Metal MEMS Membrane Based Electric Field Sensor

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Introduction: Measuring the electric field under the HVDC transmission lines is important for power utilities, as well as atmospheric analysis. Field mills are conventional devices for measuring the DC electric fields, however do to their high power consumption, there is an interest for using low power devices such as micromachined electric field mills (MEFMs) instead. In [3], our group developed an electrostatic force deflected membrane based sensor. Roncin et al. implemented a laser deflection measurement system (Figure 1) for measuring the deflection of the membrane. The problem with the laser system was large power consumption, therefore a subsequent version of the sensor was designed to use capacitive interrogation of the deflected membrane position (Figure 2) [4]. The metalized membrane will be deflected to the voltage source due to the electrostatic force and the deflection will result in the change of the capacitance between membrane and the electrode beneath. The first generation of the sensor has been successfully fabricated in an SOI wafer process, and tested. However, the SOI wafers are expensive, therefore, in order to reduce the cost of fabrication electroplating of the low stress thick metals instead of SOI wafer could be an alternative. The other benefits of electroplated thick films (copper or nickel) are their robustness. Therefore, our group is designing the next generation of our sensors with electroplated copper.

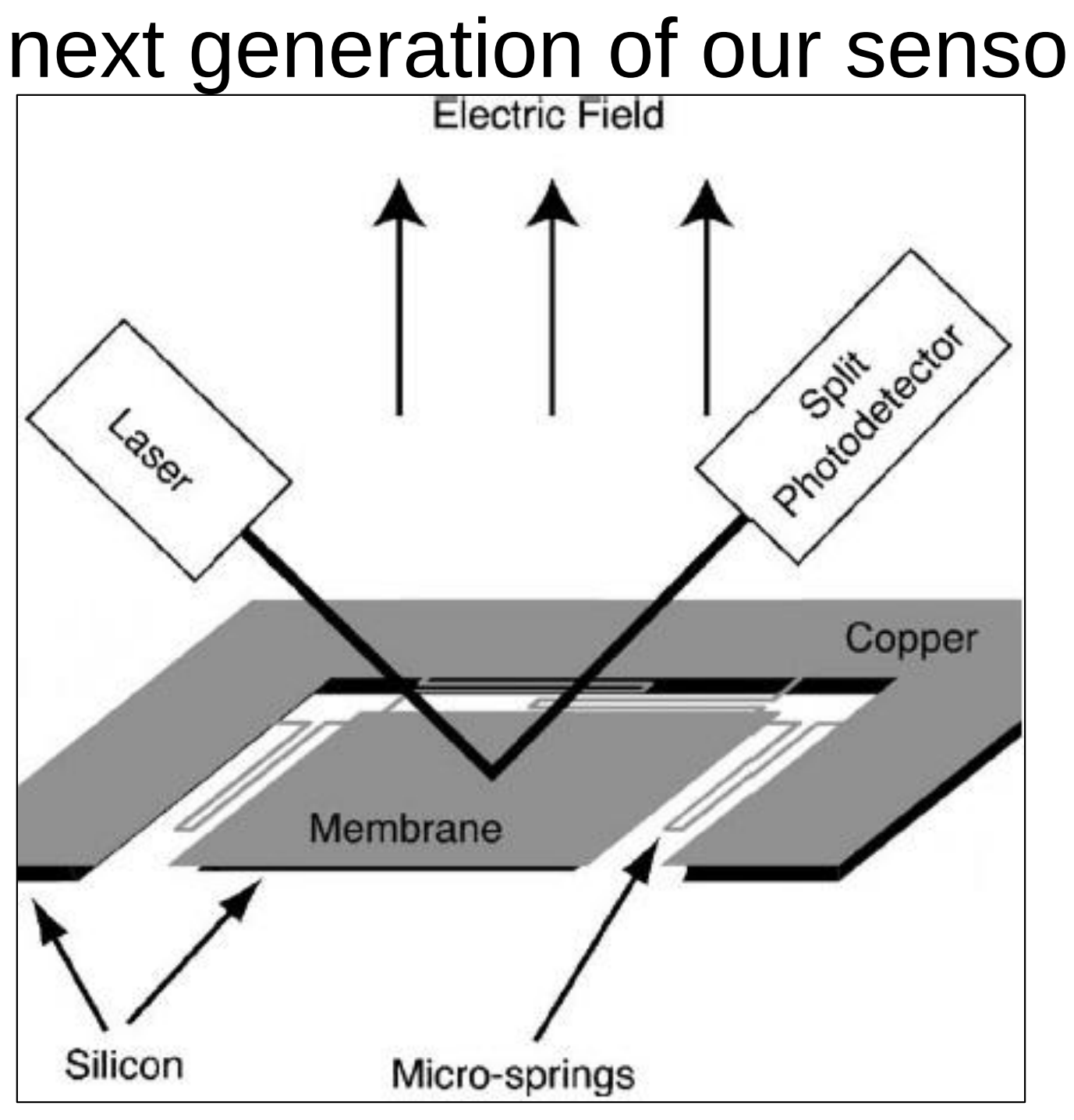


Figure 1: Laser deflection measurement system.

