# Simulation and Design of a Combo Electrostatic Micromotor for MEMS

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## Abstract
In this article, the design of a combo electrostatic micromotor for applications in MEMS is designed using CAD INVENTOR software. Its working parameters are analyzed in ALGOR through electrostatic finite element analysis (FEA). COVENTOR is used to define the stages of the manufacture process and for the device manufacturing, the PolyMUMPs process is proposed, which is a general purpose process for micromachining.
**Keywords:** Simulation, MEMS, micromotor, finite element analysis.

## 1. INTRODUCTION

MEMS (MicroElectroMechanical Systems) are the result of the integration of mechanical elements, sensors, actuators and electronic elements in a same substrate, general of millimetrical silicon are an improvement in the manufacturing processes that have improved capacities in comparison with conventional devices, above all regarding the miniaturized dimensions, cost, reduction in energy consumption, performance, reliability, and easy interconnection with multiple systems, in which the scale of all the elements is therefore microscopic. Its application impacts a wide range of sectors, such as the automobile, telecommunications, information science, medicine, consumer products and in general those that use automation systems as tool or product [1].

Silicon is the main material used to create MEMs. This is due to the fact that the Micro-technologies have risen from microelectronics and taking their processes and techniques, especially designed to work with silicon as a starting point. Given humanity's current need to solve problems that can give better quality of life, it is essential to increase MEMS research. A variety of new commercial products has risen, not due to the well established electronic properties, but rather due to its optimum mechanical properties [2]. With the development of the MEMS, programming tools have begun to rise to simplify the analysis and the design of each of the elements. One of the basic elements in MEMS is the micro-motors, that due to their micrometric structure they cannot be like the standard motors known. For this reason, it is thought that the proposal of combo electrostatic micromotor can satisfy some of the existing needs.

## 2. BACKGROUND

The debate surrounding the advantages of electrostatic actuators regarding the magnetic actuators, especially in micro-motors have been a motive of research in the area of MEMS during the last two decades. Fujita argues in favor of the electrostatic devices due to the attributes of the micromachining surfaces [6]. Micromotors have fascinated the MEMS community; in the 60's, the first electric motor of only 1/64 inches was built [7]. Currently, micromotors continue to be developed based on the concept of combo structure and linear combo.

The geometry of the combo micro-motor elements is made up of two rigid flat structures and one mobile. The second carries out the function of stator. The microstructure has the shape of a "comb with curved elements". This type of geometry can be applied in longitudinal, lateral, and vertical shift. In this case, it will be applied in a lateral shift.

All the electric micromotors have two basic components- a rotor and a stator. The rotor, which in many cases is made up of movable parts, has conductors which produce and form a magnetic field that interacts with the magnetic field generated by the stator. For the analysis, the microstructure is divided into two parts, inertial and electrostatic. The inertial is formed by two toothed side walls fixed to the substrate which impedes its shift. The electrostatic is formed by the toothed central structure, which carries out the function of stator. The position of the stator depends on the capacitance and force between the elements of the fixed part and the elements of the mobile part. The electrical behavior is modeled by a network of variable capacitors formed by each one of the structure's elements.

The force and capacitance are determined by approximations of the electrical field between the conducting components of the structure. The electrical field is calculated assuming the following approximations- 1) The shift of the fingers of the micromotor is small, so the electrical field between them is quasi-static, 2) according to the principle of superposition, the electrical field can be decomposed in partial fields; only the neighboring elements interact. The interaction of distant elements is unseen due to the weakening of the lines of the electrostatic field, 3) the degree of mechanical freedom of each one of the movable fingers is reduced to translation movements; therefore, the fingers are always parallel one to the others, 4) the tension between the fingers is constant and equally distributed, 5) all the fingers are rigid, and 6) the whole structure is flat.

## 3. DEVELOPMENT

The design is divided into three stages- A) design of the microstructure in INVENTOR, (B) analysis of parameters by finite element in ALGOR, and (C) manufacturing process in COVENTOR

### A. Design of the microstructure

The design of the microstructure of the motor was carried out in the CAD INVENTOR software, obtaining the drawing in three dimensions. For its design, the following properties were considered- origin in the xy plane, the orientation of the structure regarding the x axis, radius, longitude and width of the "fingers", as well as the distance between them.

In the real system, the element between the fingers is the air, but the finite element analysis (FEA) does not consider the contact between pieces separated by air, and therefore, the simulation cannot be carried out. To solve this problem, two pieces are included in CAD, located between the fingers of the fixed part and rotor, to give continuity to the mesh and to make the electrostatic simulation. In Figure 1, the geometry of the microstructure is shown; the dimensions are in microns.

