International Journal of Current Engineering and Technology
ISSN 2277 - 4106
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Research Article

Design and Simulation of MEMS Based Piezoelectric Accelerometers

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Accepted 12 March 2014, Available online 01 April 2014, **Special Issue-3, (April 2014)**

Abstract

MEMS Accelerometer, the new inventions which revolutionized the technical world. Now, it's time for the self assistive accelerometers. In this paper, we have designed the trampoline, annular diaphragm structured piezoelectric accelerometers using PZT-5H with COMSOL Multiphysics software tool for providing low transverse sensitivity along one axis and good temperature stability. These accelerometers are incorporated into application specific integration circuit (ASIC) and RF telemetry systems to facilitate wireless monitoring of industrial equipment.

Keywords: *Accelerometer, Piezoelectric, Piezoelectric lead zirconate titanata (PZT)*

1. Introduction

Accelerometers have been used in many fields, including for activation of automotive safety systems (airbags, electronic suspension), for machine and vibration monitoring, and in biomedical applications for activity monitoring. Micro machined accelerometers are widely used by the automotive industry, because of their low cost, small size, and broad frequency response. Three sensing mechanisms, piezoresistive, capacitive, and piezoelectric are most commonly utilized for MEMS accelerometers; each one has limitations and advantages. Compared to piezoresistive and capacitive accelerometers, there have been fewer reports of micro machined piezoelectric accelerometers. ZnO and PZT films are the two primary materials reported for use in bulk or surface-micro machined piezoelectric MEMS accelerometers.

Since the electromechanical coupling coefficients and the piezoelectric constants of PZT are much higher than those of ZnO films, the charge sensitivities of piezoelectric MEMS accelerometers using ZnO films are relatively small. Therefore, this work concentrated on the use of PZT films. Several groups have previously reported on the use of PZT MEMS accelerometers. In 1996, Nemirovsky et al. designed a PZT thin-film piezoelectric accelerometer with a calculated sensitivity of 320 mV/g, however, it has not been fabricated. In 1997, Kim et al. fabricated a surface-micro machined PZT accelerometer using cantilever beams as the sensing structure. No dynamic frequency response measurement was reported. In addition, surface micromachining limits the thickness of microstructures; as a result, the sensitivity is limited. In 1999, bulk-micro machined accelerometers were fabricated and tested by Eichner et al. A seismic mass and two silicon beams were used as the sensing structure; an average sensitivity of 0.1 mV/g was measured and the resonant frequency was calculated at 13 kHz. Beeby et al. fabricated a bulk micro machined accelerometer using PZT thick films, which were pre- pared by screen-printing processes. There are two previous reports on the development of PZT-based accelerometers fabricated using deep reactive ion etching: one optimized for high sensitivities at low frequencies (300 Hz); the other designed for broader bandwidth operation.

2. About COMSOL Multiphysics

COMSOL Multiphysics 4.3b, Computer simulation has become an essential part of science and engineering. Digital analysis of components, in particular, is important when developing new products or optimizing designs. Today a broad spectrum of options for simulation is available; researchers use everything from basic programming languages to various high-level packages implementing advanced methods. Though each of these techniques has its own unique attributes, they all share a common concern: Can you rely on the results? When considering what makes software reliable, it's helpful to remember the goal: you want a model that accurately depicts what happens in the real world. A computer simulation environment is simply a translation of real-world physical laws into their virtual form. How much simplification takes place in the translation process helps to determine the accuracy of the resulting model.

It would be ideal, then, to have a simulation environment that included the possibility to add any physical effect to your model. That is what COMSOL is

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all about. It's a flexible platform that allows even novice users to model all relevant physical aspects of their designs. Advanced users can go deeper and use their knowledge to develop customized solutions, applicable to their unique circumstances. With this kind of all-inclusive modeling environment, COMSOL gives you the confidence to build the model you want with real world precision.

3. Designing

The designing includes the annular diaphragm shape as well as trampoline model. The annular diaphragm model includes the circular surfaces with 3 layers in which two electrodes are inserted to collect the voltage generated. The trampoline model includes a rectangular diaphragm where the proof mass is located at the bottom its centre.

