International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 7, July - 2013

Design And Analysis Of Vibrational Energy Harvesting Of Mems Device Based On Piezoelectric Thin Film Cantilevers

Monika Sharma
Department of Electronics & Telecommunication Engineering
PDM College of Engineering Bahadurgarh
Deepak Rohilla
Assistant professor (ECE)
Department of Electronics &Communication Engineering (ECE)
PDM College of Engineering for women Bahadurgarh

ABSTRACT

In this paper a brief Introduction about MEMS and its components is providedNetworks of low power wireless devices are increasingly used in applications ranging from environmental to factory automation monitoring. Most of these devices must be operative 24hrs a day and may be in locations where manual battery replacement is difficult or costly. It would be desirable if there exists a miniaturized device that can convert ambient mechanical energies such as vibrations, which are readily available 24hrs a day, to power wireless devices. The concept of Energy Harvesting is introduced using PMPG circuitry Uimorphs of dimension 300mm×40mm×4mm has been modeled with 2mm thin film epitaxial layer of piezoelectric material. From the simulation results Gold is preferred over Aluminium ,Silicon ,Gallium Arsenide as about 1000Hz less frequency response is observed. A Unimorph with gold and PZT-5A material is considered the best model with resonance frequency of about 27120.92Hz with generated electric voltage of 2.00 volts whena load of 5 N/m^2 *is applied at the tip of unimorph.*

A PMPG has been designed using five unimorphs of dimensions 300×40×4 μm with one end of each is fixed and connected to a block of dimensions 40×360×4 μm. The base material of unimorph and fixed block of PMPG is of gold and piezoelectric layer of PZT 5A has been provided to each beam of microcantilvers. A force of 5N/m^2 *has been applied on the top of PMPG on z axis direction and eigen frequency of 36085 Hz has been observed with a displacement of 5.453E-11 m and voltage generated across the PMPG is around 4.775volts. which is better than the base material Aluminium.*

Key words: *MEMS;PMPG; VLSI; Unimorph; Cantilevers*

1. INTRODUCTION

Micro-Electro-Mechanical Systems, or MEMS, are integrated micro devices or systems combining electrical and mechanical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from micrometers to millimeters. These systems can sense, control and actuate on the micro scale, and function individually or in arrays to generate effects on the macro scale[1]

1.1.1MEMS components:-In the most general form, MEMS consist of In the most general form, MEMS consist of mechanical microstructures, micro sensors, micro actuators and microelectronics, all integrated onto the same silicon chip. Micro sensors detect changes in the system’s environment by measuring mechanical, thermal, magnetic, chemical or electromagnetic information or phenomena

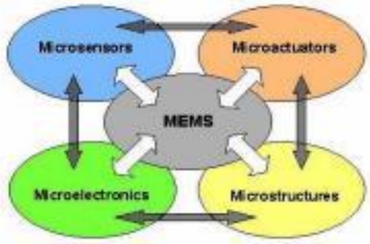


Figure 1.1 Schematic illustrations of MEMS components

Microelectronics processes this information and signal the micro actuators to react and components are usually microscopic. Levers, gears, pistons, as well as motors and even steam engines have all been fabricated by MEMS However, MEMS is not just about the miniaturization of mechanical components or making things out of silicon (in fact, the term MEMS is actually misleading as many micro machined devices are not mechanical in any sense). MEMS is a manufacturing technology; a paradigm for designing and creating complex mechanical devices and systems as wellas their integrated electronics using batch fabrication techniques.

2.MEMS Vs. VLSI:-

1.The fabrication methods for MEMS are derived from VLSI microelectronics industry. That is: on silicon wafer selectively etching away parts of the wafer and add new structural layers to form MEMS devices [2]

2.MEMS design isdeveloped from VLSI. VLSI is designed by a highly developed structured method. VLSIdesign is based on a set of routine design rules; process variations will not bring many changes in the performances of fabricated devices. Without knowing the details of the fabrication, a full level of description of a VLSI device is specified. The methodology of separation the structure and design in VLSI led to revolutionary reductions in design and prototyping costs. But MEMS have to meet each desired mechanical properties, whichclosely related to precise process specification, some modifications from VLSI design methodologies are made for use in MEMS design [3]

3. VLSI devices can be designed from a standard library and manufactured from arelatively small set of primitives. MEMS devices have a much larger set of requiredprimitives and their standard library is incomplete. Because many different devices areintegrated into MEMS, it is difficult to interconnect different parts and built small libraries forevery part.

