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Modeling and Simulation of Capacitive MEMSComb Accelerometer for sensitivity improvement with different Proof Mass Patterns

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Abstract*: This Paper presents the sensitivity of a design for three dimensional comb type beam structure based accelerometer. Initially the basic comb accelerometer is developed and displacement sensitivity is observed by modeling and simulation. It is observed that accelerometer sensitivity is improved through the optimum selection of parameters via number of fingers, beam length, beam width, mass width, , spring constant. The movable proof mass is connected to two anchors. The movable fingers are connected to the two sides of the proof mass. Every movable finger consists of two fixed fingers are connected to the left and right respectively. Any acceleration along the direction on movable mass, it will induce the inertial force and deflect the beam. Hence the capacitance will performed in between fixed and movable fingers. By changing the parameters like fingers width, number of fingers, proof mass shape, and spring constant the displacement is changed .By adjusting these parameters corresponding sensitivity can be improved.

Keywords: Capacitive Accelerometer, COMSOL Multiphysics, Deformation, Displacement, Sensitivity.

I. INTRODUCTION

An Accelerometer is a mechanical sensor which measures acceleration due to gravity or physical motion. Generally accelerometers are used in two purposes –motion measurements and vibration measurements. MEMS accelerometer can be manufactured to sense single-axis, double-axis, triple-axis acceleration. Micro Electro Mechanical Systems (MEMS) have lot of advantages in terms of weight , reduced cost, volume . A single proof mass is used to sense acceleration in all the directions to reduce the size and improve the performance . Zakriya Mohammeda.et.al. [1] has reported the high sensitivity with the chip dimension of 1.8mm x 1.8mm. Behraad Behreyni et.al.[2] have reported the displacement with the device structure consisted of a proof mass with circular shape .

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Zakriya Mohammed et.al[3] have reported the sensitivity with the thickness of 30 µm..Khairun nisa Khamil et.al. [4] reported the sensitivity can be improved by adjusting the length of the beam and adding the number of fingers d.Lufeng Che[9] have reported the sensitivity and non linearity percentage of the device using ANSYS software. M. Benmessaoud et al[10] reported the sensitivity will increased with increase in distance between plates of capacitive accelerometer.

To improve the sensitivity, to change the below parameters:

1. The displacement of sensitivity is inversely proportional to the beam width. As the beam width decreases, the sensitivity will be increased.
2. The sensitivity is directly proportional to the beam length. As the beam length increases, the sensitivity will be increased.
3. The sensitivity will be increased, by increasing the spring constant.
4. The sensitivity will be increased, by increasing the finger length and width.

The basic parameters of the comb type capacitive accelerometer shows in below table1.The comb accelerometer having one rectangle proof mass with the two springs and both sides of movable and fixed electrodes. Every electrode is also rectangular shape. When an acceleration applied, the proof mass is displaced by ‘x ‘along the X,Y,Z axis.

II. DESIGN

The proof mass is considering two different shapes i.e Square and Rectangle, The shape of the Electrodes are rectangles. The Possibilities due to applied acceleration is

1. Acceleration applied in X-Axis
2. Acceleration applied in Y-Axis.
3. Acceleration applied in Z-Axis.

The comb drive capacitive accelerometer consists of any one shape of proof mass (square or rectangle) with integrated fingers. The fingers are acts like electrodes, the power supply +5V is applied to movable fingers and 0V is applied to stationary fingers. When the power supply is applied to the fingers the capacitance is formed. The acceleration +1g to +10g is applied on the proof mass from, the proof mass is displaced. The proof mass can be finding out by using below formulae [1].

$$M_S = \rho h(W_m.L_m + N_f.W_f.L_f)\text{.....(1)}$$

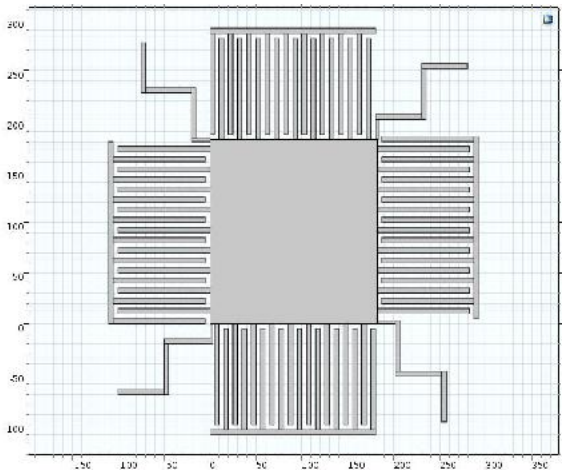
Where 'ρ' is the Density (2320kg/m3) of Poly-Crystalline Silicon material,
h is the device thickness.
With the considerations of all above equation values Proof mass is 7685x10^{-13}Kg.
The spring constant (K_s) is defined by using below formula

