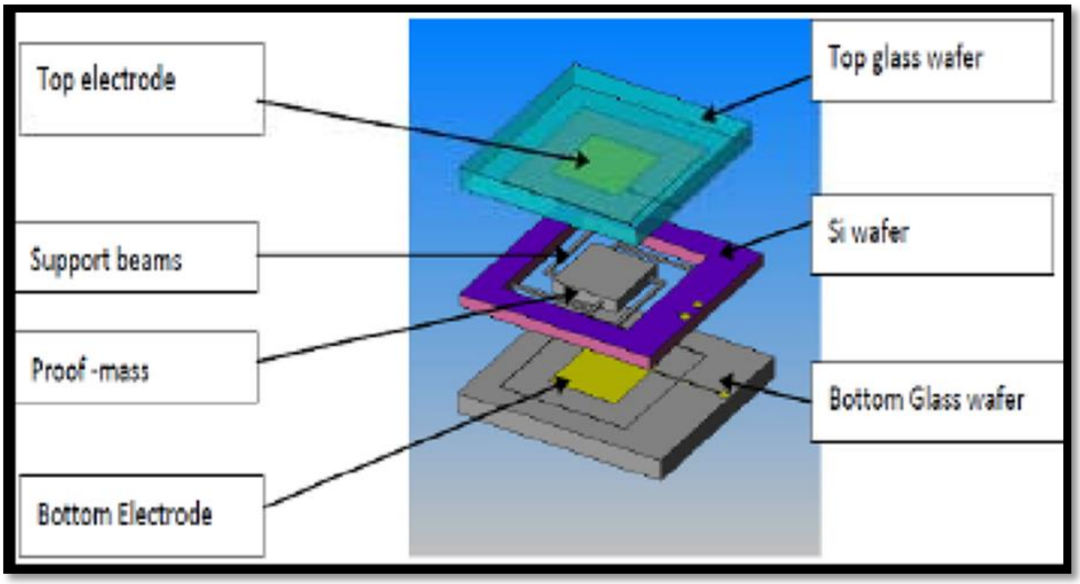
When acceleration is applied, the proof mass moves accordingly which changes the distance between capacitive plates. The voltage sensed due to capacitance is used to sense the acceleration.



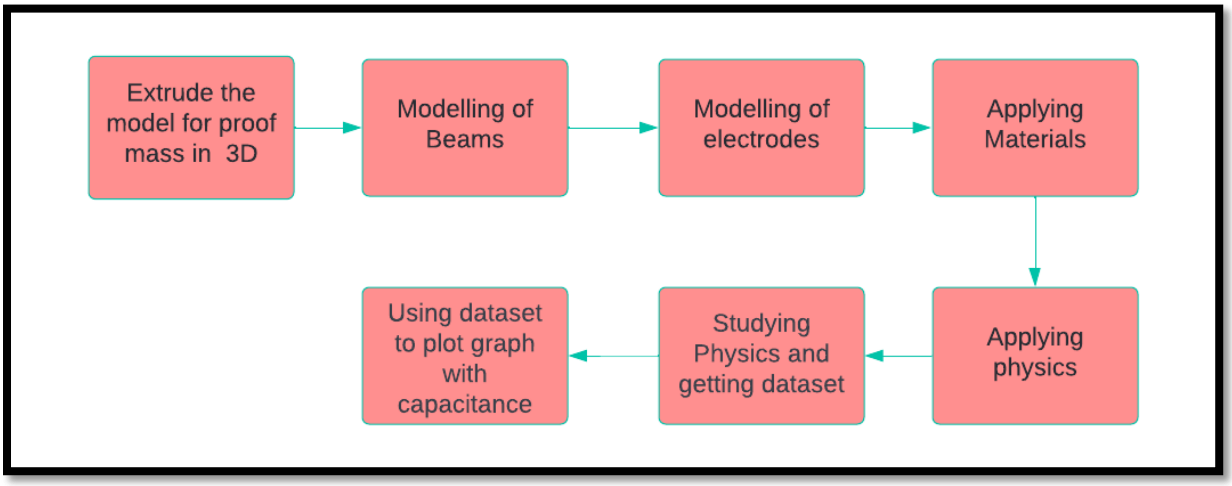


The 3-axis capacitive accelerometer is constructed using surface micro-machining process.

The z-axis acceleration is measured using a different arrangement.



