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Design and Fabrication of Piezoelectric Acoustic Sensor

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Abstract: - This paper describes a fully integrated acoustic sensor that combines high sensitivity, wide frequency range and low cost of batch processed miniaturized silicon components.
A sputtered piezoelectric ZnO layer transforms the mechanical deflection of a thin-etched-Si diaphragm into a piezoelectric charge. ZnO has transparent and conductive properties, which makes it attractive for a variety of scientific and research applications such as surface acoustic wave filters, acoustic sensors, gas sensors, ultrasonic transducers and solar cells etc. ZnO is wide band gap semiconductor with energy of 3.37 eV & high excitation energy of 60 meV A 25-micron thin diaphragm Si is etched using wet chemical etching. This is followed by a deposition of sandwiched structure composed of bottom Al electrode, sputtered 3 micron of ZnO film and top Al electrode. A glass having 1um diameter hole was bonded on backside of the sensor to maintain sound pressure inside the cavity. Modeling and analysis of the acoustic sensor is performed using FEM technique, which describes the deflection of a generic m-layer piezoelectric multimorph sensor. Fabrication steps of the MEMS acoustic sensor are described

Key-Words: - MEMS sensors, acoustic sensors, piezoelectric sensors.

1 Introduction

Piezoelectricity is the ability of certain materials to produce a voltage when subjected to mechanical stress. The effect is reversible; piezoelectric materials, subject to an externally applied voltage, can change shape by a small amount. The effect is of the order of nanometres, but nevertheless finds useful applications such as the production and detection of sound, generation of high voltages, electronic frequency generation, and ultrafine focusing of optical assemblies.

In a piezoelectric crystal, the positive and negative electrical charges are separated, but symmetrically distributed, so that the crystal overall is electrically neutral. When a stress is applied, this symmetry is disturbed, and the charge asymmetry generates a voltage. Micromachined acoustic sensors implying piezoelectric material have potential applications in hearing aids, surveillance devices, biometrics, and industrial-process monitoring. Compared with conventional sensors, the micromachined ones have potential advantages of reduced device size, low cost, and the capability of being integrated with on-chip circuitry [1].
The first microphone type acoustic sensor was realized in 1983 [2] by using bulk micro machining of silicon. Thin film Zinc oxide exhibits excellent piezoelectric properties for surface acoustic wave (SAW) [3] and for optical devices [4]. Sputtered piezoelectric ZnO layer transforms the mechanical deflection of a thin-etched-Si diaphragm into a piezoelectric charge distribution. In this work, square silicon diaphragms were realized by anisotropic etching of (100)-oriented silicon wafer. Controlled etch rate method was used to fix the final thickness of silicon membrane. TMAH based etching solution was used for controlled etching of silicon membrane at 70°C.
In the following sections the design of the MEMS acoustic sensor, its modeling, and fabrication processes are described.

2 Sensor's Design

The acoustic sensor consists of a silicon diaphragm etched in the body of the chip, piezoelectric zinc oxide layer and pair of Aluminum electrodes deposited above the silicon diaphragm. The silicon diaphragm largely controls the frequency response and lateral stresses in response to acoustic pressure. The zinc oxide layer acts as a lateral stress to transverse polarization converter and Al electrodes tap the electrical signals.

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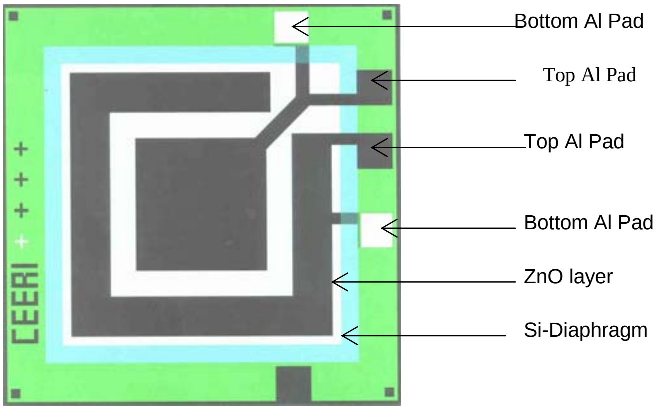