$$K_S = \frac{E.h.}{2.L_b^3} W_b^3 \text{.....(2)}$$

Where K_s is the Spring Constant, E is an Young's Modulus (1.60x10^{11}) for Poly-Crystalline Silicon.
For Rectangle proof mass model, the force ranges can be measured with respect to the acceleration from 1g to 10g and proof mass is 7685x10^{-13}Kg.
At 1g acceleration the force can be find out the multiplication of applied mass value and 9.8(1g).
At 2g acceleration the force can be find out the multiplication of applied mass value and 2x9.8(2g) etc.
The below table shows the Force values with respect to the acceleration.

I.Acceleration Vs Force

Acceleration(g)	Force(10^{-12}N)
1	753890
2	1507780
3	2261670
4	3015560
5	3769450
6	4523340
7	5277230
8	6031120
9	6785010
10	75389



(a)

(b)

Fig.1.Square and Rectangle Proof Mass

The given table shows the different parameter values for rectangle proof mass and square proof mass comb accelerometers.

II. Device Parameters

Parameters	Rectangle proof mass	Square proof mass
Capacitance gap (d_0)	5μm	5 μm
Device thickness (h)	5 μm	5 μm
Width of the mass (W_m)	475 μm	182 μm
Length of the mass (L_m)	70 μm	182 μm
Width of the beam (W_b)	10 μm	5 μm
Length of the beam (L_b)	290 μm	290 μm
Width of the Finger (W_f)	5 μm	5 μm
Length of the Finger (L_f)	100 μm	100 μm
Number of sensing fingers (N_f)	66	72
Young's modulus of poly-crystalline silicon	1.60x10^{11}	1.60x10^{11}
The density of poly-crystalline	2320kg/m^3	2320kg/m^3
Movable sensing mass (M_s)	7.69x 10^{-10}	8.01x10^{-10}
Spring constant (K_{total})	1.28x10^8	0.081x10^9
Proof Mass(M_s)	7685 x10^{-13}Kg	481 x10^{-12}Kg

Comb type accelerometer basically consists of two finger structures, called movable and fixed fingers. The fixed fingers attached to accelerometer frame and movable fingers attached to proof mass. When there is no acceleration ,the capacitance gap between each fixed and movable finger is d_0.When there is no acceleration,the accelerometer capacitance is The Capacitance is

$$\Delta C=C_1-C_2=2\,\varepsilon\frac{N_f L_f}{d_0}\,t\left(\frac{x}{d0}\right)=2C_0\left(\frac{x}{d0}\right)\text{.....(3)}$$

From the above equation we can see the small deflection

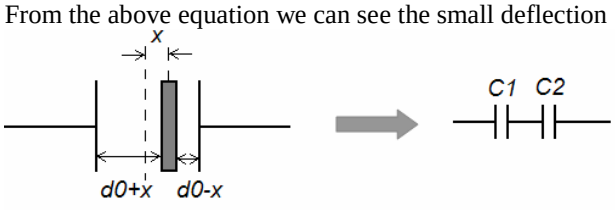


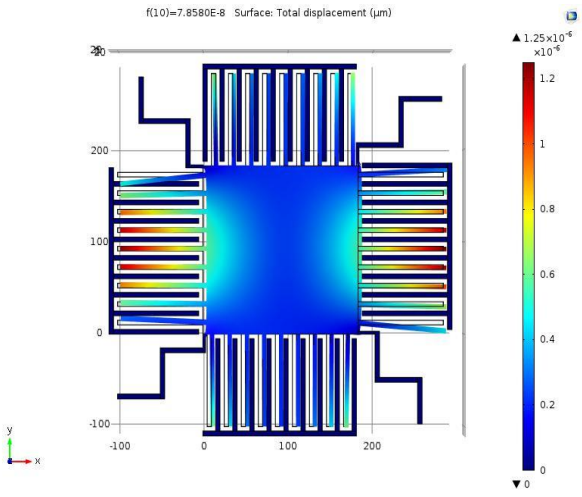
Fig.(2)Differential Capacitance of Accelerometer

III. RESULT

When an acceleration(1g to 10g) applied on top of the proof mass along x,y and z-axis ,the corresponding displacement is Shown in below Table2.

