

Piezoelectric Acoustic Sensor for Energy Harvesting

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ABSTRACT: This paper proposes to harvest energy from the mechanical vibration by piezoelectric material. Principle of piezoelectricity is to convert “pressure-to-electricity”. Piezoelectric energy harvester has an edge on electromagnetic & electrostatic energy harvesters because of higher feasibility of material and power density factors. The sensor structure consists of silicon substrate and ZnO which is sandwiched between two aluminium electrodes. The proposed acoustic sensor has been designed to withstand the dynamic sound pressure of 96-106dB and produces a maximum of 390 μ V/Pa. The simulation is done by Coventorware and verified by analytical method.

KEYWORDS: Acoustic Sensors, energy harvesting, piezoelectricity, ZnO, Silicon substrate

1.INTRODUCTION

Micro-Electro-Mechanical Systems or MEMS is a composition of an electro-mechanical and miniaturized mechanical elements that is devices and structures that are made using the micro fabrication techniques. They are manufactured utilizing IC fabrication techniques and can go in size from a couple of micrometers to millimeters. These systems can sense, control and impel on the smaller scale, and create consequences for the full scale. In the most broad structure, MEMS comprises of mechanical microstructures, micro sensors, micro actuators and microelectronics, all incorporated onto the same silicon chip. MEMS systems are very small; their parts are microscopic. Motors, levers cylinders and steam engines can also be fabricated by MEMS technique. Sensors improved utilizing MEMS are than traditional sensors because of their smaller size Lower Power consumption. Newer applications like Ear-inserts and space technology cannot be satisfied by traditional sensors.

Piezoelectricity is the capacity of specific materials to create a voltage when subjected to mechanical stress. The impact is reversible (inverse effect) in piezoelectric materials, subject to a remotely connected voltage, can change shape by a small amount. By applying lateral pressure to the piezoelectric material, the sample will get compressed along X-axis, and it will be expanded along Y-axis so by the application of lateral pressure upper side will become positive and lower side will become negative. And if we apply tension to the piezoelectric material, the sample will get compressed along Y-axis, and it will be expanded along X-axis so by the application of lateral pressure upper side will become negative and lower side will become positive so potential difference will be developed in both cases because of opposite polarity this is known as direct piezoelectric effect.

The direct piezoelectric impact was first seen in 1880, and was started by the siblings Pierre and Jacques Curie. By federating their knowledge of pyroelectricity with the concept of crystal structures and behavior, the Curie siblings exhibited the first piezoelectric effect by using crystals of tourmaline, quartz, topaz, cane sugar, and Rochelle salt. Their first demonstration showed that quartz and Rochelle salt displayed the most piezoelectricity capacity at the time.

After few couple of decades, piezoelectricity stayed in the research center, something to be analyzed as more work was embraced to investigate the considerable capability of the piezoelectric impact. The breakout of World War I

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marked the launch of the first practical application for piezoelectric device-sonar device. This initial use of piezoelectricity in sonar created intense international developmental interest in piezoelectric devices. Throughout the following couple of decades, new piezoelectric materials and new applications for those materials were investigated and created.

In the mean while of World War II, research bunches in the US, Russia and Japan found another class of man-made materials, called ferroelectrics, which displayed piezoelectric constants higher than common piezoelectric materials. In spite of the fact that quartz crystals were the primary financially exploited piezoelectric material and still utilized as a part of sonar discovery applications, researchers continued hunting down higher execution materials. This extreme research brought about the advancement of barium titanate and lead zirconate titanate, two materials that had certain properties suitable for specific applications.

The primary piezoelectric material-based microphone was displayed by Royer et al. They utilized ZnO film of thickness 3–5 μm on 30 μm -thick silicon stomach. An affectability of 50–250mV/Pa. Different creators has likewise introduced the piezoelectric ZnO-based receivers and acoustic gadgets, encouraged by fabulous similarity of ZnO with the CMOS process [1].

The work of Sravanthi Chalasani, James M. Conrad considered as a survey for identifying the sources of energy harvesting based on various technical papers available in the public domain. Here acoustic sensor is designed and fabricated using RF sputtered zinc oxide grown along the preferred C-axis orientation [2].

Aliza Aini Md Ralib, Anis Nurashikin Nordin, Hanim Salleh had given the idea for the design and simulation of MEMS based piezoelectric cantilever beam which can both harvest energy as well as monitor critical vibration frequencies in power plant gas turbines. The design of the energy harvesters consists of a cantilever beam structure with the inter digitized electrodes on the zinc oxide piezoelectric layer with nickel proof mass at the end of the beam [3].

