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A Review: Electrostatic Actuators for Microtweezer Application

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Abstract*—Finite element analysis is used to simulate electrostatic actuated, shaped comb drives operating under dc conditions (zero actuating frequency). A dynamic multiphysics model is developed using the Arbitrary Lagrangian–Eulerian (ALE) formulation. Capacitance based actuators have been extensively used in MEMS devices. The comb drives often use rectangular fingers which are simpler to fabricate, this paper explores the use of shaped comb other than the common rectangular comb.*

Keywords*— MEMS,ALE, ENIAC*

I. INTRODUCTION

A quick look-back at the evolution of technologies in our recent history will disclose a well- known fact that the invention of steam engines in 1765 triggered the first industrial revolution, since for the first time in history; "machine control" had replaced "Animal power" in producing and transporting industrial goods. Subsequent developments of machine tools paved the way for the establishment of factories for future mass production of industrial products. The electrification that replaced steam power in the early 20th Century began an era what many of us refer to as the "Second industrial revolution". While the unmatched developments in advanced manufacturing were clearly attributed to the many engineering achievements of the 20th Century one such development was the invention of transistors in 1947 and then the development of IC design and fabrication technologies. With the rapid advances in the IC technology, It is able to produce smaller and faster computers as Feynman so clearly predicted 40 years ago. One noticeable example is the miniaturization of the ENIAC computer-the first digital computer, to today's "palm-top" computer with a 108 times reduction in size and 108 times increase in computational power. Although miniaturization is not even close to what Dr. Feynman dvocated, but it is yet a considerable improvement. The micro fabrication techniques that are used to produce miniature transistors and ICs are completely different from those used in the advanced manufacturing technologies developed in the mid-1990s. These "process-related," but not "machine-tool related" manufacturing technologies has not only triggered the advances in the long sustained success of the microelectronics technology, but it has also opened the door for the manufacturing of miniaturized devices that none of the traditional machine tools could ever produce. Thus this regards the invention of transistors in 1947 to be the beginning of the "New industrial revolution". It has efficiently paved the way to the ultimate miniaturization as advocated by Dr. Feynman over 40 years ago.

II. ELECTROSTATIC ACTUATION

Electrostatic actuation is the most common type of force generation, electromechanical energy conversion scheme in micro-mechanical systems. It is the most excellent example of an energy-storage transducer. Such transducers store energy when either mechanical or electrical work is done on them. Assuming that the device is lossless , this stored energy is conserved and later on converted to the other form of energy. Electrostatic actuation is produced by the electric field of a capacitor. Figure.1 illustrates the two basic configurations of a capacitor for electrostatic actuation of a MEMS device.The parallel plate and the interdigitated comb capacitor configurations. The interdigitated comb capacitor is dominated by the fringe electrostatic field, and the parallel plate capacitor is dominated bythe direct electrostatic field.

In Parallel Plate Capacitor arrangement, one of the plate is made movable by applying V as a voltage. When an electric field is excited between two parallel plates, there will be an attractive force acting on both plates to bring them closer and minimize the electrical potential energy of the system .This produces displacement ,a mechanical form of energy. The energy stored (W) at a given voltage, V is given by equation 2:

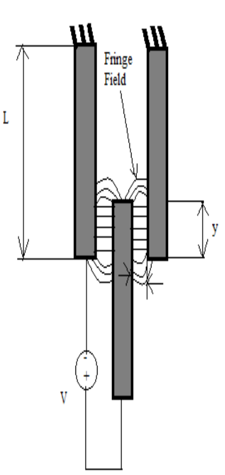
$$W=1/2\,(CV^2)=(\varepsilon AV^2)/2d \qquad (2)$$

And force (F) between the plates is given by equation 3:

$$F=[\varepsilon(AV)^2]/(2d)^2 \qquad (3)$$

Where,ε=permittivity of material between the parallel plates
A=plate area
d=gap between the plates
C =capacitance between the plates

For a fixed voltage, the electrostatic force is inversely dependent on the separation squared between the capacitor plates. So, the electrostatic force drops as the plates get farther apart. This force is also linearly proportional to the plate area. Large area with close gap separation is required for generating force of significant magnitude which imposes fabrication difficulties. For a parallel plate capacitor shown in figure 1(b), the capacitance is inversely proportional to the gap between the capacitor plates and the force is inversely proportional to the gap between the capacitor plates square. The capacitance and the force of the parallel plate capacitor are highly nonlinear.



