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Comparison and Analysis of MEMS Electrostatic Comb Drive With Different Spring Designs Using Polysilicon and Copper As The Structural Material

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Abstract

Micro electromechanical Systems (MEMS) is a growing and evolving technology. It has led to a drastic development in the recent past. This paper presents the simulation of different MEMS electrostatic comb drives with different spring designs. The analysis of different MEMS electrostatic comb drives with polysilicon and copper as the structural material is shown in this paper with the help of comsol Multiphysics 4.4. It offers Finite element analysis to prove the concept of displacement of movable comb fingers, achieved by the amount of electrostatic force applied between the comb fingers. The performance of the different comb drives are compared in terms of displacement and capacitance when a potential of 55V is applied. An enhanced displacement and capacitance is observed in the structure made up of copper.

Keywords: MEMS; Electrostatic comb drive; Polysilicon; Finite element analysis; Electrostatic force.

Introduction

MEMS technology was developed in the late 1980’s. Since then research and development is going on in every aspect. It is the technology of miniaturizing devices at micro level. MEMS usually consist of sensors and actuators at micro level, it consist of both mechanical as well as electrical properties [1]. The actuator is operated by a source of electrical energy that converts the energy into motion. It is used for the transformation of a non-mechanical input energy into mechanical output energy. Different types of mechanisms are used in MEMS technology for actuation like electrostatic actuation, thermal actuation and piezoelectric actuation. Among the different types of actuations, electrostatic actuation is one of the most common force generation mechanism. This comb drives are fabricated by the process of micro fabrication. It uses both electrostatic energy from a DC voltage applied between the fixed and moving comb structures.

Whenever a potential is applied between the comb structures, due to the phenomena of electrostatics a displacement of the movable comb fingers is observed towards the fixed comb. This displacement of the movable comb fingers is controlled by a balance between the electrostatic force and the mechanical restoring force of the spring suspension. This mechanical force are generated through the spring suspension and therefore, depends upon the stiffness of the spring suspension. Comb drive actuators can be used for measurement of large displacement at low driving voltage. Comb dive actuators are used in micro-gripper, resonators and vibrometers to measure the number of vibrations [2]. In the present work, different types of spring designs are used to analyze and compare MEMS electrostatic comb drives using polysilicon and copper as the structural material.

Structural Design of An Electrostatic Comb Drive

Electrostatic comb drive is basically a capacitive actuator which utilizes the phenomena of electrostatics and has a comb like structure, this is why it is known as electrostatic comb drive. The basic design of an electrostatic comb drive is shown in Figure.1.

