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Designing and Analysis of Rectangular Comb Drives to reduce power consumption in Biomedical Applications

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Abstract— This paper brings in the design of MEMS accelerometer actuated by a rectangular comb drives. By altering the no. of combs and the space, the comb geometries are designed and there result is analyzed. Finite element analysis is used to establish the concept of controlled displacement of the movable comb fingers, achieved by setting down the amount of electrostatic force produced by the device and to reduce power consumption.

Keywords— MEMS, COMSOL, ALE, FEM.

I. INTRODUCTION

Capacitance based actuators have been widely used in MEMS devices. Among different devices, the most commonly used and examined is the comb drive. The MEMS comb drive is a laterally driven mechanical actuator activated by electrostatic interaction. A typical rectangular shaped comb drive design involves simple fabrication steps and it is characterized by low power consumption. [6, 7, 11].

II. DESIGN AND NUMERICAL MODELLING

The electrostatic problem can be physically illustrated by equation 1.1:

$$E = -\nabla V \qquad (1.1)$$

It tracks that, since the comb drive is a capacitive gadget with air as the dielectric material, the area where the problem is distinct is charge free ($\rho_v = 0$). The electrostatic problem is then explained by the Laplace equation 1.2 in rectangular coordinates.

$$\nabla^2 V = \frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2} + \frac{\partial^2 V}{\partial Z^2} = 0 \qquad (1.2)$$

The purpose of the FEM study is to find the potential distribution which satisfy equation 1.2 for a given electrode geometry at a predefined actuation potential V. The coupled electrostatic-mechanical problem is solved by a FEM parametric study, which uses the ALE formulation. modeling is performed in the FEM software package COMSOL using three multiphysics modes: electrostatics, plane stress and moving mesh. The material used for structural part is polysilicon as it has excellent mechanical properties and its electrical properties can be modified by doping boron or phosphorous [2, 4]. The designs have few dimensions in common except the distance between the fixed and movable combs numbers of comb fingers. The dimensions of the actuator are shown in table 1.1. There are three main design ingredients in the structure designed fixed combs, movable combs and folded spring as shown in figure 1.1:

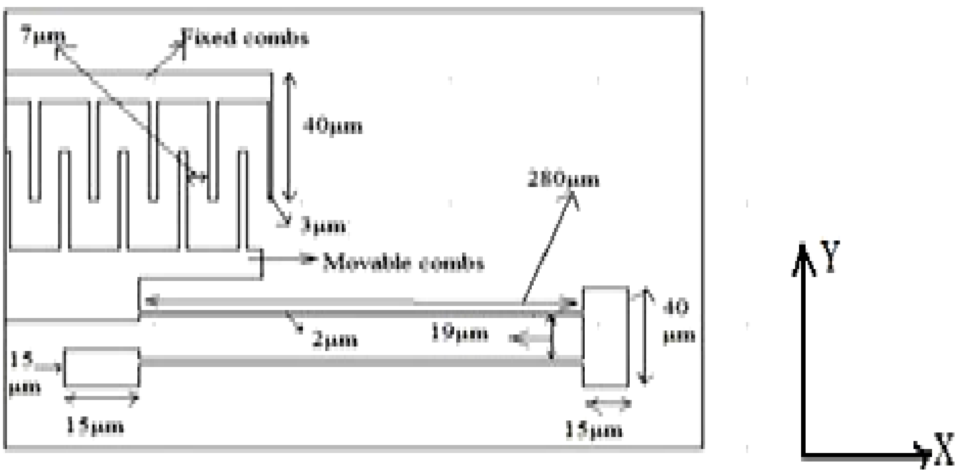

Figure 1.1: Actuator Geometry.