Fig. 1 Layout of the acoustic sensor

Figure 1 shows the layout of the designed sensor. The structure is composed of *AL/ZnO/Al/*SiO_2 multimorph layers. A $1\mu m$ Aluminum layer is used as the bottom electrode and barrier layer to prevent the diffusion between ZnO and the silicon substrate. A 0.35 μm Silicon dioxide (SiO_2) is used to fasten the bottom electrode to the Si substrate. A layer of ZnO of 3 μm is deposited as the main structure layer. And finally a $1\mu m$ of Aluminum as the top electrode.

3 Modeling of the sensor

Piezoelectric sensing is based on the piezoelectric effect of piezoelectric materials as mentioned in section 1. The electrical charge change is generated when a force is applied across the face of a piezoelectric film [5]. For a piezoelectric disc of a given thickness of t, the voltage V generated across the electrode disc (Fig. 2) when subjected to a stress (T) is given by:

$$V = gtT \qquad (1)$$

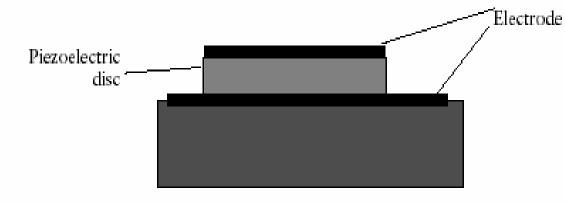


Fig. 2 Piezoelectric sensing

Where g is the piezoelectric voltage coefficient. A model describing the deflection of a piezoelectric multimorph structure can be derived by appealing to the basic mechanics principles of the static equilibrium and strain compatibility between successive layers in the device [6]. An electromechanical simulator based on FEM technique is used to obtain the relation between the stress and deflection at different operating force. Figure 3 represents this relationship.

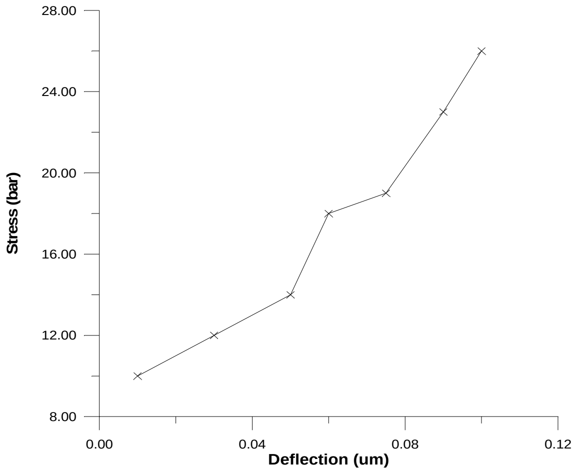
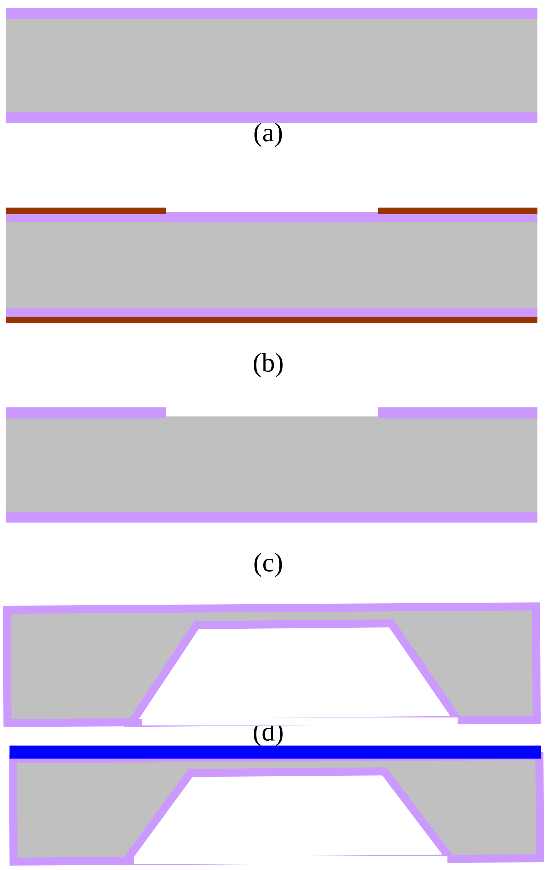