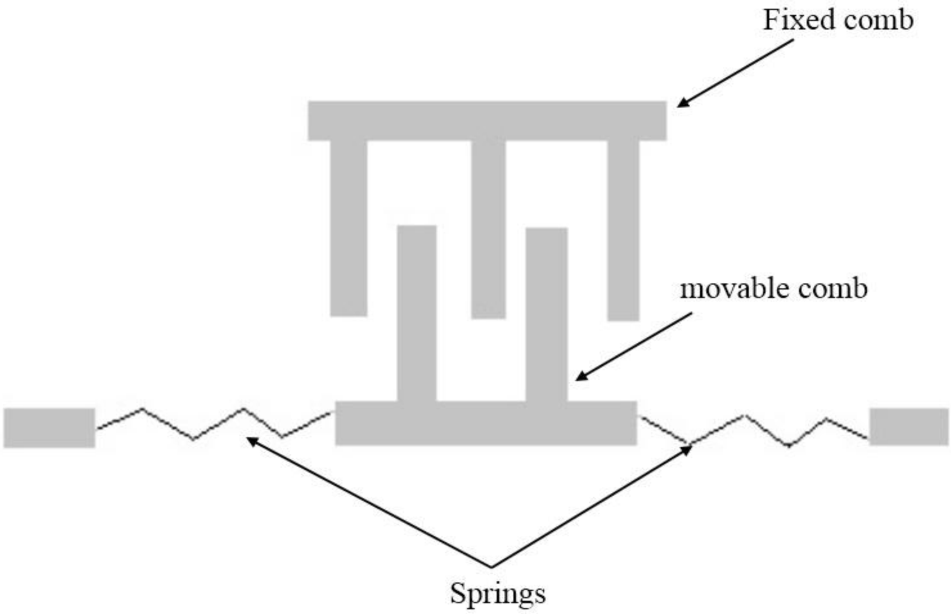

Figure 1: Basic design of a comb drive

Here, the movable comb is attached to the suspended spring structure. When a potential difference is applied between the comb structures the movable comb tends to move towards the fixed comb due to the phenomena of electrostatics. While designing a comb drive some basic parameters should be kept in mind. The basic parameters to design an electrostatic comb deals with the structure and dimensions of the comb drive which is shown in figure.2.

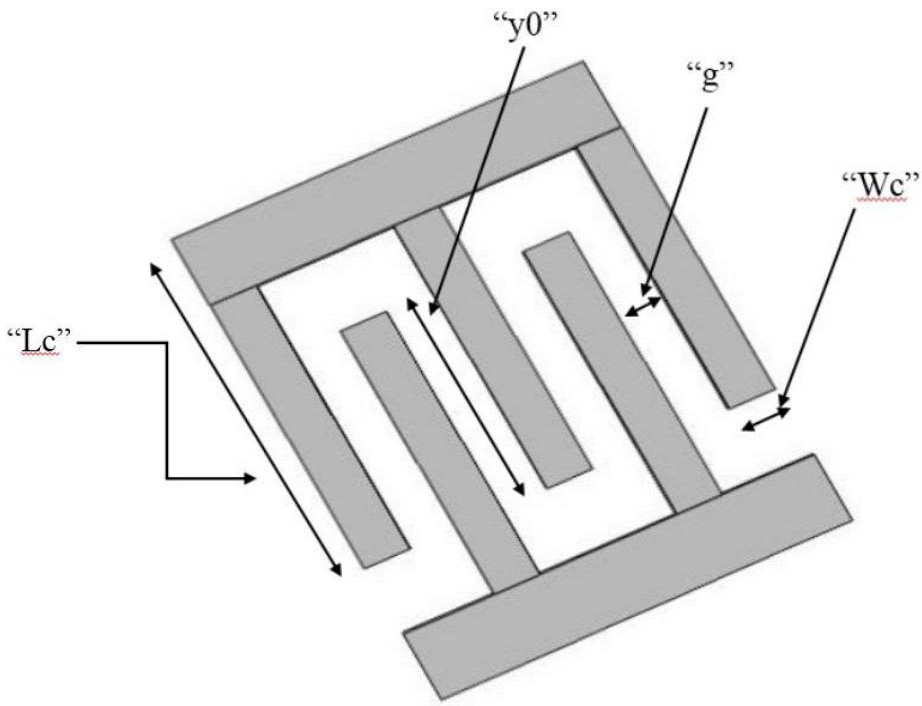

Figure 2: Basic parameters of a comb drive

Here, *Lc* is the length of the comb drive finger, *Wc* is the width of the comb, *g* is the gap between the comb fingers and *y0* is the initial finger overlap of the comb drive [3].

Mathematical Equations

Capacitance in an electrostatic comb drive between the fixed and the movable can be mathematically calculated by the given expression [4].

$$C = \frac{2n\varepsilon b(y0 + y)}{g} \quad (1)$$

In the above expression *y0* is the initial finger overlap ,*n* stands for number of moving combs, □ is the permittivity of dielectric, *b* is the thickness of the comb, *y* is the displacement and *g* is the gap between the fingers.

