Design of MEMS Based Polymer Microphone for Hearing Aid Application

Girish G.K.[1], Ramanuja H.S.[2],Deepak K[3],*Veda Sandeep Nagaraja[4],and S.L.Pinjare[5]
1,2,3,4,5 Nitte Meenakshi Institute of Technology, Yelahanka, Bangalore
*Corresponding author: ECE Dept, Govindapura, Gollahalli, Yelahanka, Bangalore
veda.nmit@gmail.com

Abstract: This paper presents a condenser microphone for hearing aid application. It gives a brief overview of different types of hearing aids available in the market. The work looks into the principle of operation a of MEMS Condenser Microphone (MCM) for hearing aid application. The stress versus pressure and Displacement versus arch length analysis has been carried out. The simulation work has been carried out in COMSOL Multiphysics using Structural mechanics and in specific Electromechanics.

Keywords: Microphone, MCM- MEMS Condenser Microphone, Readout Circuitry, CMOS.

1. Introduction

The microphones that are commercially available in market can be classified into different categories depending on their principle of operation. A condenser microphone [1] is the one that calculates the change in acoustic pressure by change in capacitance; a piezoelectric microphone is one that has the ability to produce voltage when subjected to pressure. A piezoresistive microphone is one that changes the resistance with change in applied voltage or pressure.

This paper presents a MCM which uses Polyimide as the material for the diaphragm and backplate and the dielectric is air. The paper is divided into mainly into 7 sections. The second section looks into different types of hearing aids in the market. This is followed by the third section which looks into the details of principle of operation as well as the structure of MCM. The fourth section gives a brief overview of the usage of COMSOL Multiphysics and the fifth section gives the details of the different measurements and analysis carried out in the work. The sixth section gives the simulation results which is followed by the seventh section which analyzes the results obtained.

2. Hearing Aid

The hearing aids [2] available in the market have the problem of directionality, sensitivity and audio range. During a field survey of consumers of different age groups using hearing aid for different periods, it was found that they have difficulty in hearing when driving, talking over the phone and difficulty distinguishing background noise. There are many types of hearing aids like Behind The Ear (BTE), In The Ear (ITE), In the Canal (ITC) and Completely In the Canal (CIC). A new type of hearing aid that has been able to overcome severe hearing loss is the Cochlear Implant hearing aid. There are also different types of hearing losses. Conductive hearing loss refers to a decrease in sound caused by a problem in the outer or middle ear and usually is treated by medical or surgical intervention. The other type of hearing aid is sensorineural loss which refers to the problem located in the inner ear or along the pathway between the inner ear and the brain. This type of hearing loss is almost not treatable but Cochlear Implant [3] hearing aids are able to overcome this loss to some extent.

3. MEMS Condenser Microphone

The MEMS condenser microphone has gained importance in the last decade or so because of its ease to fabricate. It basically works on the principle of operation of change in capacitance with the applied voltage or pressure [4]. The basic structure of the MEMS condenser microphone used in this paper is shown in figure 1.

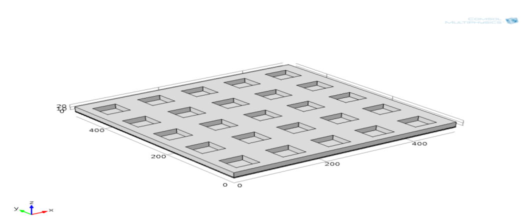

Figure 1. Structure of the MCM

It is made up of four layers. The bottom plate is the gold electrode and it is required to give the input to the readout circuitry. The material properties of Gold are given in table 1.

Table 1: Physics properties of Gold

Description	Values	Units
Young's Modulus E	70E9	Pascal
Poisson's ratio	0.44	Unit Less
Relative Permittivity	0	Unit less

On top of this electrode the diaphragm is fabricated. The diaphragm is made up of Polyimide. The material Properties of the Polyimide plates are given in table 2.

Table 2: Physics properties of Polyimide

Description	Values	Units
Young's Modulus E	3.14E9	Pascal
Poisson's ratio	0.35	Unit Less
Relative Permittivity	3.5	Unit less

The dielectric air is on top of the diaphragm and its thickness is 2μm. The polyimide backplate is on top of the air dielectric medium. The backplate has a thickness of thickness of 17μm. The microphone designed in this paper has a diaphragm of 1mm X 1mm dimension. For ease in simulation, a 1/4th model has been used. The device dimensions used in the 1/4th model has been listed in table 2.

Table 2: Dimension of the MCM

Structure name	Dimensions	Units
Diaphragm length	500	μm
Diaphragm width	500	μm
Air layer length	500	μm
Air layer width	500	μm
Air layer thickness	2	μm
Back plate length	500	μm
Back plate width	500	μm
Back plate thickness	17	μm

The backplate has acoustic holes. The backplate makes up the fixed plate of the variable capacitor of MCM and the diaphragm makes up the variable plate. Due to air pressure the diaphragm deflates and hence the distance between the two plates changes and hence the capacitance varies. This change in capacitance is readout using the gold electrode.

