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Design and Implementation of Thin-filmed Piezoelectric Pressure Sensor

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Abstract— this paper offers an analytical modeling of thin-filmed, multi-layer piezoelectric sensor. In this work, analysis and simulation of a thin plate pressure sensor is carried on using both mathematical models and finite element analyses. Experimental methods, in the form of full-field-of-view laser microscopy, are applied to show the internal structure of the fabricated pressure sensor and update the computational models. The combined approach of the two methods is used to determine the elastic modulus and the thickness of the diaphragm of the pressure sensor. MEMS pressure sensors are based on a piezoelectric capacitive thin diaphragm that is fabricated using standard Integrated Circuit (IC) procedures including anisotropic etching. During operation, the thin diaphragm of the sensor deflects under pressure loadings, which produces electrical outputs. Analytical simulation using COMSOL software and theoretical computations using equations will be offered in order to determine the parameters for optimal design setting.

Index Terms— COMSOL modeling and simulation, MEMS, Piezoelectric microphone, square diaphragm, ZnO.

1 Introduction

There has been significant advances in the area of thin film, multi-layer piezoelectric with application to MEMS. This paper describes a piezoelectric sensor built on a square silicon diaphragms 25mm thick (SD) Using MEMS Technology. The advantages of the new piezoelectric are high sensitive, wide frequency response range, low electrical power consumption, high precision, and simplified instrumentation.

2 Theoretical considerations

In this paper, two methods are used to expose the process that determines electro mechanical parameters of multi-layer sensors. The first method uses mathematical formulation to analyze the relationship between applied surface contact pressure on the surface of the sensor and the resulting bending and displacement. Furthermore, the relationship between displacement and voltage is established.

The second method is on the basis of analytical simulation of micro cantilever using COMSOL software, also by using the MATLAP this relation was plotted This Sensor is used to analyze, measure, and expose the pressure.

2.1 Analytical method

The diaphragm of the sensor is modeled using Kirchhoff's thin plate theory [5]. For a fully constrained plate subjected to a uniform pressure, Timoshenko's solution indicates that the maximum deformation,w_{max} of the diaphragm is [5],

$$w_{max} = -\beta \frac{Pa^4}{Eh^3} \qquad (1)$$

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Where, p is the applied pressure, and a, E, and h are the side length, the elastic modulus, and thickness of the diaphragm, respectively. β = 0.0138 for a square diaphragm.

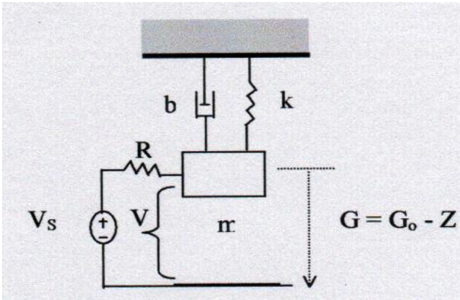


Figure 1: Schematic diagram of the parallel plate model

The voltage equations for the circuit of Figure 1:

$$V_s = iR + V, \qquad i = \frac{dQ}{dT} \therefore \frac{V_s}{R} = \frac{V}{R} + i$$

$$\frac{V_s}{R} = \frac{V}{R} + \frac{dQ}{dT} \qquad (2)$$

The system mechanical equations can be expressed as following:

$$m\frac{d^2Z}{dT^2} + b\frac{dZ}{dT} + KZ = F_{elect} \qquad (3)$$

And

$$F_{elect} = \frac{Q^2}{2C_oG_o} = \frac{\varepsilon_o AV^2}{2Z^2} \qquad (4)$$

In order to examine the energy storage and the power dissipation in this system, it is useful to normalize these equations. Distance is normalized to the initial gap Go, time is normalized to the inverse of the un-damped mechanical resonance frequency (Do, voltage is normalized to the pull-in voltage V_{PI}, and charge is normalized to the "pull-in charge" Q_P which is the charge. stored when the capacitor voltage is equal to V_{PI} and gap is reduced to 2/3 of the initial gap; The new normalized variables are:

$$z = \frac{Z}{G_o}, \qquad t = \omega_o T, \qquad q = \frac{Q}{Q_P}$$

$$v = \frac{V}{V_{PI}}, \qquad v_s = \frac{V_s}{V_{PI}}$$

3 Simulation and design

I Computational analyses

The MATLAB code was used as an analyses method, figure 2. Shows the code used and the parameters, where the result was used for the analyzing the relation between the different applied pressure and the deformation (plate displacement) accurse as shown in figure 3:

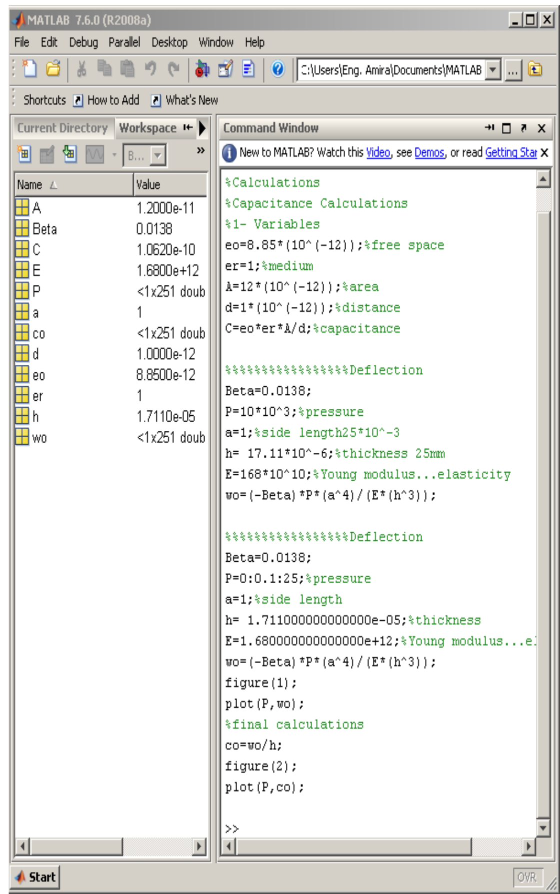


Figure 2: MATLAB code

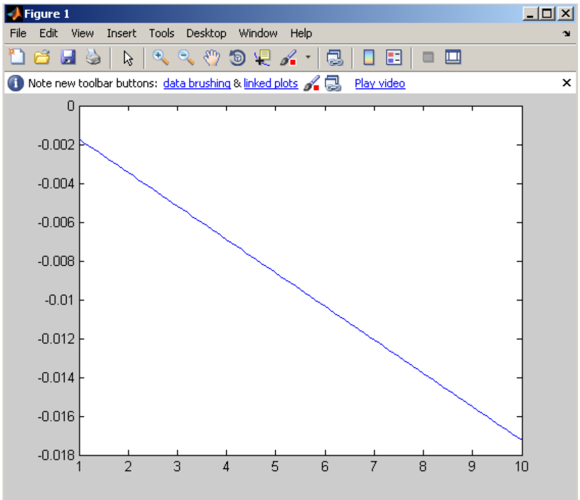


Figure 3: Displacement versus stress applied

II- FEM analyses (COMSOL)

In this work the MEMS pressure sensor is modeled using FEM technique by COMSOL in order to obtain the maximum deflection occurred at the center of the thin plate structure layers, and the distributed voltage through the sensor due to the distributed pressure in the surface area of the thin plate layers, Figure 4 shows representative calculated deformation for a diaphragm subjected to different loading conditions.

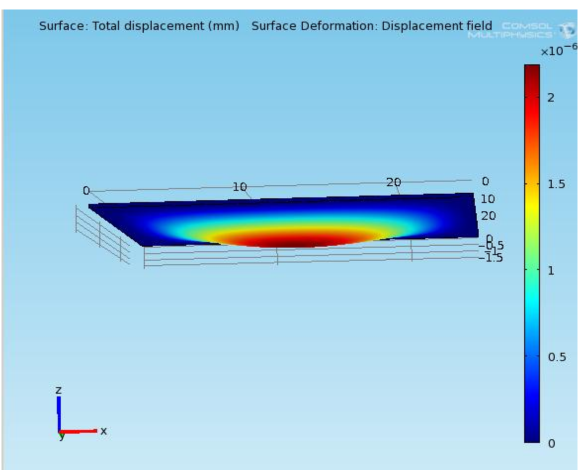


Figure 4: Representative Diaphragm deformation

The meshing procedure of the multilayer diaphragm is shown in Figure 5.

