Simulation and Mathematical modelling of MEMS Acoustic Sensor

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Abstract- The paper presents the Simulation and Mathematical modelling of MEMS Acoustic sensor. Silicon diaphragm is used for acoustic sensor of thickness 35μm and the size of diaphragm is 3mm *3mm in order to enhance the resonance frequency and sensitivity by changing the design parameter which results to enhance the resonance frequency upto 51khz using COMSOL Multiphysics. The paper also focus on comparison of sensitivity and resonance frequency of Si, SiC and Polysilicon diaphragm. Different material diaphragm is used with small thickness to increase the sensitivity as thickness is inversely proportional to sensitivity. Result increases the sensitivity to 2.01E-12 F/MPa using polysilicon.

***Keywords*— Si Diaphragm, Sensitivity, Resonance frequency, Load v/s displacement.**

I. Introduction

MEMS is Micro Electro Mechanical System where the word system indicates that there is some form of interconnection and combination of components. It is a technique to design and create miniature system. MEMS Acoustic sensor provide a small footprints with sensitivities that are either comparable or exceed any macro sensor, along with capabilities of mass production and low cost unit. MEMS acoustic sensors are also known as pressure sensor. These sensors use a diaphragm that displace in response to any external pressure or sound and convert the displacement into a measureable electrical signal. These are the device that transduce the mechanical quantity (Pressure) into another (stress) [2,5]. The MEMS acoustic sensors has various applications in telecommunication field, underwater acoustics, the monitoring of closed systems such as water pipe lines irregularities, turbulence, noise in hydraulic and pneumatic systems and pressure fluctuations[3].

The structure of Acoustic sensor is based on various shapes of the diaphragm but the most widely used structure is square shaped diaphragm because of easier fabrication and give better results in terms of sensitivity than circular and rectangular shape diaphragms [4-6].

In acoustic sensor high residual stress on diaphragm causes unwanted effects such as film buckling, high actuation voltage [7] and diaphragm cracking. This stress also effects sensitivity, cut off frequency, resonance frequency. The resonance frequency depends on various material properties and on various geometric parameters such as residual stress, young's modulus [7], poison's ratio, length and thickness of diaphragm, density etc.

A zinc oxide based MEMS acoustic sensor of resonance frequency 41.8 kHz was described in [8] by using ANSYS harmonics analysis. In the present work the resonance frequency analysis has been done using COMSOL 4.3a and frequency has been increased to 51.058 KHz and the value of Sensitivity is 7.34E-22 F/MPa for h 63 μm [9]. When h is 35 μm as considered for frequency 51.058 KHz then sensitivity is increased up to 4.55E-16 F/MPa.

II. Mathematical Analysis

The structure that we are consider for mathematical modelling of MEMS acoustic sensor is same as designed by Mahanth Prasad in 2012 [8] as shown in fig (1).

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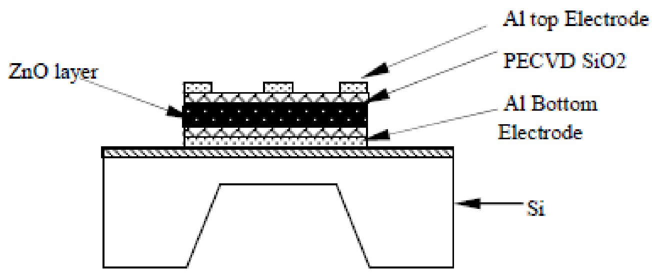

Fig 1 Schematic diagram of MEMS acoustic sensor

The square Si diaphragm comprising thickness 35μm and the size of diaphragm is 3mm *3mm is used. To enhance the resonance frequency the equation (1) is used as given in [8].

$$fr = \frac{1.654Cph}{a2} \qquad (1)$$

Where
a is length of diaphragm
h is thickness of diaphragm

and Cp is given as

$$Cp = \sqrt{\left(\frac{E}{\rho(1-v2)}\right)} \qquad (2)$$

ρ is the density of the substrate, E is the Young's modulus, v is the poison's ratio. The value of these Si material properties is given in table I as in [10].

TABLE I
Material properties of Si Diaphragm

Properties	Value	Unit
E	135	GPa
V	0.28	-------------
ρ	2330	Kg/m3

Hence the resonance frequency obtained using this formula is 51.001 KHz.

Now the equation (3) used for sensitivity is same as given in [8]

$$S = \frac{49\varepsilon a^6}{2025Dd^2} \qquad (3)$$

Where, a is half of the length of the diaphragm, ε is permittivity of free space, d is the gap between the electrodes and D is flexural density as in equation (4).

$$D = \frac{Eh^3}{12(1-v^2)} \qquad (4)$$

By using these equations the resultant sensitivity calculated is 4.55E-16 F/MPa for Si diaphragm.

