Design and fabrication of Si-diaphragm for ZnO-based MEMS acoustic sensor

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Abstract. A Si-diaphragm for ZnO-based MEMS acoustic sensor has been designed and fabricated for higher sound pressure level (SPL) range 120-200 dB. The optimization of Si-diaphragm thickness was done using MEMS-CAD-Tool COVENTORWARE. A 50 μm-thick Si-diaphragm was found to be more suitable for the above specified SPL range. A 10 μm-deep microtunnel for pressure compensation in MEMS acoustic sensor has been designed. The lower cut-off frequency of the sensor was calculated and found to be 0.06 Hz. The resonance frequency of structure was obtained using modal analysis and found to be 78.9 KHz. Based on simulation results, the optimum sensitivity of acoustic sensor was calculated and found to be 116.4 μV/Pa.

1 Introduction

The measurement of high sound pressure is an important requirement for aerospace applications because, sound pressure produced by launch vehicle and large booster rocket can cause fatigue of metal panels and structures. A ZnO-based MEMS acoustic sensor [1], [2] fabricated using silicon wafer is most suitable for this purpose. The frequency response of the sensor reported by the authors is approximately 30 Hz to 8 KHz within SPL range 120-180 dB. In present approach, the acoustic sensor was designed for higher SPL range 120-200 dB. The Si-diaphragm thickness for above specified SPL range was optimized.

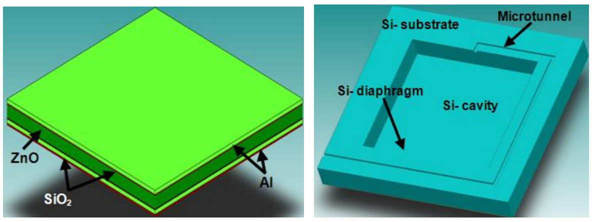
2 Design and Simulation

A 3D model of ZnO-based acoustic sensor designed using COVENTORWARE is shown in Figure 1. A ZnO layer sandwiched between two Al electrodes covered by thin PECVD layer is placed on an oxidized silicon diaphragm. The complete structure consists of silicon diaphragm, SiO_2, Al, PECVD SiO_2, ZnO, PECVD SiO_2, and Al. The thickness of ZnO layer was taken as 3.0 μm because; the value of piezoelectric coefficient is saturated beyond this value. A microtunnel which relates the cavity to the atmosphere was designed for pressure compensation. The specifications of the sensor are given as follows: SPL range; 120-200 dB, lower cut-off frequency 0.06Hz and resonance frequency 78.9 KHz.

2.1 Si-diaphragm design

The deflection of suspended film can be measured as a function of applied pressure. The load-deflection of a flat square diaphragm is given by the following equation [3]

Here, is applied pressure (Pascal), is center deflection of the diaphragm, is half of side length, is the diaphragm thickness, is Young's modulus and is Poisson ratio of diaphragm material.



(a) (b)

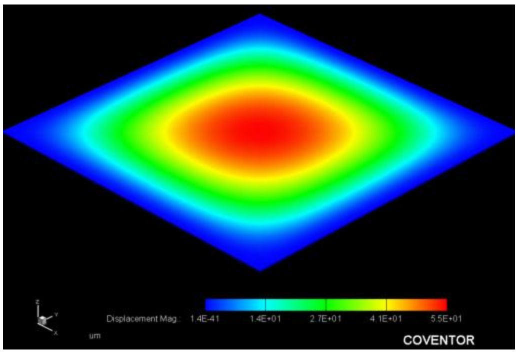
Fig.1. 3D-view of ZnO based acoustic sensor designed using COVENTORWARE: (a) front view of the device, and (b) back view of the device.

To operate the device in linear region, the optimization of silicon diaphragm thickness for higher SPL range is necessary. For this purpose, we have considered the different Si-diaphragm thicknesses from 10-50 µm in step of 5 µm. The size of the diaphragm was taken as 3 mm × 3 mm. The simulation of the device was carried out using MEMS CAD Tool COVENTORWARE. The materials properties used in simulation work are given in Table 1.