III. Acceleration Vs Displacement along X,Y,Z –Axis for Square proof mass.

Acceleration (g)	Displacement(μm)		
	X-axis	Y-axis	Z-axis
1	1.25e-7	1.25e-7	2.79e-6
2	2.49e-7	2.49e-7	5.58e-6
3	3.74e-7	3.74e-7	8.37e-6
4	4.99e-7	4.99e-7	1.12e-5
5	6.23e-7	6.23e-7	1.39e-5
6	7.48e-7	7.48e-7	1.67e-5
7	8.73e-7	8.73e-7	1.95e-5
8	9.97e-7	9.97e-7	2.23e-5
9	1.12e-6	1.12e-6	2.51e-5
10	1.25e-6	1.25e-6	2.79e-5



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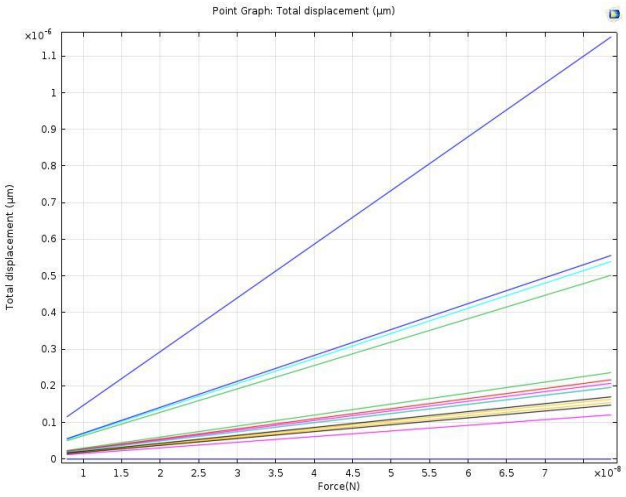

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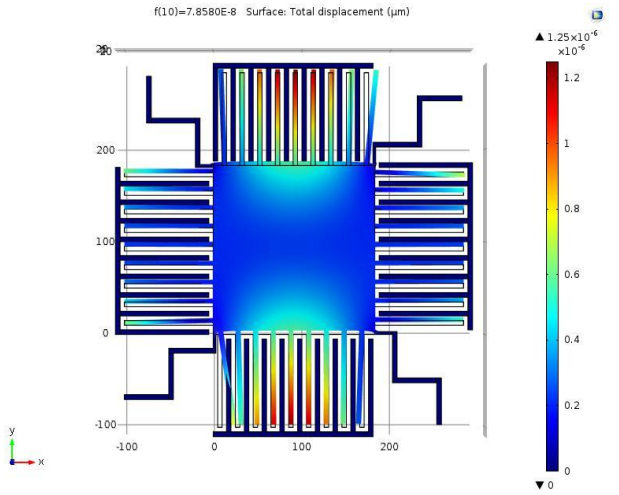
Fig.3 Force Vs Displacement of Square Proof Mass along X-Axis



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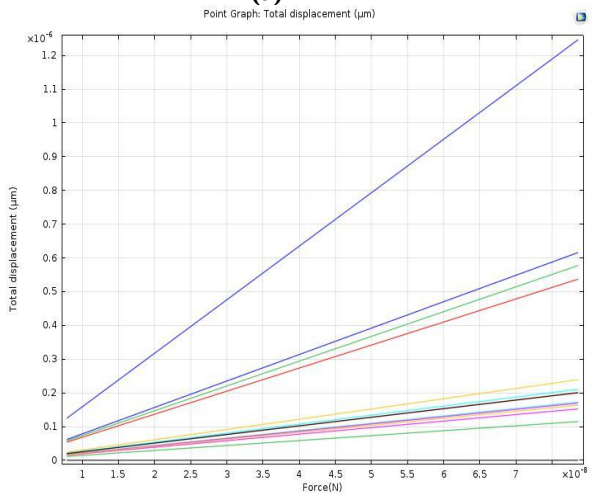

