Design and Multiphysics Analysis of MEMS Capacitive Microphone

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Abstract: In this paper, design and analysis of a novel MEMS capacitive microphone which uses corrugations and perforations in diaphragm is presented. The corrugation and perforation in diaphragm reduces the residual stress and increases the mechanical sensitivity of diaphragm. Instead of perforated back plate, holes have been made on the diaphragm, therefore KOH etching can be avoided to make back chamber and fabrication cost will reduced. The holes in diaphragm reduces air damping in gap. The proposed structure is modeled and studied using COMSOL multiphysics software. The analysis result are presented and compared with microphone structure having perforated back plate.

Keywords: MEMS Microphone, Corrugated diaphragm, Perforated diaphragm

1. Introduction

Micro-Electro-mechanical system or MEMS, is a technology of very small systems that are made using technique of microfabrication[1]. MEMS technology is widely used in microphone fabrication[2]. A microphone is an acoustic to electrical transducer or sensors that converts sound into electrical. The application of MEMS technology to microphone has led to the development of small microphone with high performance. The first capacitive microphone was introduced in 1983 by Royer et al.[3][4]. MEMS microphone offers low power consumption, good sensitivity and are available in very small packages[5]. The MEMS microphones are used in mobile phone applications, laptops and other consumer applications, medical application such as hearing aids, automotive and military applications[6].

One of the important part of microphones are diaphragms. The majority of diaphragm have been flat and either square or rectangular. Most of the capacitive microphone uses flat diaphragm with perforated back plate. The cavity or back chamber is etched into substrate by KOH etching[7]. Cavity forming by KOH etching is slow and time consuming process. For making holes in back plate is done from the backside in the cavity. The fabrication process are long and expensive. This complex and expensive fabrication can be avoided by making holes in diaphragm[8][9].If air damping is not reduced, it affects the displacement of diaphragm and sensitivity decreased. perforation in diaphragm controls the air damping in gap and increases the sensitivity of microphone[10].At low pressure range, nonlinearity is caused by diaphragm stress in flat diaphragm[11]. The corrugation technique have been developed to increase linearity of load-deflection behaviour of diaphragm. The corrugated diaphragm can provide large deflection than flat diaphragm for equivalent load[12] - [14].The corrugation in diaphragm reduces residual stress and increases mechanical sensitivity of microphone[14][16].

In this paper, design and analysis of MEMS capacitive microphone with corrugated and perforated diaphragm is presented. Investigate the effect of corrugation and perforation in diaphragm of capacitive microphone on mechanical sensitivity and diaphragm deflection. Then compared the analysis result with microphone having perforated back plate.

2.Use of COMSOL Multiphysics

The software COMSOL multiphysics version 4.3b is selected to model and simulate MEMS capacitive microphone. It is a powerful interactive environment for solving problems based on partial differential equation. The 3D model is created for the proposed MEMS capacitive microphone. The model selected a Stationary study, the assumption is that the load, deformation and stress do not vary in time.The model uses the electromechanics interface to solve the coupled equations for the structural deformation and the electric field.

An electrostatic force caused by applied potential difference between the diaphragm and back plate bends the diaphragm towards back plate beneath it. As the diaphragm bends, the geometry of air gap changes continuously, resulting a change in electric field. The coupled physics is handled automatically by the Electromechanics interface.

The force density that acts on the diaphragm of microphone results from Maxwell's stress tensor:

$$F_{es} = -{}^{1}/{}_{2}\,(E\,.\,D)n + (n\,.\,E)D$$

where **E** and **D** are the electric field and electric displacement vectors, respectively, and **n** is the outward normal vector of the boundary.

The bottom of diaphragm connected to the voltage terminal V_{in} and top of the back plate is grounded, while all other boundaries are electrically insulated. The terminal boundary condition automatically compute the capacitance of the system.

3.Proposed MEMS Capacitive Microphone

In this proposed work, MEMS capacitive microphone uses corrugations and perforations in diaphragm. Figure 1 shows the cross section view of the proposed capacitive microphone. Corrugated diaphragm with perforation and back plates are two parallel plates and air gap as dielectric. The corrugation in diaphragm increase the mechanical sensitivity of diaphragm. The perforations in diaphragm helps to avoid complex and expensive fabrication. By this way, proposed microphone sensitivity increased and fabrication cost is reduced.