Working Diagram

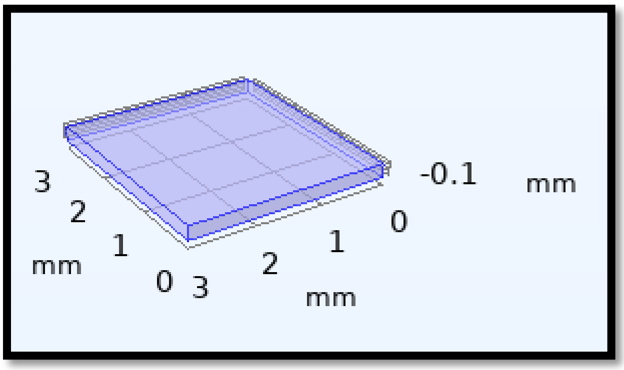


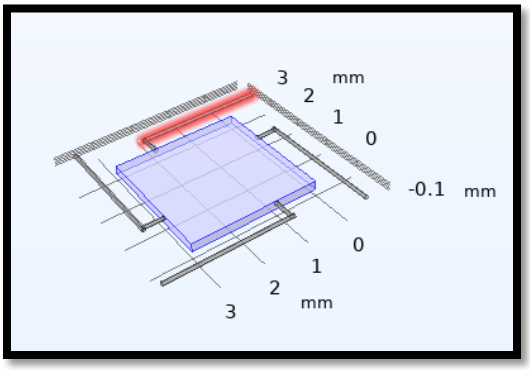
<u>Implementation in COMSOL Multiphysics: -</u>

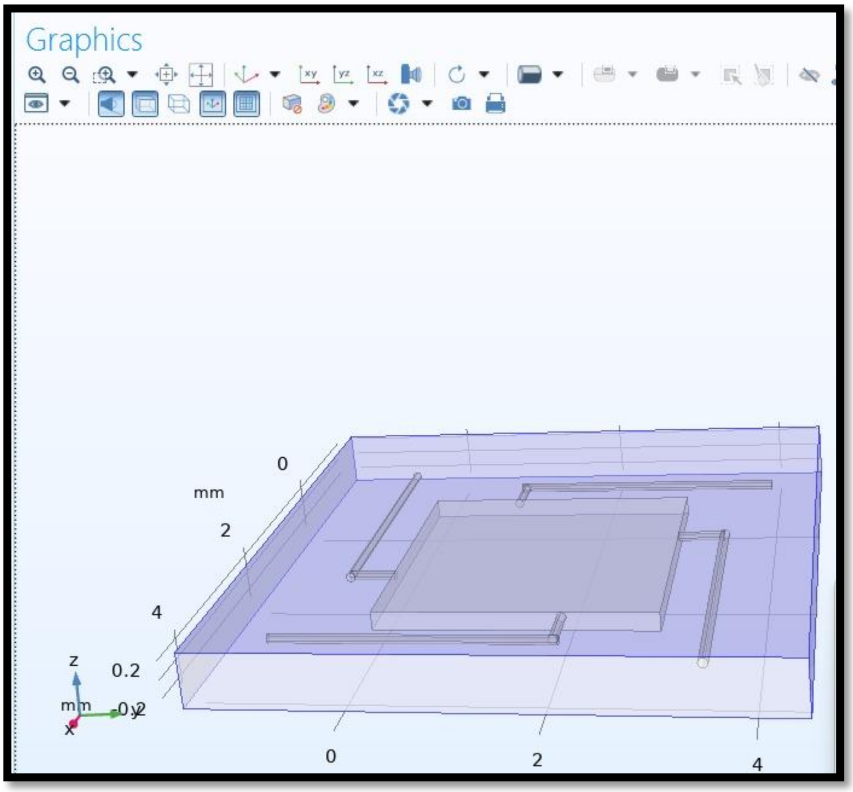
COMSOL software is based on advanced numerical methods for modelling and simulation.