The designing is done by going through the two different stages i.e. first we have to construct the required shape on work plane in 2D and then it has been extruded for 3D geometry with the required thickness. Once the model has been designed and desired thickness has been obtained the next stage of designing process will be application of required materials to constructed model Fig 1 and Fig 2 represents two stages of designing annular diaphragm model and Fig 3 and Fig 4 represents the designing of trampoline model.

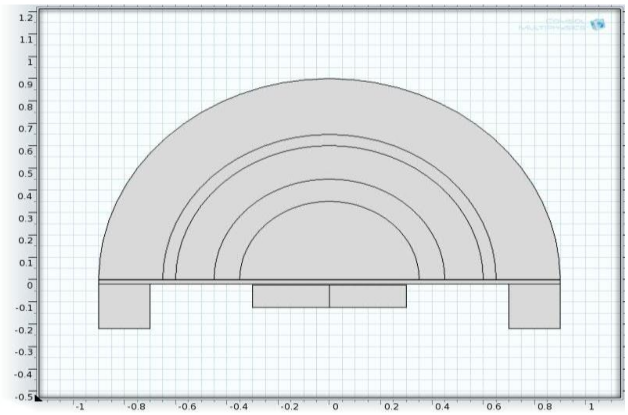

Fig 1. Construction of annular diaphragm on work plane

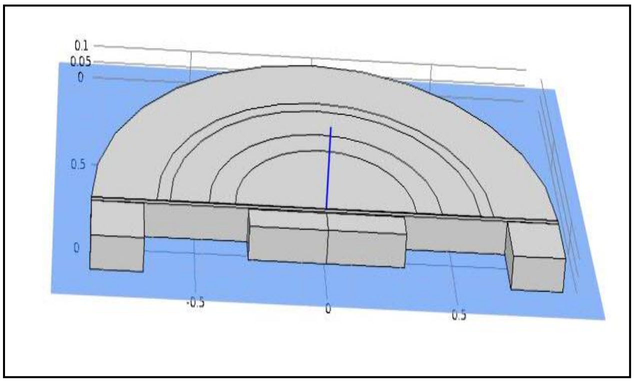

Fig 2. After extruding from the work plane

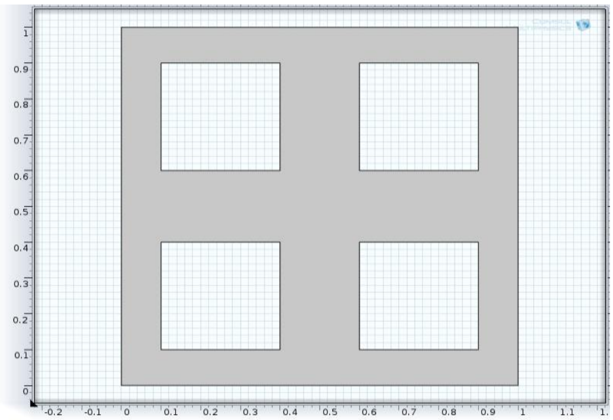

Fig 3: construction of trampoline model in work plane

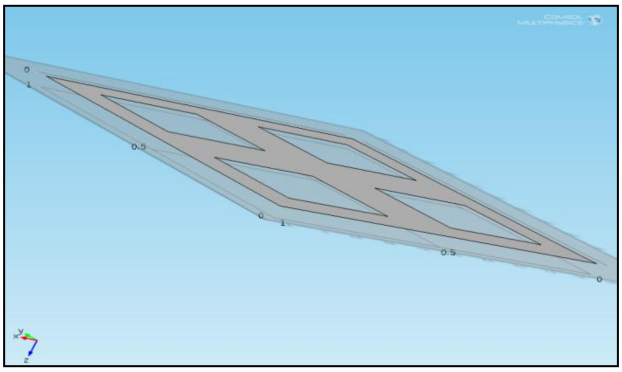

Fig 4: extruding to 3D surface

From the figure 5a shown below the materials applied for different parts are as specified for annular diaphragm:

- Piezoelectric layer-lead Zirconate Titanate
- Ring shaped electrodes
  Yellow- gold
  Red - platinum
- Mounting frame-cast iron
- Proof mass-SiO_2
- Membrane-SiO_2

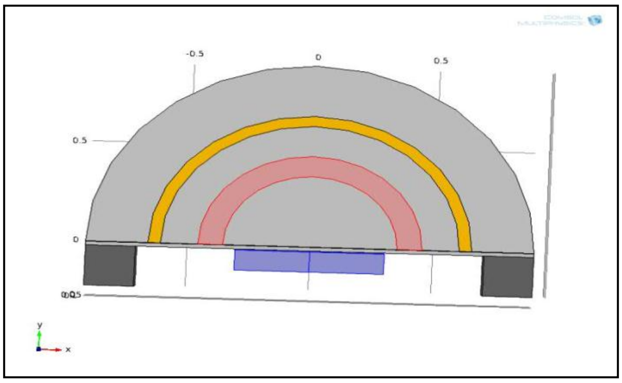

Fig 5a: After application of materials

The following are the materials applied for trampoline model:

- Blue -- Piezoelectric Lead Zirconate Titanate.
- Gray -- SiO_2

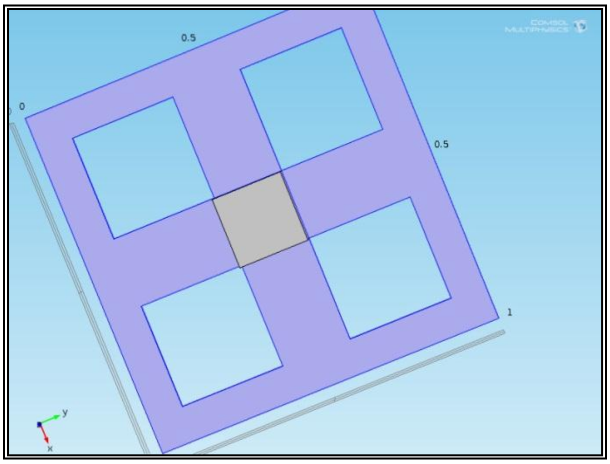

Fig 5b: materials applied for trampoline model

3.1 Meshing

Meshing is done for the device in order to have good study of results, i.e. when the meshing is done the force or the stress applied on the device will be equally distributed so that the results will be exact. The meshing can of different ways fine, extra fine wider etc. according to the device we can select the type. Here the normal meshing have been used. The following pictures show the mesh formed for annular diaphragm as well as trampoline models .

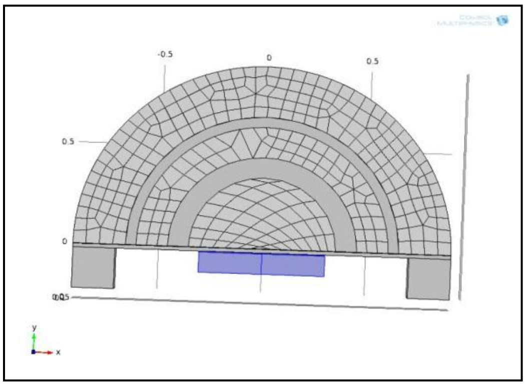

Fig 6a. After the application of mesh

3.2 Working

The common principle of accelerometer is to find acceleration, by using different principles. The different principles may be capacitive, piezoresistive, resistive etc. but for the today's generation the device must be low power consuming as well as highly resistant. So, as discussed earlier the self-power producing piezoelectric accelerometer works on the principle piezoelectric i.e. when the stress or force is applied on the piezoelectric material it produces voltage due to the colliding of atoms at the time of application of force. So, to measure acceleration when we place this the amount forced corresponding to the amount of acceleration is applied on it and the respective voltage is generated by the piezoelectric material.