The lateral electrostatic force is denoted by *Fel,* it can be expressed as given below.

$$\text{Fel} = \frac{1}{2}\frac{\partial C}{\partial y}V^2 = \frac{n\varepsilon b}{g}V^2 \quad (2)$$

Here, force is inversely proportional to the gap *g* between the fingers and directly proportional to the voltage applied between the comb fingers [5]. Now, the displacement *y* (along the *y*-axis) is a function of the applied voltage and can be calculated by the given expression.

$$y = \frac{\mathrm{Fel}}{\mathrm{K}} \tag{3}$$

$$y = \frac{n\varepsilon b}{Kg} V^2 \tag{4}$$

In the above expression *y* is the displacement which is covered by the movable comb fingers when a potential is applied between the combs and the mechanical stiffness of the spring is denoted by *K* which can be calculated as:

$$\mathrm{K} = 2\mathrm{Eb}[\frac{W}{L}]^3 \tag{5}$$

Where the Young's modulus of the material is denoted by *E*,*W* is the width and *L* is the length of the spring.

Electrostatic Comb Drive With Crab Leg Spring Design

An electrostatic comb drive with crab leg spring design is shown below in figure.3. Here, the comb drive structure consist of 10 movable fingers and 11 fixed fingers which is attached to the suspended spring structure.

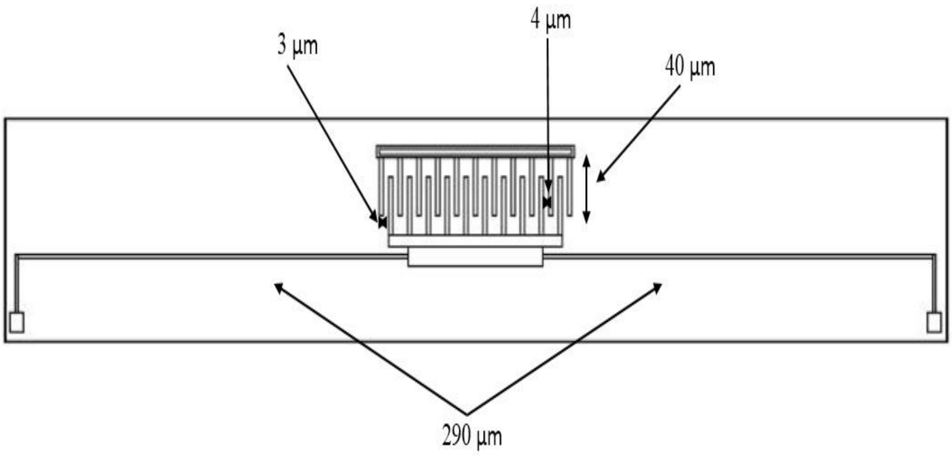

Figure 3: Comb drive with crab leg spring design

In the above figure, different dimensions of the comb drive is shown where *g* is 4 µm, *Lc* is 40 µm, *Wc* is 3 µm and the spring length is 290 µm. The detailed description of the structural parameters are given below in the table.1.

Table 1: Dimensions of the comb drive with crab leg spring design

Structural Parameters	**Dimensions**
Overlapping area (y0)	30 µm
Gap between the teeth (g)	4 µm
Spring length (L)	290 µm
Spring width (W)	2 µm
Thickness of the comb (t)	2 µm
No. of moving fingers (n)	10
Length of the comb (Lc)	40 m

A. Comb drive with Crab leg spring design using polysilicon as the structural material:

Polysilicon is a semiconductor material which is a multicrystalline form of silicon. It has excellent electrical and mechanical properties. In both the structures polysilicon is used as the structural material. The properties of polisilicon is given in the table.2. below.

Table 2: Properties of polysilicon

Property	**Expression**
Young's modulus	$160e^{9}$ [Pa]
Poisson's ratio	0.22
Density	2320 [kg/m^{3}]
Thermal expansion	$2.6e^{-9}$ [1/k]
Relative permittivity	4.5