Table 1.1: Dimensions of Actuator

DIMENSIONS OF ACTUATOR	
Geometry	**Value**
Comb length(l)	40 µm
Comb width(w)	3 µm
Gap between moving and fixed combs(d)	d µm
Initial engagement (A)	20 µm
Spring length(k_l)	280 µm
Spring width(k_w)	2 µm
Gap b/w spring legs(k_g)	19 µm
Thickness of actuator (t)	2µm
No. of moving combs	N

The design shown in figure 1.1 consists of 5 fixed combs which are grounded as this type of actuator work on the principle of electrostatic actuation so, it is necessary to develop negative and positive charge in the fixed and movable combs. Due to this reason the fixed combs are grounded. As the electric potential is applied to the movable combs an electrostatic force is generated which provides the actuation in the direction of the length of the comb fingers. In the folded flexure spring the beams are anchored near the movable combs and the truss allows expansion or contraction of the beams along axis. This spring exhibits a much larger linear deflection range so; it is suitable for large deflection actuators. Another important effect that is considered is the stiffness of the folded flexure beam in the x-direction reduces with increasing displacement in y- direction [3, 6, 7]. The fixed combs are grounded and the electric potential is applied on movable combs. Applying a voltage difference between the comb structures will result in a deflection of the movable comb structure by electrostatic forces as shown in the figure.1.2. This deflection causes change in area between the combs i.e. ($y+y_0$), as the overlapping area changes, the capacitance between the fixed and movable combs changes. The capacitance can be expressed as in equation 1.3:

$$C = \frac{2n \in_0 h(y+y_0)}{d} \quad (1.3)$$

Where, *n* is the number of combs, ε_0 is the dielectric constant in air, *h* is the height of the comb fingers, y_0 is the initial comb finger overlap, *y* is the comb displacement and *d* is the gap spacing between the comb fingers and *V* is the applied voltage between the movable and fixed combs.. The lateral electrostatic force in the y-direction can be expressed in equation 1.4 as:

$$F_{e1} = \frac{1}{2}\frac{\partial C}{\partial y}V^2 = \frac{n \in_0 h}{d}V^2 \quad (1.4)$$

For understanding the basic design specifications and their effects 5 fixed and 4 movable combs structure was designed using COMSOL Multyphysics. The gap spacing between the fixed and movable comb fingers was taken as 7µm. The main requirement of these types of actuators is low driving voltage with large deflection and this can be achieved by increasing the number of comb fingers, the height of comb fingers and by reducing the distance between the comb fingers.

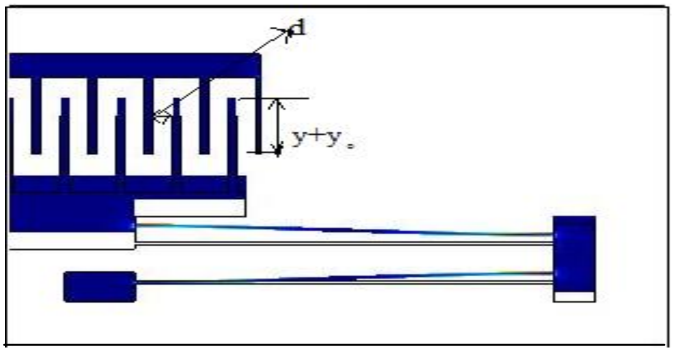

Figure 1.2: Deflected Combs.

As given in equation 1.3 and equation 1.4 the number of combs and the thickness of combs is directly proportional to the electrostatic force, so if the number of combs are increased, there is increase in capacitance as well as the electrostatic force. Large deflection comb drive actuators at low driving voltages should employ large number of comb fingers [8, 9]. If the distance between the comb fingers is reduced, then the electrostatic force and the capacitance between the fixed and movable combs gets increased. The 3D effects like fringing fields, comb finger end effects are neglected [1, 12].

The design consists of 4 movable combs on which electric potential is applied and 5 fixed which are grounded. These comb structures are designed using polysilicon as material as shown in figure 1.3 and its properties specified in table 1.2. In this structure as the applied potential difference electric potential is applied on the movable comb fingers and ground to the fixed combs, the electrostatic force, due to which there is some displacement along movable combs and spring as shown in figure.1.3.

