Design and Simulation of Novel MEMS based Capacitive Microphone

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Abstract: ***Nowadays, MEMS (Micro-electromechanical Systems) technology is widely used to design various types of microphone. The capacitive microphone is highly preferable because of its high achievable, sensitivity, miniature size, batch fabrication, integration feasibility and long stability performance. In this paper, a novel MEMS capacitive microphone operating at a low actuating voltage is presented. It consists of Aluminum diaphragm arranged over the rigid Silicon back plate in which the diaphragm includes a number of holes to reduce the acoustical damping as well as stiffness. The design and simulation has been done using the three modules of Intellisuite- Intellimask, 3D builder and TEM (Thermo-electromechanical) analysis. Comparing the diaphragm of two different thicknesses, the thinner one gives higher deflection under the same applied pressure. The variation in the capacitance with the increase in pressure is analysed.The simulated result shows that the pull-in Voltage is0.3V and the zero bias capacitance is 5.09 Pf. A process flow for the fabrication is designed and simulated using Intellifab.***

Keywords: MEMS, microphone, TEM, Pull-In voltage, Intellifab

1. Introduction

MEMS microphone is a transducer that converts acoustic energy into electrical energy. Some of its application includes voice communication device, hearing aids, surveillance and military aims, ultrasonic and acoustic distinction under water and noise and vibration control [1]. In MEMS Capacitive microphone design, it is important to focus on small size and high mechanical sensitivity as the two most desirable factors. Mechanical sensitivity is determined by the material properties (such as Young's modulus and the Poisson's ratio), thickness and intrinsic stress in the diaphragm.

Many researchers have investigated the fabrication of MEMS microphone by selecting different structures and materials to optimize the sensitivity. Most surfaced and bulk micro machined capacitive microphone uses fully clamped diaphragm with perforated back plate [6].The fabrication process involved are very long, cumbersome, expensive and not compatiblewith high volume process. Moreover they are not small in size. Many traditional MEMS capacitive microphone are fabricated in high temperature [7] where the structure is easily damaged. A condenser microphone is proposed with a p+ silicon membrane without acoustic holes [8]. Because of the absence of holes, the air gap is increased to 7.5µm in order to alleviate the acoustical damping.

In this work, we proposed a novel MEMS capacitive microphone, which uses perforated Aluminum diaphragm to obtain small size, low cost and improved microphone sensitivity. The process requires the design of only three masks layers thereby making it simple and easy to fabricate.

2. Design Aspects

The structure of the microphone consists of three layers as shown in figure 1. The topmost layer consists of flexible Aluminum diaphragm, anchor made out of Silicon dioxide as the insulating layer and the fixed bottom Silicon electrode. The diaphragm includes a number of holes to allow the air in the gap between the diaphragm and the lower electrode to escape and thus reduce acoustical damping in the microphone.

When the diaphragm is exposed to the acoustic wave, it causes flexural vibration and changes the average distance from the back plate. This in turn will produce a change in capacitance giving rise to a time varying voltage on the electrodes. The static capacitance s given by

$$C=\varepsilon_{\circ}\frac{A}{d} \quad (1)$$

Where $\varepsilon_{\circ}$ is the dielectric constant of the air and A is the surface area of the membrane.

In order to actuate the microphone, it should be provided with a DC bias voltage across the capacitor structure. The electrostatic force is induced by the bias voltage across the two electrodes which is given by

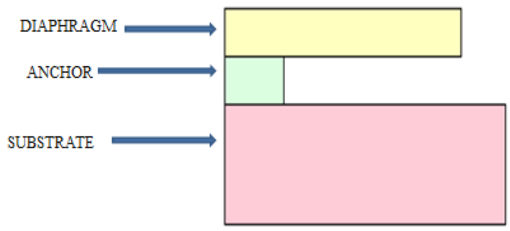
$$F_s=\frac{v^2\varepsilon_{\circ}A}{2g^2} \quad (2)$$

Where V = applied voltage
$\varepsilon_{\circ}$ = permittivity of free space
g = gap between the electrodes
A = area of the surface electrode

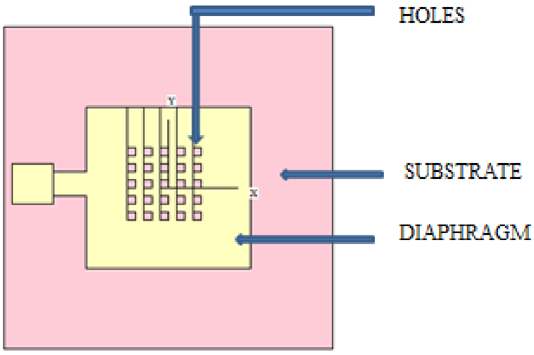
In order to optimize the sensitivity of the microphone, the design parameters used for the proposed structure are shown in table 1

Table 1: Design parameters

Parameters	Value
Diaphragm material	Aluminum
Diaphragm area	1mmx 1mm
Diaphragm thickness	3µm
Air gap	2µm
Number of holes	25
Back plate thickness	10µm
Acoustic hole size	50µm x 50µm



(a) Side View



(b) Top View

Figure 1: Structure of the microphone

3. Simulation

The three masks layers in 2D structure is created using the Intellisuite module (Intellimask), which is imported to the 3D builder in figure 2 where the thickness of the layers and different entities are defined. Next, the 3D structure is imported to TEM (Thermo-electromechanical) module where the material types, boundary and loads are defined. Finally, TEM analysis is performed to obtain the final simulated results.