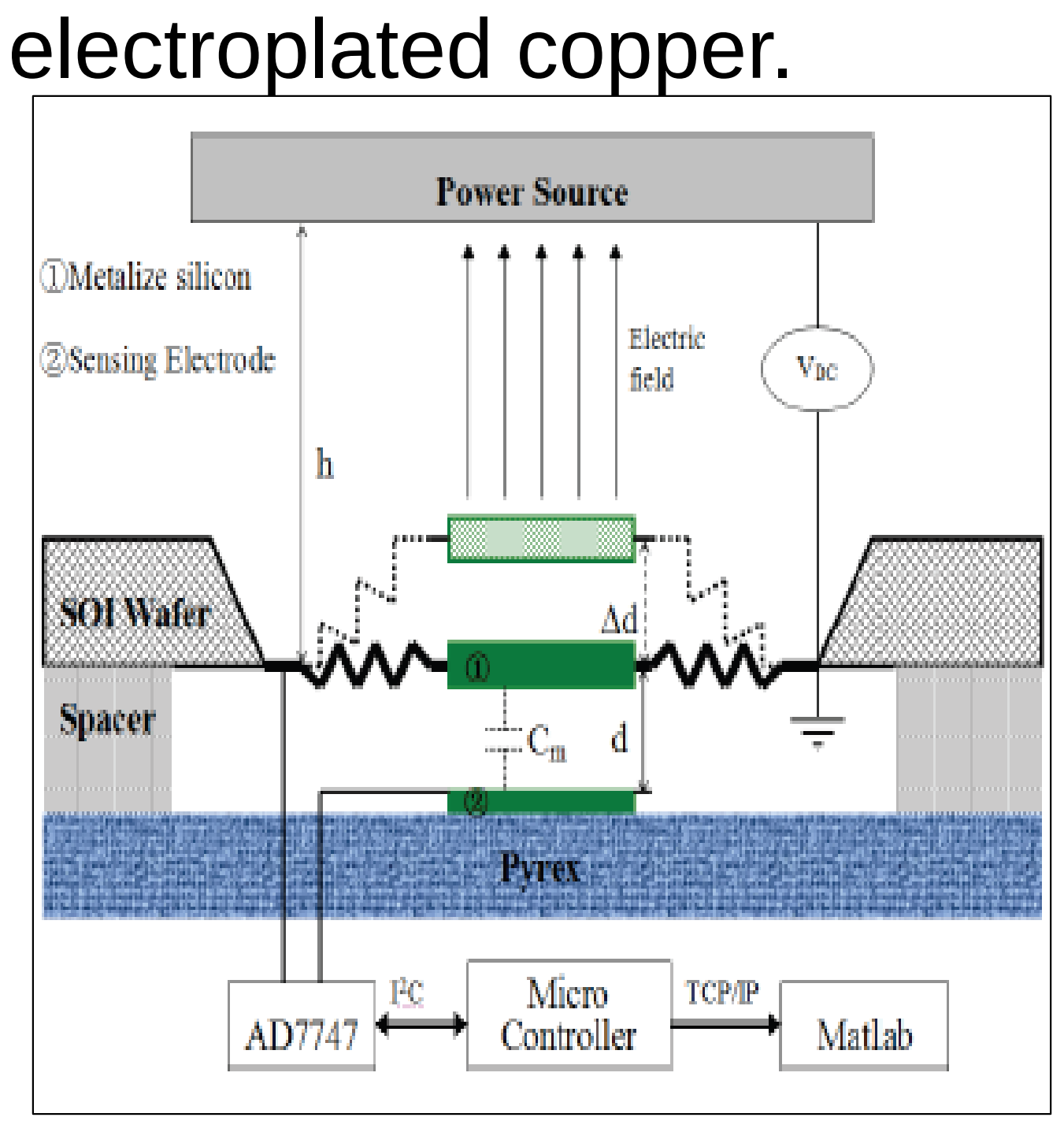


Figure 2: Laser deflection measurement system.

Sensor Design and Operation Principle:

The sensor consists of a membrane that is suspended by the four springs (Figure 3). The membrane measures 1 mm x 1 mm and the springs are 30 µm wide with width of 470 µm. The whole membrane structure and springs are made of copper, and the ends of the springs are fixed by connecting to a copper substrate. Two sets of simulations have been done with 5 µm and 10 µm as the thickness of the membrane and springs. These thicknesses are chosen to have a robust and flexible membrane at the same time. The relationship between the incident electric field that causes membrane motion, and the variation of the capacitance measured by the position sensing electrode, derived by Chen et al. [6].

$$\Delta C = \frac{C_{\mathrm{m\,initial}}^2}{\frac{2k}{E^2} + C_{\mathrm{m\,initial}}}$$

where $\Delta C = C_{m\ initial} - C_{m\ final}$.