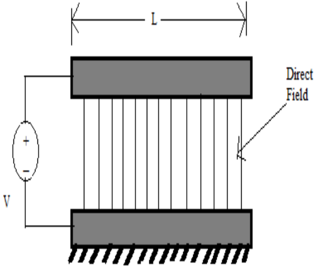


Figure1(a): Interdigitated Comb Capacitor

Figure1(b): Parallel Plate Capacitor

When a voltage under a certain threshold is applied, an electrostatic attractive force brings the plate closer to the ground whereas the displacement induced mechanical restoring force balances the electrostatic force, and system equilibrium is reached when the two forces equate.

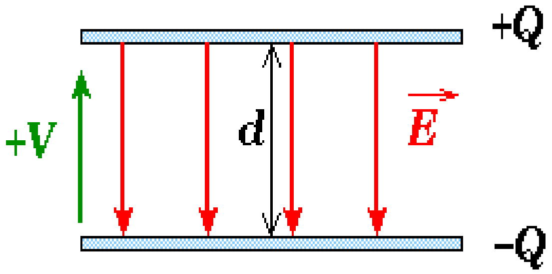


Figure 2: Planar Capacitor Actuator

Though the electrostatic and mechanical forces have different dependencies on the displacement of the plate, and when the voltage exceeds the threshold level, the mechanical force cannot balance the electrostatic force. The plate experience a positive force gradient and accelerates away from that particular equilibrium point. This threshold voltage is the pull-in voltage shown in figure 2.

III. LITERATURE REVIEW

Staircase comb geometry using Polyisilicon and Polyimide as structural materials is compared. Polysilicon is most basic structural material for MEMS devices, with staircase geometry. Polysilicon shows first step of prescribed displacement of upto 0.5 µm starts nearly from 10V to 30V, then a Sharpe change in voltage occur between 30 to 45 V and then again a second slow movement of nearly 0.8 µm takes place between 45 to 70,polyimide which gives 82.3% improvement[1].

Capacitance based actuators have been extensively used in MEMS devices. The comb drives often use rectangular fingers which are simpler to fabricate,this paper explores the use of shaped comb other than the common rectangular comb. Such shaped comb fingers allow us to reduce the actuation voltage. In order to design and analyze shaped fingers, the FEM software package COMSOL is used, using three multi physics modes: electrostatics, plane stress and moving mesh. A triangular geometry design in this paper is 57% more effective than the traditional rectangular comb[2].

Fabricated a microactuator array on a flexible sheet. The design was based on the concept of smart MEMS sheet", a flexible version of autonomous decentralized MEMS. The fabricated actuator array consists of thermally driven cantilever actuators (ciliary actuators) and theflexible sheet is Kapton sheet. Both are made of Polyimide, a flexible material. They succeeded to fabricate 768 actuators on the sheet of 18mm × 24mm and tried to operate it as a 2D manipulator on acurved surface [3].

Finite element analysis used to simulate electrostatic actuated, shaped comb drives operating under dc conditions (zero actuating frequency). The work showshow the different shapes of the comb drives affect the displacement versus actuation voltage curve. A new jagged shape has been tried so as to improve the slippage actuation voltage. Results show the coupled interaction between the electrostatic and mechanical domains of the transducer. The analysis is based on the evolution of electrostatic force versus comb finger engagement. The relationship between incremental lateral displacement and actuation voltage illustrates the potential for stepped movement for a shaped comb drive. In addition, through numerical simulations, this project determines an optimum design for a dc-actuated comb drive, which has controllable force output and stable engaging movement[4].