Table 1.2**:** Polysilicon Properties

Properties of Polysilicon	
Property	Expression
Young's Modulus	$160e^{9}$[Pa]
Poisson's Ratio	0.22
Density	2320[kg/m^3]
Thermal Expansion	$2.6e\text{-}^{6}$[1/k]
Relative Permittivity	4.5

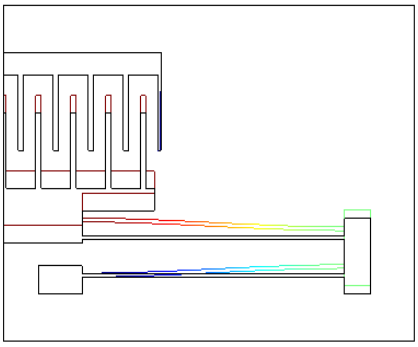

Figure 1.3: Actuator with Polysilicon Material

II. RESULT

Using polysilicon as the structural material this design shows maximum displacement of 8.132µm at 700.1V (maximum voltage) in figure 4.5. Corresponding to this displacement, capacitance measured i.e. $0.4402\text{x}10^{-3}$ µF and the electrostatic force in y-direction is 1.7902µN. As discussed earlier by increasing the number of comb fingers and by reducing the distance between the combs there is large deflection at low actuating voltage and increase in capacitance and electrostatic force across the combs.

- Firstly, by reducing 7µm spacing to 1µm spacing between the 4 movable and 5 fixed combs as shown in figure 1.4.
- By increasing the number of combs i.e. 9 movable combs having 7µm distance between fixed and movable combs as shown in figure 1.5.
- Then by reducing the distance 7 µm to 1 µm for 9 movable comb structures as shown in figure.1.6.

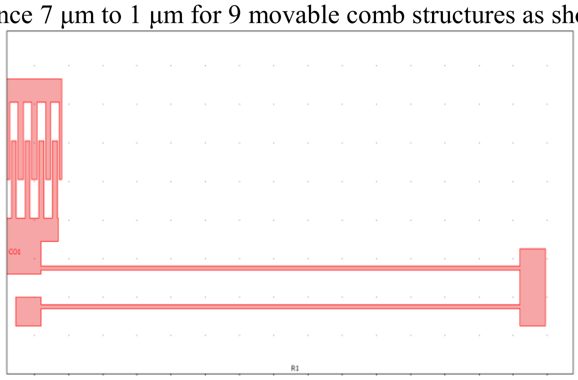

Figure 1.4: Actuator with 1 µm Spacing and 4 Moving Combs.

Table 1.3 shows that by comparing 4 comb actuator structure having 1µm spacing it can be seen that the maximum voltage get lower to 80.1V and at such a lower actuation voltage, acceptable displacement is obtained.

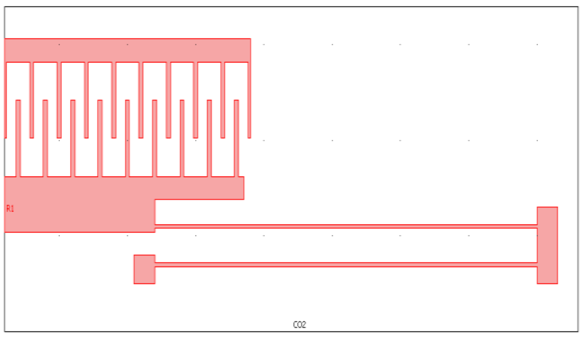

Figure 1.5: Actuator with 7 µm Spacing and 9 Movable Combs.

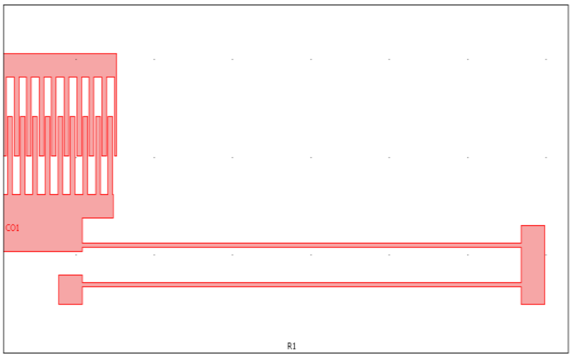

Figure 1.6: Actuator with 1 µm Spacing and 9 Movable combs.