4. Use of COMSOL Multiphysics

The physics chosen in COMSOL multiphysics for this work is Structural Mechanics -> Electromechanics. The MCM works like a parallel plate capacitor as shown in figure 2.

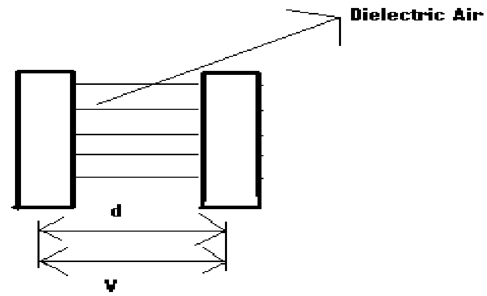

Figure 2. Parallel Plate Capacitor

The capacitance of the parallel-plate capacitor is a function of the distance between the two plates (d), the area of the plate (A), and the constant (k) of the dielectric which fills the space between the plates. It can be expressed as in equation 1.

$$C = k\varepsilon_0 A / d \qquad (1)$$

In COMSOL to compute the sensor's capacitance, the 2D model first solves for the electric field in the geometry that has been deformed. The capacitance is obtained from the energy of the electric field from the equation 2.

$$C = \frac{2}{U^2} \int_{\Omega_d} W_e \, d\Omega_d \qquad (2)$$

where U is the potential difference between plates and W_e is the electric energy density. The area Ω_d is the area of the dielectric which is in this case, the air gap.

In the 3D model, the capacitance is calculated by integrating over the surface of the capacitor according to the equation 3.

$$C = \varepsilon \int \frac{1}{h} dA \qquad (3)$$

here h denotes the local distance across the capacitor and ε is the permittivity of air.

5. Measurements

In this work the pressure versus displacement analysis has been carried out. The subsequent section gives the graphical analysis of the measurement. The displacement of the diaphragm with respect to the pressure applied changes the capacitance which in turn can be fed to a CMOS readout circuitry for further processing of the speech signal. The change in capacitance is very minimal and hence there is a need for a preamplifier at the beginning of the CMOS readout circuitry to amplify the signal from the MCM and give it to the ADC and other stages of the readout circuitry [5]. The stress versus pressure analysis has also been carried out in this work. For simulation purposes, we have used only the bottom two layers of gold and diaphragm for applying the pressure. The measurement has been carried out for four different thickness of the diaphragm.

6. Simulation results

The simulation work has been carried out for the diaphragm thickness of 1µm, 2µm, 3µm and 4µm. Figure 3 gives the stress versus pressure analysis for a 1µm thick diaphragm.

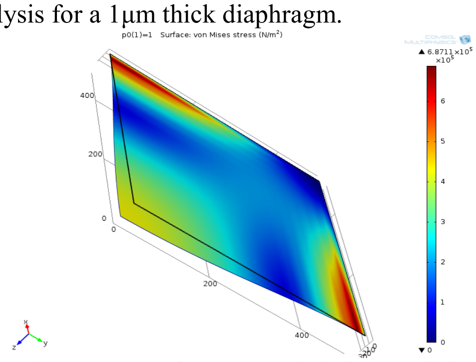

Figure 3: Stress v/s pressure analysis for 1µm thick diaphragm

The displacement versus arc length 3D plot is shown in figure 4 and the same 1D plot is shown in figure 5. Both of them are analyzed with the diaphragm thickness of 1µm.

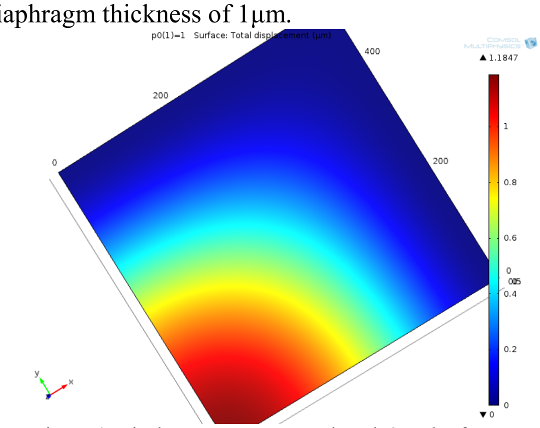

Figure 4. Displacement versus arc length 3D plot for a diaphragm thickness of 1 1µm.