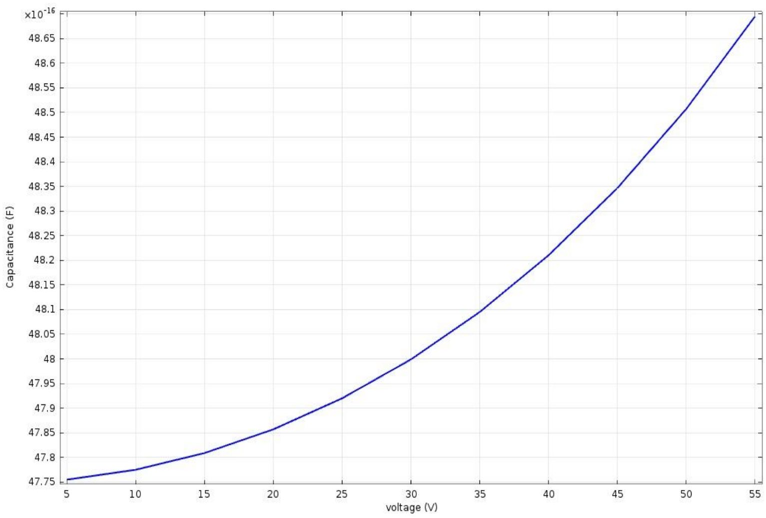

Figure 3: Capacitance Vs. voltage graph in comb drive With crab leg spring deign

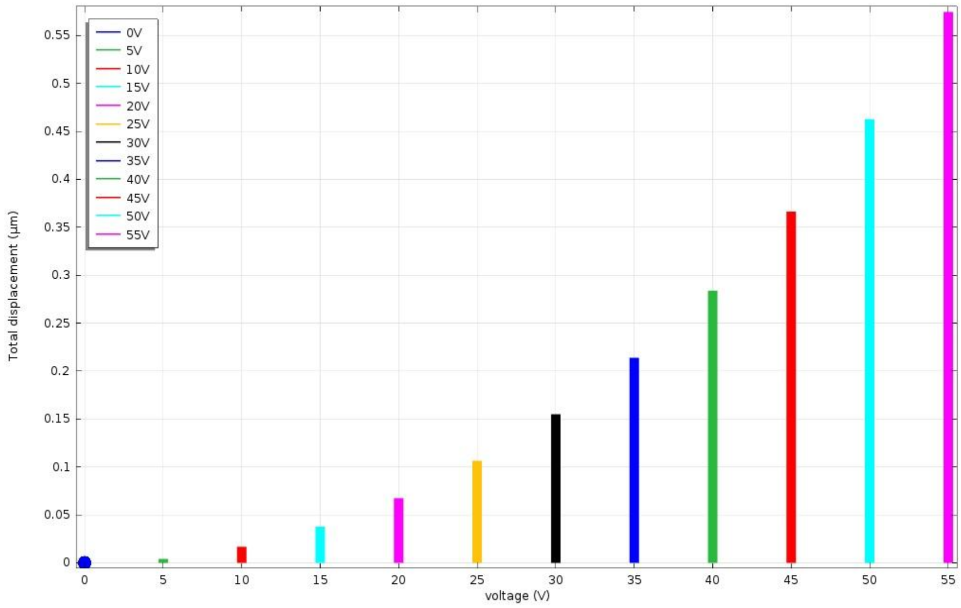

Figure 4: Displacement Vs. voltage graph in comb drive with crab leg spring design

Figure.3. Shows the capacitance vs. voltage graph when a potential of 55V is applied to the comb drive. A maximum capacitance of 0.004869 pF is observed at 55V and figure.4. Shows the displacement vs. voltage graph when the same potential is applied to the comb drive. A maximum displacement of 0.57 µm is observed at the same potential.

B. Comb drive with crab leg spring design using copper as the structural material:
Copper is a metal and an excellent conductor with exceptional properties as shown in the table.3. below.