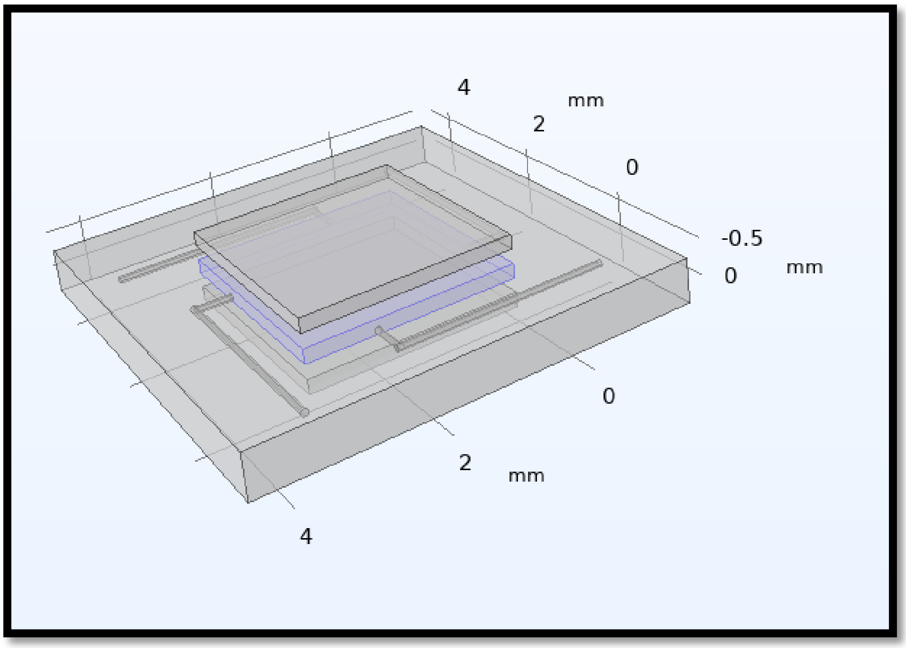
By using required materials, the study is added with the feature of powerful meshing and the model is tested for the applied force using plot annotations.

STEP 1: - Constructing geometrical shapes as shown below.