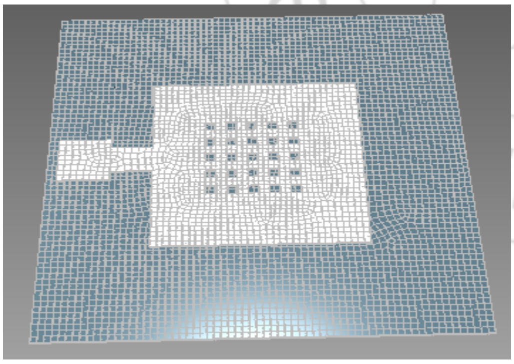


Figure 2: 3D View of the structure

3.1 Pressure versus Displacement

The required voltage of around 0.29V is applied to the lower and upper electrodes of the structure while a pressure of 0.7 Pa is applied to the top surface of the diaphragm. The resultant deformation of the diaphragm is shown in figure 3,which is taken along the Z-axis.

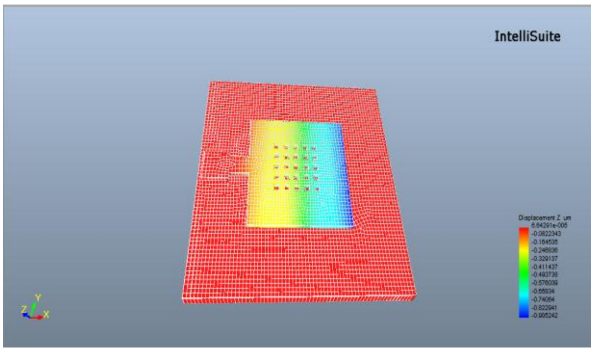


Figure 3: Displacement of the diaphragm

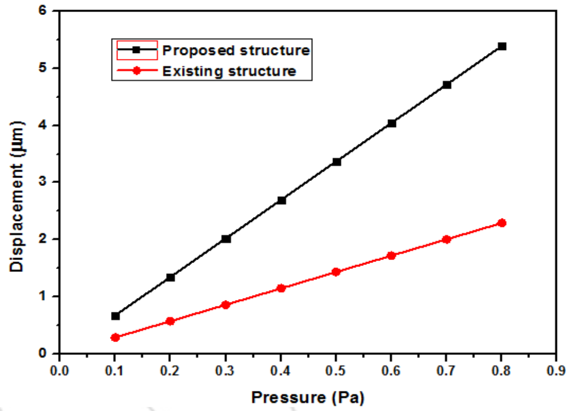


Figure 4: Graph of pressure versus Displacement for two different diaphragms

The same analysis is done for the diaphragm of different thicknesses of 3µm and 4µm respectivelyfor the pressure ranging from 0.1Pa to 0.8 Pa. It is found that the thinner diaphragm shows greater deflection in comparison with the thicker one. The higher deflection in turn gives better sensitivity of the microphone. The displacement increases linearly with the pressure in figure 4.

3.2 Pressure versus Capacitance

When the diaphragm is applied with different load pressure ranging from 0Pa to 0.07Pa, there is change in the capacitance value due to deformation. The graph is plotted between the pressure and the corresponding capacitance as shown in figure 5. The result shows that the capacitance increases non linearly with the increase in pressure.

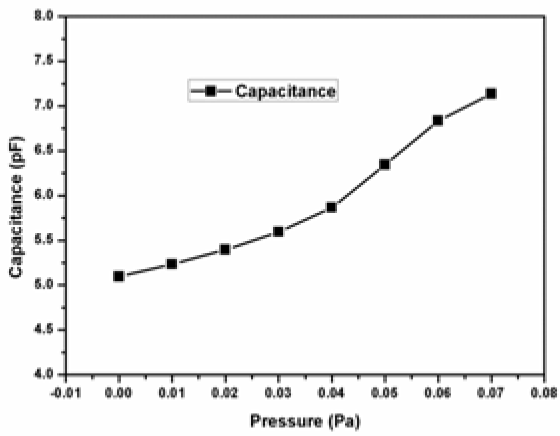


Figure 5: Graph between Pressure and Capacitance

3.3 Voltage versus Capacitance

When the applied voltage is increased, the electrostatic force of attraction between the upper and the lower electrode increases and pulls the beams towards the bottom elctrode. This leads to an increase in the resulted capacitance due to the variable gap distance. When the height of the diaphragm reaches $\frac{2}{3}$of the initial gap, the electrostatic force becomes greater than the natural restoring force and the beam collapses to touch the bottom electrode. The voltage at this point is called “pull-In voltage” or “collapse voltage”,

$$V = \sqrt{\frac{8Kg_o^3}{27\varepsilon_o A}} \quad (3)$$

The simulated graph of voltage Vs Displacement along the Z-axis is auto generated in the Intellisuite software as shown in figure 6.

