Modelling and Simulation of Diaphragm Based MEMS Acoustic Sensors

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Abstract—**In this paper we present a simpler technique for designing an acoustic sensor based on Zinc Oxide as thin film for diaphragm. This diaphragm thickness has been optimized to withstand sound pressure level range of 100–200 dB.Stress distributions using Intellisuite has been plotted. We utilize MEMS technology to design acoustic displacement sensor chips on single crystalline silicon. A SiO_2 layer behaves as dielectric. The diaphragm exhibits excellent physical and chemical properties that include membrane forming ability, insensitive to the background pressure and good mechanical strength. The diaphragm shows relative change in displacement in response to different sound pressure level.**

Keywords— **MEMS, Diaphragm, Acoustic, Intellisuite.**

I. INTRODUCTION

Acoustic sensor has a wide application in urban road monitoring, it can be used to measure the vehicles and pedestrians traffic accurately. The acoustic vibration sensor manufactured by MEMS technology has the features of high sensitivity, wide range of low frequency, easy to be integrated and manufactured etc.Through measuring and processing the acoustic vibration signals from the pedestrians and vehicles, extracting effective characteristic parameters, target classification can be achieved, and the intelligent monitoring management of the road traffic can be realized.[1]

Sound pressure or acoustic pressure is the local pressure deviation, caused by a sound wave. Sound pressure level (SPL) is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level.The reference sound pressure in air or other gases is 20 µPa, which is usually considered as the threshold of human hearing. The number of sound pressure level vibrations per second denotes the frequency. Infrasonic, sonic, and ultrasonic frequencies are measured in Hertz [2].Humans have a maximum audible range that varies in range of 20-20,000 Hz under ideal conditions. Sound propagates through compressible media like in air and water as longitudinal waves and as transverse waves in solids. The sound source creates vibrations in the surrounding medium. As the source continues to vibrate in the medium, the vibrations propagate away from the source, thus forming the sound wave. At a fixed distance from the source, the pressure & velocity of the medium may vary in time. At an instant in time, the pressure and displacement vary in space [3]. The behaviour of sound propagation generally get affected by following parameter:--

- A relationship between density and pressure. These relations depend upon temperature which determines the speed of sound within the medium.
- The propagation is also affected by the motion of the medium itself, for eg. sound movement through wind.
- The viscosity of the medium also affects the motion of sound waves. It decides the rate at which sound is attenuated. For many medium, such as air or water, attenuation is almost negligible.

II. DESIGN METHODOLOGY

A. Theoretical background

In load deflection technique, the deflection of suspended film is measured as a function of applied pressure. The load deflection relationship of diaphragm is given by eq as below

$$\frac{P\times a^4}{E\times h^4}=\frac{4.2}{(1-v^2)}\times\frac{y}{h}+\frac{1.58}{(1-v)}\times(\frac{y}{h})^2 \text{ ..... (1)}$$

Where P is applied pressure, y is deflection from the centre of diaphragm, a represents half of the side length, h is the diaphragm thickness, E is Young's modulus and v is Poisson's ratio of diaphragm material.[4]

The working principle is that the vibration signal from the outside is delivered to sensitive chip through acoustic coupling material, under the action of the internal mass of the sensitive chip, the elastic beam deformation occurs which needs to be measured.

B. Design challenges

The main challenges of this method are the proper design and layout of the experimental setup.Further design considerations includes the application of an excitation layout and a detection mechanism. We have also designed several possible structures for the simulations and finally worked out with the following structure.