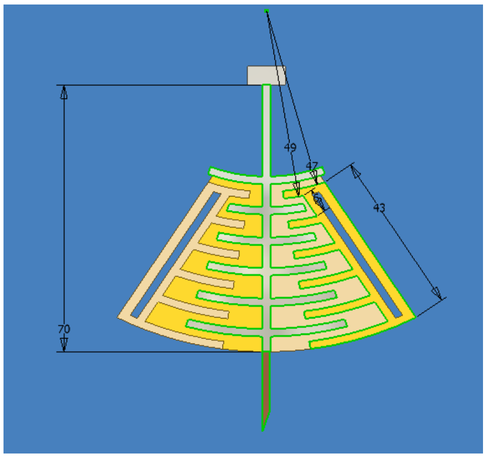


Figure 1. Geometry of the combo micro-motor.

### B. Analysis of parameters

The file with the microstructure of the motor is exported to ALGOR to carry out the analysis of parameters by the computerized method of finite element analysis (FEA) and predict the effects of the electrostatic forces acting on the elements of the same. To calculate the electrostatic forces it is necessary to carry out a multi-variable analysis; that is, for the electrical fields they are calculated according to the tension applied, and then the electrostatic forces are determined according to the electrical field. In Figure 2, the distribution of tension in the microstructure elements is shown.

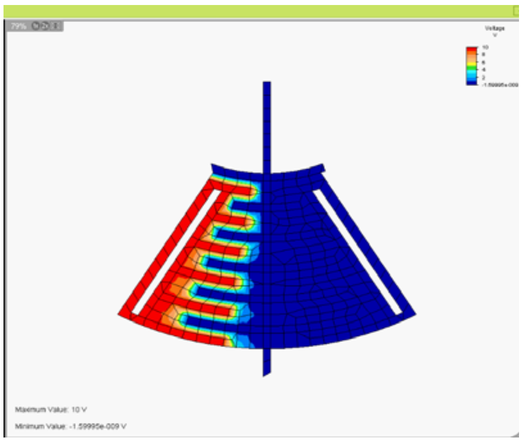


Figure 2. Distribution of tension.

The electrical field is calculated with the Electrostatic Field Strength and Voltage analysis. The electrostatic forces that produce the electrical fields are calculated with the Static Stress with Linear Material Model analysis.

The process for the Electrostatic Field Strength and Voltage analysis is: a) Create the node network and elements that represent the model of the FEA analysis, b) define the units, c) define the global properties of the model, d) define the properties of the elements, e) apply the tension and border conditions that will create the electrical fields, f) assemble the matrixes of the electrostatic elements, and g) solve the equations and calculate the results. In Figure 3, the intensity of the electrical field generated by the tension applied is shown.

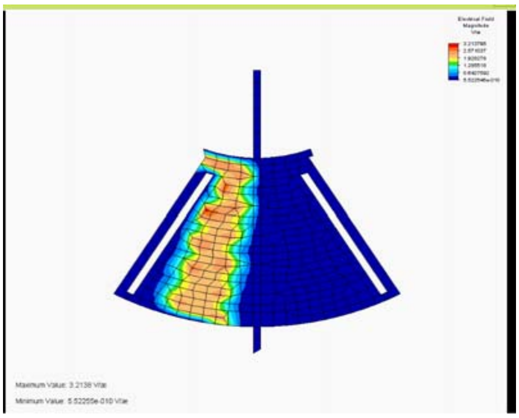

Figure 3. Electrical field.

The electrostatic analysis is carried out taking into account the mathematical model described by the partial differential equation of POISSON,

$$\nabla(\varepsilon\nabla\Phi) = Q \qquad (1)$$

where,

$\varepsilon$ is the permittivity or conductivity of the material.

$\Phi$ is the distribution of the potential.

$Q$ is the load density per unit of volume.

The electrical field in a point is defined as,

$$E = -\Delta\Phi \qquad (2)$$

The analysis process "Static Stress with Linear Material Model" generates the mechanical forces applied to the microstructure is begun with the electrical field determined in the electrostatic analysis. The model is transferred to the ALGOR Superdraw interface and the electrostatic forces are applied to the selected surfaces of the microstructure. In Figures 4 a and b, the result of this stage is shown.

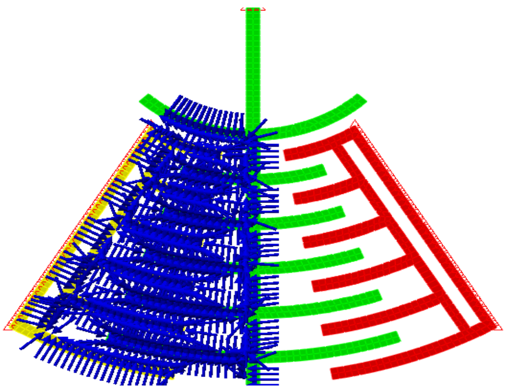

Figure 4a. Forces applied to the microstructure.

