Design a Capacitive Sensor

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1 Abstract

The comb-drive actuator is widely used for microelectromechanical systems (MEMS). it usually operates at micro- or nanometer scale. the comb drive is considered as a capacitor but with an array of fingers which gives better capacitance. Such capacitors provide alternative fabrication and operation modes compared with parallel-plate capacitors. They involve interdigitated fingers (IDT) to increase the edge coupling length. It can be manufactured using any metal but it is preferred to be silicon. In this project we are aiming to design a capacitive sensor, test it before being fabricated, measure the capacitance, plot the potential and electric field using COMSOL simulator.

2 Introduction

Comb drive consists of two combs each one with specific number of teeth and specific gabs between them. One of these combs in fixed in the substrate and the other one is free to move to get closer and away from the fixed comb. The fixed comb is grounded and the movable one has an applied voltage that changes the displacement between the two combs as shown in figure (1)

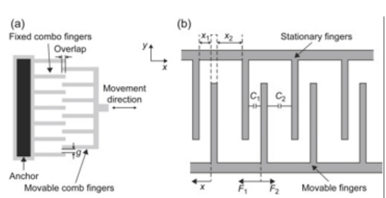

Figure 1: Comb-drive actuator

Each comb has got certain no. of fingers separated by gaps. these gaps should be as small as possible. However, it could be limited by: lithography resolution.

It should be taken into consideration also that the greater the thickness of the comb the larger the capacitance obtained. The fringe capacitance is pronounced but difficult to be estimated analytically. The most accurate way to estimate the fringe capacitance is by using finite element method, which is a popular method for numerically solving differential equations arising in engineering and mathematical modeling. Therefore, we are going to use comsol simulator to figure out the capacitance of our sensor by solving Poisson equation.

$$\nabla^2 = \frac{-\rho}{\epsilon}$$

3 Methodology

First of all, we are going to design the sensor given some dimensions and specifications of the geometry.

3.1 Comb design

The first comb of depth =4um mainly consists of 5 fingers so, we built 6 blocks and set their dimensions and positions as follow: the first block which is the body of the comb is of L=30um and w= 15*4+5*5=85um.
The rest 5 blocks which are the comb fingers are of the same dimensions but different position where their x-position changes as it decreases about 20um as we go right so, the final result will be as shown:

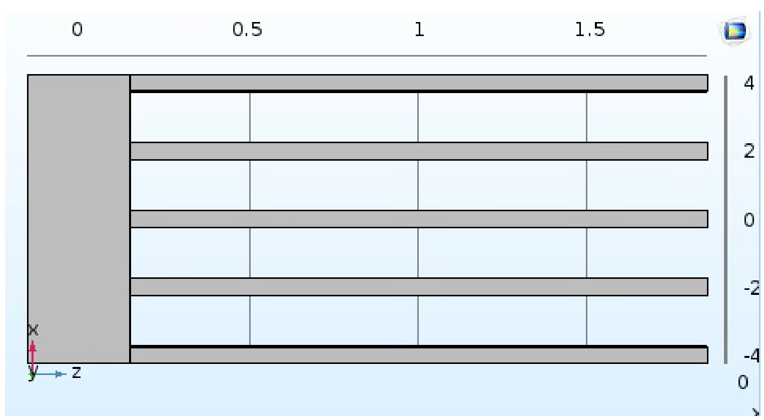

Figure 2: The first Comb

The 2nd comb is of the same depth=4um. We are going to generate 5 blocks.
The first block has dimensions L=30um and w=4*5+15*3=65um. The rest 4 blocks are of the same dimensions as the fingers of the first comb and only their position changes with the same rate as the distance between each finger= 15um so we shifted 20um in the -x direction.

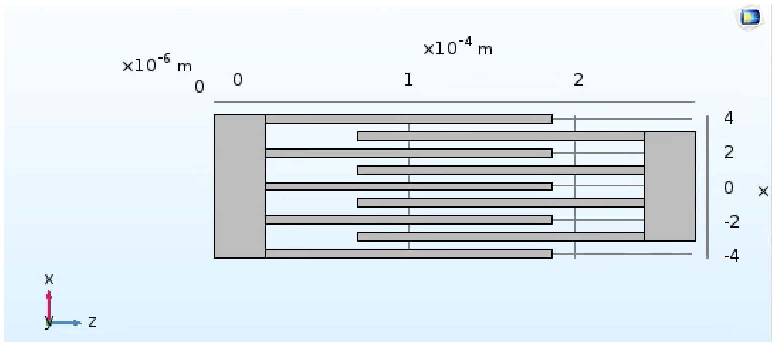

Figure 3: The second Comb

After building the 2 combs we are going to union the components of the first and second comb to act as 2 blocks only.