K. Y. Madhavi, Sumithradevi.K.A, M Krishna discussed the various factors which play a critical role in the performance of a MEMS pressure sensor. The design of the diaphragm is vital for the efficiency of the sensor. The dimensions of the diaphragm like length, radius, thickness and shape are taken into consideration and the effects of variations in pressure on the geometry of the sensing element are discussed using the Weka data mining tool [4].

Aliza Aini Md Ralib, Anis Nurashikin Nordin, Hanim Salleh , Raihan Othman mentioned details of the design of a piezoelectric cantilever beam as a MEMS energy harvester. Aluminium doped zinc oxide (AZO) was chosen as the piezoelectric layer [5].

All the previous literatures on a cantilever structure of acoustic sensor for energy harvesting but here we are working on diaphragm structure of acoustic sensor for energy harvesting by expecting energy generated will be more at the centre of diaphragm than cantilever.

II. RELATED WORK

Sherif Saleh in his paper has given a brief introduction on the work base on the acoustic Sensor technology fully integrated acoustic sensor that combines high sensitivity, wide frequency range and low cost of batch processed miniaturized silicon components [6]. 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.

Vasudha Hegde reported the effect of diaphragm design on the efficiency of acoustic pressure sensor for energy harvesting, designed the model on different parameters of diaphragm such as shape, dimensions and thickness, type of piezoelectric material of diaphragm and studied the effect of stress and voltage of diaphragm for different parameters[7].

Mahanth Prasad reported a simple technique for fabrication steps of mems based acoustic sensor on piezoelectric zinc oxide (ZnO) thin film by utilizing SOI wafers. In this work, the author has achieved the sensitivity of 382 $\mu\text{V}/\text{Pa}$ [8].

In this work, we have concentrated on 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

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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. This is followed by a deposition of sandwiched structure composed of bottom Al electrode, sputtered 100 of ZnO film and top Al electrode.

III. SENSOR DESIGN

MEMS based acoustic sensor for energy harvesting purpose is designed by using piezoelectric zinc oxide (ZnO) thin film on silicon substrate. ZnO is used because of its low deposition temperature quality, high piezoelectric coupling coefficient and it does not require polling like as PVDF and PZT. The sensor structure consists of silicon substrate, ZnO film of thickness 1µm is deposited by using RF magnetron sputtering, aluminium electrodes of thickness 0.5µm is deposited magnetron sputtering, Si₃N₄ which act as a diffusion layer between different material, Si₃N₄ is of thickness 0.3µm is deposited by plasma enhanced chemical vapour deposition at the temperature of 300-400⁰c and its deposited on silicon substrate and the diaphragm thickness is of 10µm. The 10µm thickness is chosen to withstand the dynamic sound pressure level range of 96-106db. The simulated sensor gives 390µV/Pa sensitivity.



Figure 1: Model of acoustic sensor

The silicon diaphragm largely controls the frequency response and lateral stresses in response to sound pressure. The oxide layer (SiO₂) of 0.3µm thickness is deposited on the silicon diaphragm by thermal oxidation method at a temperature of 850-1200⁰c. The top and bottom Aluminium electrodes of thickness 0.5µm are deposited by RF magnetron sputtering at 600W, piezoelectric zinc oxide (ZnO) is used because of its low deposition temperature quality, high piezoelectric coupling coefficient, ease of deposition quality with high quality thin film exhibiting piezo-electric properties, less demanding vacuum condition and it does not require polling like as PVDF and PZT. ZnO film of thickness 1µm is deposited by using RF magnetron sputtering, 0.3µm thickness of Si₃N₄ is deposited as seed layer in between Al and ZnO by the method of plasma enhanced chemical vapour deposition at 300-400⁰c. Finally the silicon substrate is etched from the backside by using deep reactive ion etching (DRIE) method.

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Table 1: Details of different layers and there thickness in μm

LAYERS	THICKNESS(μm)
Silicon substrate	400 μm
Silicon diaphragm	10 μm
Oxide	0.3 μm
Aluminium	0.5 μm
Si_3N_4	0.3 μm
ZnO	1 μm

IV. MEASUREMENTS AND SIMULATION RESULTS

The measured voltage value of $390\mu\text{V}/\text{Pa}$ - $3.9\text{mV}/10\text{Pa}$. Here the MEMS based acoustic sensor is designed by FEM technique by Coventorware in order to get the deflection and voltage. The voltage (μV) will vary in accordance with the pressure (Pa) is linear in the applied pressure (Pa) range of 1-10 Pascals.