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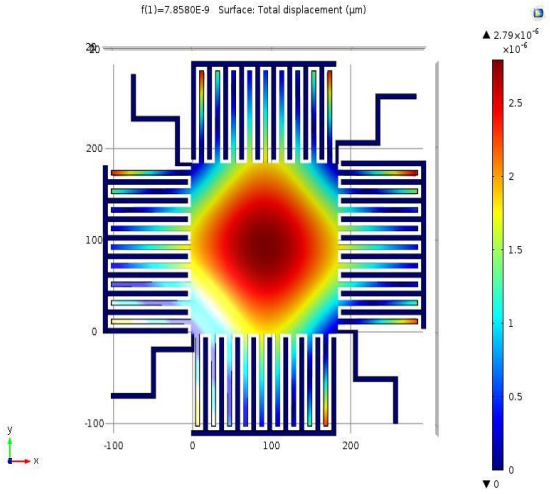
Fig.4 Force Vs Displacement of Square Proof Mass along Y-Axis



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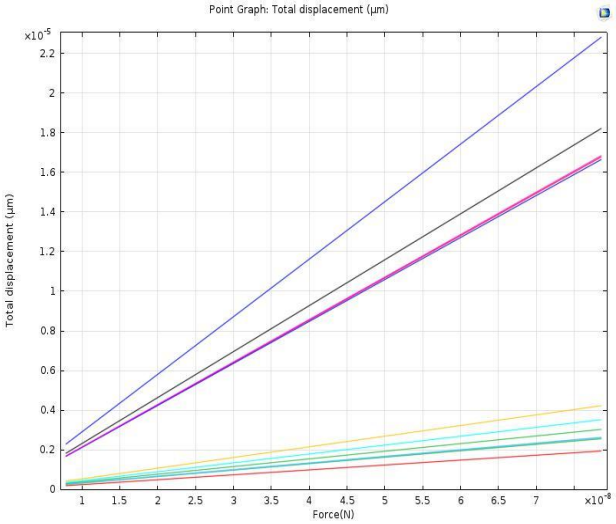

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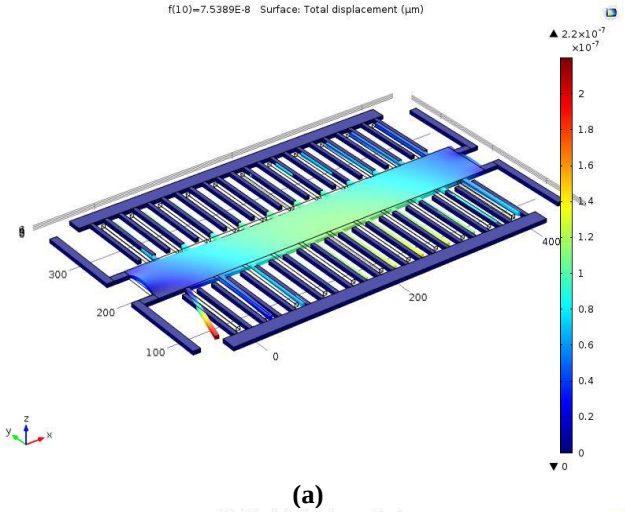
Fig.5 Force Vs Displacement of Square Proof Mass Along Z-Axis

Table III. Acceleration Vs Displacement of Square Proof Mass

Acceleration(g)	Displacement(µm)
1	2.79e-6
2	5.58e-6
3	8.37e-6
4	1.12e-5
5	1.39e-5
6	1.67e-5
7	1.95e-5
8	2.23e-5
9	2.51e-5
10	2.79e-5



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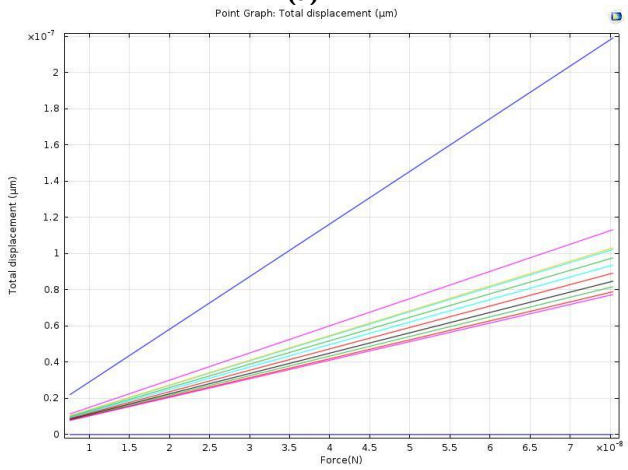