Then it is seen that by increasing the number of combs (4 movable combs to 9 and 7µm spacing) the maximum of 7.719µm displacement occurs at 201V and total capacitance is 0.8595x10^{-3}µF and force is 0.8043µN. So, by increasing the number of combs there is acceptable change in displacement, capacitance and force at lower actuation voltage as compared to design consist of 4 movable combs with 7 µm spacing. Then it can be seen that by increasing the number of the maximum of 7.719µm displacement occurs at 201V maximum voltage and total capacitance is 0.8595x10^{-3}µF and force is 0.8043µN.

Table 1.3: Displacement Vs Number of Combs Fingers.

No. Moving combs	4 comb fingers		9 comb fingers	
Gap b/w combs	d =1(µm)	d = 7(µm)	d = 7(µm)	d = 1(µm)
Max. Voltage(V)	80.1	700.1	201	80.1
Displacement(µm)	2.411	8.132	7.719	4.080
Capacitance $(cap * 10^{-3})$ (µF)	1.858	0.4402	0.8595	4.413
Force (µN)	0.399	1.7902	0.8043	1.019

The table 1.3 shows the comparison between 4 moving combs versus 9 movable combs and it can be concluded that the all the geometries should consists of the set of 10 fixed combs and 9 movable combs.

The rectangular comb device as shown in figure 1.4 has a constant force-to-displacement relationship, which is a function of the change in capacitance with respect to engagement, rather than total capacitance.

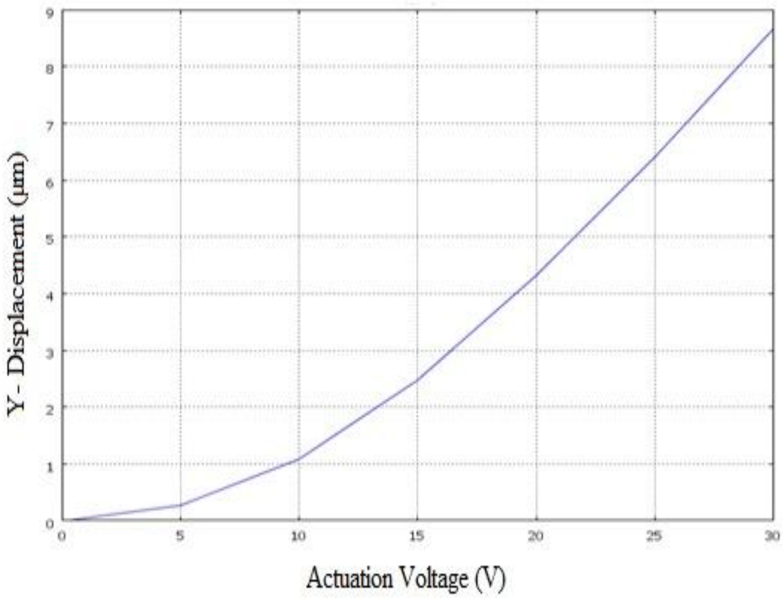

Figure 1.8(a): Displacement Vs Voltage Curve.

The displacement shown in figure 1.8 (b) increases very slowly between 0-5V, then it increases linearly between 5-10 V, then there is sharp change in the force w.r.t. actuation voltage.

