Characterization of MEMS Electrostatic Comb Drive with Six Movable Comb Fingers using Different Structural Parameters

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Abstract—*In this paper, Electrostatic phenomenon between the comb drive is used to determine the displacement, capacitance and stress of the comb drive. Two MEMS electrostatic Comb Drive with different structural parameters are characterized having a maximum capacitance of 0.003658 pF and 0.004308 pF, respectively. A maximum displacement of 0.038 µm and 0.61 µm was observed in the comb dive with six movable comb fingers and comb drive with modified comb fingers, respectively after Simulation.*

1. INTRODUCTION

Microelectromechanical systems (MEMS) is a technology of miniaturing devices in microscale (µm). This paper is one such approach towards it. MEMS electrostatic comb drive is used to calculate the displacement and capacitance when a potential is applied. Electrostatic comb drive can be used as the base for designing an accelerometer, it is used for electrostatic actuation and capacitive sensing. 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. Whenever a potential is applied, the movable comb tends to move towards the fixed comb due to the phenomena of electrostatics. Due to this displacement there is a change in capacitance. The displacement of the movable comb depends upon the electrostatic force and the mechanical restoring force of the spring attached to the comb [2].

2. DESIGN METHODOLOGY

MEMS electrostatic comb drive is basically a capacitive actuator having a comb like structure which deals with the phenomena of electrostatics. A basic design of a comb drive is shown in the Fig. 1. The capacitance of a comb drive depends on various structural parameters [3, 4]. This parameters are the gap between the electrodes, structural material used, length, height, width and thickness of the comb. The electrostatic comb drive proposed in this paper consist of six movable comb fingers.

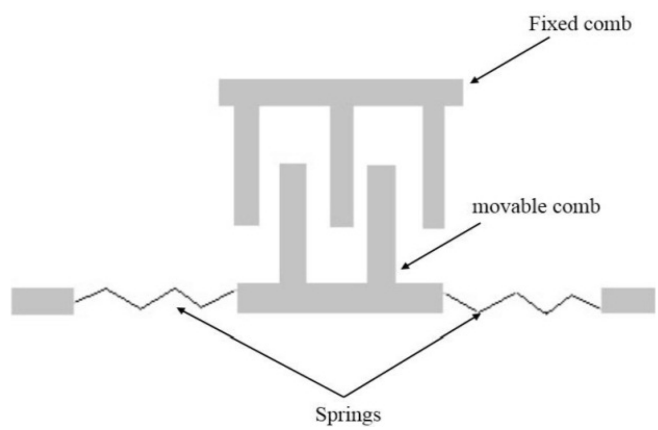

Fig. 1: Basic model of a comb drive.

The upper part of the comb drive is fixed and the lower part of the comb drive i.e. the six comb fingers attached to the spring is set to move whenever a potential is applied between the comb fingers.

3. MATHEMATICAL MODELLING OF COMB DRIVE

The mathematical equation for finding the capacitance of the comb drive is related to the displacement of the comb fingers [5, 6]. The capacitance of the comb drive can be written as:-

$$C = 2n\varepsilon b(y_0+y)/g \tag{1}$$

Where "n" is the number of overlapping combs, "ε" is the permittivity of free space, "y_0" is the initial electrode overlap, "g" is the gap between electrode and "y" is the displacement of the comb which is given by:-

$$y = F_{el}/k \quad (2)$$

$$Fel = \frac{1}{2}\frac{\partial C}{\partial y}V^2 = \frac{n\varepsilon b}{g}V^2 \quad (3)$$

Gap "g" is inversely proportional and applied potential is directly proportional to the lateral electrostatic force. Therefore, the displacement "y" can also be written as:

$$y = \frac{n\varepsilon b}{Kg}V^2 \quad (4)$$

Where, "k" is the mechanical stiffness and can be expressed as:-

$$k = 2Eb[W/L] \quad (5)$$

"W" is the width of the spring and "L" is the length of the spring and "E" is the young's modulus.