4. In VLSI, Hardware Description Language (HDL) (Verilog, VHDL, SystemC etc.) is used to describe the designed system, while languages for describing MEMS do not exist.MEMS HDL language will be formed and standardized through developing VLSI designlanguage.

3.CONCEPT OF ENERGY HARVESTING

Most of the studies in MEMS have been on micro sensors and micro actuators. In many applications, embedded and remote systems are getting more attraction. The encountered problem is that the microsystems need to be self-powered. One of the possible solutions is to design the power supply at the same scale as sensors, actuators, and electronics. Batteries are the most commonly used devices. Due to disadvantages such as limited amount of energy, relatively short life span, and possible chemical contamination, batteries are not so desirable. An alternative to the battery is the embedded power supply, which provides renewable power.

Usually, a power supply has four main components: (1) a source of energy (2) a device to convert energy (3) an energy storage device (4) a mechanism to provide actuation.

Energy from the ambient is the ideal energy source for a microscale power supply. The possible ambient energy source includes: (1) thermal energy (2) light energy (3) volume flow (4) mechanical energy

(1) Piezoelectric: using piezoelectric material to generate electrical potential (2) Electromagnetic: a coil attached to a mass which vibrates through a magnetic field to induce voltage according to Faraday’s law

(3) Electrostatic: inducing capacitor voltage through the movement of a moving mass, which has its permanent charges electrically, arranged.

Among these three mechanisms, the electrostatic transducer has the lowest conversion efficiency; therefore, its application is limited

Anisotropic Effects and Coupling Modes

Piezoelectric materials have a built-in polarization, and therefore respond differently to stressesdepending on the direction. There are two primary modes of electromechanical coupling forpiezoelectric materials: the 3-1 mode and the 3-3 mode. In the 3-1 mode (Figure 2.1a), the electric field is produced on an axis orthogonal to the axis of applied strain, but in the 3-3 mode(Figure 2.1b), the electric field produced is on the same axis as the applied strain.

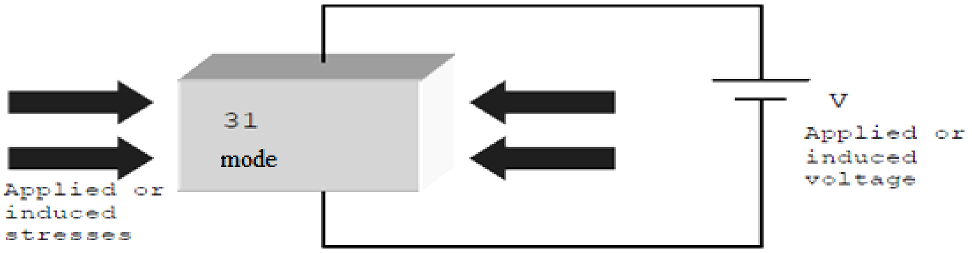


Figure 2.1a

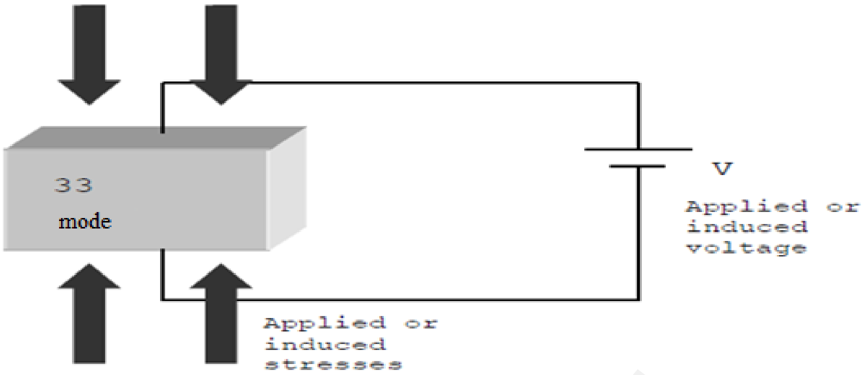


Figure 2.2b

While the piezoelectric coefficient is higher in the 3-3 mode for most materials, taking advantage of the larger coefficientrequires a much more complex design. Instead of impleplanar electrodes, a series of interdigitated electrodes (IDE) can be used to take advantage of the 3-3 coupling mode [4]

