

Analyzing the Trapezium Shaped Comb Drive Actuator

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ABSTRACT: The Large displacement comb actuators at low actuation voltage should employ large number of comb fingers, reduced distance between the combs and by increasing the width of the fingers. Polysilicon has been the dominant mechanical materials for MEMS fabrication (PDF) MEMS Electrostatic comb actuators with a novel trapezium comb shape produces less actuation voltage then regular rectangular shape.

KEYWORDS: Actuator, shaped Comb Drive, Capacitance,electrostatic microweezers.

I. INTRODUCTION

In the last decades it was noticed a massive development of micro and nanotechnologies and in order to manipulate micro-scale objects, very precise tools like micro grippers are necessary in order to firmly hold the object wanted with a sufficiently high force for retaining it between the grips but also with sufficiently low force to avoid damaging the material [1].

Comb-drive actuator topology, which is the base of traditional electrostatic microweezers was described in [2, 3]. A typical comb-drive actuator is composed from one comb structure with electrode fingers interdigitated with the fingers of another fixed comb. The movable comb is carried by a shuttle at which a compliant suspension is attached. Each pair of interdigitated electrodes form a parallel capacitor [4] and simple manufacturing actions are involved, one structural layer from polysilicon being necessary in most of the cases. Lateral electrostatic force acting on the movable comb is produced in the y-direction by applying a potential difference between the electrodes of the capacitor.

II. DESIGNING

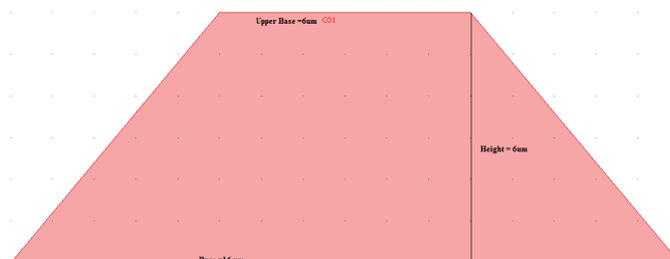


Figure 1: Basic Trapezium

A novel (trapezium shaped) comb drive electrostatic actuator is designed using COMSOL 3.5 tool. First a single trapezium with parallel side of length 16um and 6um and height 6um is designed.

The array of the basic trapezium is designed using x-displacement of 32um, which create 2um gap between the combs. The y-displacement of 6um and array size of 5 will place five trapeziums above all of it.

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Vol. 7, Issue 6, June2018

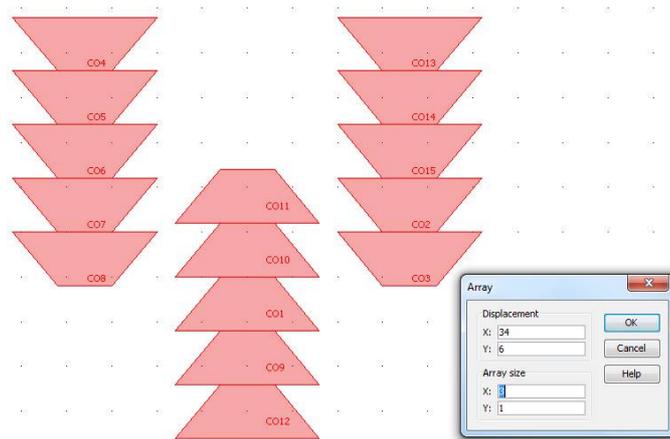


Figure 2: Array

The design shown in figure 3 consists of 2 fixed combs of 30um in length 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 comb of 30um of length an electrostatic force is generated which provides the actuation in the direction of the length of the comb fingers. The engagement between fixed and moving comb is 13um. The vertical air gap between the combs is 17um and lateral air gap of 2um. In the folded flexure spring of 2um width and 80um length, 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 decreases with increasing displacement in y- direction [13, 16, 17]. 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. The capacitance can be expressed as in equation 1:

$$C = \frac{2n\epsilon_0 h(y + y_0)}{d}$$

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 energy required to charge a capacitor should equal that of the electrostatic field, which is

$$W_e = \frac{Q^2}{2C}$$

W_e is readily available in the Electrostatics application mode; the software calculates it by integrating across the domain

$$W_e = \int_{\Omega} (\mathbf{D} \cdot \mathbf{E}) d\Omega$$

where \mathbf{D} is the electric displacement, and \mathbf{E} is the electric field. The capacitance, C , is related to the charge on the two conductive plates, Q , and the voltage difference across those plates, ΔV , by

