DESIGN AND SIMULATION OF A NOVEL MEMS ACOUSTIC SENSOR

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Abstract: A Piezoelectric Directional Microphone is demonstrated based on a bio-mimetic design inspired by the parasitoid fly Ormia ochracea using the PiezoMUMPs multi-user foundry. The device simulation was conducted using Comsol Multiphysics 5.0 which achieves a directional sound field response and frequency band of 3.5 KHz to 4.5KHz.The sensitivity of the device is 3.8nV/pa.

Keywords: MEMS Microphone, Comsol Multiphysics 5.0, Ormia Ochracea, PiezoMUMPs.

1. Introduction

Miniaturization of the device with improved sensitivity, functionality and drastic cost reduction is the major goal of MEMS technology. A MEMS Acoustic sensor has huge demand in various applications such as consumer electronics, defense equipment, automobiles etc. Acoustic sensor i.e. Microphone is a transducer that accumulates the incoming sound signal and produces equivalent electrical signal for further signal processing. There are different types of sensing mechanisms that are utilized to sense incoming acoustic signals, the most common techniques are Capacitive, Piezoresistive and Piezoelectric.

In capacitive sensing technique [1], the Microphone works on the principle of change in capacitance as the distance between the plates are varied. Here there are two electrode plates such that one plate is fixed and another plate deflects according to the application of the sound pressure. Such Microphone requires external bias for it to work.

In Piezoresistive sensing mechanism, a diaphragm with resistive materials mounted on the four ends is exposed to the incoming acoustic signals to detect the change in resistance. In Piezoresistive effect there is an additional process of conversion as it causes only change in electrical resistance not electric potential.

A Piezoelectric Microphone [2] is the one that has the ability to develop charges when subjected to acoustic pressure. These charges in turn determine change in capacitance which is read out in terms of the voltage generated.

This paper presents a Piezoelectric Directional Microphone which is biologically inspired for miniaturization and better sensitivity also the aim is to obtain an equivalent electric potential for applied acoustic pressures and to desired audio frequency responses.

In this paper design and implementation of the Piezoelectric Microphone is described in section 2. Section 3 illustrates the PiezoMUMPS process flow. Use of Comsol Multiphysics software is detailed in section 4 and Simulation results are discussed in section5.

2. Design and Implementation

A piezoelectric Microphone [3] is a device that has the capability to detect the direction of the incoming acoustic signal and produce equivalent change in electric potential. The proposed model is Bio-Inspired by the hearing system of the parasitoid Ormia –Ochracea fly which is of a dimension of 500um but exhibits a high accuracy of 2°as shown in figure 1.

Figure 1. SEM image of parasitoid fly

The piezoelectric Microphone concept is implemented by using PiezoMUMPs process flow from MUMPS foundry.

The Novel biomimetic Microphone has two membranes that are mechanically coupled to achieve directionality as shown in figure 2.

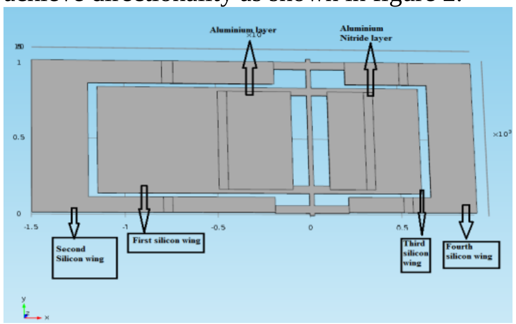

Figure 2. Proposed model of piezoelectric Microphone.

The overall external dimensions of the Microphone are 2.5mmx1mmx10um. The acoustic response of the microphone is determined by transduction of the displacement amplitudes generated by the sound pressure gradients between the front and back of the wings of both membrane parts. The displacement is sensed indirectly through the stress induced in a 500nm thick piezoelectric aluminum nitride (AIN) film deposited on the sections of the device located close to the torsion beam. A1um thick aluminum (Al) layer allows electrical routing of the signals created in piezoelectric sensing layer.