4.ENERGY HARVESTING USING PMPG (piezoelectric micro power generator)

Energy harvesting is a method to capture energy naturally present in the environment for powering low power electronics [5,6-7] energy harvesting devices provide electricity with high-added-value lasting for extremely long time period As energy conversion principles from kinetic energy of mass to electricity for energy harvesting, electromagnetic induction, piezoelectric, and electrostatic induction are used. Electromagnetic induction [8-9] prevails in macro scale, but it is not always the case in energy harvesting; since induction voltage is proportional to the area of coil and the relative speed between permanent magnet and coil, the power output is proportional to square values of those. Thus, the power output is decreased drastically for small-scale generators operating at low frequencies. In contrast, power output of piezoelectric and electrostatic induction is proportional to the frequency, which makes those principles are superior to electromagnetic counterpart power Energy harvesting devices, capable of converting wasted ambient energy to electrical are rapidly gaining popularity as a source of green and renewable energy. The design of the energy harvesters consists of a cantilever beam structure with the interdigitated electrodes on the zinc oxide piezoelectric layer with nickel proof mass at the end of the beam. Wireless sensor networks have gained tremendous attention and popularity in commercial application

5.ENERGY HARVESTING ELECTRONIC CIRCUITRY

This section presents the electronic components involved in capturing the energy harvested by various transducers. Specifically, piezoelectric harvesting is of greatest interest, and therefore will be used as the foundation of understanding the electronic circuitry involved in energy harvesting. Only passive circuitry is discussed in this section. While active components are an area of ongoing research, they are not presented here. The energy required to operate such components is greater than that which can be supplied by power harvesting alone.

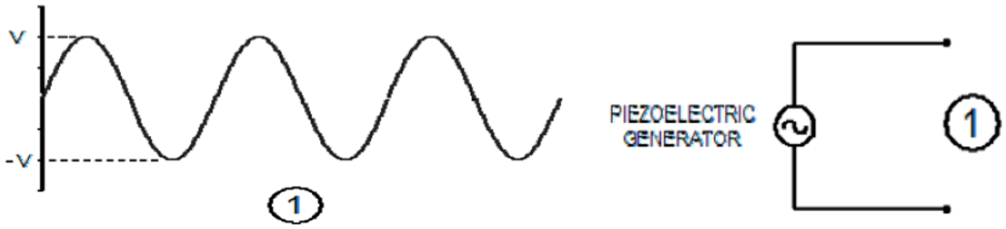


Figure5.1. Simple model of a piezoelectric generator

In its very simplest form, a piezoelectric or electromagnetic generator is modeled as an AC voltage source However, this output is not useful for most electronic applications. The generator is first connected to a full bridge rectifier, which consists of four standard diodes connected in such a way that the voltage reaching the load is always positive, as shown in the graph Thermoelectric and photovoltaic generators typically do not require such rectification, since their output is fairly DC or at least always positive

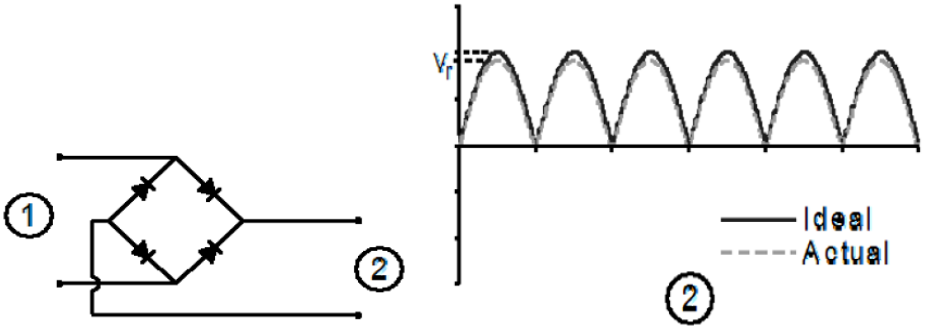


Figure5.2. Voltage output after signal is sent through a full bridge diode rectifier.[9] In the ideal-diode model, the device acts as a perfect conductor with no voltage drop in the forward direction and acts as an open circuit in the reverse direction. [9]

7. OBJECTIVE:

Harvesters delivering sufficient power for sensors operating in industrial environment have been developed, but difficulties are encountered when the devices to be powered are located on the human body. In this case, a design based on the impact of a moving mass on piezoelectric bending structures will be considered. The sole aim of the proposed work is to use ambient energy for producing useful power from MEMS with the use multi physics tools like ANSYS, COMSOL, COVENTOR-PRO etc. different structures of unimorph/bimorph are to be designed and further simulation will be done.