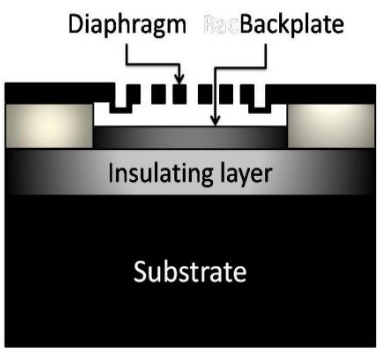

Figure 1. Cross section view of capacitive microphone with corrugated and perforated diaphragm Creating the PDF

The dimensions for the proposed microphone are chosen as 1 × 1mm². The structure has diaphragm with 0.5×0.5mm² size, with thickness 3µm and air gap of 1µm. The material used for diaphragm is Aluminium. As per the requirement of pressure-displacement, geometric parameters of corrugation such as number of corrugation, depth of corrugation are designed by designer. The mechanical sensitivity of microphone can be controlled by geometrical parameters of corrugation. Figure 2 shows the 3D model of MEMS capacitive microphone with corrugated and perforated diaphragm. The model is created by using multiphysics software COMSOL.

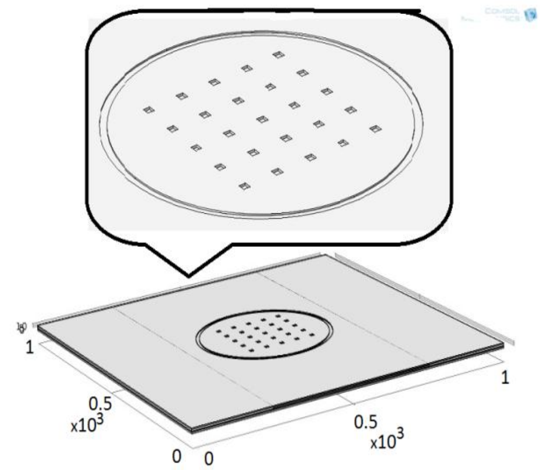

Figure 2. 3D model of capacitive microphone with corrugated and perforated diaphragm

The centre deflection equation for corrugated diaphragm is expressed as[9][11]

$$\frac{PR^4}{E'h^4} = A_p\frac{Y}{h} + B_p\frac{Y^3}{h^3}$$

Where P is the pressure across the diaphragm, R is the diaphragm radius, h is the diaphragm thickness, E is Young's modulus, ʋ is the Poisson's ratio and Y is the central deflection of the diaphragm.A_p is the dimensionless linear coefficient and B_p is non linear coefficient.

Where

$$A_p = \frac{2(q+3)(q+1)}{3(1-\frac{\upsilon^2}{q^2})}$$

$$B_p = \frac{165(q+1^3(q+3))}{q^2(q+4)(q+11)(2q+1)(3q+5)}$$

and

$$E' = \frac{E}{1-\upsilon^2}$$

The most important and fundamental element used in calculating design characteristics of corrugated diaphragm is quality factor q. Profile factor in terms of corrugated depth and diaphragm thickness h, expression is

$$q^2 = 1 + 1.5\frac{H^2}{h^2}$$

4.Result and Discussion

In this section, present the displacement and mechanical sensitivity of MEMS capacitive microphone with corrugated perforated diaphragm and compared it with MEMS capacitive microphone with perforated back plate. Simulation of MEMS systems are becoming important. Before fabrication, the model of the device is build and predict its behaviour. It helps to change the parameters quickly rather than actual fabrication, then easily redesign and fabricate. In this paper models finite element analysis(FEA) is carried out with the help of multiphysics simulation software.

Following Figure 3 shows the displacement obtained for the capacitive microphone with corrugated perforated diaphragm by using simulation software COMSOL at pressure 1kPa.It shows that centre of the diaphragm has maximum displacement 0.7169µm.

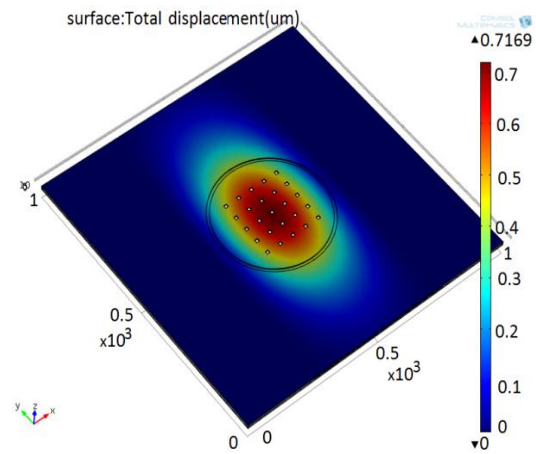

Figure 3. Displacement analysis of capacitive microphone with corrugated and perforated diaphragm

MEMS capacitive microphone with perforated back plate is shows in Figure 4. The diaphragm is made up of Aluminium and have thickness of 3µm, size of 0:5 × 0:5mm2 and air gap of 1µm. The size of structure is same as that of proposed structure. The structure is modelled and simulated by using software COMSOL multiphysics.