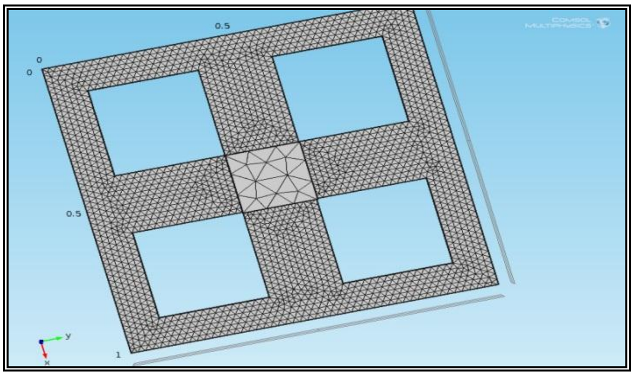

Fig 6 b: meshed trampoline model

3.3 Computational results

Now the constructed models are computed with Eigen frequencies and the following results are obtained. The annular diaphreamic model is done with the eigenfrequency 8.826164e9

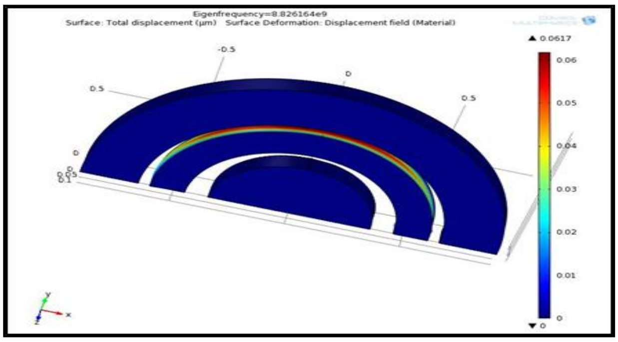

Fig 7a .Displacement obtained in the piezoelectric layer

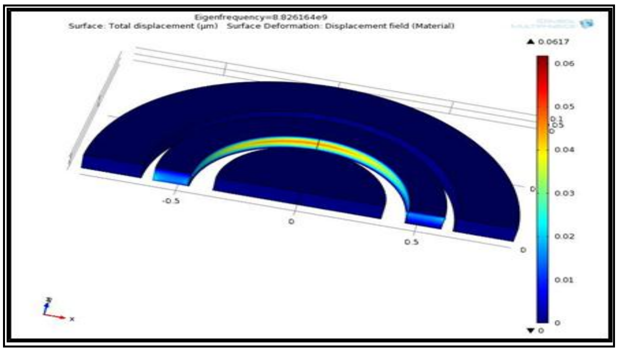

Fig 7b. Displacement from the down view

From the obtained results we can say that the construction with the 3 piezoelectric layers and with the Lead Zirconate Titanate is undergoing the displacement of 0.0467 um and potential is of 4.1003V. We can consider this as good result as the deformation of the material is very low and potential is better high.

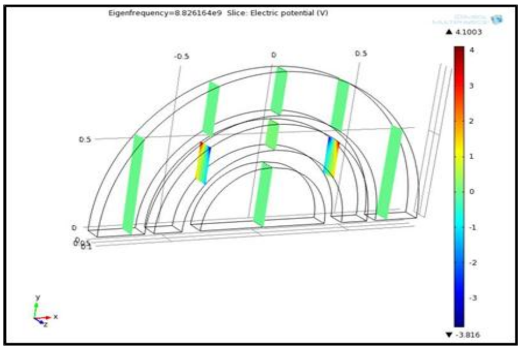

Fig 7c. Obtained potential of 4.1003

The trampoline model is computed with the eigenfrequency 4.5118051e10 and the results are as follows :