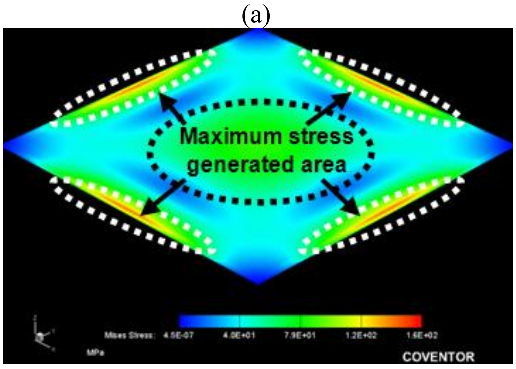
Table1: Material properties used in simulation

Materials	Young's Modulus (GPa)	Poisson's Ratio	Density (kg/m^3)	TCE(1/K)	Electric Conductance(S/m)	Dielectric const.
Si	135	0.278	2331	2.49e-6	1400	-
SiO_2	70	0.17	2150	5e-7	e-10	3.9
Al	70	0.3	2300	2.31e-5	3.69e+7	-
ZnO	210	0.33	5680	-	2.5e-7	-

The deflection in the structure at 200 dB SPL is given in Figure 2(a). The corresponding stress generated in structures is shown in Figure 2(b). At different SPL 120-200 dB for different diaphragm thicknesses: 10-50 µm, the variation of deflection with thickness of structure is plotted in Figure 3. Hence, to operate the device in linear region with optimum sensitivity and for safety of the structure, the 50 µm-thick Si-diaphragm is selected for device fabrication. The estimation of resonance frequency of structure (50 µm-thick silicon) was calculated using MEMS CAD Tool COVENTORWARE and found to be 78.9 KHz.



(a)



(b)

Fig. 2. 10 μm-thick Si-diaphragm at 200 dB SPL: (**a**) displacement of the diaphragm and (b) generated stress.

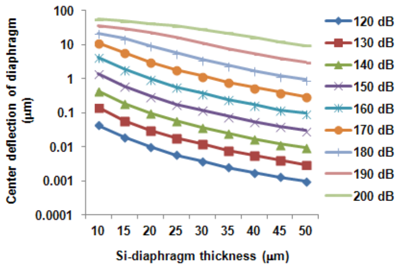


Fig. 3. Si diaphragm thickness versus center deflection of the diaphragm at different SPLs.

2.2 Microtunnel design and Sensitivity calculation

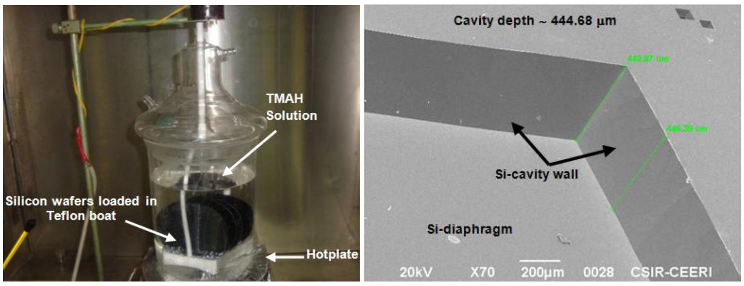
The design of Si-cavity and microtunnel gives the lower cut-off frequency of the device. The lower cut-off frequency can be as follows:

Here, is the microtunnel resistance and is the cavity compliance. By putting the values of and , the value of is calculated and found to be 0.06 Hz for a

10 μm deep microtunnel. The unamplified sensitivity of the acoustic sensor was calculated as 116.4 μV/Pa.

3. Fabrication

The fabrication of 50 μm-thick Si-diaphragm was done using bulk micromachining technique. The experimental setup and fabricated silicon diaphragm are shown in Fig. 4(a) and 4(b) respectively.



(a) (b)

Fig. 4. Bulk-micromachining of Si for diaphragm fabrication (a) experimental setup, and (b) SEM image of structure.

4 Conclusions

The optimization of Si-diaphragm thickness for ZnO-based MEMS acoustic sensor within SPL range 120-200 dB has been done using MEMS-CAD-Tool COVENTOWARE. A 50 μm-thick Si-diaphragm was found to be more suitable for SPL range 120-200 dB. For linear operation of the sensor, the resonance frequency of the structure has been obtained. A microtunnel for pressure compensation in MEMS acoustic sensor has been designed which gives the lower cut-off frequency. The fabrication of Si-diaphragm was done using bulk-micromachining technique. The designed acoustic sensor can be used to measure the sound pressure level in launch vehicles, rocket motors and weapons' discharge.

References

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