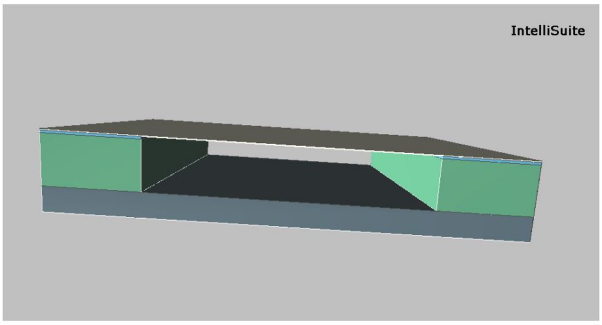

Fig.1 Design of Acoustic Sensor using 3D Builder

The schematic design of the MEMS acoustic sensor is shown in Fig.1.The active layered structure for the acoustic device in the present study consists of the diaphragm of piezoelectric thin film i.e. ZnO. The passivation layer of Si_3N_4 is now deposited on the clean surface of Si using the low pressure chemical vapour deposition (LPCVD) technique. Prior to the deposition of passivation layer, thin SiO_2 layer film is grown on Si wafer using conventional thermal oxidation.

III. FEM SIMULATION

To investigate the different displacement parameter, we have utilized the FEM software Intellisuite version 4.7. This software is also being used to model the excitation mechanism accurately. To obtain the simulation output, the sound pressure level is converted into corresponding pressure equivalent which is then applied on the diaphragm for static analysis.

When static pressure is applied, the portion of air passes through diaphragm to enter the cavity that compresses the wall and elongate the cavity. Once the pressure equilibrium is reached on diaphragm interface, the deformation of the diaphragm is minimum and resultant cavity length will be closed to the initial value. This property of designed diaphragm can eliminate back pressure drift issue, which is the major problem faced by most of the Extrinsic Fabry-Perot Interferometer (EFPI) sensor. On the other hand, the area of which the air enters the cavity is much smaller compare to the area of the diaphragm, so when coming to acoustic pressure measurement, the energy that is diffracted into the cavity through the diaphragm is negligible.[5]

Therefore, the sensor is expected to be insensitive to the background pressure drift while maintaining its sensitivity for both static and dynamic pressure measurement. The acoustic pressure cause a change for the displacement of the diaphragm, and this displacement is related to the output intensity change.

IV. RESULTS AND DISCUSSION

The sound pressure level (SPL) or Lp is defined as

$$Lp = 20\times \log_{10}\left(\frac{P_{rms}}{P_{ref}}\right)\text{ dB} \;\ldots\ldots\; (2)$$

Where P_{ref} is the reference sound pressure and P_{rms} is the rms sound pressure being measured. Here we take reference sound pressures as 20 μPa in air and 1 μPa in water. Here we have done a conversion of SPL in decibel into Pressure equivalent. For experimentation we have taken SPL range from 20-200dB .A table is as shown below.

Table-1
Dimension & Material Property

LAYERS	**DIMENSION (μm)**	**MATERIAL**	**YOUNG MODULUS (GPa)**	**POISSON RATIO**	**DENSITY (gm/cc)**
Substrate	100×80×10	Silicon	170	0.26	2.32
Diaphragm	20×80×0.5	Silicon Nitride	296	0.27	3.1
Sensing layer	100×80×1	Zinc Oxide	123	0.68	5.606

Table-2
Displacement output of Acoustic Sensor

SPL (dB)	**SPL(Pa)**	**Displacement(μm)**
20	2 E-4	0.028738
40	2 E-3	0.028738
60	2 E-2	0.028741
80	0.2	0.028756
100	2.0	0.028915
120	20	0.030506
140	2 E 2	0.046416
160	2 E 3	0.205523
180	2 E 4	1.79658
200	2 E 5	17.7072