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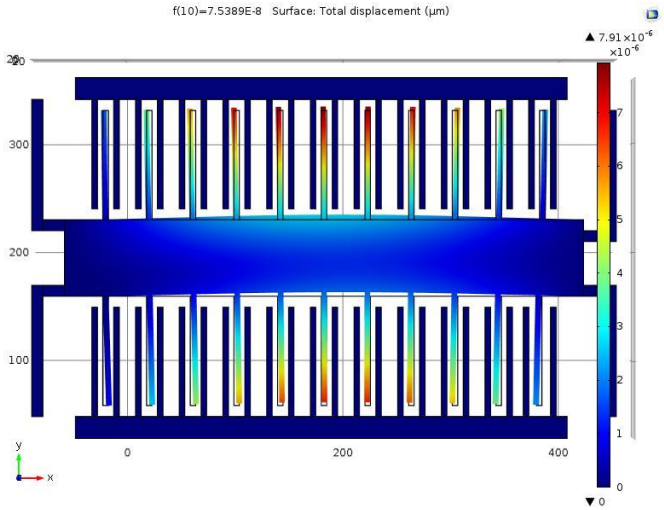
Fig.6. Force Vs Displacement of Rectangle Proof Mass Along X-Axis



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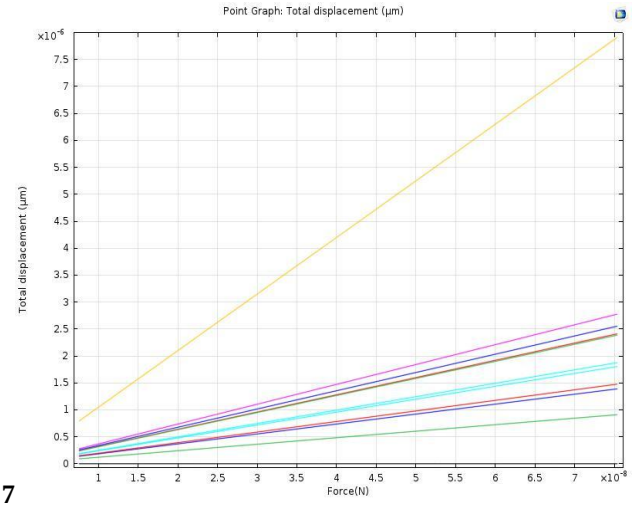

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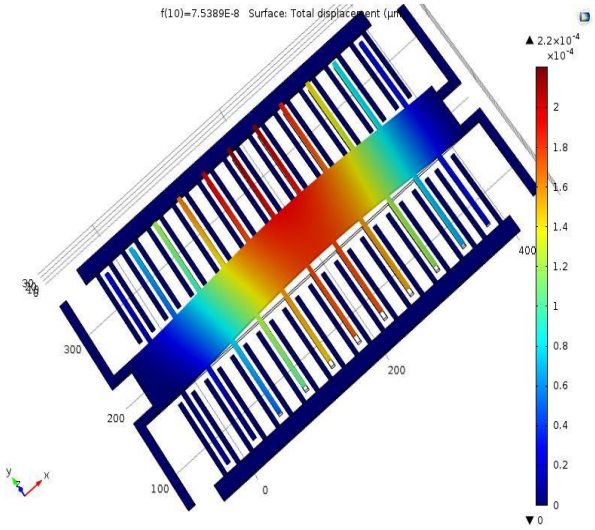
Fig.7 Force Vs Displacement of Rectangle Proof Mass Along Y-Axis



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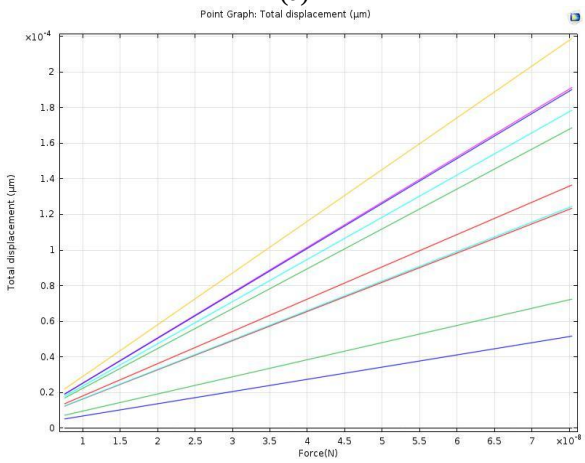