III. Simulation

For the simulation of MEMS acoustic sensor COMSOL MULTIPHYSICS 4.3a has been used. The structure of 35 μm thick square diaphragm is shown in fig 2 and fig 3 shows maximum deflection of silicon diaphragm is observed in centre in z-axis. These structure observed in COMSOL.

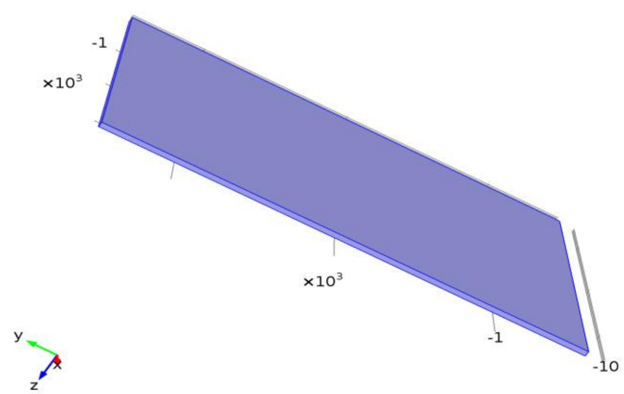

Figure 2 shows 35 μm thick square Si diaphragm.

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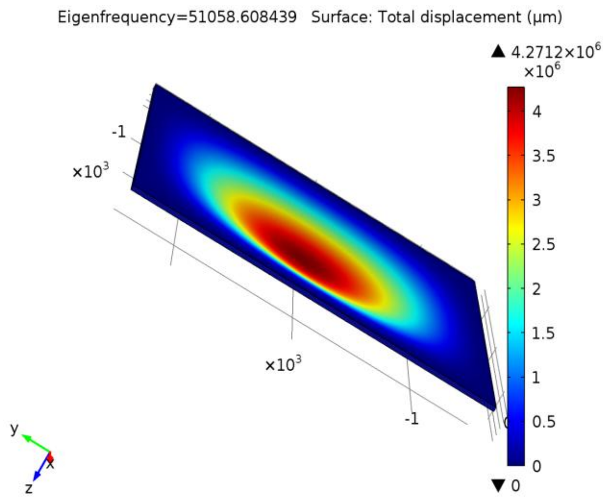

Figure 3 shows that maximum deflection of diaphragm is observed in centre with Eigen frequency 51.058 kHz for Si diaphragm.

Hence the simulation result of eigen frequency is received as given in figure above which is same as of mathematical result which is 51.001 KHz for Si diaphragm.

A. Frequency Domain

Frequency domain is the next parameter for simulation. The frequency response analysis solves for the deformation of a structure subjected to harmonic loads. The shape of frequency response of MEMS Acoustic Sensor is determine by resonance frequency in the frequency domain by set the range of frequencies at which the structural displacements is compute. Figure 4 that show the maximum deflection of square diaphragm in the centre at frequency 51.058 KHz.

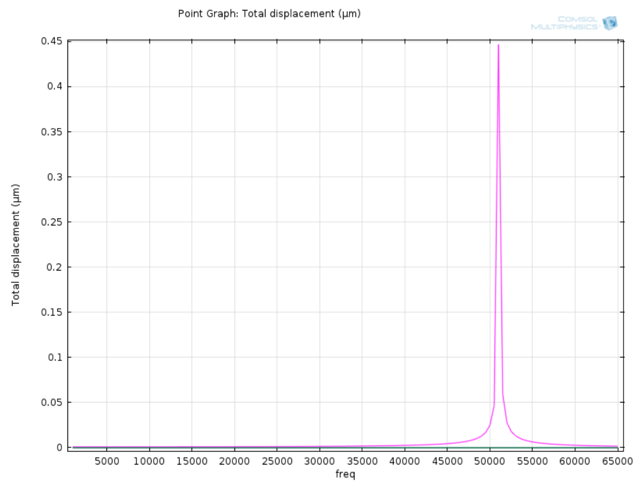

Figure 4 Frequency domain graph shows maximum deflection of diaphragm at 51.058 KHz

B. Load v/s Displacement

This is another parameter of simulation for square Si diaphragm. In the Acoustic Sensor when stress applied on diaphragm then it is essential to know about the displacement of diaphragm. So this is done by simulation of Load versus displacement. Figure 5 shows the linear relationship between Load versus Displacement by simulation.