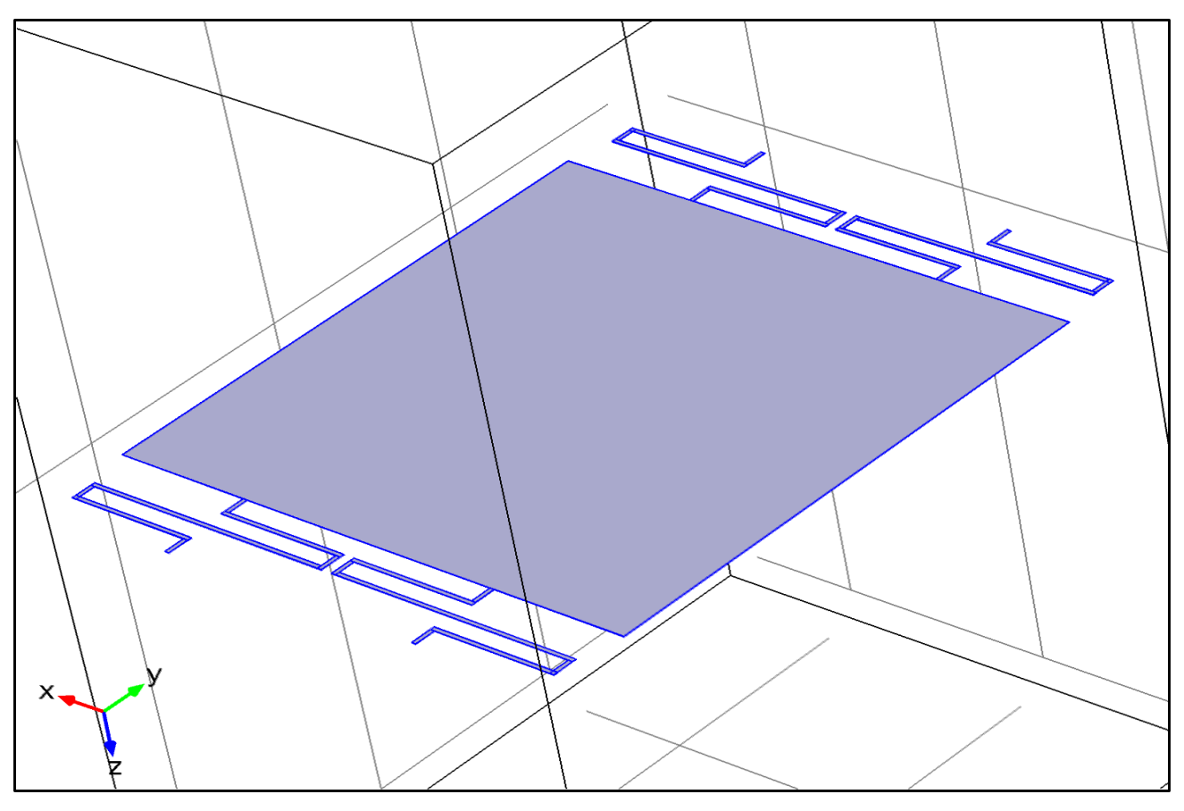


Figure 3:sensor structure.