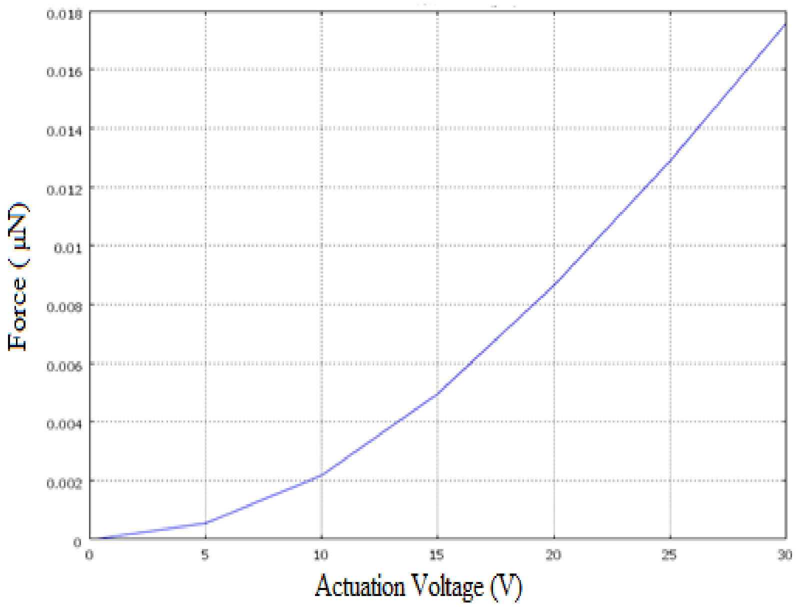

Figure 1.8(b): Force Vs Voltage Curve.

The force shown in figure 1.8 (b) increases very slowly between 0-5V, then it increases linearly between 5-10 V, then there is sharp change in the force w.r.t. actuation voltage.

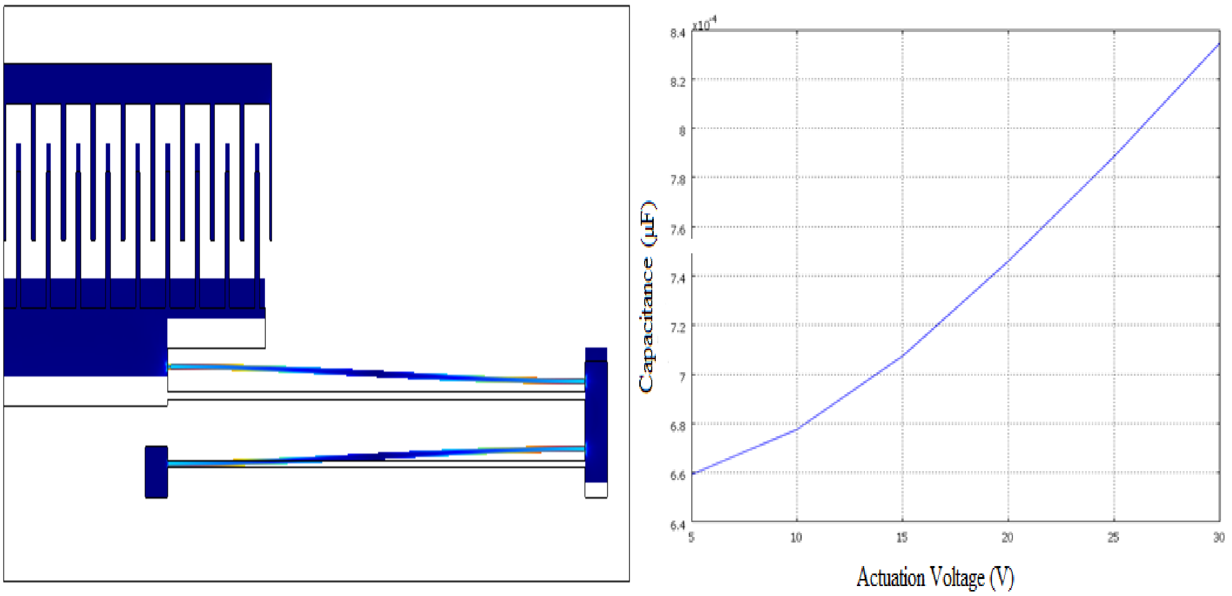

Figure 1.8(c): Capacitance Vs Voltage Curve.

III. Conclusions

It can be concluded that by increasing the number of combs there is acceptable change in displacement, capacitance and force at lower actuation voltage as compared to 4 movable combs with 7 µm spacing. Then by increasing the movable combs and reducing the distance between the movable and fixed combs i.e. 7 µm to 1 µm. The geometry with large numbers of comb and fewer gaps between comb fingers can give low power consumption and greater sensitivity.