6. METHODOLOGY:

In this section, the process is defined and the basic cantilever structure for energy harvesting and the analysis used is highlighted.

Basic Structure: In this work our main area of interest is to design the basic structure for energy harvester i.e Cantilever. After the designing issue analysis to be done for knowing the various parameters on which it's performance depends on.

Cantilever: Cantilevered beams are the most ubiquitous structures in the field of microelectromechanical systems (MEMS). MEMS cantilevers are commonly fabricated from silicon (Si), silicon nitride (SiN), or polymers. The fabrication process typically involves undercutting the cantilever structure to *release* it, often with an anisotropic wet or dry etching technique. Without cantilever transducers, atomic force microscopy would not be possible. A large number of research groups are attempting to develop cantilever arrays as biosensors for medical diagnostic applications. MEMS cantilevers are also finding application as radio frequency filters and resonators.

Two equations are key to understanding the behavior of MEMS cantilevers. The first is *Stoney's formula*, which relates cantilever end deflection δ to applied stress σ:

where ν is Poisson's ratio, *E* is Young's modulus, *L* is the beam length and *t* is the cantilever thickness. Very sensitive optical and capacitive methods have been developed to measure changes in the static deflection of cantilever beams used in dc-coupled sensors.

$$\delta = \frac{3\sigma(1-\nu)}{E}\left(\frac{L}{t}\right)^2$$

The second is the formula relating the cantilever spring constant *k* to the cantilever dimensions and material constants:

where *F* is force and *w* is the cantilever width. The spring constant is related to the cantilever resonance

frequency ω0 by the usual harmonic oscillator formula $\omega_0 = \sqrt{k/m}$.

A change in the force applied to a cantilever can shift the resonance frequency. The frequency shift can be measured with exquisite accuracy using heterodyne techniques and is the basis of ac-coupled cantilever sensors. The principal advantage of MEMS cantilevers is their cheapness and ease of fabrication in large arrays. The challenge for their practical application lies in the square and cubic dependences of cantilever performance specifications on dimensions. These super linear dependences mean that cantilevers are quite sensitive to variation in process parameters. Controlling residual stress can also be difficult.

Unimorph:

A unimorph is a cantilever that consists of one active layer and one inactive layer. In the case where active layer is piezoelectric, deformation in that layer may be induced by the application of an electric field. This deformation induces a bending displacement in the cantilever. The inactive layer may be fabricated from a non-piezoelectric material. A piezoelectric unimorph has one active (i.e. piezoelectric) layer and one inactive (i.e. non-piezoelectric) layer.

Bimorph:

A bimorph is a cantilever that consists of two active layers: piezoelectric and metal. These layers produce a displacement via:

- thermal activation (a temperature change causes one layer to expand more than the other).
- Electrical activation as in a piezoelectric bimorph (electric field causes one layer to extend and the other layer to contract).
- **Device Configuration** The vast majority of piezoelectric energy harvesting devices use a cantilever beam structure When the generator is subjected to vibrations in the vertical direction, the support structure will move up and down in sync with the external acceleration. The vibration of the beam is induced by its own inertia; since the beam is not perfectly rigid, it tends to deflect when the base support is moving up and down (see Figure 6.1).

$$k = \frac{F}{\delta} = \frac{Ewt^3}{4L^3}$$

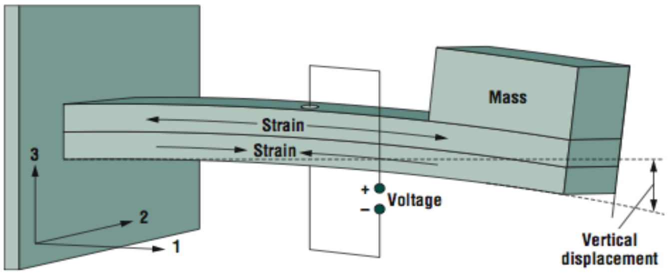


Figure 6.1: Shows that strain is generated along the length of the beam, 4-1 mode Typically, a proof mass is added to the free end of the beam to increase that deflection amount. This lowers the resonant frequency of the beam and increases the deflection of the beam as it vibrates. The larger deflection leads to more stress, strain, and consequently a higher output voltage and power. Electrodes covering a portion of

the cantilever beam are used to conduct the electric charges produced to an electrical circuit, where they can be utilized to charge a capacitor or drive a load. Different electrode lengths or shapes have been shown to affect the output voltage, since strain is not uniform across the beam.