SIMULATION RESULTS

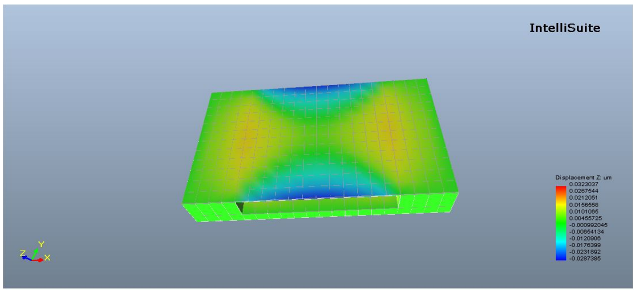

Fig.2 Output Displacement for SPL-20 dB

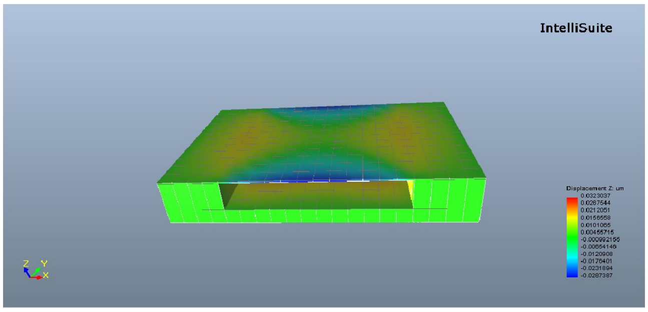

Fig.3 Output Displacement for SPL-40 dB

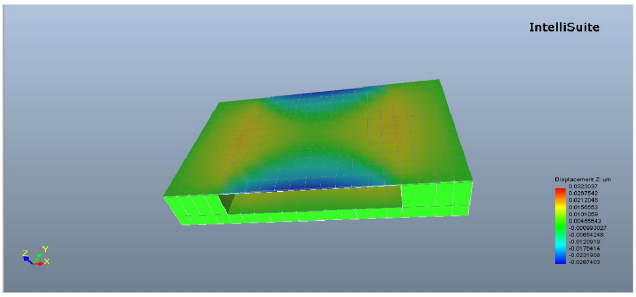

Fig.4 Output Displacement for SPL-60 dB

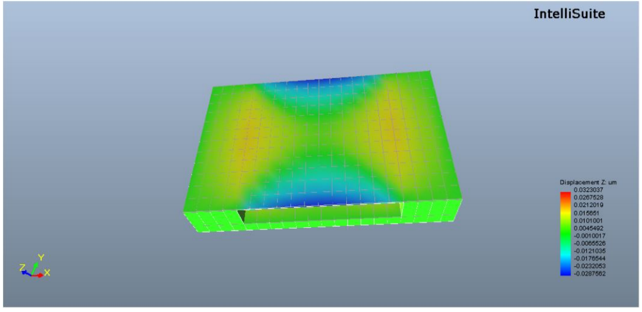

Fig.5 Output Displacement for SPL-80 dB

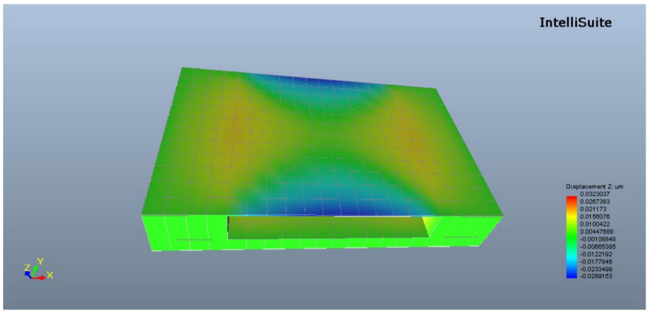

Fig.6 Output Displacement for SPL-100 dB

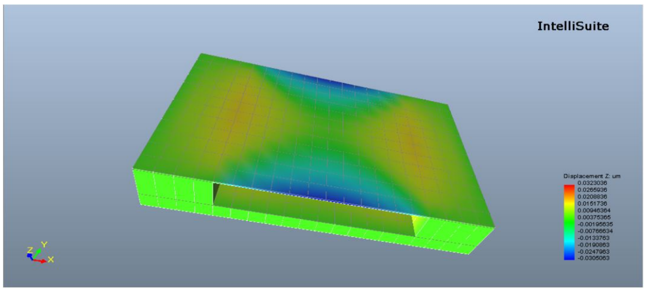

Fig.7 Output Displacement for SPL-120 dB

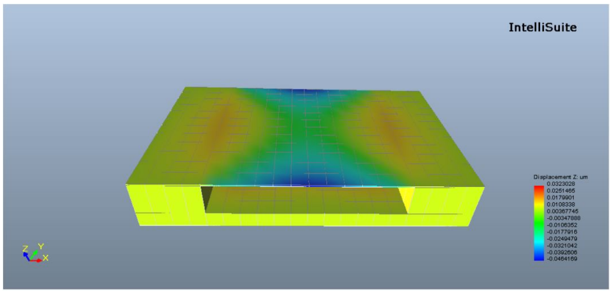

Fig.8 Output Displacement for SPL-140 dB

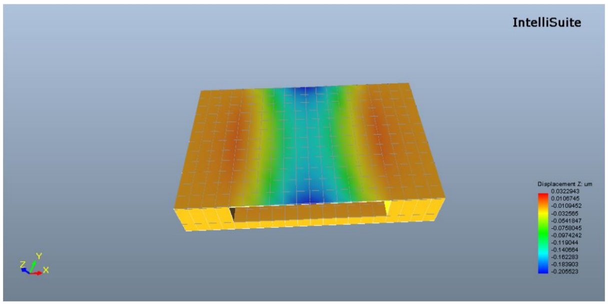

Fig.9 Output Displacement for SPL-160 dB

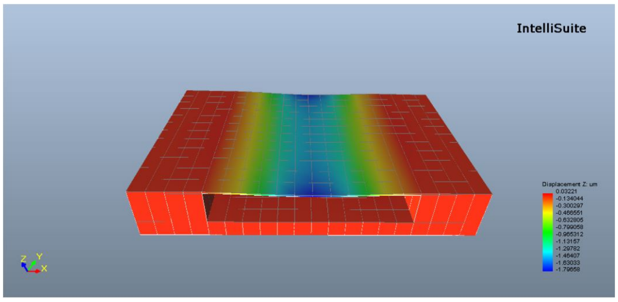

Fig.10 Output Displacement for SPL-180 dB

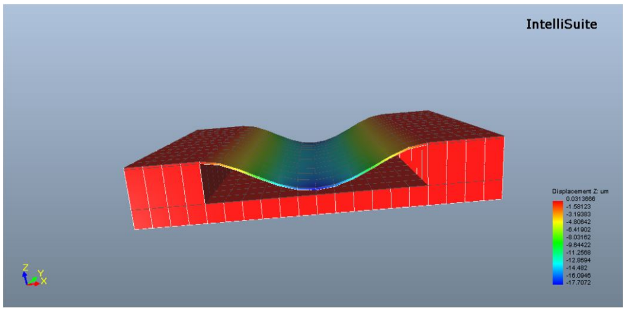

Fig.11 Output Displacement for SPL-200 dB

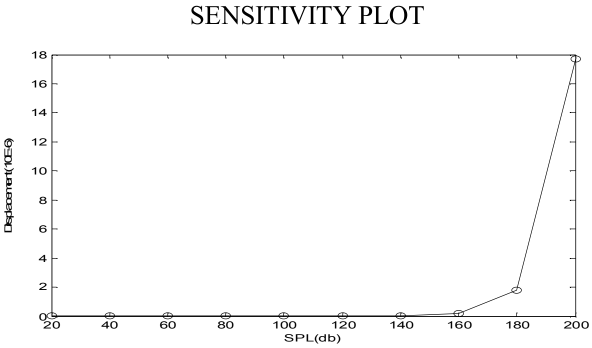

Fig.12 Displacement vs Sound Presure Level(dB)

V. CONCLUSION

A ZnO thin film-based MEMS acoustic sensor is successfully designed using 3D module of Intellisuite Software. A diaphragm based acoustic pressure sensor described here preserves the advantages of all conventional silica based miniature EFPI sensor while offering higher sensitivity.

The sensitivity of sensors is evaluated through simulations. Sensitivity shows low rise for lower value of SPL (dB) but it increases sharply after 160dB.The proposed model shows good response for the desired decibel range of Sound pressure level.

The presented sensor technology exhibits the potential for production of high resolution low cost transducers for industrial applications. With further advancement of micro and nanofabrication technology such as highly miniaturized structural air gap size and beam width, the sensitivity can be enhanced.

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