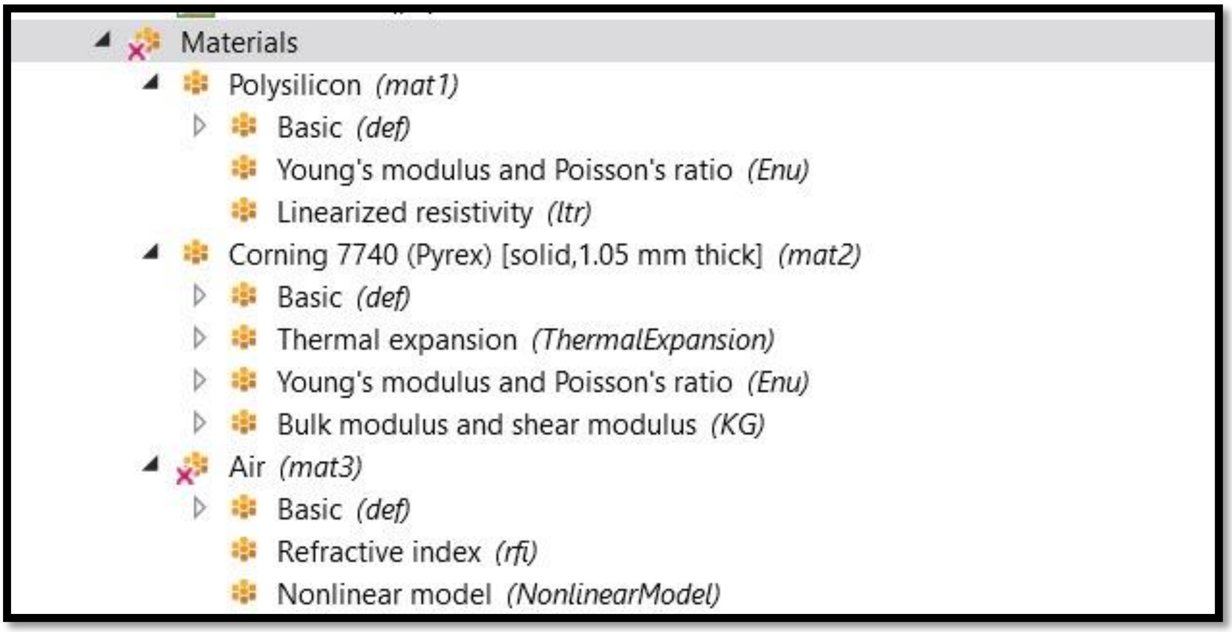




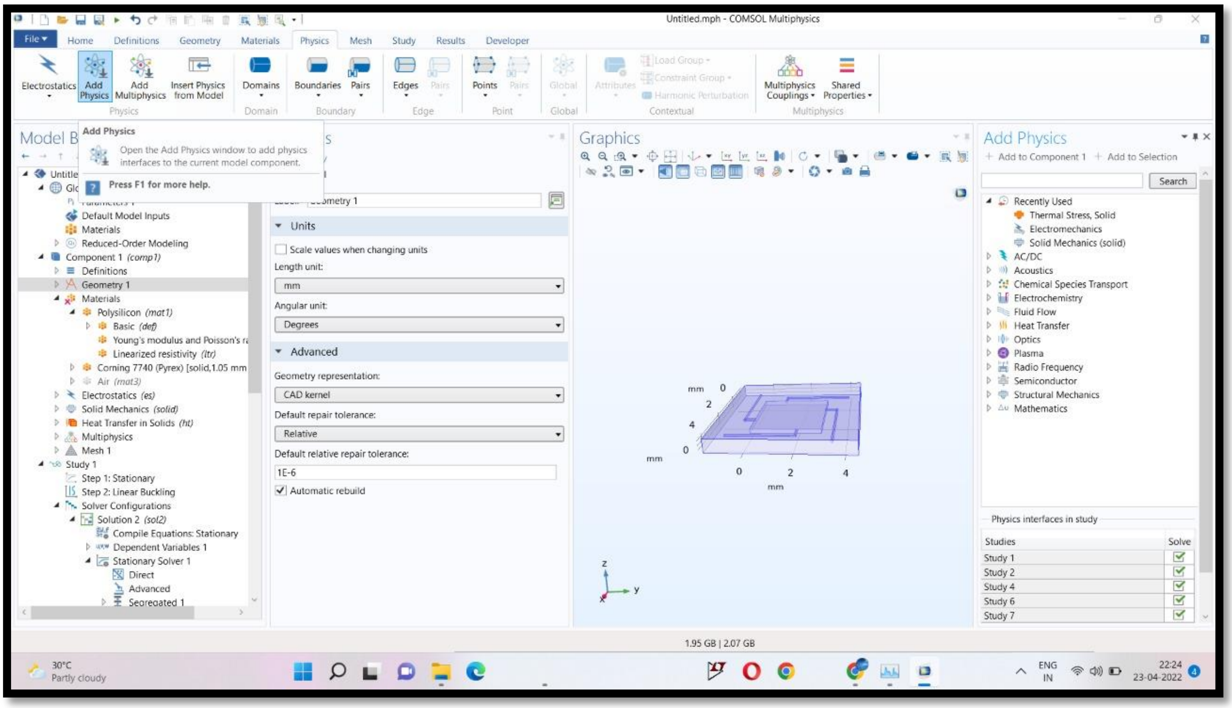




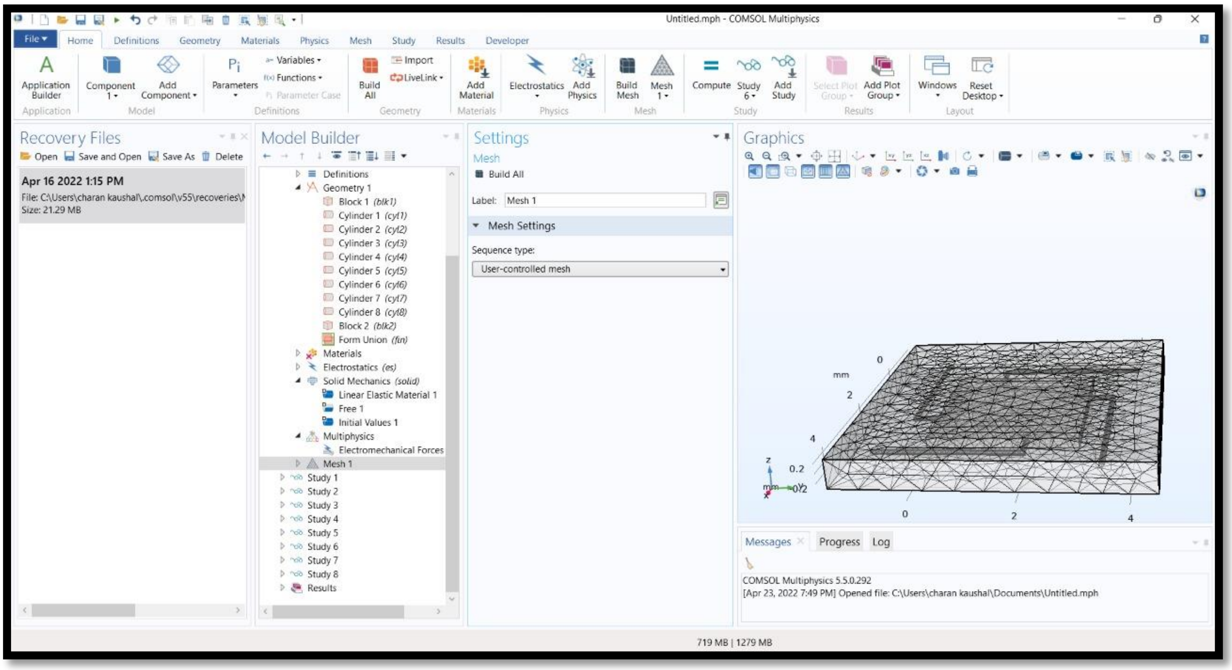
STEP 2: - The material that we want to use is selected for the model.