4. COMB DRIVE WITH SIX MOVABLE COMB FINGERS

An electrostatic comb drive with six movable comb fingers is shown in Fig. 2. The structural material used is polysilicon. Polysilicon is a high purity, multicrystalline form of silicon. Polysilicon has excellent electrical and mechanical properties. The properties of polysilicon and the dimensions of the comb drive are given in Table 1 and Table 2, respectively.

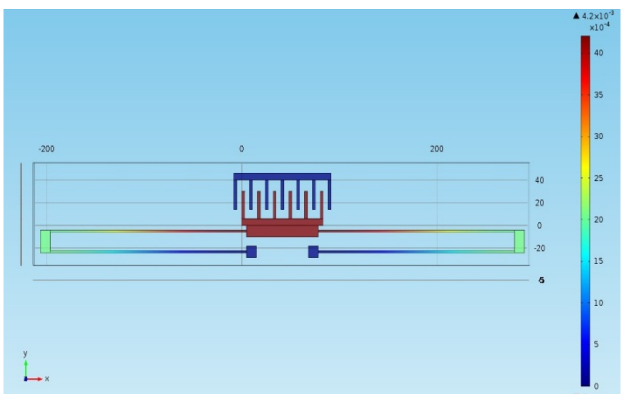

Fig. 2: Comb drive with six movable comb fingers in Comsol model builder.

Table 1: Properties of polysilicon

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

Table 2: Dimensions of the comb drive

Structural Parameters	Dimension
Overlapping area (y_0)	10 µm
Gap between the teeth (g)	5 µm
Spring length (L)	250 µm
Spring width (W)	2 µm
Gap between the spring legs (L_g)	16 µm
Thickness of the comb (b)	3 µm
No. of moving fingers (n)	6
Length of the comb ((L_c)	24 µm

5. COMB DRIVE WITH MODIFIED COMB FINGERS

The proposed structure with modified comb fingers is shown in Figure.3. The dimension of the comb teeth is also shown. The comb drive consist of six movable comb fingers. Here, polysilicon is used as the structural material. Some structural parameters of both the comb drives shown in Fig. 1 and Fig. 2 kept same. The various dimensions of the comb drive with modified comb fingers is given in Table 3.

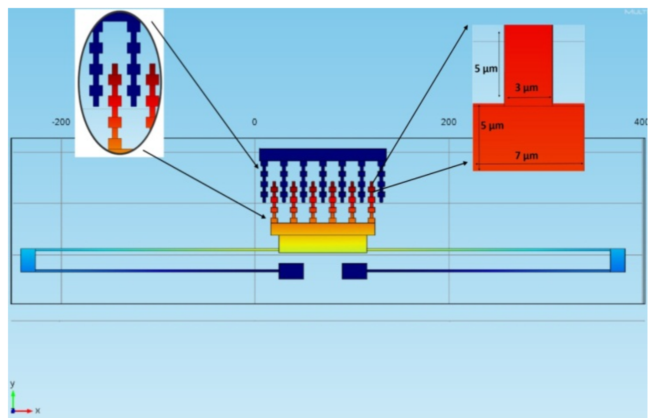

Fig. 3: Comb drive with modified comb fingers in Comsol model builder.

Table 3: Dimensions of the comb drive with modified fingers

Structural Parameters	Dimension
Overlapping area (y_0)	20 µm
Gap between the teeth (g)	5 µm
Spring length (L)	250 µm
Spring width (W)	2 µm
Gap between the spring legs (L_g)	18 µm
Thickness of the comb (b)	3 µm
No. of moving fingers (n)	6
Length of the comb (L_c)	40 µm

6. RESULTS AND DISCUSSION

The capacitance is a function of displacement. So, with change in displacement, capacitance changes. Whenever a potential is applied between the comb fingers there is a change in capacitance as well as displacement. Therefore, in the following figures, the change in capacitance, displacement and stress w.r.t actuation voltage is shown.