Fig. 3 The relation between stress and deflection

4 Sensor's Fabrication Steps

The fabrication process starts with a 100 mm diameter p-type, both side polished, (100) orientation, RCAI and RCAII Clean methods are used for initial wafer cleaning followed by deposition of $1\mu m$ thick thermal silicon dioxide at 1000° C Fig. 4 (a), which was subsequently used as masking layer for silicon anisotropic etching in TMAH, using negative photo resist, Fig.4 (b,c). Silicon diaphragm of $25-30\mu m$ thickness is formed using TMAH etching at 70° C, with etching rate $0.3\mu m/\min$, Fig. 4(d).

Processing steps like oxide etching dilute HCl rinse and RCA Clean follows the diaphragm formation. A fresh $0.5\mu m$ thick silicon dioxide is thermally grown at 1000° C Fig. 4(e), before Aluminum film deposition by RF sputtering, for 40 min using 600 watt power. Lithography, followed by Al metal etching, delineated the bottom electrodes of the sensor using Aluminum etchant at 55^0C with etching rate $100\overset{0}{A}/\min$, Fig. 2(e,f). This Al electrode was covered by $0.3\mu m$ thick plasma enhanced chemical deposition (PECVD) silicon dioxide at *300 °C* and pressure 0.3 torr for 5 min, Fig. 4(g). A $3\mu m$ thick zinc oxide layer is sputtered by RF sputtering at 600W, pressure 10 mtorr and the sputtering time is 125min, Fig 4(h). The A lithography, followed by ZnO etching in ultra diluted hydrochloric acid, delineates the piezoelectric zinc oxide layer pattern, Fig. 4(i). A $0.3\mu m$ thick PECVD silicon dioxide layer, Fig. 4(j) with the same conditions covered the patterned zinc oxide before sputtering a $1\mu m$ thick Al metal film, Fig. 4(k). A lithography, using thick resist followed by Al etching, delineates the top electrodes of the sensor, Fig. 4(l). Again, a $0.35\mu m$ thick PECVD silicon dioxide layer coveres the top electrode. A lithography, using thick resist coating followed by reactive ion etching (RIE) of PECVD oxide layers till the Al bottom electrodei s arrived at, opened the device. Finally, the plasma stripping of the resist completed the sensor fabrication. The finished chip was bonded to 1mm thick Pyrex glass base with a $1\mu m$ diameter hole at the center using glass to silicon anodic bonding Fig. 4(m). Connections to the dc power supply and output signal were provided through wire bonding on the chip to the respective pins. The packaged acoustic sensor chip is shown in Fig.5.