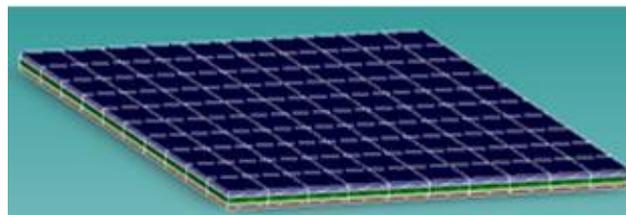


Figure 2: Meshing of diaphragm layers

The meshing model of the diaphragm in Coventorware is shown in the figure 2. Meshing is one of the bases of finite element analysis. Meshes are created on solid models in the Pre-processor. The solid models may have been built from 2-D layout and process information by the native solid model tool. The mesh tool offers a variety of mesh types and meshing algorithms so that the most effective mesh for a particular simulation may be used, here manhattan meshing was used for acoustic sensor in Covetorware as shown in figure 2.

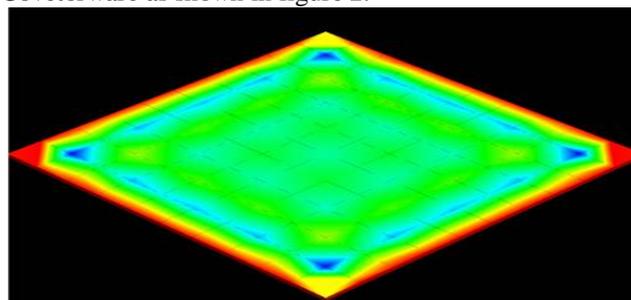


Figure 3: Simulated result for voltage

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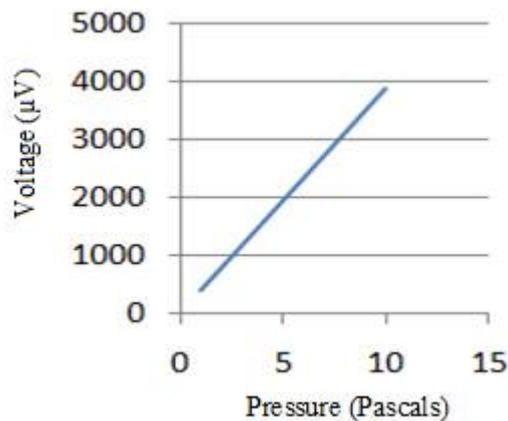


Figure 4: pressure and voltage relation

Figure 3 shows the results in the Visualizer. Visualizer is a visualization module that displays 2-D graphs and fully rendered 3-D models that may be rotated to any position in 3-D space. The potential difference, displacement, stress with different colourings are viewed by applying the pressure. The measured voltage values for different pressures and verified with analytical results are shown in table 2. Figure 4 signifies that the voltage (µV) generated verses pressure (Pa) graph is linear in the applied pressure (Pa) range.

In this work, we have focused on a fully integrated acoustic sensor that gives high sensitivity of 390µV/Pa applying 1-10 Pascal of pressure to the diaphragm of thickness 10µm .Simulated result of acoustic sensor is shown in figure 3.

FORMULAE USED

- **POTENTIAL(V):**

$$V = \frac{D \cdot A}{c} \quad (1)$$

$$D = d_{33} \cdot \sigma \quad (2)$$

Where, V=Electric potential(potential)

C= Capacitance

A=Area of piezoelectric material

d= Thickness of piezoelectric material

D=Charge density

σ= Stress

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Table 2: comparison results of voltage (μV) in Coventorware and analytical

Pressure	Analytical Results	Coventorware Results
1	386.76	390
2	773.5	790
3	1160.3	1200
4	1547.1	1600
5	1933.9	2000
6	2320.7	2400
7	2707.5	2700
8	3094.3	3100
9	3481.1	3500
10	3867.9	3900

V. CONCLUSION

MEMS technology based acoustic sensor with piezoelectric material ZnO is designed and simulated using Coventorware and verified by analytical method. A sensitivity of $390\mu\text{V}$ - 3.9mV was achieved by applying 1-10 Pascals of pressure to the diaphragm of thickness $10\mu\text{m}$.

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