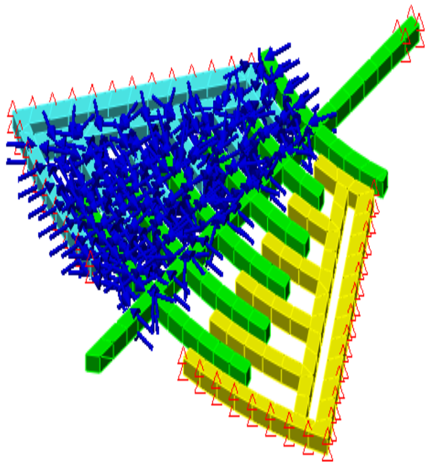

Figure 4b. Force applied to the microstructure.

Once the forces are applied on the indicated surfaces, the simulation follows. The results are presented in Figures 5 a and b. In Figure 5 a, the shift of the rotor to the left of its resting point is shown. The shift the other way is achieved by modifying the curve of application of the structure force.

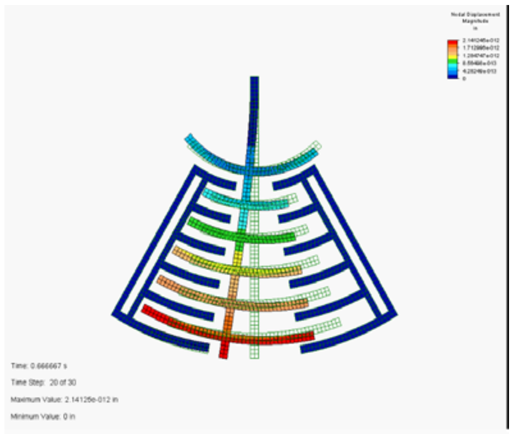

Figure 5a. Rotor shift to the left.

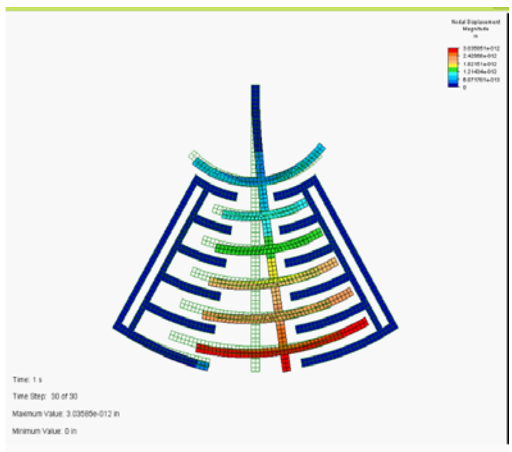

Figure 5b. Rotor shift to the right.

### C. PROCESO DE MANUFACTURA

*Coventor* offers the “CoventorWare” emulator and a virtual tool that generates the exact and detailed representation in 3D, through which one can determine the stages of the manufacture process. For this purpose, the standard PolyMUMPs process is used which forms part of the commercial program MUMPs[3,4,5], and whose surface micromachining process is made up of three poly silicon layers; the specific characteristics of the process are presented in the “Process Editor” as shown in Figure 6a.