3.2 Substrate design

In this step, we are going to build a block of depth=10um, L and W bigger than that of the 2 combs which is going to be L=300um and w=150um and we'll set it bellow the 2 combs neglecting any space so that they seem to be touching each other. The final result of the design is going to be as shown:

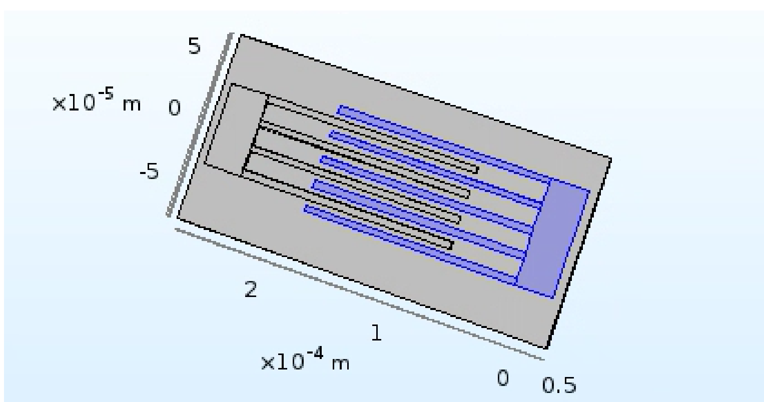

Figure 4: The sensor design

3.3 choosing material

As known, about most of the comb drives are made of silicon which has permittivity about 11.7. However, we preferred to add a blank material in order to be able to freely select its permittivity. We applied the material on the whole figure and put its permittivity to be about 11.9 as declared in the project description.

3.4 The electrostatic module

In this section we applied the specified boundary conditions as we applied 4V on the first comb on the right side and we connected the terminals of the second comb to the ground; then, we generated a parametric sweep by defining a parametric value= D which ranges from 0 to 65 in order to make the 2 combs start moving in and out and then we studied the capacitance at each D value so that finally we could graph it.
Finally, we applied mesh to the system and we chose it to be extra fine.

4 Analytical solution

given that

$$C_t = \frac{\epsilon_0 \epsilon l_0 t}{d}$$

where l0 is the common length and t is the comb thickness and

$$C_f = \epsilon_0 \frac{wl}{G}(1 + ln\frac{2\pi w}{G})(1 + \frac{G}{\pi l}(1 + ln\frac{2\pi l}{w}))$$

where L is the Length of comb finger, W is comb finger Width and G is the gap between the comb fingers.

$$\therefore C = C_f + C_t$$

substituting by our numbers which are:

$$C_t = \frac{11.9 * 40 * 10^{-6} * 4 * 10^{-6} \epsilon_0}{5 * 10^{-6}} = 1.685 * 10^{-14}$$

$$C_f = \epsilon_0 \frac{5 * 10^{-6} * 0.00017}{5 * 10^{-6}}(1 + ln\frac{2\pi * 5 * 10^{-6}}{5 * 10^{-6}})(1 + \frac{5 * 10^{-6}}{0.00017\pi}(1 + ln\frac{2\pi * 0.00017}{5 * 10^{-6}})) = 3.034 * 10^{-15}$$

$$C = C_f + C_t = 1.988 * 10^{-14}$$

using different values of D and graphing them in excel sheet will be as shown:

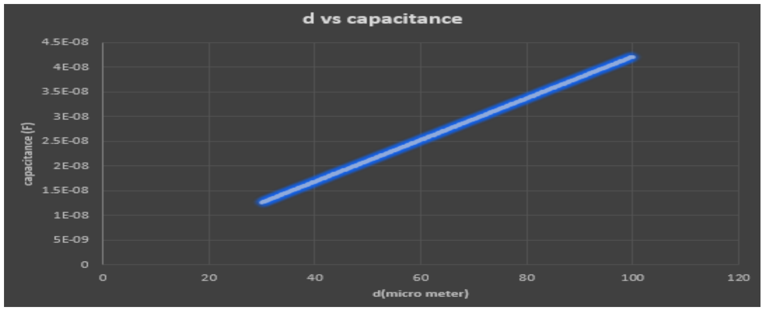

Figure 5: D vs Maxwell capacitance graph

5 Results

Finally, after designing the whole sensor and applying the voltage in the terminals, now we can measure the capacitance, electric field and electric potential distributions.