6.1 Comb Drive with Six Comb Fingers

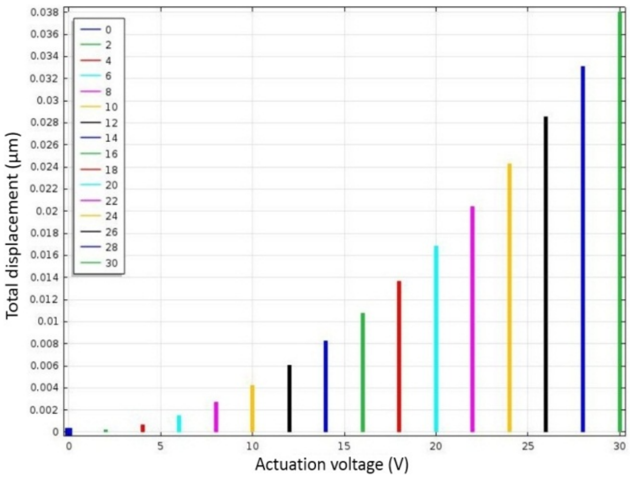

Fig. 4: Displacement vs. Actuation voltage graph.

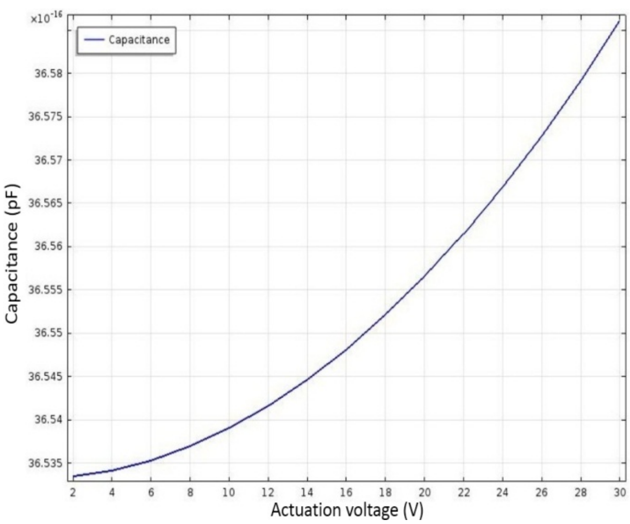

Fig. 5: Capacitance vs. Actuation voltage graph.

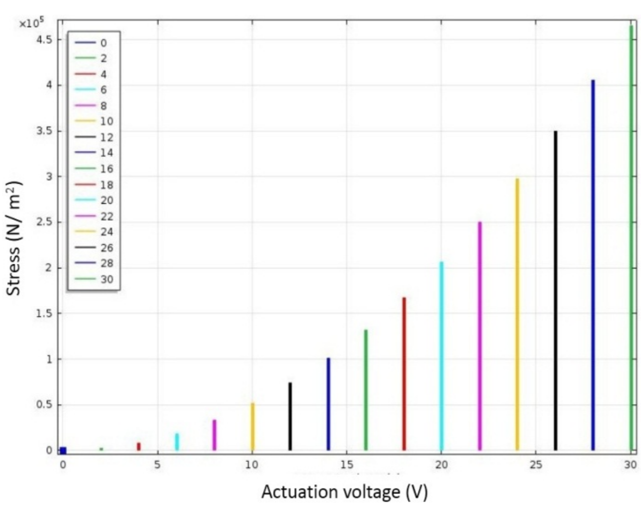

Fig. 6: Stress vs. Actuation voltage graph.

The graphs shown in Fig. 4, Fig. 5 and Fig. 6 the relationship of stress, capacitance and displacement with actuation voltage. Fig. 4.shows the displacement of the comb drive when an actuation voltage of 30V is applied to the comb drive. A maximum capacitance of 0.003658 pF, displacement of 0.038 µm and a maximum stress of $4.6x10^5$ N/m^2 is obtained at 30V.

6.2 Comb Drive with Modified Comb Fingers

The fingers of the comb drive is modified as shown in Fig. 3. The modification is done to get enhanced performance in terms of displacement, capacitance and stress whenever an actuation voltage of 30V is applied to the comb drive. Fig. 7 shows the displacement vs. actuation voltage graph when an actuation voltage of 30V is applied. A maximum displacement of 0.61 µm and a stress of $3.7x10^6$ N/m^2 is observed at 30V