ProcessEditor: C:\casho\Design_Files\PolyMumps\Devices\PolyMUMPS.proc

File Edit View Help

| Step | Action | Type | Layer Name | Material | Thickn... | Color | Mask Name/ Polarity | Depth | Offset | Sidewall Angle |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | Base | | Substrate | SILICON | 50.0 | blue | GND | | | |
| 1 | Deposit | Planar | POCL3 | SILICON | 1.0 | cyan | | | | |
| 2 | Deposit | Planar | NitSil | SI3N4 | 0.6 | white | | | | |
| 3 | Deposit | Planar | Poly0 | POLYSILICON | 0.5 | oran... | | | | |
| 4 | Etch | Front, Last L... | | | | oran... | POLY0 + | 0.5 | 0.0 | 0.0 |
| 5 | Etch | Front, Last L... | | | | light... | HOLE0 - | 0.5 | 0.0 | 0.0 |
| 6 | Deposit | Conformal | 1erOxido | PSG | 1.25 S... | yello... | | | | |
| 7 | Deposit | Conformal | 1erOxid... | PSG | 0.75 S... | yello... | | | | |
| 8 | Etch | Front, Last L... | | | | pink | DIMPLE - | 0.75 | 0.0 | 0.0 |
| 9 | Etch | Front, By De... | | | | yello... | ANCHOR1 - | 2.0 | 0.0 | 0.0 |
| 10 | Deposit | Conformal | POLY1 | POLYSILICON | 2.0 S... | green | | | | |
| 11 | Etch | Front, Last L... | | | | green | POLY1 + | 2.0 | 0.0 | 0.0 |
| 12 | Etch | Front, Last L... | | | | dark... | HOLE1 - | 2.0 | 0.0 | 0.0 |
| 13 | Deposit | Conformal | 2doOxido | PSG | 0.75 S... | light... | | | | |
| 14 | Etch | Front, Last L... | | | | red | POLY1_P... - | 0.75 | 0.0 | 0.0 |
| 15 | Etch | Front, By De... | | | | mag... | ANCHOR2 - | 2.75 | 0.0 | 0.0 |
| 16 | Deposit | Conformal | POLY2 | POLYSILICON | 1.5 S... | dark... | | | | |
| 17 | Etch | Front, Last L... | | | | dark... | POLY2 + | 1.5 | 0.0 | 0.0 |
| 18 | Etch | Front, Last L... | | | | medi... | HOLE2 - | 1.5 | 0.0 | 0.0 |
| 19 | Deposit | Conformal | METAL | GOLD | 0.5 S... | light... | | | | |
| 20 | Etch | Front, Last L... | | | | light... | METAL + | 0.5 | 0.0 | 0.0 |
| 21 | Etch | Front, Last L... | | | | cad... | HOLEM - | 0.5 | 0.0 | 0.0 |
| 22 | Sacri... | | | PSG | | | | | | |

Figure 6a. Process editor

The layers obtained using different growth techniques are shown in Figure 6b.

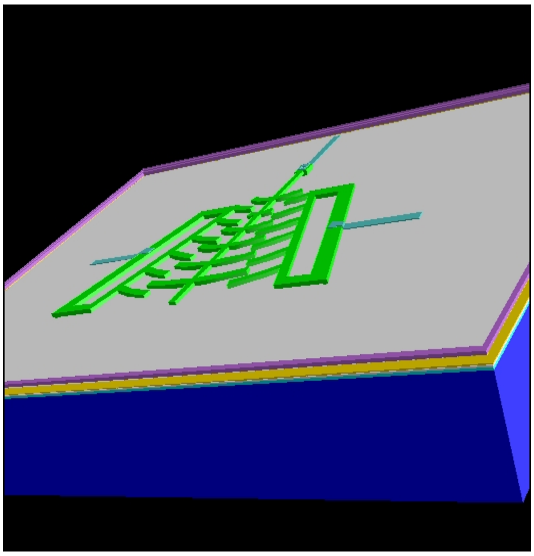

Figure 6b. Growth layers of the COMBO radial micromotor

The MEMS rotor and stator can be better seen in figure 6c.

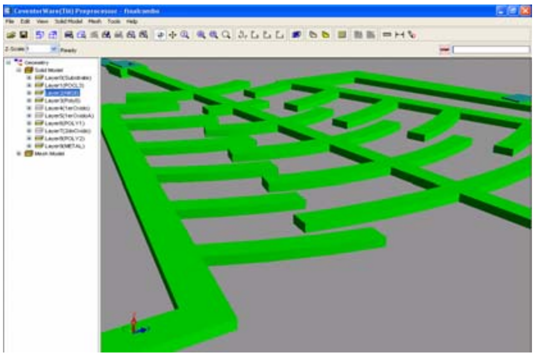

Figure 6c. COMBO Micro-motor

In the xz plane of the Figure 6d, one can see with greater precision the combination of the mechanical parts with the electronic parts.

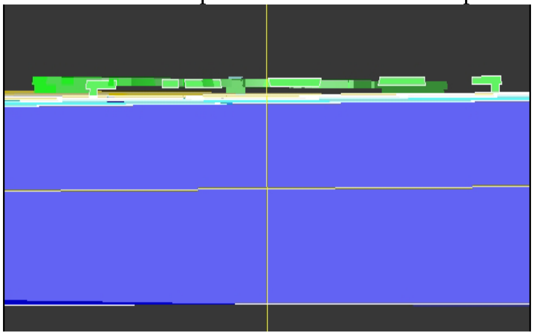

Figure 6d. Cross-section view of the combo micro-motor

## 4. CONCLUSIONS

The working of the combo micromotor was designed and simulated. The results show the feasibility of its manufacture. With a feeding tension of 10V. The manufacture process was also simulated, putting in detail the stages and masks to use. Upon concluding the manufacture, the micro-motor can be characterized as for example the value of torque and its response time to the excitation signal and some other properties of interest for the specific applications.

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