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Fig.8. Force Vs Displacement of rectangle Proof Mass Along Z-Axis

Table IV.Acceleration Vs Displacement along X, Y Z Axis For rectangle proof mass

Acceleration	Displacement(μm)		
(g)	X-axis	Y-axis	Z-axis
1	2.20E-08	7.91E-07	2.12E-05
2	4.39E-08	1.58E-06	4.24E-05
3	6.59E-08	2.37E-06	6.36E-05
4	8.78E-08	3.17E-06	8.48E-05
5	1.10E-07	3.96E-06	1.06E-04
6	1.32E-07	4.75E-06	1.27E-04
7	1.57E-07	5.54E-06	1.48E-04
8	1.76E-07	6.33E-06	1.70E-04
9	1.98E-07	7.12E-06	1.91E-04
10	2.20E-07	7.91E-06	2.2E-04

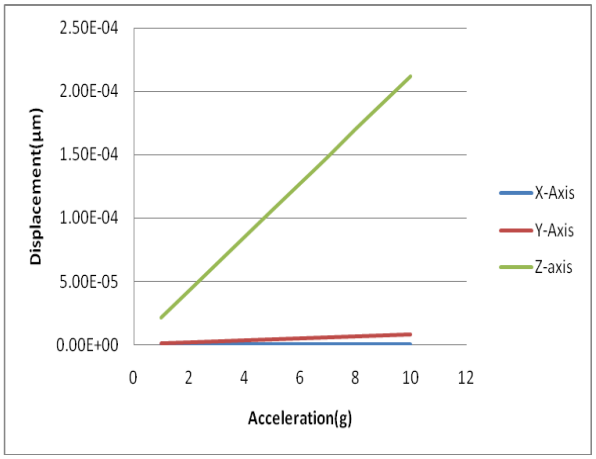

Fig.9.Acceleration Vs Displacement

The change in capacitance is represented in below Table 3.for square and rectangular proof mass along X,Y and Z-axis .

TableV.Capacitance for square and rectangle proof mass

Proof mass-Shape	CapacitanceΔC(nF)		
	X-Axis	Y-Axis	Z-Axis
Square	$6.49x10^{-14}$	$6.49x10^{-17}$	$7.43 x10^{-17}$
Rectangle	$9.33 x10^{-17}$	$6.7 x10^{-17}$	$1.4 x10^{-16}$

The sensitivity of Mechanical and Electrical has measured for square and rectangle proof mass.

Table VI.Mechanical Sensitivity and Electrical Sensitivity for square and rectangle proof mass

Proof mass-Shape	Mechanical Sensitivity(nm/g)	Electrical Sensitivity(nF/g)
Square	0.00275	$7.43 x10^{-17}$
Rectangle	0.022	$1.4 x10^{-16}$

The below graph represents the sensitivity for square and rectangle patterns. The square proof mass accelerometer mechanical sensitivity is 0.00275nm/g and Electrical sensitivity is $7.43 x10^{-17}$.The rectangle proof mass accelerometer electrical sensitivity is 0.022nm/g and Electrical Sensitivity is $1.4 x10^{-16}$.

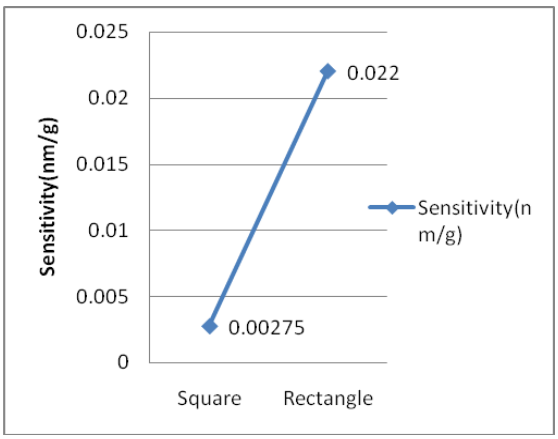

Fig.10. Acceleration Vs Displacement with width of the fingers 10 µm

IV. CONCLUSION

A comb type capacitive MEMS accelerometer has been designed and simulated under conditions of Square and Rectangle proof mass for the input acceleration from 1g to 10g,At 10g acceleration the displacement of proof mass is found increase. It is observed the rectangle sensitivity is high compare to square proof mass accelerometer.

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