8.Analysis

A unimorph of dimensions 300×40×4µm has been designed in COMSOL with base material as Gold and varying upper layer of Piezoelectric material i.e. Lithium Niobate, Cadmium Sulphide, PZT2, PZT5A, PZT8. A force of $5N/m^2$ had been applied to the upper layer of piezoelectric material in Z axis direction. The displacement, eigen frequency and voltage generated is shown in table 8.1

Piezoelectric material	**Displacement m**	**Frequency Hz**	**Voltag eV**
Lithium Niobate	1.381e-9	37992.14	2.003
Cadmium Sulphide	1.082e-7	26272.82	2.054
PZT2	5.656e-10	29292.87	2.000
PZT5A	1.569e-9	27120.92	2.001
PZT8	2.946e-9	29533.28	2.001

TABLE8.1: Analysis summary with GOLD as base material for different piezoelectric layers.

A PMPG has been designed using five unimorphs of dimensions 300×40×4 µm with one end of each is fixed and connected to a block of dimensions 40×360×4 µm.

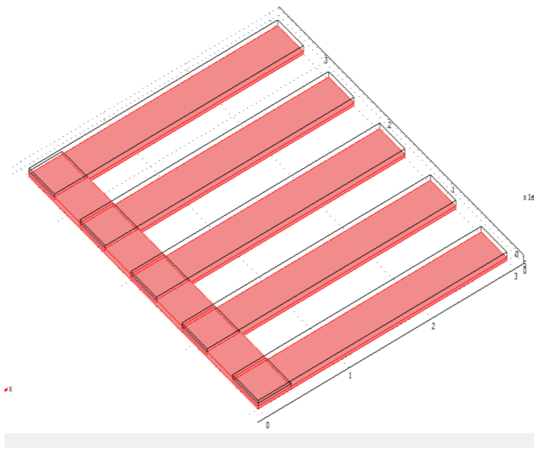


Fig 8.1Comb drive with five unimorphs

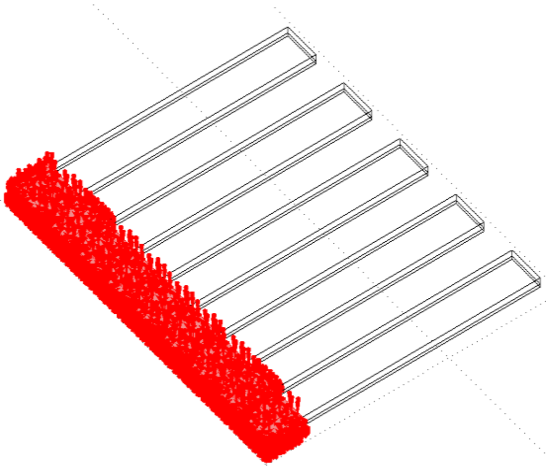
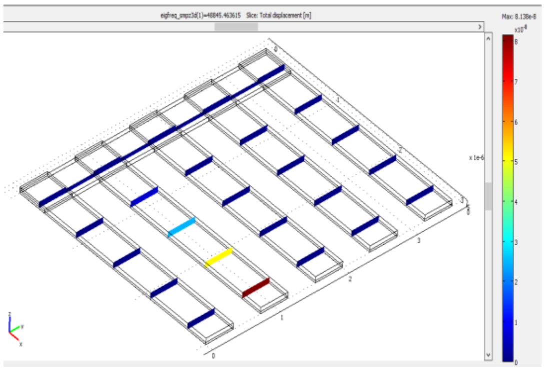