Table 1. Dimensions of the device

Parameters	value	units
First silicon wing	1300x1000	um
Second silicon wing	700x1000	um
Third silicon wing	1050x700	um
Fourth silicon wing	500x700	um
Aluminum Nitride(left)	400x650	um
Aluminum Nitride(right)	300x650	um
Aluminum (left)	350x650	um
Aluminum (right)	250x650	um

3. PiezoMUMPs Process flow

The Multi-User MEMS Processes [4] or MUMPs® is a commercial program that provides cost-effective proof-of concept MEMS fabrication to industry, universities and government worldwide. The PiezoMUMPs is utilized for designing general purpose micromachining of piezoelectric devices in silicon -on- insulator framework.

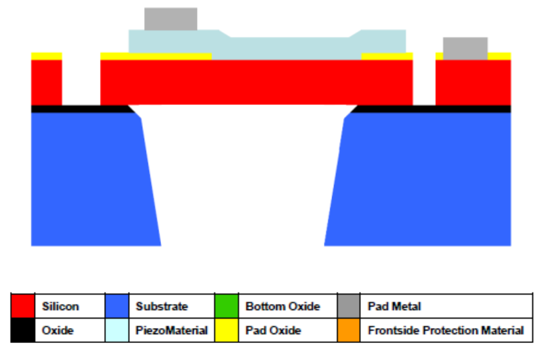

Figure 3. Cross sectional view showing all layers of the piezoMUMPs process.

3.1 PROCESS FLOW:

- A silicon-on-insulator (SOI) wafer is used as the starting substrate. The substrate characteristics:
  - 150 mm(100) oriented SOI wafer
  - Silicon thickness: 10um
  - Oxide thickness: 1um
  - Substrate thickness: 400um
- The silicon layer is doped, then patterned and etched down to oxide layer. This layer can be used for mechanical structures, resistor structure or electrical routing.
- The Substrate can be patterned and etched from the bottom side to the Oxide layer. This allows for through hole structures.
- A thermal oxide layer is patterned and etched to provide isolation between the SOI layer and the AIN and pad metal layers.
- A piezoelectric layer, AIN, allows for the development of piezoelectric sensors.
- A pad-metal feature that allows finer metal features and precision alignment.

4. Use of COMSOL Multiphysics® Software

The proposed model was designed and simulated on Comsol Multiphysics 5.0 tool by using piezoelectric physics which incorporates both solid mechanics and electrostatic physics to carry out coupling analysis of both mechanical and electrical parameters.

The design was modeled as 3D object in geometry then suitable in built materials were added to the model. Solid mechanics physics were utilized to define parts of silicon layer to be fixed and apply boundary load (pressure: 1pa) such that free edges are deflected to create stress near torsion and AIN layer is mentioned as piezoelectric material such that charges are developed due stress. In electrostatic domain, AIN layer is selected for electric analysis and one side is grounded to obtain electric potential developed due to change in charges.

Maximum stress of rectangle at the edge is given by:

σ= 0.378 P (a2/h2) (1)

Where,
p= Pressure applied
a= Side length
h= Thickness of the geometry

Charge density in the absence of External electric field is given by [5],

D=dσ (2)

Where,
σ= Mechanical stress
A=Area
d= Piezoelectric strain co-efficient
D= Charge density

Accumulated charge and voltage is given by

Q = D.A (3)

V = Q/C (4)

C = εA/h (5)

Where,
Q= Charge
D= Charge Density
C= Capacitance of AIN
E=Permittivity of AIN
h=Thickness of AIN

The frequency responses of the model were analyzed by adding Eigen frequency and frequency domain studies.

5. Simulation Results

This section gives the graphical analysis of the Stress, Displacement, Voltage, Eigen frequencies and Frequency responses using Comsol Multiphysics tool as shown in figure. The piezoelectric analysis was carried out to determine the electrical potential developed for an applied pressure of 1pa.

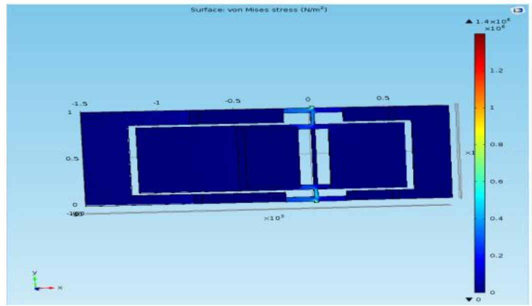

Figure 4. Von Neumann stress: 1.4 x10(pow6).