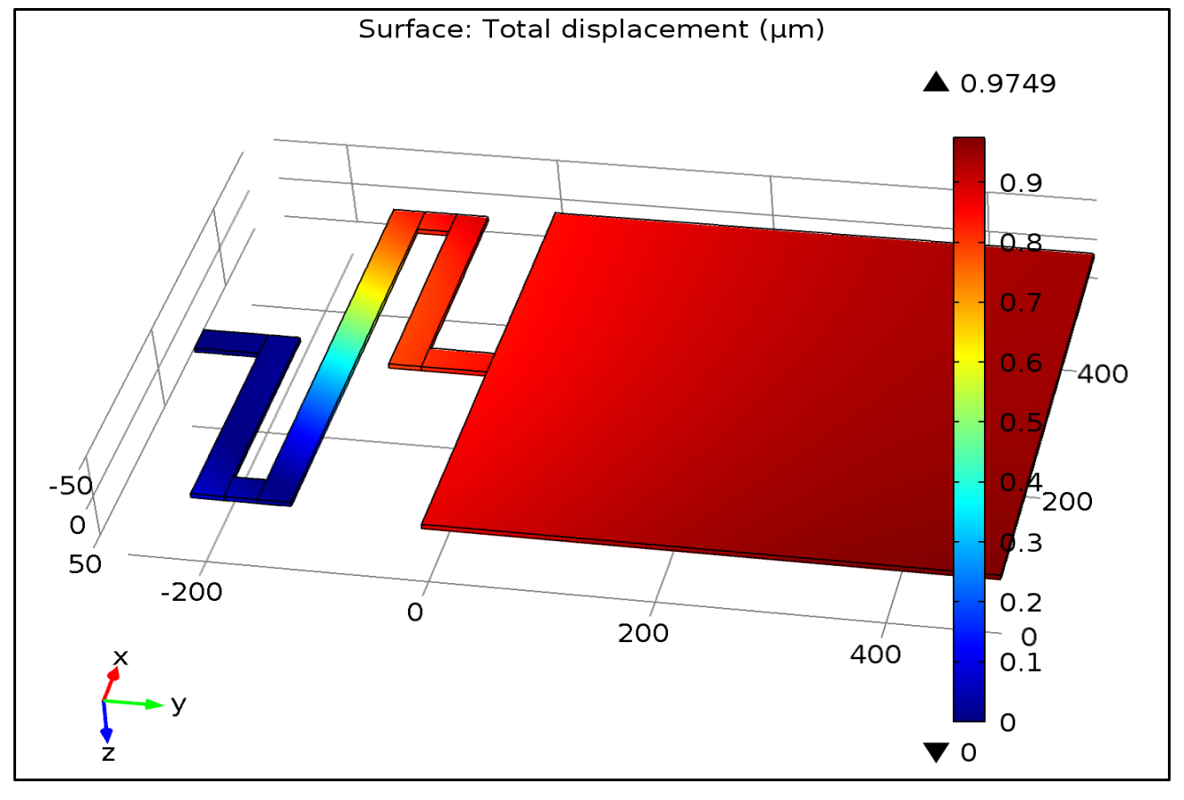
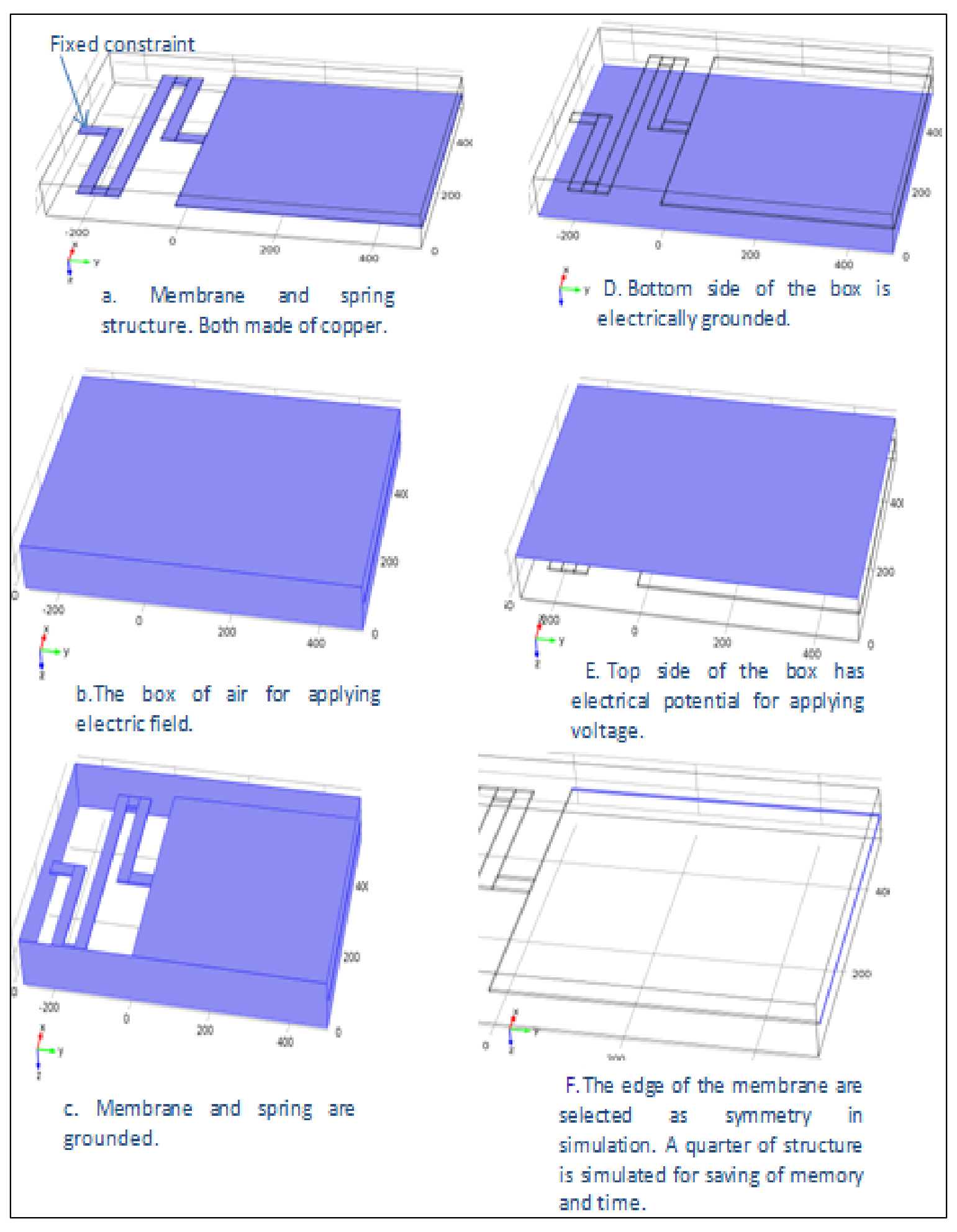


Figure 5:deflection of the membrane.



a. Membrane and spring structure. Both made of copper.