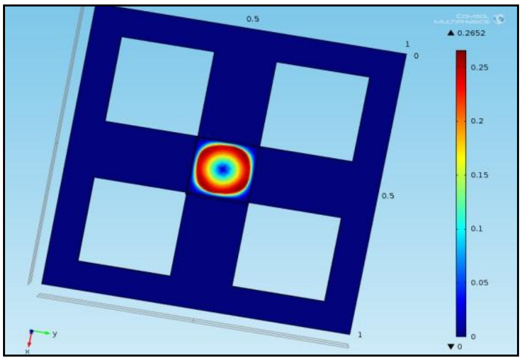

Fig 8a : Displacement obtained in the piezoelectric layer

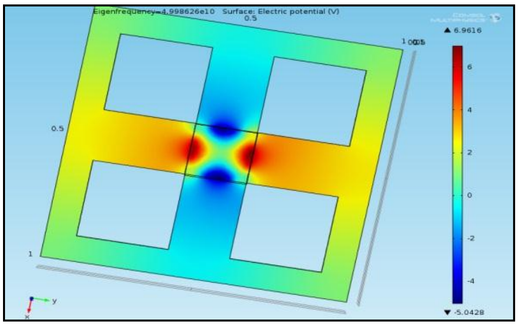

Fig 8b: potential obtained is 6.9616 V

Here the piezoelectric crystal is undergoing a displacement of 0.2652 um. this is also obtaining good potential value of 6.9616 V. Therefore both the models are giving good results. But in case of piezoelectric material the considerations are the amount of displacement should be uniform and potential output should be high. which in case the annular diaphragm model can be considered as better one.

3.4 Simulation

Any device on the earth is not perfect but a device is said to be better than the other by only due to comparison. So at any place simulation or comparison plays a major role in judging the performance of the device. All the simulated results will be as given in table 1.So the simulation has been done here for annular diaphragm model in the following 3 ways:

1. Simulation with materials
2. Simulation with geometry
3. Simulation with Eigen frequencies

Simulation with materials

Here the simulations for the constructed model are done with the materials quartz, ZnO, Lead Zirconate Titanate-5H. In the above results we had seen for Lead Zirconate titanate-5H

Quartz

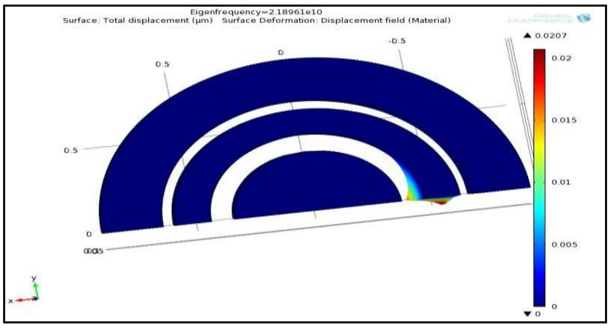

Fig 9.Displacement undergone

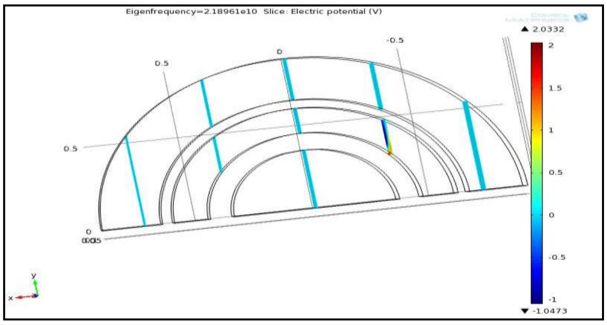

Fig 10. Potential generated

Zinc Oxide (ZnO)