References

[1] Farshad Shadbakhsh1,*, Mohammadali Shahriari2, Abolghasem Zabihollah3, " Conceptual Design of a Micro Gripper with Electrostatic Micro Stepper-Motor Actuation", Life Science Journal, pp 290-293, 2013.

[2] Anurag Singh and Vijay Kumar Anand () Simulation of Shaped Comb Drive as a Stepped Actuator with Improved Slippage for Microtweezers Application. Journal of Information Systems and Communication, Volume 3, Issue 1, pp.- 179-181, 2012.

[3] Binglei Wang and Shenjie Zhou; "*Size Dependent Pull-in Instability of Electrostatically Actuated Micro Beams based on MEMS*", Journal of Micromechanics and Microengineering, Vol. 21 No. 2, pp 304-309, Feb. 2011.

[4] Zakri Ghazalli, Asnul hadiahamad, Mohd Fazli Ismail and Khairul Fikri Muhamad "*Design of Electrostatic Comb Actuators Based on Finite Element Method*" International Conference on Enabling Science and Nanotechnology, Malaysia, pp 1-3,Dec. 2010.

[5] Ndu Osonwanne and Jason V. Clark *"MEMS Comb Drive Gap Reduction Beyond Minimum Feature Size: A Computational Study*"; Excerpt from the Proceedings of the COMSOL Conference, Boston, pp 317-322, 2010.

[6] G.k. ananthasuresh, k.j. vinoy, k.n. bhat, s. Gopalakrishnan and v.k.aatre; "*micro and smart systems*" wiley – india; first edition, pp 115-129 2010.

[7] J. Varona, E. Saenz, S. Fiscal- Woodhouse and A.A. amoui; *" Design and Fabrication of a Novel Microgripper Based on Electrostatic Actuation*" , 52nd IEEE International Midwest Symposium on Circuits and Systems, pp 827-832, Aug. 2009.

[8] Badariah Bais and Burhanuddin Yeop Majlis; "*Low-g Area-changed MEMS Accelerometer using Bulk Silicon Technique*" American Journal of Applied Sciences vol.5, Issue 6, pp. (626-632), 2008.

[9] Stephen A. Wilson a. And Renaud P.J. Jourdain "*New Materials for Micro-scale Sensors and Actuators: An Engineering Review*" Materials Science and Engineering R: Reports, Vol. 56, Issue 6, pp 119–129 2007.

[10] W. Merlijn van Spengen and Erwin C. Heeres "*A Method to Extract the Lateral and Normal Component of the Motion from the Capacitance Change of a Moving MEMS Comb Drive*" Journal of Micromechanics and Microengineering, Vol. 17, No. 3, pp 447-451, 2007.

[11] G. Somlay, Z. Szucs, A. Poppe and M. Rencz "*Simulation of a Comb Drive for Fracture Lifetime Measurements*" Excerpt from the Proceedings of the COMSOL Users Conference, Grenoble, pp 149-152, 2007.

[12] Isabelle P.F. Harouche, C. Shafai and Richard Gordon, "*Design and Simulation of Microtweezers using a Controlled Displacement Comb Drive*" Canadian Conference on Electrical and Computer Engineering, Ottawa, pp 341-343, May 2006.

[13] Kanchan Sharma, Isaac G. Macwan, Linfeng Zhang, Lawrence Hmurcik and Xingguo Xiong; "*Design Optimization of MEMS Comb Accelerometer" Sensors and Transducers*, Vol. 108, Issue 7, pp 15-30, 2006.

[14] Isabelle P.F. Harouche and C. Shafai "*Simulation of Shaped Comb Drive as a Stepped Actuator for Microtweezers Application*" Sensors and Actuators A Vol.123–124, pp 540–546, March 2005.

[15] Tai-Ran Hsu; "*Micro Assembly: A Technology on the Frontier of New Industrial Automation*" J. Microelectromech. Syst. Vol.10 Issue 2, pp1481–1490, 2005.