Fig 8.2Comb drive with one end fixed



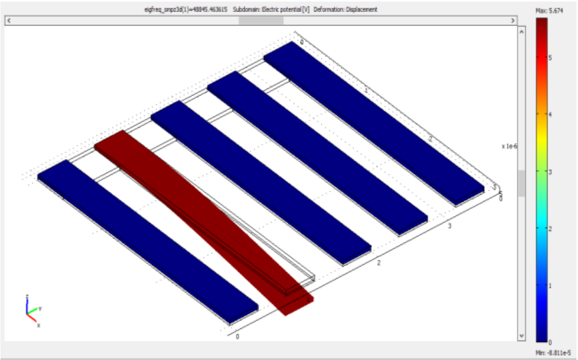
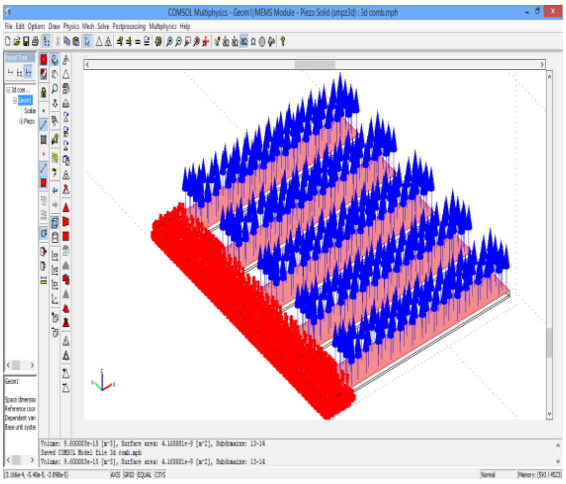


Fig 8.3Comb drive solution for subdomain plot Fig 8.4Comb drive solution for electric volts

The base material of unimorph and fixed block of PMPG is of Aluminium and piezoelectric layer of PZT 5A has been provided to each beam of microcantilvers. A force of -5N/m^2 has been applied on the top of PMPG on z axis direction and eigen frequency of 48845 Hz has been observed with a displacement of 8.138 E-8 m and voltage generated across the PMPG is around 5.674 volts.

A PMPG has been designed using five unimorphs of dimensions 300×40×4 μm with one end of each is fixed and connected to a block of dimensions 40×360×4 μm.



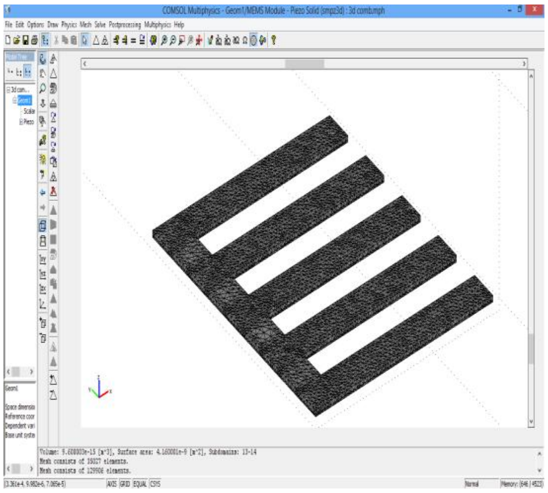
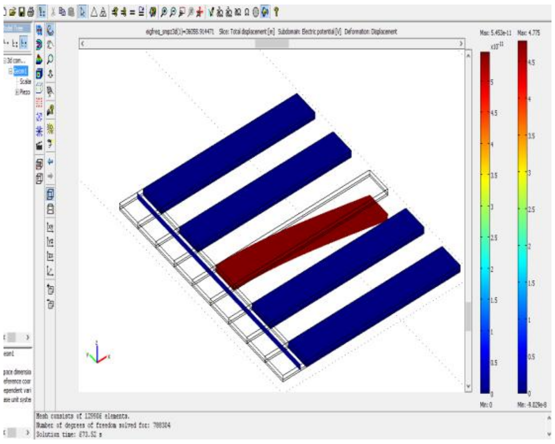
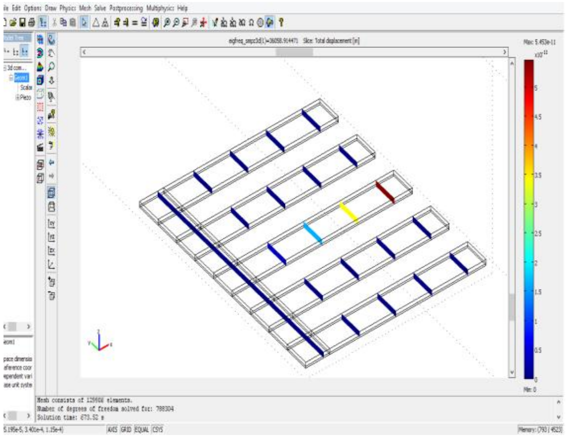