D. Bottom side of the box is electrically grounded.

b.The box of air for applying electric field.

E. Top side of the box has electrical potential for applying voltage.

c. Membrane and spring are grounded.

F. The edge of the membrane are selected as symmetry in simulation. A quarter of structure is simulated for saving of memory and time.

Figure 4: Applied conditions.

By using symmetry, only a quarter of the sensor has been simulated in order to save time and memory. A box of air is surrounding the sensor in the model and an electrical potential is applied to the topside while the springs, membrane and bottom side of the box are electrically grounded. The end of each spring is defined as a fixed constraint.

Simulations and Results:

The previous version of the sensor [6] was a silicon based. Since the membrane of this paper will be made entirely from copper, the first set of simulations should be done to check the range of the deflection of membrane, in order to see whether the new design have enough deflection range to be sensed with the capacitance interrogation system. Second, the model should determine if results are agree with theoretical expected values.

Table 1: Simulation results for membrane sensor deflection

Electric Field	10 (kV/m)	50 (kV/m)	100 (kV/m)	500 (kV/m)	1000 (kV/m)
5 µm thick copper membrane	3.77e-4	9.33e-3	0.0374	0.975	4.55
10 µm thick copper membrane	5.98e-5	1.49e-3	3.98e-3	0.151	0.616

Table 2: Theoretical expected values for membrane sensor deflection

Electric Field	10 (kV/m)	50 (kV/m)	100 (kV/m)	500 (kV/m)	1000 (kV/m)
5 µm thick copper membrane	4.23e-4	10.6e-3	0.0422	0.106	4.22
10 µm thick copper membrane	6.41e-5	1.60e-3	6.41e-3	0.160	0.641

This sensor system can also be implemented for the measurement of AC electric fields. This is only possible when the membrane's resonance is higher than the AC field frequency, and if air drag effect is minimized. For studying this situation a new model for the sensor designed with holes. . Holes added to the surface of the membrane reduce its mass and allow for air flow through the membrane, However the electrostatic force should be measured to see if there is any reduction in senor sensitivity.