Successfully developed finite element models to analyze the electrostatic force produced in electrostatic comb actuator. The finite element modelling and analysis is to design comb structure, and its limitation are important for a realistic design. Design objective were to achieve higher actuation force. Since a computational model for design analysis at micro-scale based on FEM had never outdated. With reference to the simulation results, it was fair to say that FEM can be applied to design MEMS components prior to actual fabrication to improve design, and also save time and fabrication cost. Results showed that the comb structure with more fingers and high aspect ratio produce higher actuation force. The geometry of FEM model used for verification would be created exactly the same as the one in real world. The mathematical foundation needs to be revaluated. Stress induced in the components due to actuation force should be addressed[5].

Reducing the gap space between comb drive fingers it can increase its sensitivity i.e. by change in capacitance due to displacement. The minimum feature size of standard fabrication foundries is 2 microns. To reduce the gap beyond a minimum feature size, authors proposed that the comb drive fingers be initially disengaged to facilitate the fabrication of gaps without conventional limits. Post-fabrication assembly however required to electrostatically translate the stator to engage the comb fingers. Previously, researchers had investigated using engaged variable finger widths; however, compared to what this paper propose, the previous method results in a jump in the electrostatic force and non-passive sensing. Through modelling and simulation, it can examine that various stator translation configure and comb drive instability were reduced due to the smaller gap size. MEMS comb drives have been frequently used for electrostatic capacitance sensing. For comb fingers with reduced gap, the capacitance of the plates change by larger amounts as the structure is deflected. Having larger sensitivity to changes in capacitance will improve the device sensing. Moreover, undesirable stray capacitances known as parasitic capacitances often interfere with capacitance sensing. Although the stray capacitances may be minimized by shielding and good layout practices, the parasitic capacitances may limit the charging and discharging of the comb finger plates and affect the sensing. Thus, it is beneficial to have reduced gap space between comb fingers as this gives larger capacitance readouts with smaller displacements, much higher than the noise from stray capacitances, to greatly improve accuracy in sensing. MEMS comb drives uses capacitive sensing in measuring physical variables such as acceleration or pressure[6].

Fabricated a device which requires just over 45V for closing the gripper and which may find applications in microrobotic arms and also concluded that a lower pull-in voltage could be achieved through optimization of the restoring springs. The parallel plate configuration can be a good approach for realizing switching actuators where intermediate position control is not of concern. Parallel plate electrostatic actuators occupy a smaller area than that needed by a comb-drive design for a given output force and are more suitable for the typical postprocessing and microassembling handling that is required in the realization of complex micromachines[7].

IV. RESEARCH METHODOLOGY

The research will be carried out by COMSOL tool at circuit level. The simulation at circuit level will be done to verify the feasibility of proposed design. By designing various structures we can analysis various parameters of the actuator and then find out the best for required biomedical application.

IV.CONCLUSION

The MEMS comb drive is a laterally driven mechanical actuator activated by electrostatic interaction. A rectangular shaped comb drive design requires simple fabrication steps and it is characterized by low power consumption. Low actuation power consumption is favorable not only for economic reasons, but also for heat generation considerations. Large deflection comb actuators at low driving voltage should employ structures with large amount of comb fingers and minimum distance between the comb fingers. This designed structure can be mainly used as a microtweezer actuator for application in areas such as biological sample handling. Polysilicon is an attractive material for high strength applications i.e. commonly used for mechanical elements. For MEMS materials like polymers, ceramics, and metals alloys can provide the opportunity to create flexible MEMS structures. Microscale actuators can also make use of the low modulus of the structural materials like polymers, alloy and displacements at smaller actuation voltage and force can be achieved.

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