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 7, Issue 6, June2018

$$C = \frac{Q}{\Delta V}$$

Now calculate C from the stored electric energy in the capacitor, W_e , and the voltage across the capacitor:

$$C = \frac{Q^2}{2W_e} = \frac{C^2 \Delta V^2}{2W_e} \Rightarrow C = \frac{2W_e}{\Delta V^2}$$

The upper half of the comb is fixed, as is the end of the beam spring. The system applies an electric potential to the beam spring and the lower comb; the upper comb is grounded. In the air surrounding the comb drive, the model solves the electrostatic equation

$$-\nabla \cdot (\epsilon \nabla V) = 0$$

The electrostatic force density is

$$F_{es} = \frac{\epsilon E^2}{2}$$

and the simulation applies it to each comb as a perpendicular boundary load.

The lateral electrostatic force in the y-direction can be expressed as:

$$F_{el} = \frac{1}{2} \frac{\partial C}{\partial y} V^2 = \frac{n \epsilon_0 h}{d} V^2$$

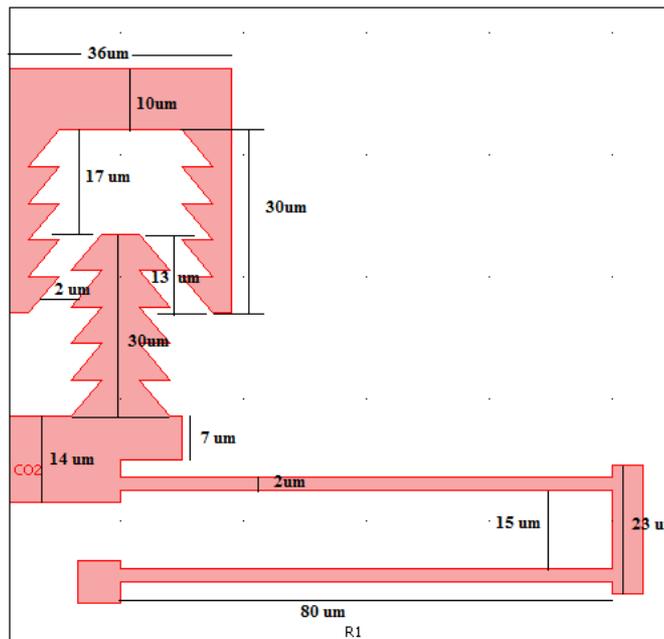


Figure 3: Trapezium Shaped Comb Drive.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 7, Issue 6, June2018

III. BOUNDARY SETTING

Because electrostatic forces attract the combs to each other, any geometric change has an impact on the electric field between them. To account for this effect, the model uses an arbitrary Lagrangian-Eulerian (ALE) method implemented in COMSOL Multiphysics' Moving Mesh application mode. This application mode automatically keeps track of the movements and translate application mode equations between the fixed (reference) and moving frames.

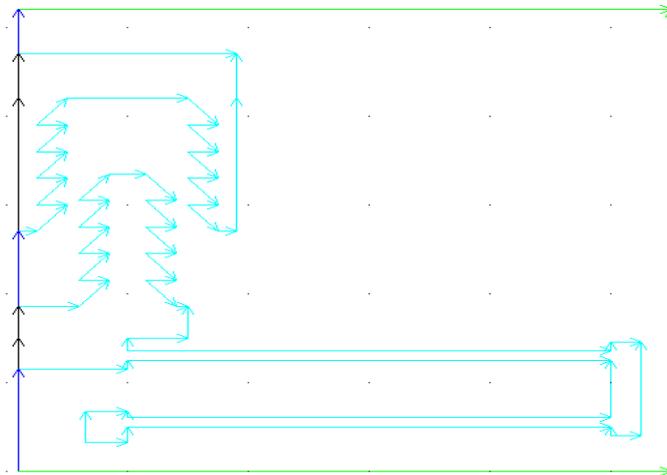


Figure 4: Moving Mesh Boundary.