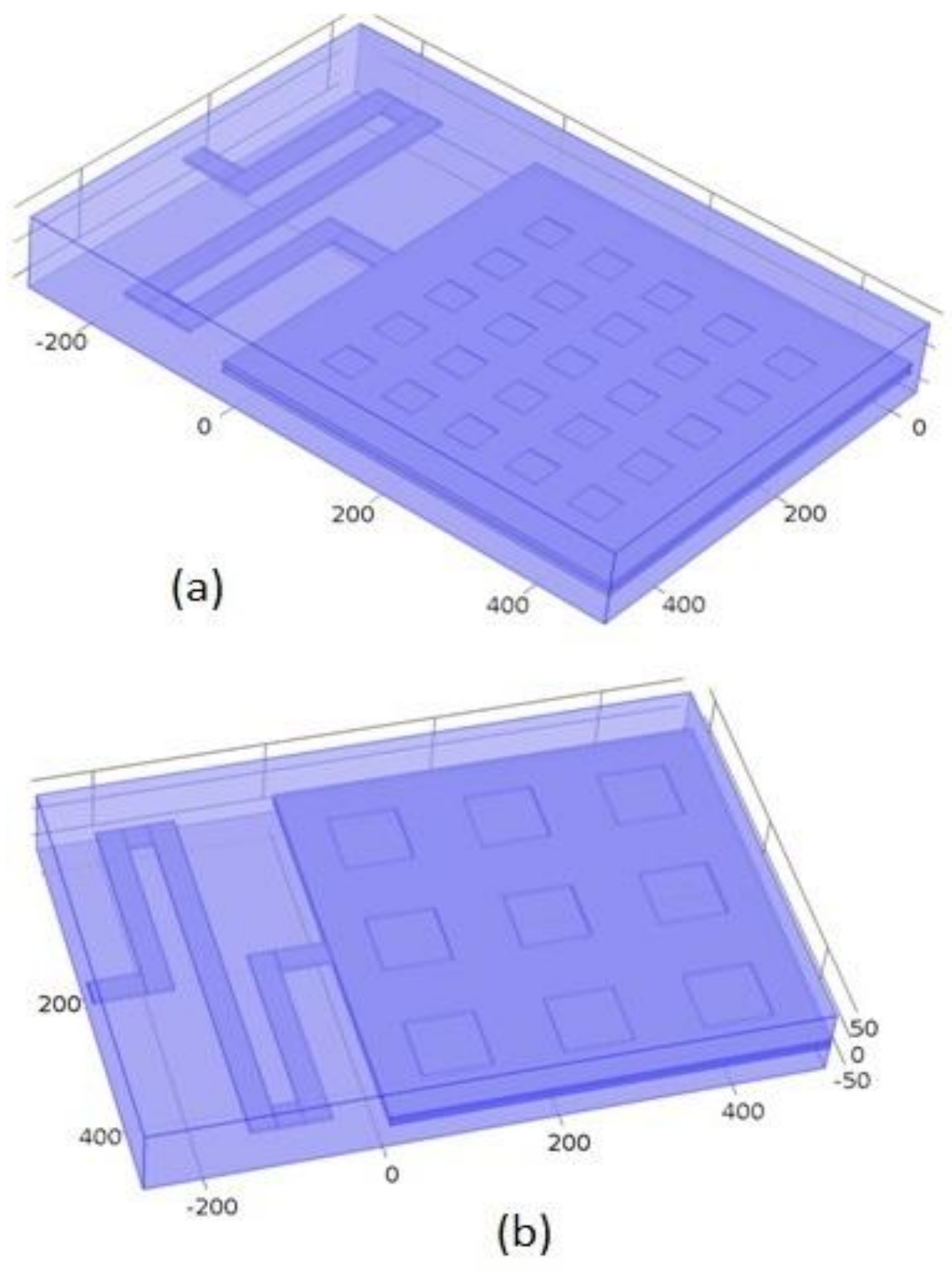


Figure 6:Membrane design with 50% duty cycle holes.

Table 3: Total charge at the surface and the lower electrode

Hole size	Q1: Membrane charge (C)	Q2: Underlying electrode charge (C)
No holes	-5.59e-14	-5.64e-16
10x10 µm	-5.57e-14	-5.62e-16
20x20 µm	-5.51e-14	-6.29e-16
30x30 µm	-5.44e-14	-8.36e-16
40x40 µm	-5.36e-14	-1.10e-15
50x50 µm	-5.32e-14	-1.41e-14
60x60 µm	-4.99e-14	-2.67e-13

Table 4: Total charge at the surface with 50% duty cycle holes

Hole size	Q1: Membrane charge (C)	Q2: Underlying electrode charge (C)
20x20 µm	-4.84e-14	-2.23e-16
40x40 µm	-4.49e-14	-3.70e-16
80x80 µm	-4.00e-14	-6.22e-15

Conclusion:

For DC electric field measurement simulations, the electrostatic force applied to the membrane deflects the membrane vertically towards the field. The deflection of the membrane has been calculated from both theory and simulation by COMSOL. Comparing the simulation results and the expected theoretical values shows that the model is working properly and this design potentially is a proper design for the sensor. In addition, the range of the deflection of membrane is large enough to be detected by our capacitance to digital convertor (AD7747). Simulations were done to explore perforated membranes for operation in the presence of AC fields. Holes added to the surface of the membrane reduce its mass and allow for air flow through the membrane. However, larger holes result in reduced the electrostatic force on the membrane, reducing sensor sensitivity.

References

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