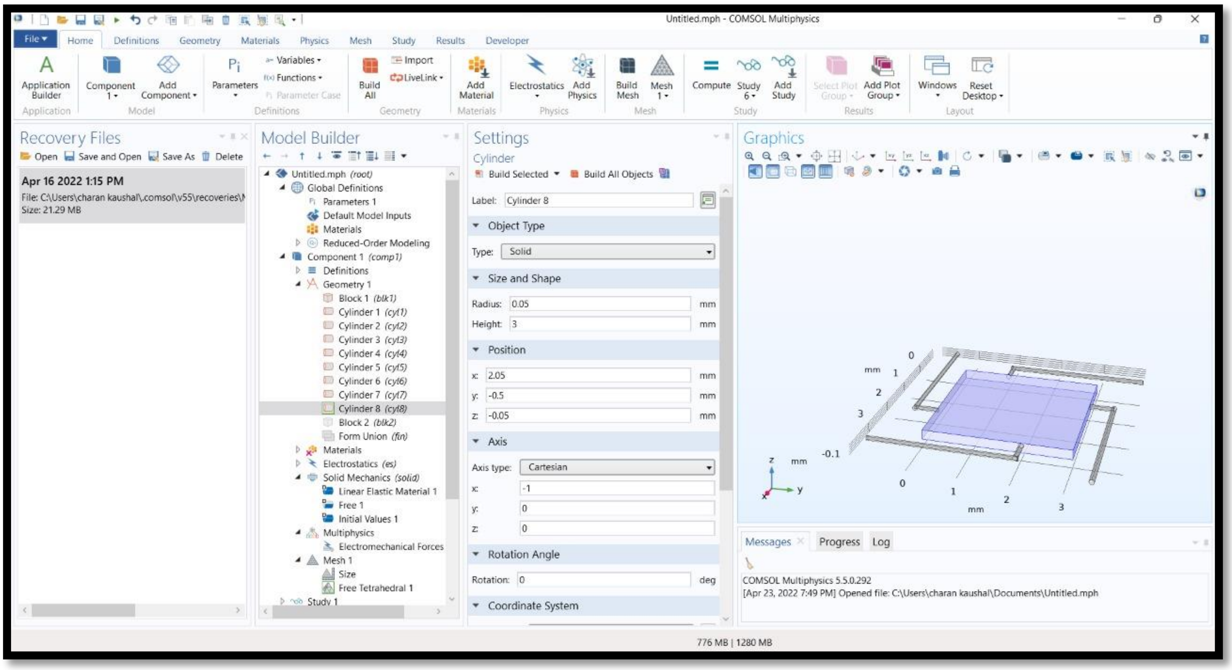
STEP 3: - The physics for the model is selected.



STEP 4: - Meshing is carried out and solution for the model is found.