Boundary settings for Moving Mesh (ALE) application mode is shown in figure 4. Inactive boundaries are black, symmetry boundaries are blue, moving comb drive is in cyan color and the fixed outer boundaries are green in color.

Therefore, the Plane Stress application mode's support for large deformations is used. Boundary settings for the Plane Stress application mode is shown in figure 5. Electrostatically actuated boundaries are cyan, symmetry boundaries are green, fixed boundaries are blue, free boundaries (and inactive boundaries) are black in color.

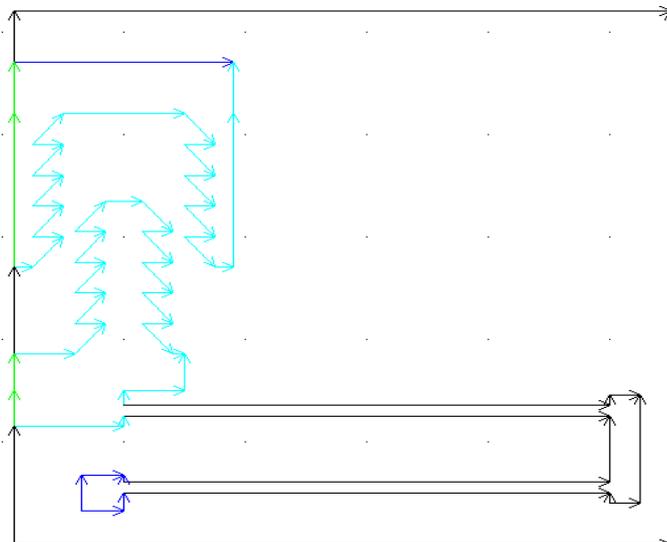


Figure 5: Boundary for the Plane Stress.

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Vol. 7, Issue 6, June2018

To define the electrostatic force, the Electrostatics application mode's Maxwell surface stress tensor boundary variables is used. Boundary conditions for the Electrostatics application mode is given in figure 6. Grounded boundaries are shown by blue color, electric potential (V_{in}) by cyan, Zero charge/Symmetry boundaries by black and Continuity boundaries are green.

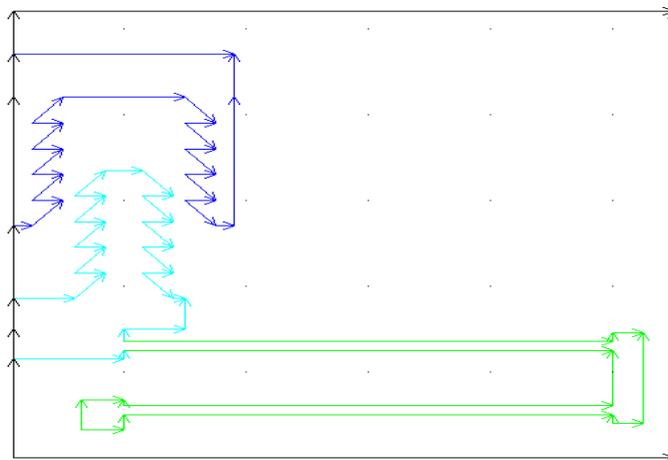


Figure 6: Electrostatics Boundary.

The geometry of this design is rather complex and thus the boundary conditions are laborious to enter. As it is faster and easier to set up by using the Moving Mesh application mode. The structure is made of polysilicon and has a thickness of a 2 μm .

IV. EXPERIMENTAL RESULTS

The displacement at the tip of one of the fingers of the lower comb as a function of the actuation voltage larger the voltage greater is the displacement.