In figure 4 the average stress analysis is carried out as a result the maximum stress of 1.4x 10(pow6) is obtained near fixed region.

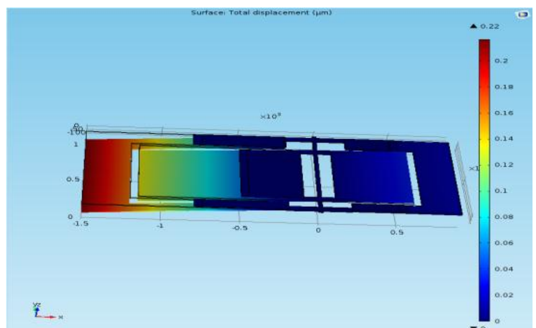

Figure 5. Total Displacement: 0.22um

Total Displacement analysis is carried out by applying a pressure of 1pa that deflects the wings about 0.22um as shown in figure 5.

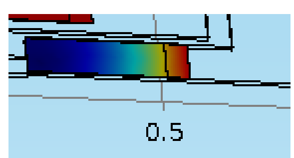

Figure 6. Electric potential obtained:3.8x10(pow-9) V

As shown in figure 6 the electric potential obtained by applying 1 pa pressure is 3.8x10(pow-9) V.

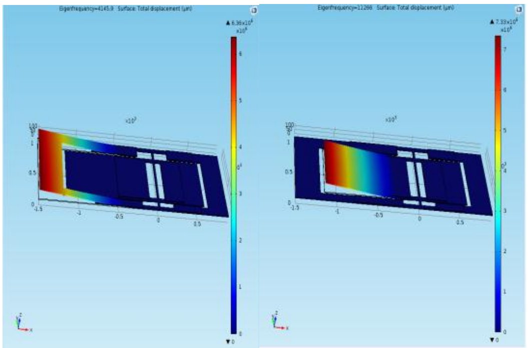

Figure 7(a). 1st natural Frequency: 4145.9 Hz **Figure 7(b).** 2nd natural Frequency: 11266 Hz.

The Eigen frequency analysis was carried out to obtain natural frequencies at which the model vibrates freely. As shown in figure 7(a) the first natural frequency obtained is at 4145.9 Hz and second natural frequency obtained is at 11266 Hz as shown in figure 7(b).

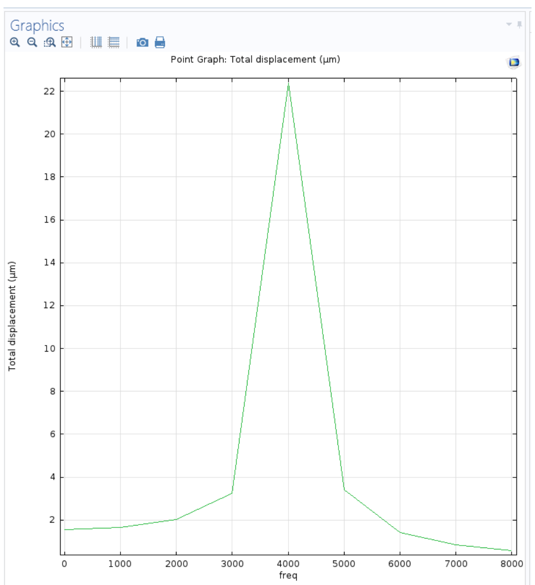

Figure 8. Frequency response graph.

In frequency domain study the 1D frequency response point graph was plotted. As shown in figure 8 the maximum displacement is obtained at the frequency range of 3.5 KHz to 4.5 KHz thus model responses to audio range.

6. Conclusions

This paper gives the details about piezoelectric MEMS microphone and its principle operation. The Microphone is designed and simulated using Comsol Multiphysics 5.0 tool to mimic the biologically inspired hearing system of parasitoid Ormia Ochracea which the hearing resolution upto 2°.The model designed was analyzed for various parameters such stress, displacement, electric potential and desired frequency response for audio range 3.5 KHz to 4.5 KHz is obtained.

7. References

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8. Acknowledgements

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