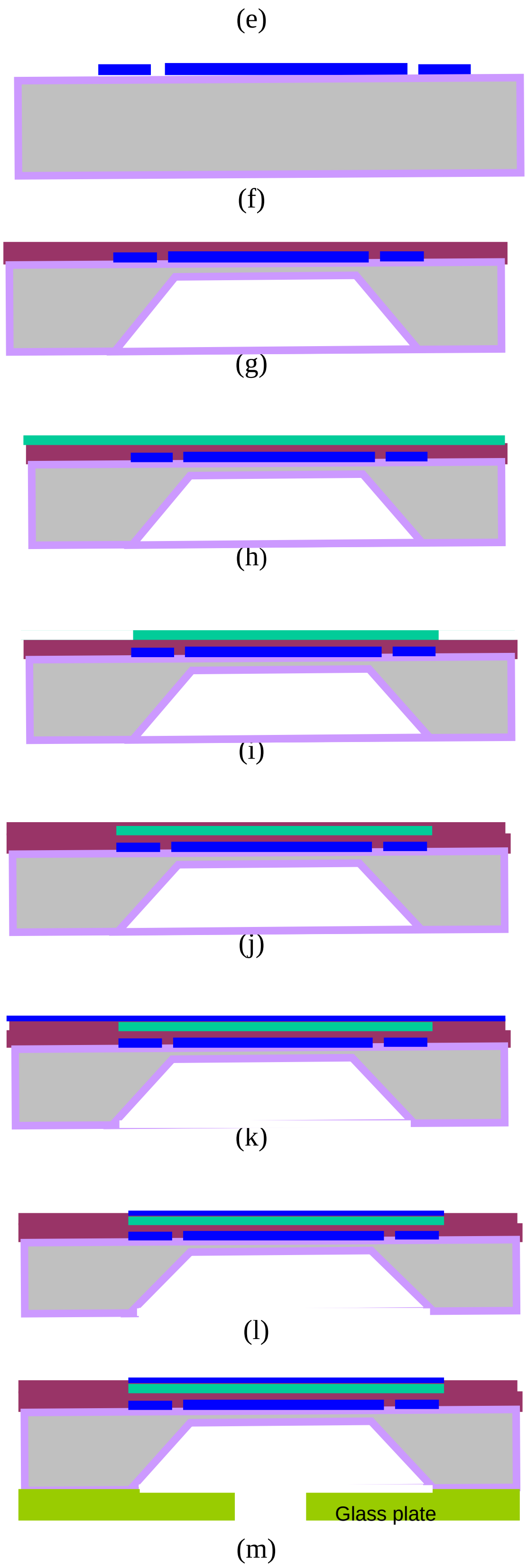


Fig.4 Fabrication and process flow of the acoustic sensor

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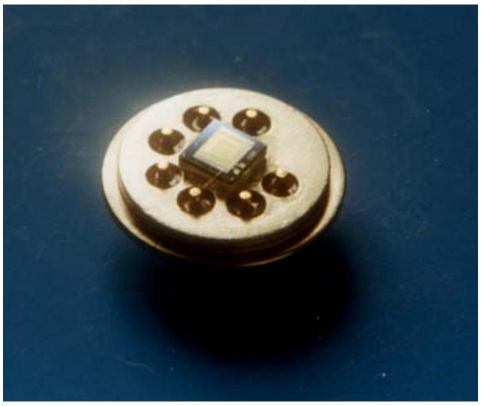


Fig. 5 MEMS based acoustic sensor chip

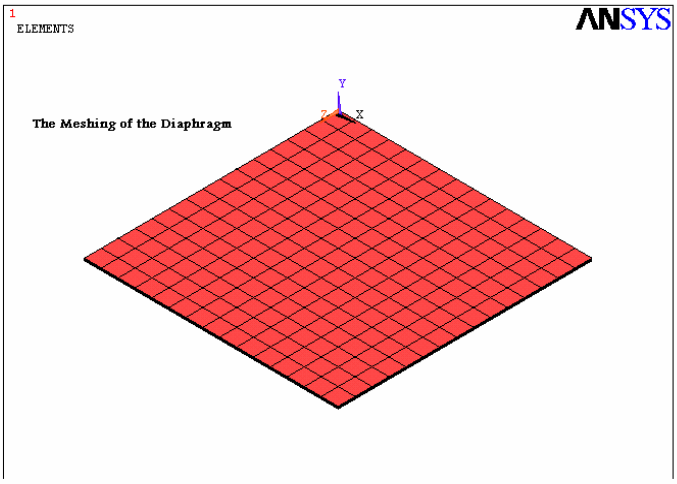


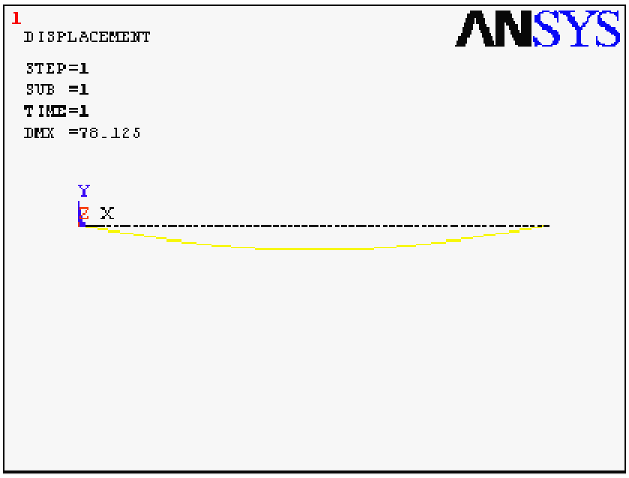
Fig. 6 The Meshing of the diaphragm layers