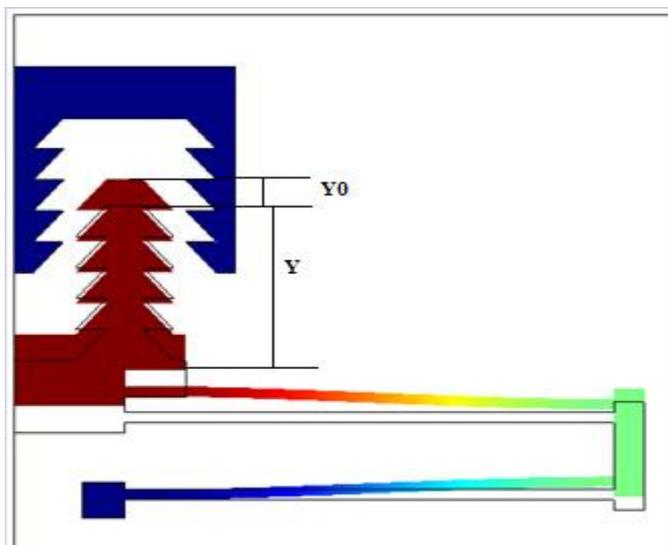


Figure 7: Displacements in the y direction.

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Vol. 7, Issue 6, June2018

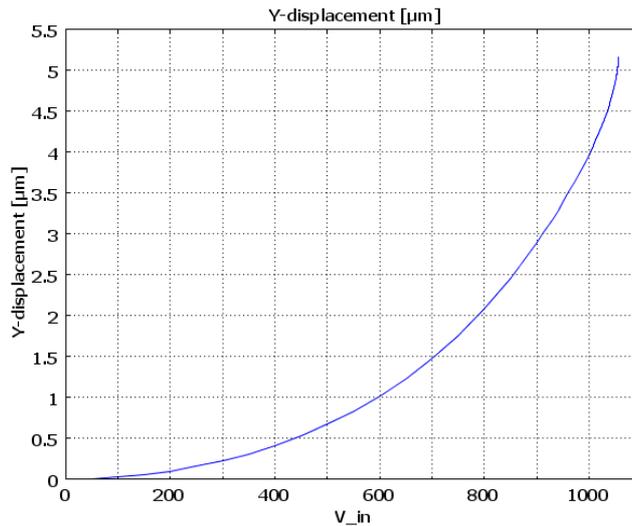


Figure 8: Displacement Plot

Figure 8 shows the displacement of 5.5 μm at 1056.1V actuation.

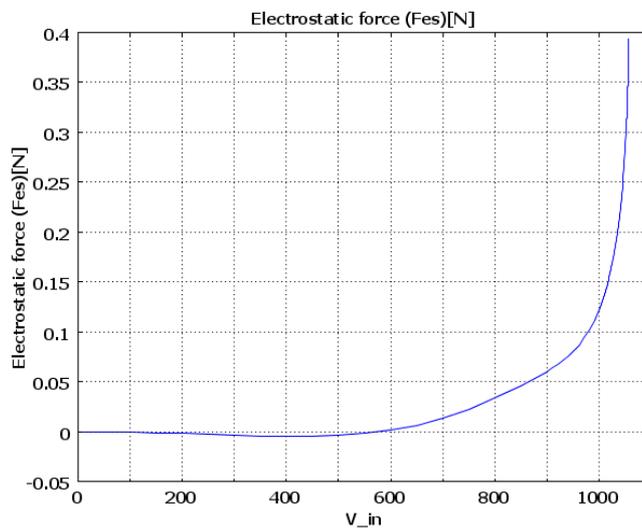


Figure 9: Force Plot

Figure 9 shows the maximum force of 0.4 N at 1056.1V actuation.