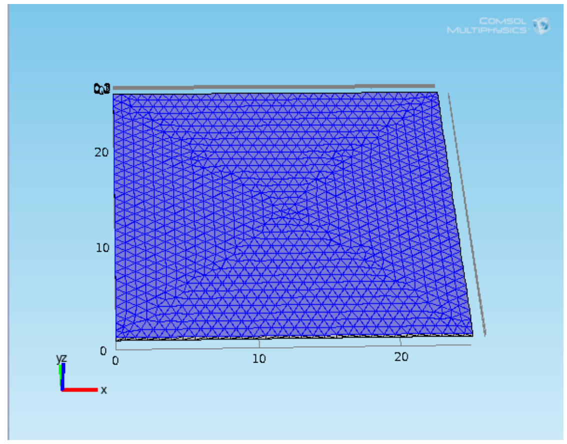
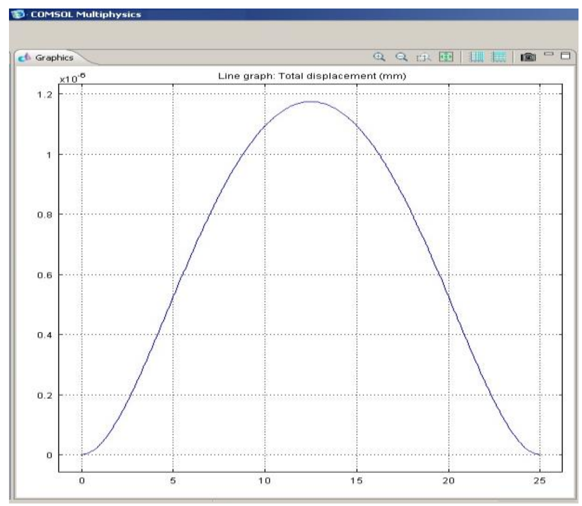
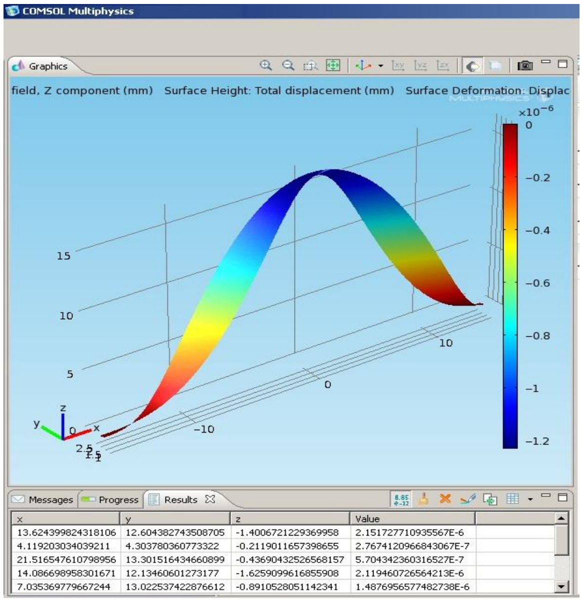


Figure5: the Meshing of the diaphragm layer

The maximum deflection of the clamped-clamped diaphragm was obtained by applying pressure 0.2bar which gives 1.55um as shown in figure 6 (a), and the diaphragm voltage distribution is shown in figure 6 (b) which show that the maximum surface displacement value is at the center of the diaphragm and reduced at the tip of the diaphragm, and this displacement increased by increasing the applied stress which reach the maximum value at 2 bar then it is saturated because of the ZnO material.



(a) Deflection of the diaphragm



(b) Diaphragm surface height total displacement

Figure 6: Diaphragm simulation output RESULTS

The maximum deformations as a function of applied pressure data obtained with analytical, computational, and experimental results. From these data, the elastic modulus and the thickness of the diaphragm of the MEMS pressure sensor of interest are, determined.

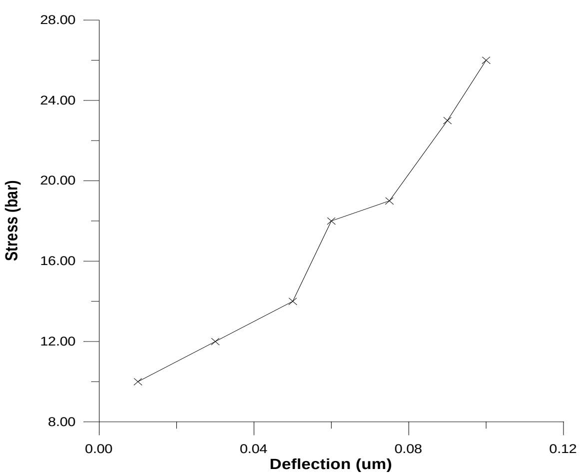


Figure 8: The relation between stress and deflection

A model describing the deflection of a piezoelectric thin plate structure can be derived by appealing to the basic mechanics principles of the static equilibrium and strain compatibility between successive layers in the device. An electromechanical simulator based on FEM technique is used to obtain the relation between the stress and deflection at different operating force. Fig.8 represents this relationship.

4 CONCLUSIONS

The measured capacitance value of 115-120pF on the central region is carried out using the C-V Plotter Instrument. 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 COMSOL in order to obtain the maximum deflection occurred at the tip of the thin plate structure layers, and the distributed voltage through the sensor due to the distributed pressure in the surface area of the thin plate layers.

The maximum deflection of the clamped-clamped diaphragm was obtained by applying pressure 0.2bar which gives 30um, and the diaphragm voltage distribution 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 increased by increasing the applied stress which reach the maximum value at 2 bar then it is saturated because of the ZnO material.

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