Table 3: Properties of copper

Property	**Expression**
Young's modulus	$120e^9$ [Pa]
Poisson's ratio	0.34
Density	8960 [kg/ m^3]
Thermal expansion	16.5 e^{-6} [1/k]
Relative permittivity	1.5

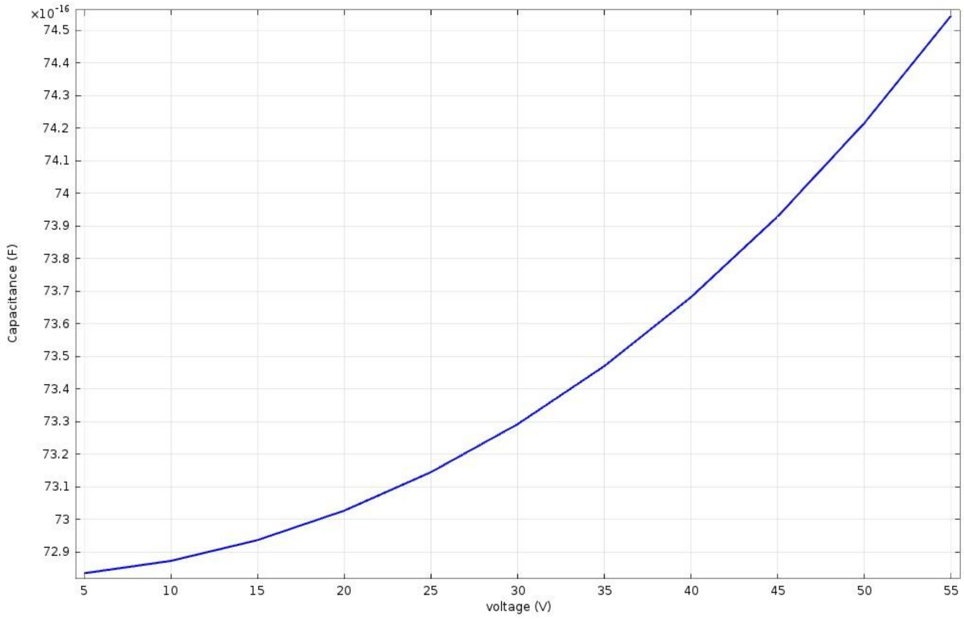

Figure 5: Capacitance Vs. voltage graph in comb drive With crab leg spring deign

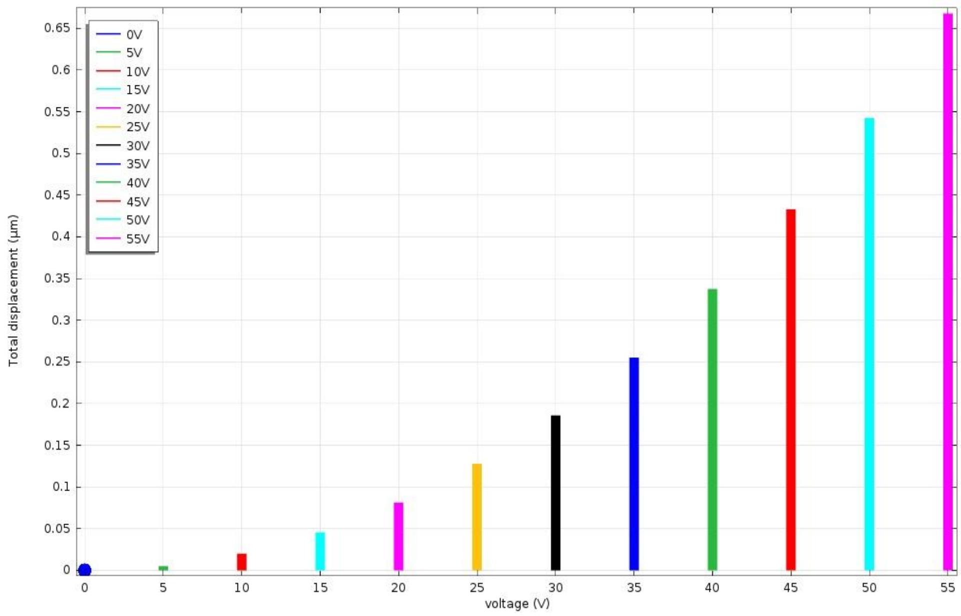

Figure 6: Displacement Vs. voltage graph in comb drive with crab leg spring design

Figure.5. Shows the capacitance vs. voltage graph when a potential of 55V is applied to the comb drive. A maximum capacitance of 0.007457 pF is observed at 55V and figure.6. Shows the displacement vs. voltage graph when the same potential is applied to the comb drive. A maximum displacement of 0.67 µm is observed at the same potential. Whenever a potential is applied to the comb drive there is a change in the capacitance as well displacement [6].