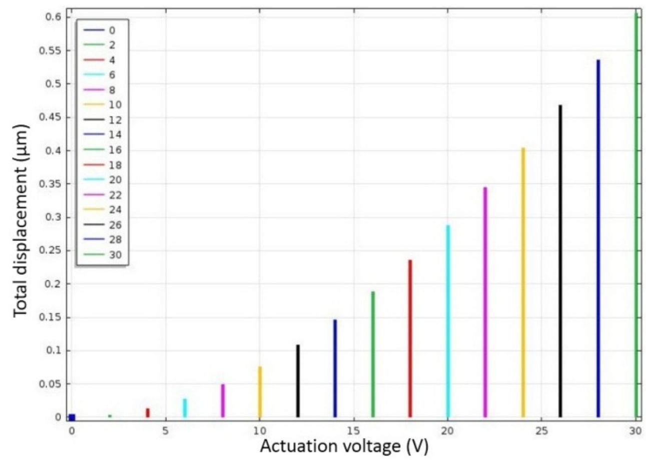

Fig. 7: Displacement vs. Actuation voltage graph in the comb drive with modified comb fingers

Fig. 8 shows the capacitance vs. actuation voltage when the same actuation voltage is applied. A maximum capacitance of 0.004308 pF is observed. A comparison of both the comb drive in terms of capacitance, displacement, structural material used and stress is given in Table 4.

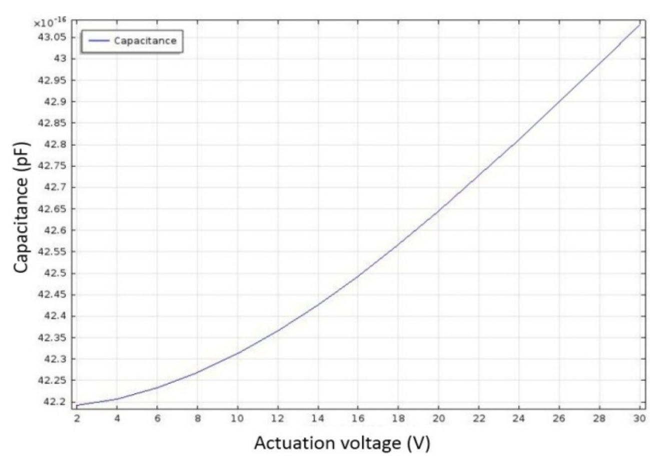

Fig. 8: Capacitance vs. Actuation voltage graph in the comb drive with modified comb fingers

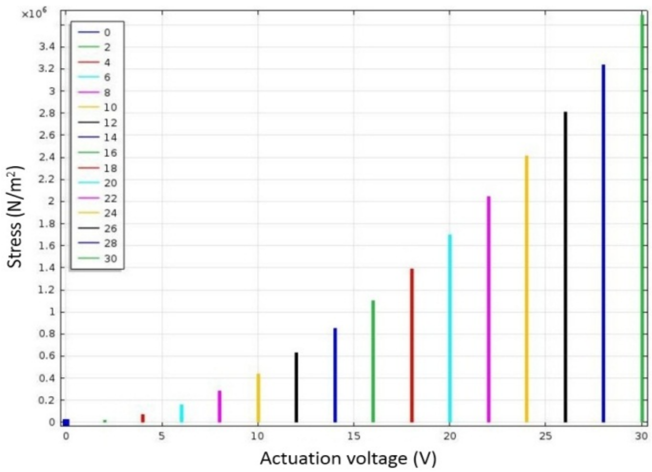

Fig. 9: Stress vs. Actuation voltage graph in the comb drive with modified comb fingers.

Table 4: Comparison between both the comb drives

Parameter	**Comb drive with six movable comb**	**Comb drive with modified comb fingers**
Material	Poly-Si	Poly-Si
Potential applied	30 V	30V
Displacement	0.038 µm	0.61 µm
Capacitance	0.003658 pF	0.004308 pF
Stress	4.6 e^5 N/m^2	3.7 e^6 N/ m^2

7. CONCLUSION

From the above observations we can conclude that the comb drive with modified comb fingers gives better performance in terms of displacement and capacitance. The comb drive with modified comb fingers gives a maximum capacitance of 0.004308 pF and displacement of 0.61 µm which proves to be better than the comb drive shown in the **Fig.** 2 at the same actuation voltage.

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