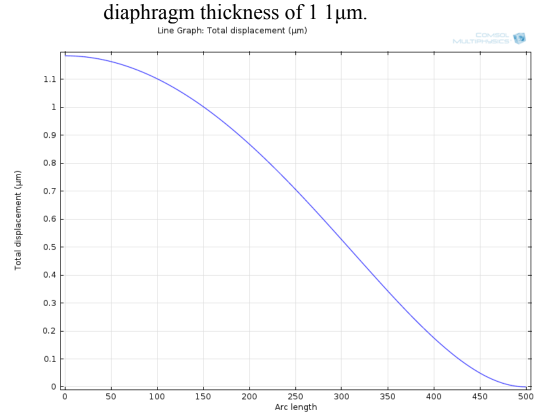

Figure 5. Displacement versus arc length 1D plot for a diaphragm thickness of 1 1µm.

7. Result Analysis

Table 4 gives the variation of the maximum displacement for the four different thickness of the diaphragm.

Table 4: Diaphragm thickness versus Maximum displacement

Sl No	Diaphragm thickness in µm	Maximum displacement in µm
1	1 µm	1.184
2	2 µm	0.188
3	3 µm	0.065
4	4 µm	0.029

Figure 6 shows the above mentioned variation of the displacement as the thickness of the diaphragm is increased. As can be seen from the analysis, the maximum displacement of the diaphragm is decreased as the thickness is increased.

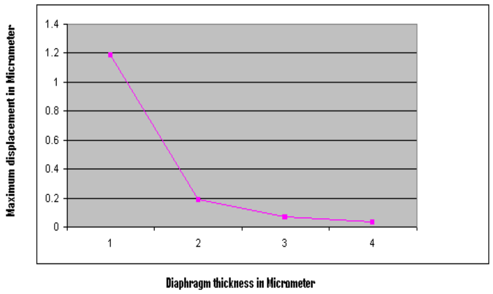

Figure 6. Diaphragm thickness versus Maximum displacement

The stress versus pressure analysis shows a similar analysis. That is as the thickness of the diaphragm increases the stress induced decreases and the same is depicted in table 5 and figure 7.

Table 5: Diaphragm thickness versus Stress Induced

Sl No	Diaphragm thickness in µm	Stress Induced in N/m^2
1	1 µm	6.87 E 5
2	2 µm	2.72 E 5
3	3 µm	1.42 E 5
4	4 µm	9.84 E 4

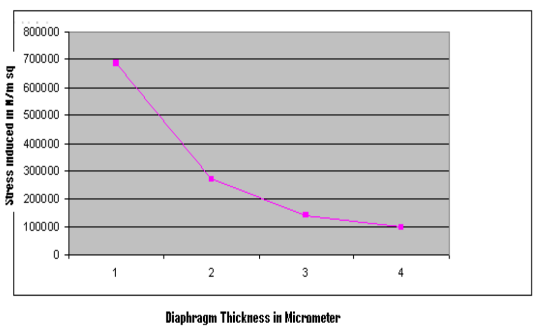

Figure 7. Diaphragm thickness versus stress induced

8. Conclusions

The work gives a brief introduction into the different types of hearing aid currently in use. The paper also talks about the different types of MEMS microphone and its principle of operation. The MEMS Condenser Microphone designed in this work has been simulated using COMSOL Multiphysics and in specific Electromechanics. The measurement has been carried out for different thickness of the diaphragm. The stress induced in the diaphragm decreases as the thickness increases and also the maximum displacement decreases with increase in thickness. The work will be continued to find the resonant frequency of the diaphragm with variation in the thickness. The frequency analysis in the audio range needs to be carried out.

9. References

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Biography


Girish GK was born in Chitradurga, Karnataka on March 27, 1984. He graduated from VTU in 2006. He received Masters from Visvesvaraya Technological University in 2008 and is currently working as Lecturer in E&CE Dept NMIT, Bangalore and also pursuing Ph.D. under University of Mysore.


Ramanuja H S was born on April 28, 1982. He received his Masters degree from Bangalore University in 2006. He is a research scholar in Electronics Department, Nitte research and Education Academy, Bangalore.


Deepak K was born on Feb 16, 1985. He received his Masters degree from Kuvempu University in 2007. He is a research scholar in Electronics Department, Nitte research and Education Academy, Bangalore.


Veda was born in Belgaum, Karnataka, India, on August 18, 1979. She graduated from University of Mysore in 2001. She received her Master’s from Visvesvaraya Technological University in 2009 and is currently working as Assistant Professor in E&CE Dept NMIT, Bangalore and also pursuing Ph.D. under University of Mysore.


Pinjare was born in Betul Bazar in Betul District MadhyaPradesh, India, on May 10, 1953. He graduated from the University of Mysore. He completed his Ph.D from IIT Madras in 1981.He worked at ITI Ltd as Deputy Chief Engineer. Currently he is a professor and PG Coordinator in E&CE Department NMIT Bangalore