C. Comparison:

Table.4 shows the comaprison between the comd drives with crab leg spring design using polysilicon and copper as the structural material.

Table 4: Comparison of Comb Drive With Crab Leg Spring Design Using Different Structural Material

Parameter	**Crab Leg Spring**	
Material	Poly-Si	Copper
Potential applied	55V	55V
Displacement	0.49 µm	0.67 µm
Capacitance	0.007405 pF	0.7457 pF

Electrostatic Comb Drive With Folded Spring Design

An electrostatic comb drive with folded spring design is shown in the figure.6. Here the comb drive structure consist of 8 movable comb fingers and 9 fixed comb fingers which is attached to a suspended folded spring.

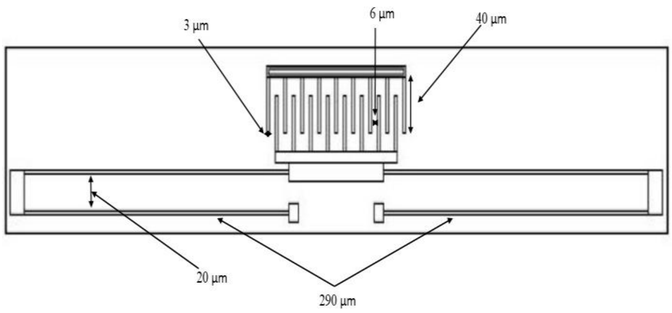

Figure 6: Comb Drive With Folded Spring Design

In the above figure the dimensions of the comb drive is shown where *Lc* is 40 µm, *Wc* is 3 µm, *g* is 6 µm length of the spring is 290 µm and the gap between the spring is 20 µm. All the structural parameters are same as the crab leg design except some enhanced, modified and new parameters like the gap between the comb fingers, number of movable comb fingers, gap between the springs and the spring length. The structural dimensions in detail is shown in the table below.

Table 5: Dimensions of the comb drive with folded spring design

Structural Parameters	**Dimensions**
Overlapping area (y0)	30 µm
Gap between the teeth (g)	6 µm
Spring length of the folded design (L)	580 µm
Spring width (W)	2 µm
Thickness of the comb (t)	2 µm
No. of moving fingers (n)	8
Length of the comb (Lc)	40 µm
Gap between the spring (Lg)	20 µm

D. Comb drive with folded spring design using polysilicon as the structural material:
Here polysilicon is used as the structural material to build the comb drive. The displacement and the capacitance obtained when a potential of 55V is applied is shown in the figure below.