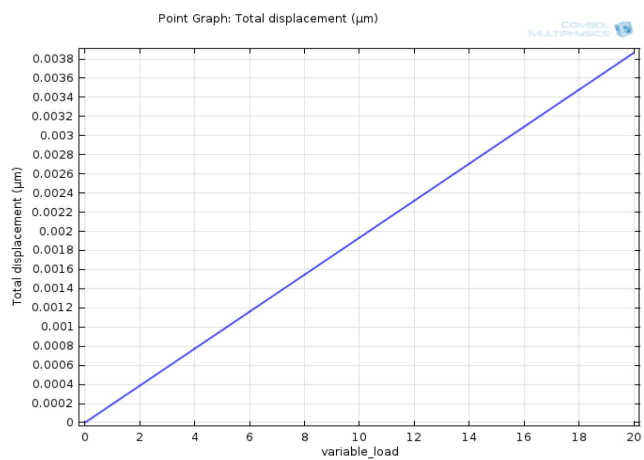

Figure 5 Linear relationship between load and displacement

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IV. RESONANCE FREQUENCY AND SENSITIVITY OF SIC AND POLY-SI DIAPHRAGM

In the above section the Resonance Frequency and sensitivity of Si diaphragm has been studied. Now these parameters have been studied using another material i.e. SiC and Poly-Si. But the thickness used for these is different because to get the high sensitivity, the diaphragm thickness should be thin to maximize the load-deflection responses [11].

Different material properties have been used for SiC and Poly-Si diaphragm as given in table II and III.

TABLE III
Material properties of polysilicon diaphragm.

Properties	Value	Unit
E	169	GPa
V	0.22	-------------
ρ	2320	Kg/m3

TABLE IIIII
Material properties of silicon carbide diaphragm.

Properties	Value	Unit
E	415	GPa
V	0.16	-------------
ρ	2329	Kg/m3

By using these properties of SiC and Poly-Si material diaphragm of 2μm thickness, the sensitivity using equation (3) and simulated resonance frequency has been calculated. The 2μm thickness is used to enhance the sensitivity because sensitivity is inversely proportional to the thickness of diaphragm.

So, the sensitivity that has been computed of SiC is 8.39E-13 F/MPa and for Poly-Si is 2.01E-12 F/MPa. The simulated resonance frequency is shown in fig 6 for SiC and 7 for Poly-Si.

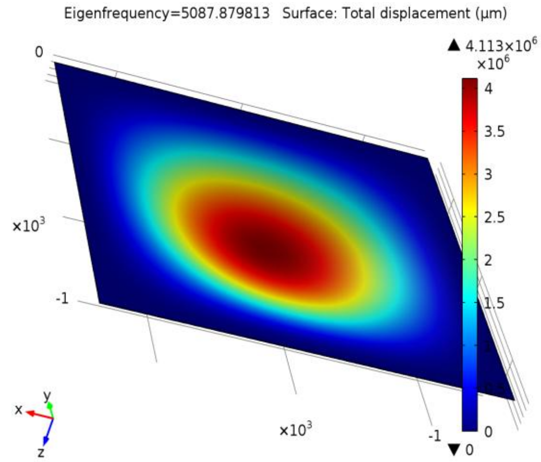

Figure 6 Eigen frequency of SiC with thickness 2 μm

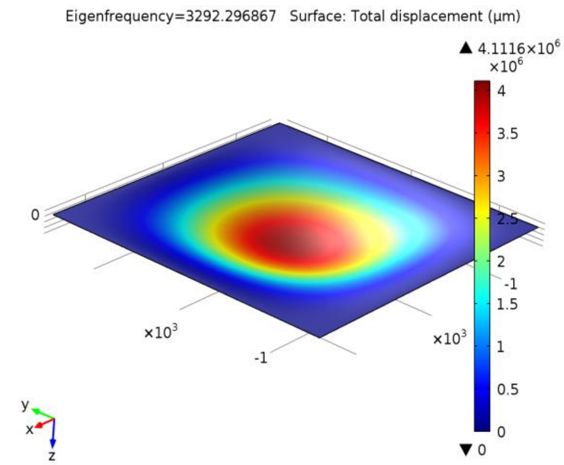

Figure 7 Eigen frequency of Ply-Si with thickness 2 μm

Now, the various design parameters which are computed using different material are compared in a table is given below having thickness (h) 2μm for SiC and Poly-Si and 35μm for Si.

TABLE IVV
Comparison of various design parameter of different material of diaphragm

Material	F(KHz)	S(F/MPa)
Si	51.001KHz	4.55E-16
SiC	50.8KHz	8.39E-13
Poly-Si	32.9KHz	2.01E-12

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V. Conclusion

Mathematical analysis and Simulation of MEMS Acoustic Sensor has been done in the present work. The frequency of Si diaphragm is increased upto 51.001 KHz but sensitivity is 4.55E-16 F/MPa. To increase the sensitivity we decrease the thickness of diaphragm as we know that thickness is inversely proportional to the sensitivity and use different material as SiC and Polysilicon and resultant increased sensitivity is 2.01E-12 F/MPa using Poly-Si but the resonance frequency of Poly-Si and SiC are less than Si diaphragm.

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