Fig 8.7 Comb drive with applied force on z axis Fig 8.8 Comb drive with refine mesh view



Mesh consists of 129906 elements.
Number of degrees of freedom solved for: 788304
Solution time: 673.52 s

Fig 8.5 Comb drive solution for subdomain plot for electric volts



Mesh consists of 129908 elements.
Number of degrees of freedom solved for: 788304
Solution time: 673.52 s

Fig 8.6 Comb drive solution

The base material of unimorph and fixed block of PMPG is of Gold and piezoelectric layer of PZT 5A has been provided to each beam of microcantilvers. A force of 5N/m^2 has been applied on the top of PMPG on z axis direction and Eigen frequency of 36058 Hz has been observed with a displacement of 5.453 E-11 m and voltage generated across the PMPG is around 4.775 volts.

9.CONCLUSION AND FUTURE WORK

CONCLUSION

From the simulation results Gold is preferred over Aluminium, Silicon and Gallium Arsenide, as about 1000Hz frequency difference is observed. A Unimorph with gold and PZT-5A material is considered the best model with resonance frequency of about 27120.92Hz with generated electric voltage of 2.00 volts when a load of 5N/m^2 I applied at the tip of unimorph

FUTURE SCOPE

The performance of the piezoelectric cantilevers can be largely improved by using engineered extensions. Thus, it is worth further investigation of the effect of these extensions. The following future work may be pursued:

a. In this dissertation, unimorph piezoelectric cantilevers were designed. Bimorph piezoelectric cantilever is another commonly used piezoelectric energy harvester. It is also of interest to investigate the effect of beam extensions on the performance of the bimorph cantilevers both experimentally and theoretically. The analytical model for the bimorph cantilever can be obtained by including a second piezoelectric layer in the model of the unimorph cantilevers in this work.

b. In this dissertation, the beam extension was formed by using fixed lengths for the piezoelectric layer and nonpiezoelectric layer. Thus, the extension beam had the same width and thickness as the mother beam. In fact, these parameters can also affect the properties of the PUC, such as the resonant frequency and strain distribution. Thus, a further investigation of the geometry of the extension beam is worth pursuing

10. LIMITATION:

The vibration amplitude must not exceed the strain limit of the peizoelectric material and beam should not extended more than its load limit.

11.REFRENCES

[1]. Adisorn Tuantranont and Victor M. Bright, “Introduction to MEMS”, Published in NSF Center for Advanced Manufacturing and Packaging of Microwave, Optical, and Digital Electronics (CAMPMODE), University of Colorado at Boulder, CO, USA 80309-0427

[2].Sio 2002“ System for High Density SOC Interconnection”

Circuits and Systems, ISCAS 2002, IEEE

[3]. InternationalSymposium on. Wannok Sio (2002), “MEMS (Microelectromechanical System)”. 24. Erik K. Antonsson et al. (1996), “Structured Design Methods for MEMS”.Published in a workshopsponsored by the National Science foundation, California Institute of Technology, USA 1996.

[4].Y.B. Jeon, R. Sood, J.H. Jeong, S.G. Kim, “MEMS power generator with transverse modethin film PZT”, Sensors and Actuators A 122 (2005) 16-22.

[5].Yuji Suzuki “Development of MEMS Energy Harvester with high performance polymer electrets” Department of Mechanical Engineering, The University of Tokyo, Bunkyo-ku, Tokyo, Japan

[6].C. B. Williams, and R. B. Yates, “Analysis of a micro-electric generator for microsystems,” Sensors Actuators A, 52,8-11, 1996

[7]. R.J.M.Vullers, R.van Schaijk, I.Doms,C.Van Hoof, and

R.Merten “Micropower Energy Harvesting”

[8]. Solid-State Electron., 53, 684-693, 2009. 49. D. P. Arnold,

“Review of microscale magnetic power generation,” IEEE Trans. Magnetics, 43,2007

[9].Hambley, A. R. Electronics (2nd Edition). Prentice Hall: Saddle RivNJ, 1999