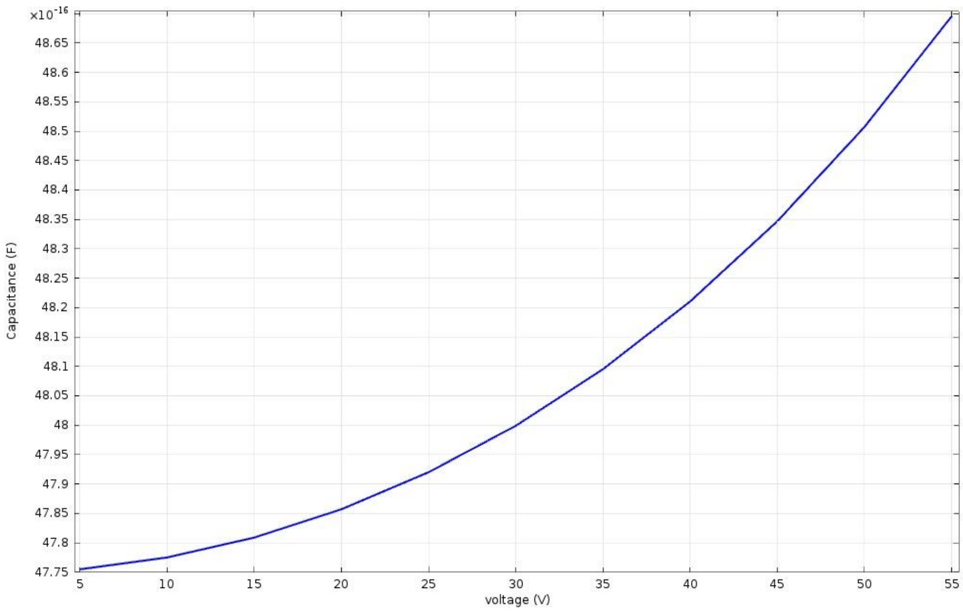

Figure 7: Capacitance Vs. voltage using polysilcon as structural material

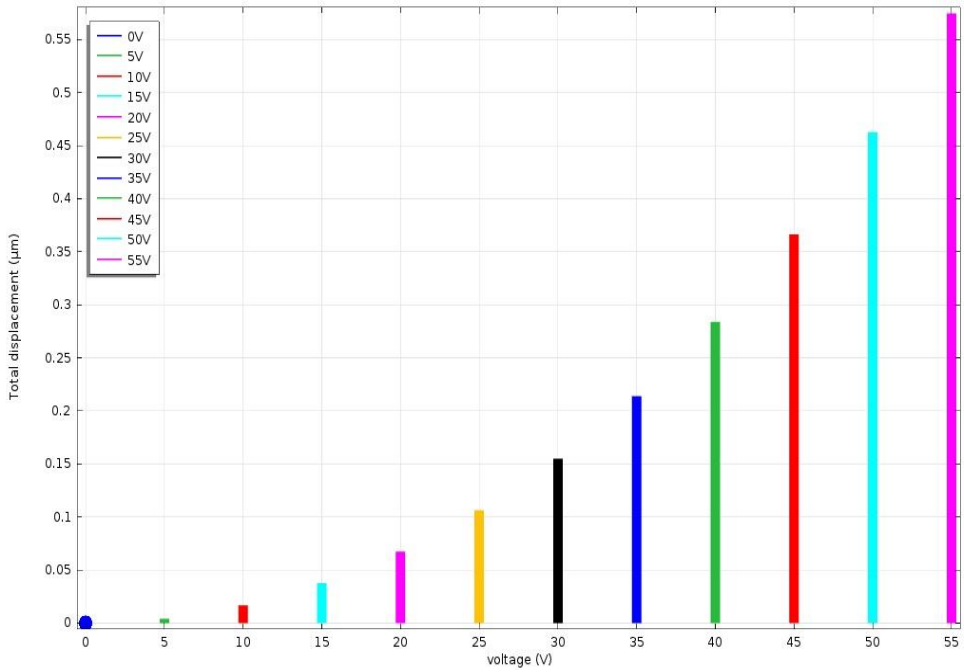

Figure 8: Displacement Vs. voltage using polysilcon as structural material

E. Comb drive with folded spring design using copper as the structural material:

Here copper is used as the structural material to build the comb drive. The displacement and the capacitance obtained when a potential of 55V is applied is shown in the figure below.