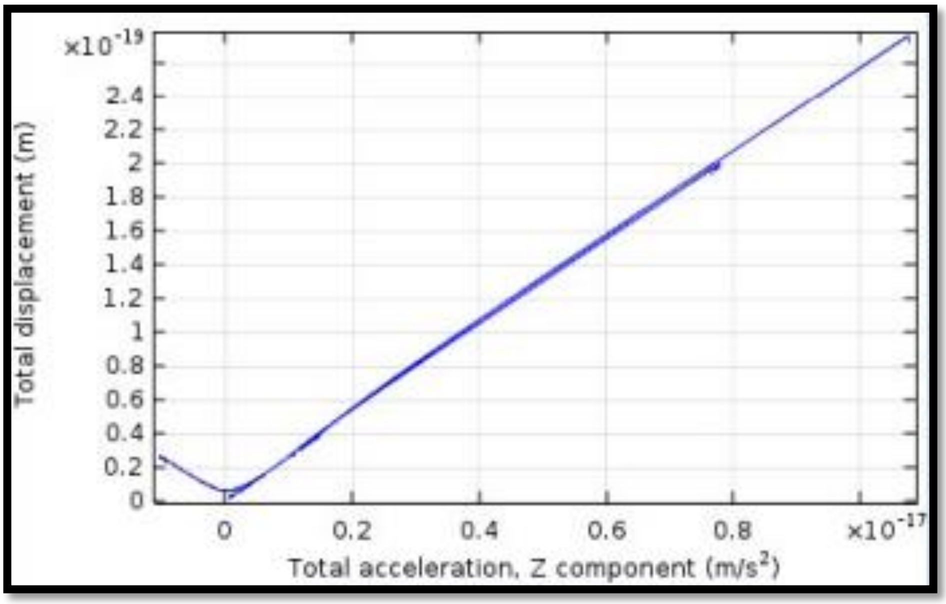


STEP 5: - Displacement of proof mass is studied.

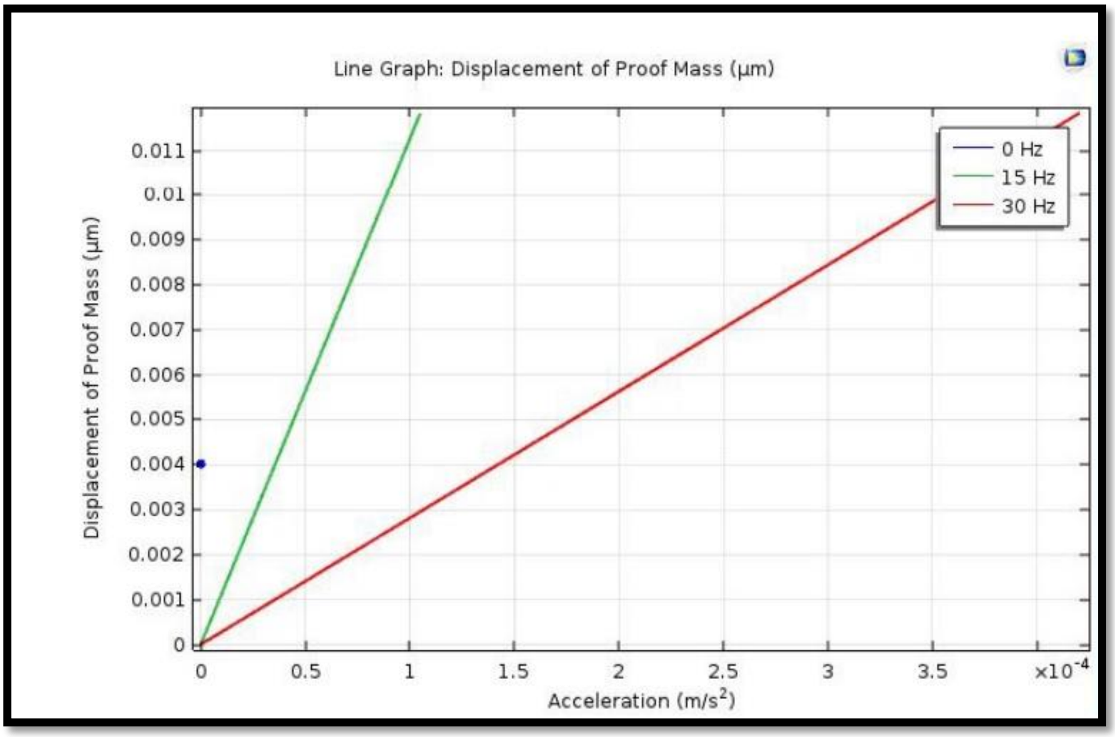


STEP 6: - Proof mass is designed for displacement in X-Y directions.