5. Measurements and Simulation Results

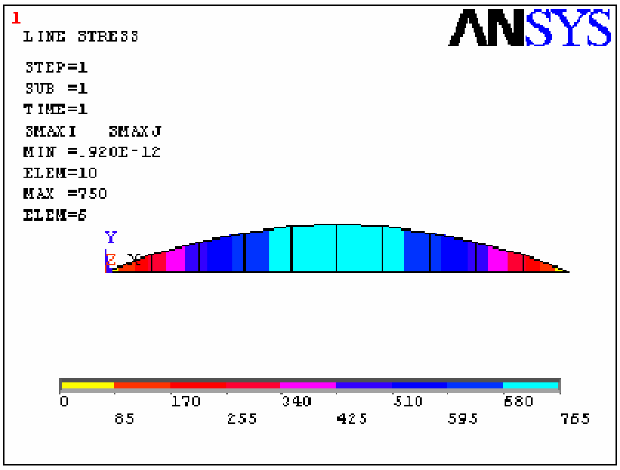
The measured capacitance value of 115-120pF on the central region is carried out using a C-V Plotter. The acoustic sensor showed a flat frequency response from 31.5Hz to 8 KHz. The measured average sensitivity is 50mVrms /Pa and a reasonably linear output over 110-160dB of SPL.

In this work the MEMS acoustic sensor is modeled using FEM technique by ANSYS in order to obtain the maximum deflection occurred at the tip of the multimorph structure layers, and the distributed voltage through the sensor due to the distributed pressure on the surface area of the multimorph layers. The meshing procedure of the multilayer diaphragm is shown in figure 6.

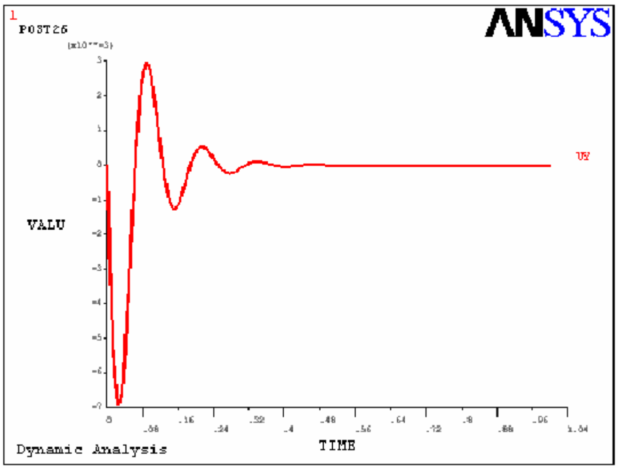
The maximum deflection of the clamped-clamped diaphragm was obtained by applying pressure of 0.2bar which gives 30um as shown in Fig.7 (a), and the diaphragm voltage distribution is shown in fig.7 (b) which show that the maximum voltage value is at the centre of the diaphragm and reduced at the tip of the diaphragm, and this voltage is increased by increasing the applied stress which reach the maximum value at 2 bar then it is saturated because of the ZnO material as shown in Fig.7 (c) [8].



(a)



(b)



(C)

Fig. 7 Simulation of the sensor

6. Conclusions

A MEMS technology based acoustic sensor is designed and fabricated using RF sputtered zinc oxide grown along the preferred C-axis orientation.
The frequency response is in the range of 30Hz to 16KHz, the average sensitivity is 50μV rms. /Pa, fairly flat frequency response. A reasonably linear output is between 110-160dB's SPL . Average rim side Capacitance is 150-160pF and the central region Capacitance -Average 115-120pF.

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