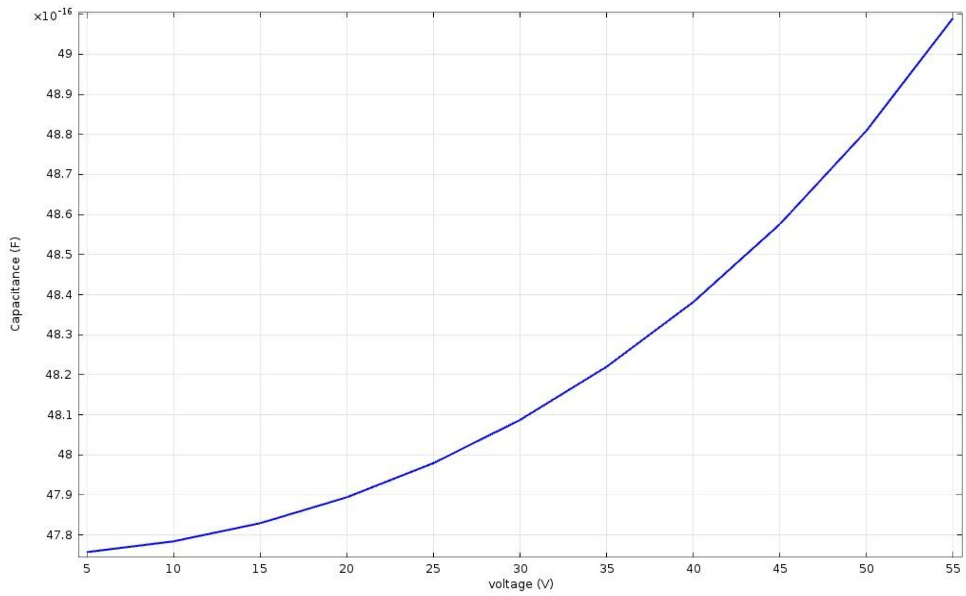

Figure 9: Capacitance Vs. voltage using copper as structural material

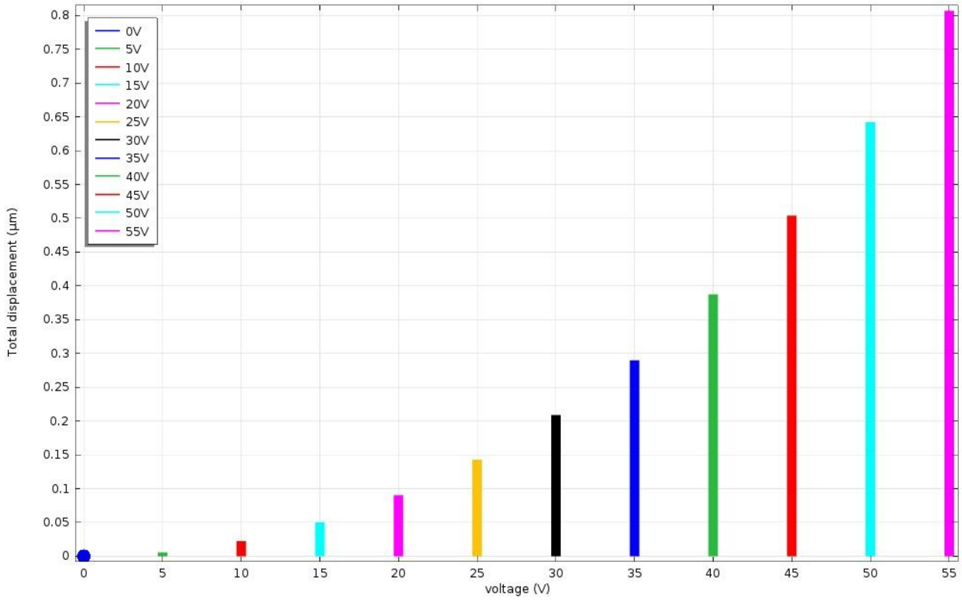

Figure 10: Displacement Vs. voltage using copper as structural material

F. Comparison:

Table.6. Shows the comaprison between the comd drives with crab leg spring design using polysilicon and copper as the structural material.

Table.6. Comparison of comb drive with folded spring design using different structural material

Parameter	**Folded Spring**	
Material	Poly-Si	Copper
Potential applied	55V	55V
Displacement	0.57 µm	0.81 µm
Capacitance	0.004896 pF	0.00490 pF

Conclusion

From the above observations we conclude that comb drive with double folded spring design gives maximum performance in terms of displacement and capacitance then comb drive with crab leg spring design. Moreover, the comb drive with folded spring design using copper as the structural material gives maximum displacement of 0.81 µm and capacitance of 0.00490 pF as compared to comb drive with folded spring design using polysilicon as the structural material when the same potential is applied.

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