Analysis and Results: -



Displacement vs Acceleration in Z-direction



Acceleration is linearly proportional to displacement

Calculations involved: -

- If we consider, proof-mass length $\rightarrow l_1$, width $\rightarrow b_1$, thickness $\rightarrow h_1$ | Beam length $\rightarrow l_2$, width $\rightarrow b_2$, thickness $\rightarrow h_2$

Proof mass size :- $(l_1 \times b_1 \times h_1) = 10 \times 10 \times 2\ (\mu m)^3$

$l_2 = 4.5\mu m$; $b_2 = 1\mu m$; $h_2 = 1\mu m$; Airgap $= 22\mu m$

Area of proof-mass :- $l_1 \times b_1 = 100 \times 10^{-12} m^2$

Mass of proof-mass :- $m = V\rho = (A^{*}h_1)\rho$

$= 23 \times 10^{-14}$ kg

Let, F be the acting Force on the proof mass,

$F = ma = 23 \times 10^{-14} \times 9.8$

$= 225.63 \times 10^{-14}$ N

For each beam, $w = \frac{F}{4} = 56.4 \times 10^{-14}$ N

$I = \frac{b_2 h_2^3}{12} = 0.0833 \times 10^{-48}\ m^4$

$\delta_1 = \frac{w l_2^3}{12EI}$; $\delta_2 = \frac{w l_3^3}{12EI}$

$\delta = \delta_1 + \delta_2 = \frac{w}{12EI}(l_2^3 + l_3^3) = 0.0000072169627\ m/g.$

Bending stress :- $\sigma = \frac{M}{I} y$

Capacitance :- $C_0 = \frac{\epsilon_r \epsilon_0 a}{d}$ $(\because \epsilon_0 = 8.85 \times 10^{-2}\ F/m)$

$C_1 = \frac{\epsilon_r \epsilon_0 a}{d + \delta} = 36.26217 \times 10^{-9}$ pF

$C_2 = \frac{\epsilon_r \epsilon_0 a}{d - \delta} = 45.16597 \times 10^{-9}$ pF

$\Delta C = C_2 - C_1 = 8.9038 \times 10^{-9}$ pF

Applications: -

- Airbags Control, Crash Detection, Navigation, GPS with E-compass.
- Freefall Detection, Image Stabilization, Screen Rotation.
- Pacemaker.

Conclusion: -

- First, we studied about various types of accelerometers and the various materials required in its designing are studied thoroughly.
- A 3-axis MEMS capacitive accelerometer is implemented in COMSOL Multiphysics where we are applying the force in the z-direction.
- The results can be used to calculate change in distance between the capacitive plates with respect to change in capacitance.

Contribution: -

- Subash J – Model Design and Simulation
- Jnaneswar S– Model Design and Simulation
- Sai Sriram – Analysis and Results
- Charan Kaushal – Understanding Theory and Report

References: -

Neuzil, P., Yong Liu, Han-Hua Feng and Wenjiang Zeng (2005). Mi-cromachined bolometer with single-crystal silicon diode as temperaturesensor. IEEE Electron Device Letters, 26(5), pp.320-322.

N, D., V, J. and Kumar B, R. (2015). Design and Simulation of MEMSAccelerometer Using COMSOL Multiphysics Software. International Journal of Engineering Trends and Technology, 20(5), pp.244-247.

A. Jadhav, T. Agarkar and S. Kodagali, ”Advanced real time high performance time based 3 axis capacitive accelerometer”, International Conference by ISTE, ISBN. 978-93-86171-02-3, 2017.

Matsumoto, Y., Iwakiri, M., Tanaka, H., Ishida, M. and Nakamura, T.(1996). A capacitive accelerometer using SDB-SOI structure. Sensors and Actuators A: Physical, 53(1-3), pp.267-272.

MacDonald, G. (1990). A review of low cost accelerometers for vehicledynamics. Sensors and Actuators A: Physical, 21(1-3), pp.303-307.

Chen, H., Bao, M., Zhu, H. and Shen, S. (1997). A piezoresistive ac-celerometer with a novel vertical beam structure. Sensors and Actuators A: Physical, 63(1), pp.19-25.

Kavitha, S., Joseph Daniel, R. and Sumangala, K. (2016). Design andAnalysis of MEMS Comb Drive Capacitive Accelerometer for SHMand Seismic Applications. Measurement, 93, pp.327-339.