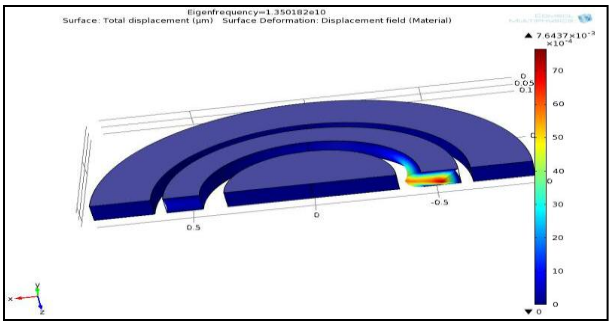

Fig 11. Displacement in ZnO

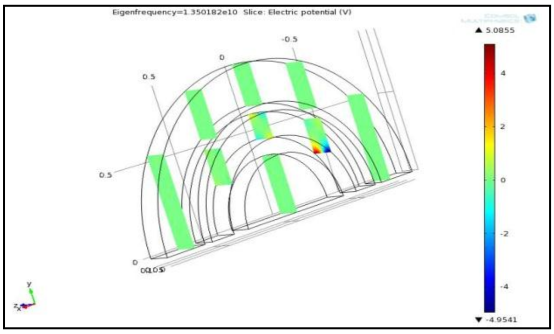

Fig 13. Potential obtained for ZnO

Rochelle salt

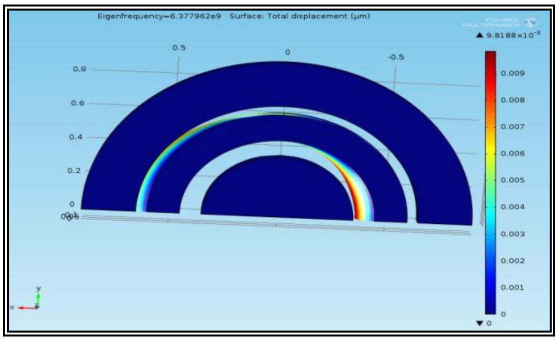

Fig 14: displacement undergone

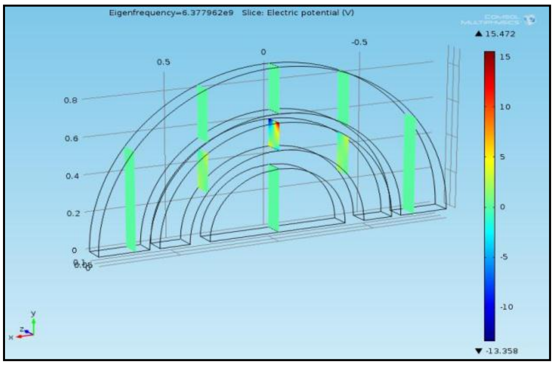

Fig 15: potential released

Simulation with varying geometry

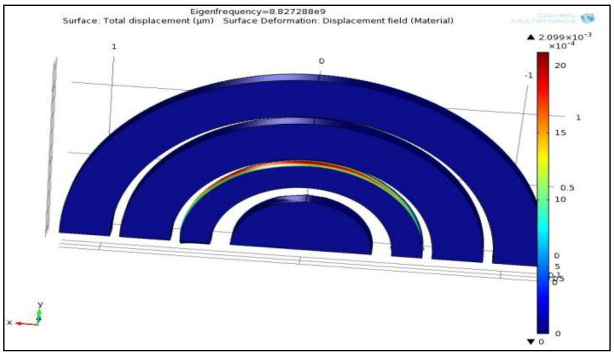

Fig 16. Displacement for the varied geometry

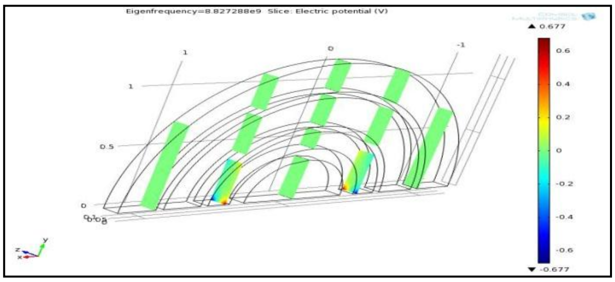

Fig 17. Potential obtained for the varied geometry

Simulation with varying Eigen frequencies

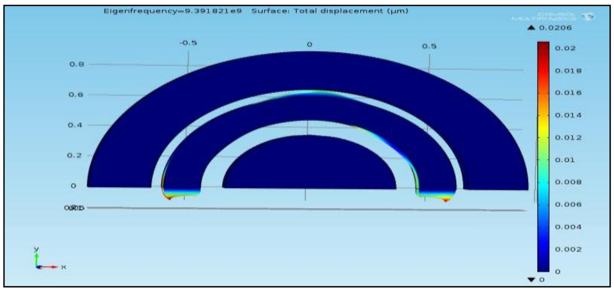

Fig 18 : Displacement for eigenfrequency 90391821e9

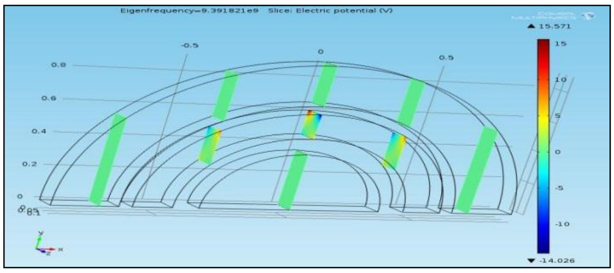

Fig 19: Potencial obtained for eigenfrequency 9.391821e9

The simulations done for the trampoline model are as follows:

- simulation with materials
- simulation with Eigen frequencies

Simulation with materials

Quartz

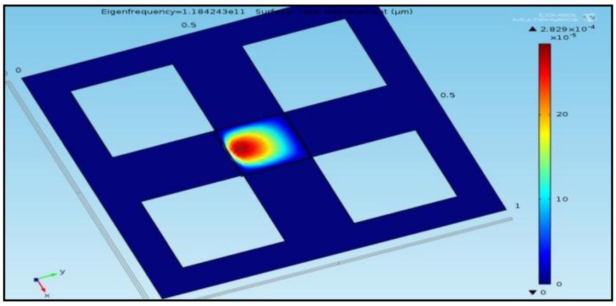

Fig 20: displacement undergone

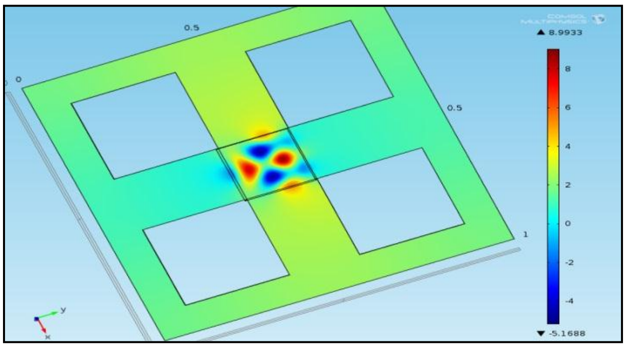

Fig 21: Potential obtained

ZnO(Zinc Oxide)