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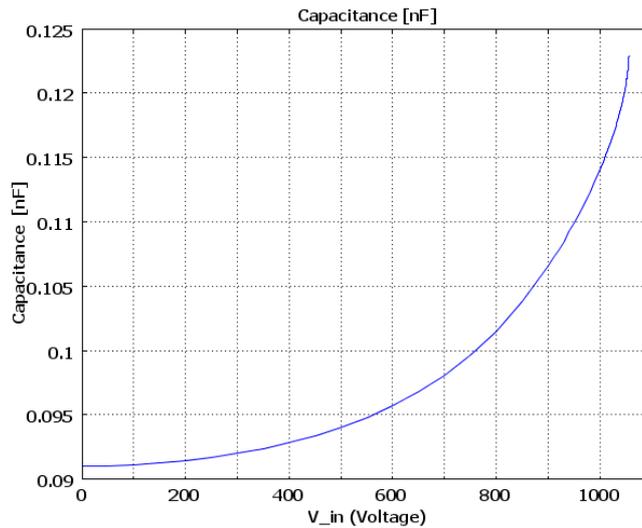


Figure 10: Force Plot

Figure 10 shows the maximum capacitance of 0.125nF at 1056.1V actuation.

To reduce actuation voltages it is common to construct comb drives with many more teeth than in this design. Preferably, should design such comb drives using a periodic approximation, therefore by allowing the simulation of only one pair of fingers.

Design with 10 fingers is also analysed to reduce the applied voltage.

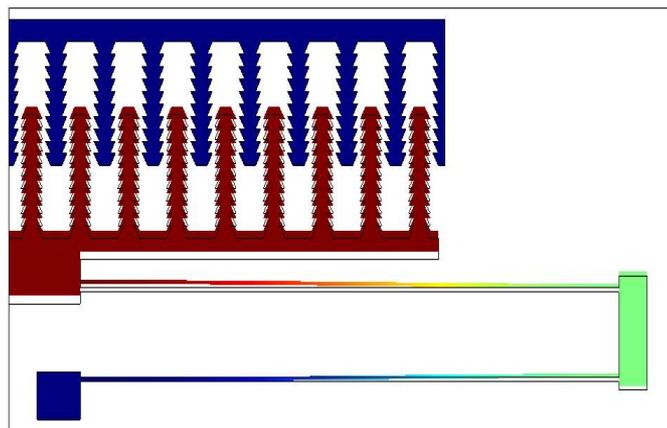


Figure 11: Trapezium Comb Drive with 10 Fingers.

Trapezium Comb Drive with 10 fingers is shown in figure which shows the total displacement of the actuator.

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Vol. 7, Issue 6, June2018

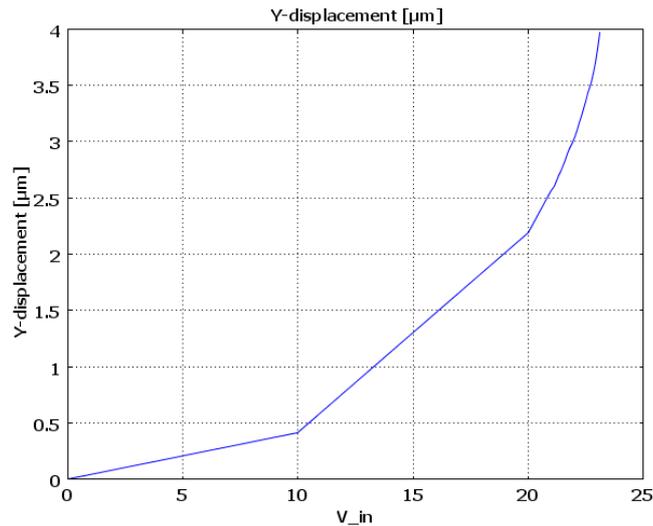


Figure 12: Displacement of trapezium Comb Drive with 10 Fingers.

The figure shows the actuation voltage is reduced to only 23V as compared to 1000V of mono finger comb drive.

V. CONCLUSION

Capacitor is mainly defined as two conducting plates that can hold the opposite charges on it. These plates can be used either as a sensor or an actuator. If the relative distance between the two conductors changes as result of given input, then capacitance values will change. This results in basic of capacitive or electrostatic sensing configuration. On the other hand, if a voltage or the electric field were given across the two conducting plates as the input, an electrostatic force would develop between these two plates. This is defined as the electrostatic actuation. The trapezium shaped comb drive actuator consume less voltage then rectangular comb actuator and by increasing the number of comb fingers. The voltage of 1000V is reduced to 23V.

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Vol. 7, Issue 6, June2018

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