Figure 5 shows displacement obtained for the capacitive microphone with perforated back plate by using simulation software COMSOL multiphysics version 4.3b. The diaphragm deflects 0.4875µm at 1kPa pressure. It can seen that capacitive microphone with corrugated and perforated diaphragm has more displacement than the capacitive microphone with perforated back plate.

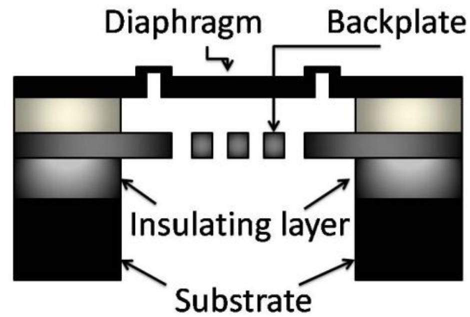

Figure 4. crosss section view of capacitive microphone with perforated back plate.

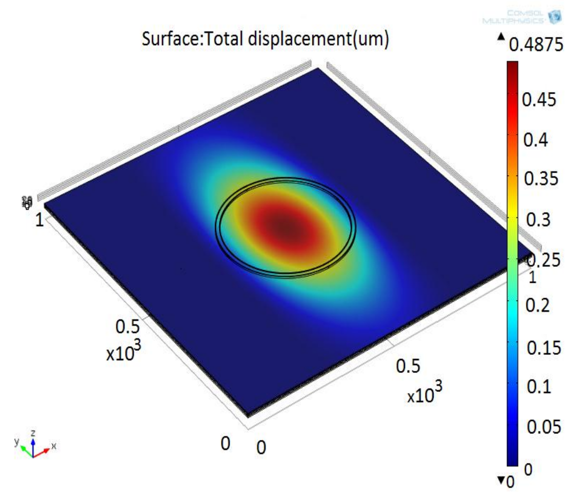

Figure 5. Displacement analysis of capacitive microphone with perforated back plate.

The Pressure deflection relationship plot for MEMS capacitive microphone with corrugated perforated diaphragm and MEMS capacitive microphone with perforated back plate have been presented in Fig.6. It can be seen that, the proposed microphone diaphragm has more deflection than microphone with perforated back plate at same working pressures.

Figure 7 shows the sensitivity plot of microphone with corrugated perforated diaphragm and microphone with perfo rated back plate versus pressure. It can be seen that the sensitivity of proposed microphone increases by increase of pressure.

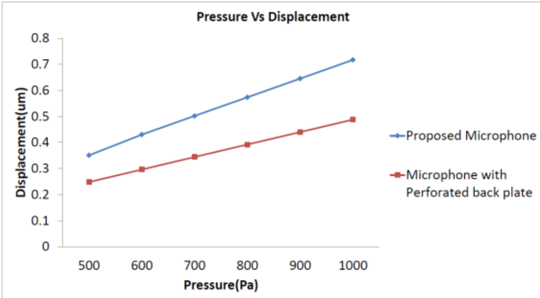

Figure 6. Pressure-Deflection plot.

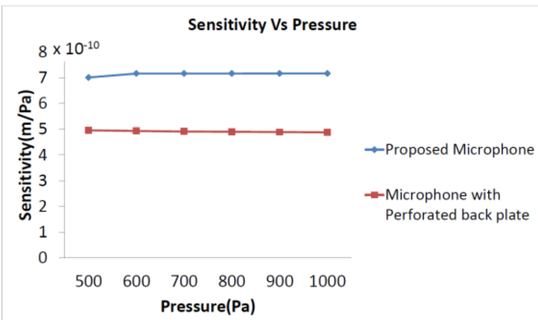

Figure 7. Sensitivity Vs Pressure plot.

5.Conclusions

In this paper, a MEMS capacitive microphone with corrugated perforated diaphragm is presented. The result is compared with capacitive microphone with perforated back plate. The microphone sensitivity is increased while complex and expensive fabrication is avoided by making holes in the diaphragm instead of back plate. The result shows center deflection of capacitive microphone with corrugated perforated diaphragm is 0.7169µm and capacitive microphone with perforated back plate is 0.4875µm. This shows sensitivity and deflection of proposed microphone is more than microphone with perforated back plate.

5.References

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