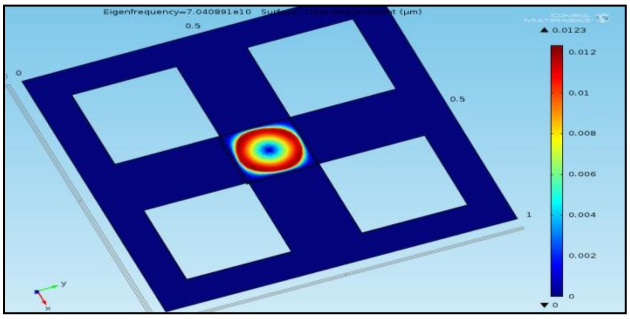

Fig 22: Displacement undergone

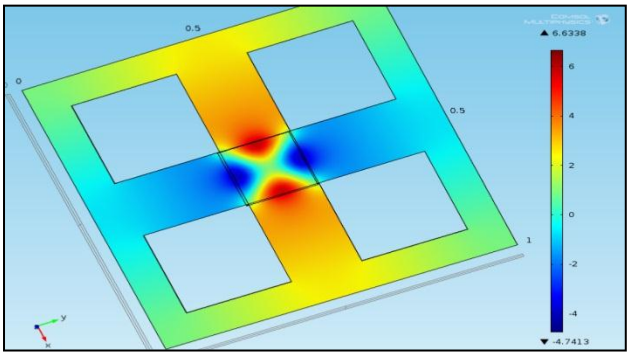

Fig 23: Potential obtained

Rochelle Salt

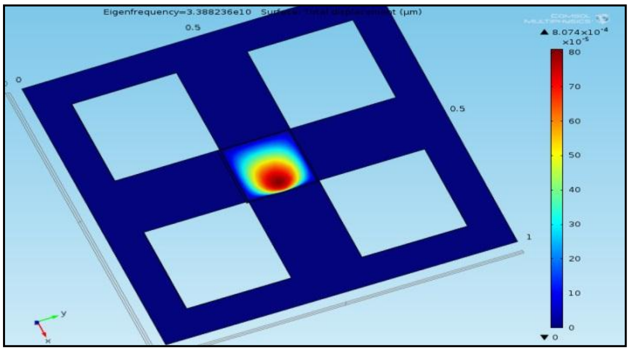

Fig 24: Displacement undergone

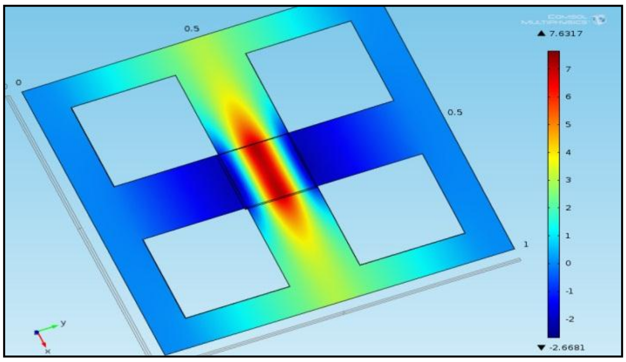

Fig 25: Potential obtained

Simulation with Eigen frequencies

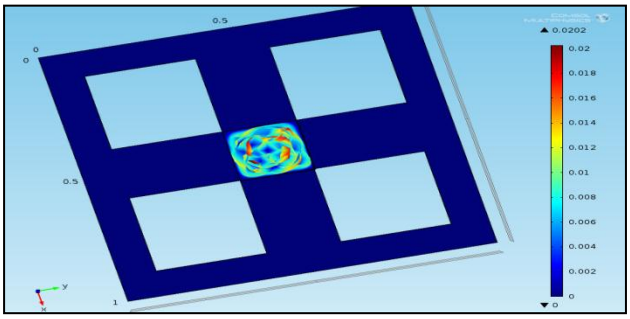

Fig 26: Displacement undergone

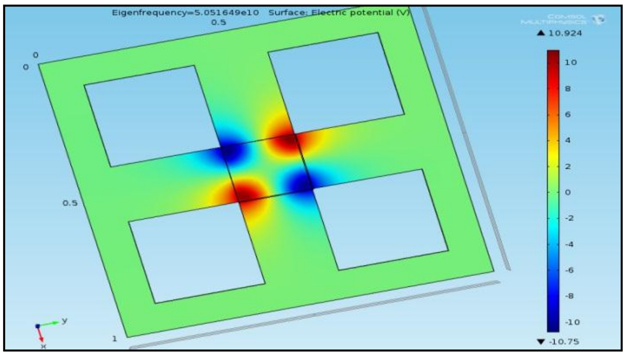

Fig 25: Potential obtained

By the study of the Obtained Results we can say that the annular diaphragm model is more sensitive when compared to trampoline model as these are more sensible to low frequencies. table.1 summarizes the amount of potential with the corresponding displacement in each case.

4. Conclusions

The MEMS accelerometers especially created a revolution in the electronic devices, so to keep up the standards of accelerometers and to cop up with the developing technology, today the MEMS accelerometers should be developed with various principles and different models for better results. The piezoelectric MEMS accelerometers,

Table 1 Amount of potential with the corresponding displacement in each case.

Type of Simulation		Material				Geometry 4-Layer	Eigen frequencies
model	out put	PZT-5H	Quartz	Rochelle Salt	ZnO		
annular diaphragm	displacement	0.0617um	0.0207um	0.00981um	0.7643um	0.2099um	0.206um
annular diaphragm	potential(V)	4.1003	2.0332	15.472	5.0855	0.677	15.571
trampoline	displacement	0.2652um	2.829*10-9m	8.074*10-9m	0.0123um	not applicable	0.0202um
trampoline	potential(V)	6.9616	8.9933	7.6317	6.6338	not applicable	10.924

combining a novel annular diaphragm , trampoline design and high electromechanical coupling thick PZT films, demonstrate high sensitivities and with broad usable frequency ranges. In this paper our results shows, the design accelerometer provides good sensitivity and good temperature stability.

Acknowledgement

We would like to thank the Director and the Management of LBRCE for providing us the necessary facilities to carry out this work.

We also want to extend our sincere thanks to incharge & coordinator of National MEMS design Centre for their constant support.

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