5.1 Capacitance vs displacement

In the results section in comsol, we plotted a graph between capacitance and the parametric D to show the behaviour of the capacitance as the 2 combs start to move near to each other.
To demonstrate the relation between the displacement of the movable comb and the value of capacitance we used [definitions: global value probes: terminals: maxwell capacitance], then we get the relation as shown in figure (6):

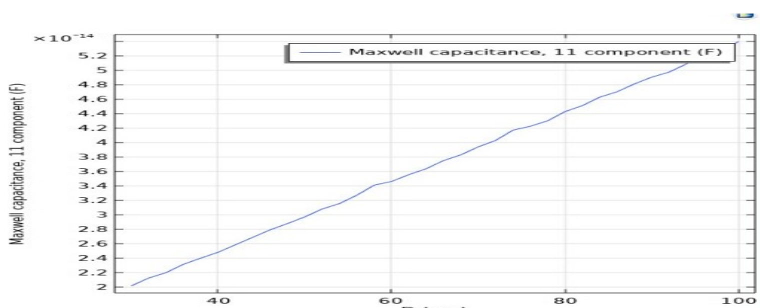

Figure 6: D Vs Maxwell capacitance graph

The prvious graph showed that the capacitance resulted from comsol at D= 40um is about 2.5*10-14 so the error value will be

$$\therefore \epsilon_r = \frac{1.98 - 2.5}{1.98} * 100 = 25\%$$

5.2 Electric Potential and electric field distribution

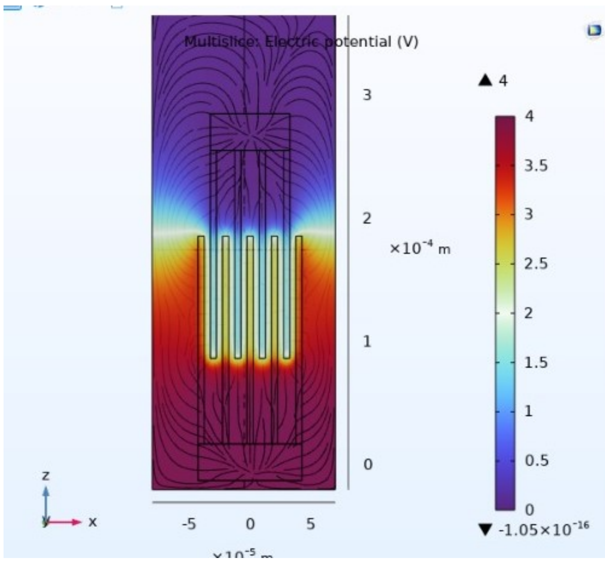

Fig7: The electric potential distribution

Go to volume with expression [es.EX] and plot:

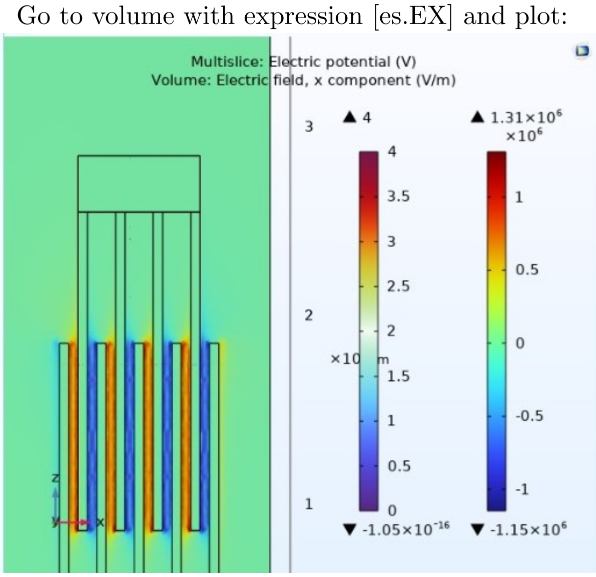

Fig8: The electric field distribution

6 References

[1]Cai, C. and Qin, M. (2016) Fringing capacitance and tolerance of Drie effect on the performance of bulk Silicon Comb-drive actuator - microsystem technologies, SpringerLink. Springer Berlin Heidelberg. Available at: https://link.springer.com/article/10.1007/s00542-016-3014-0 (Accessed: January 28, 2023).

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