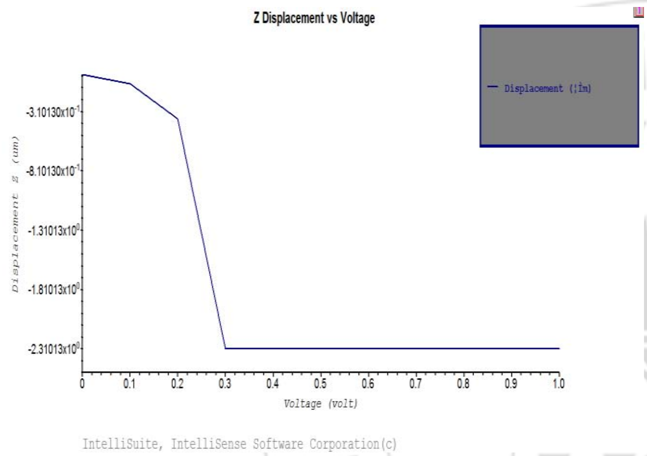


Figure 6: Graph of Voltage versus Capacitance

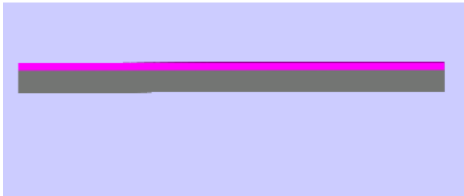
It is seen that the displacement increases with the increase in voltage applied upto a certain point and remains constant.From this ,it can be inferred that the pull-In voltage occurs at 0.3V after which the diaphragm membrane snapped to the bottom surface.

4. Fabrication

A process flow is designed for the fabrication of the proposed microphone on a Silicon substrate. The proposed fabrication process is designed using three masks. The masks for the design are generated in Intellimask. Mask-0 is used for the Silicon substrate, mask-1 is used for the anchor part Silicon dioxide and mask-2 is used to create the Aluminum diaphragm membranes with holes. The process flow is designed and simulated using Intellifab/ Fabviewer by importing the mask layout from the Intellimask file. The important stages of the process flow are shown in figure 7.

The fabrication process starts with the definition of Silicon substrate on top of which 2µm Silicon dioxide is deposited as shown in figure 7 (a). A positive photoresist is applied followed by UV exposure of the surface to pattern mask-1 in figure 7(b). Etching of the Silicon dioxide followed by Reactive Ion etching leads to the formation of anchor part in figure 7(c). An Aluminum layer of thickness 3µm is deposited on top of the PSG layer in figure 7(d), which will form the flexible diaphragm and patterned using mask-2 in figure 7 (e). To create the gap between the diaphragm and the bottom electrode, a sacrificial layer of PSG is deposited which is etched out in the later part. Finally, the desired structure is released by etching off the sacrificial layer. The top view of the final structure is as shown in figure 7(f).

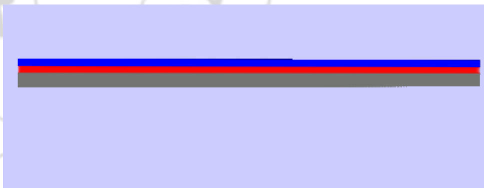
The resulting steps of fabrication are as follows:



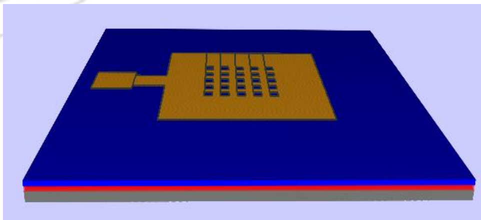
a) Deposition of SiO_2 on the Si substrate

b) Deposition of the positive photoresist and UV exposure for mask 1

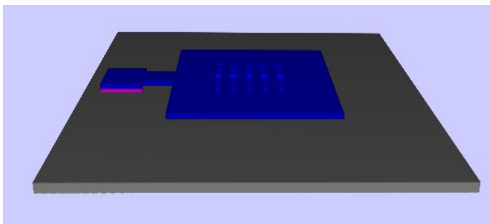
c) Etching to form the anchor part SiO2



d) Deposition of PSG and Al for the diaphragm



e) Deposition of the positive photoresist and UV exposure for mask 2



f) Final etching to release the perforated diaphragm

Figure 7: Process flow for the design simulated in Intellifab

5. Conclusion

In this paper, a novel MEMS Capacitive microphone operating at a lower voltage is successfully designed and simulated. The design is simple and easy to implement since it uses only three mask layers. The simulated result shows that thin diaphragm has greater displacement which in turn gives better sensitivity. The pull-In voltage obtained using analytical calculation is 0.39V and the simulated results shows 0.3V. A process flow for the fabrication has been designed and simulated using Intellifab.

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