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Design and Simulation Analyses of a Cantilever Based Energy Harvester with Hinge Suspension for Enhanced DOF

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ABSTRACT

A piezoelectric based energy harvester for the MEMS based Sensor nodes and actuator is designed as a replacement of the conventional rechargeable batteries or cells in the field, where the frequent replacements and maintenance of nodes with proper energy resource in remote zone is quite tedious. Harvester beams are composed of lead zircon ate material with few modifications implemented in the structure. The harvester proposed here is composed of a series of cantilever beams and the beam from the fixed end is suspended with the Hinges which enables the higher degree of freedom for mechanical vibrations. The cantilever beam structure proposed is to generate the energy of about ~1.29 volts and a comparative analysis of efficiency is carried out between the usual harvester and proposed beams. The Mechanical phenomenon like stress, strain propagations in the beam and the corresponding Yield point for the proposed structureis addressed in this article which may be related for the estimation of theoretical energy generated in beam extracted out of the Resonant frequency calculations.

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INTRODUCTION

The Micro Electro Mechanical Systems finds its applications in variety of fields and domains ranging from soil sensing to sensing of atmospheric parameters such as moisture content in air, ionization potentials, wind pressure manipulations etc. The one such major domain where the increasing need is to deploy the MEMS Based devices is for the Energy harvesting in the sensor fields as a replacement of the conventional batteries and cells. The MEMS based energy harvesters are in use since the MEMS devices got its electronic profile integration and since the development of ASIC devices. The MEMS based energy harvesters are usually developed based on the three mechanisms such as Piezo-Electric method, Electromagnetic or Electrostatic implementations from natural sources. The piezoelectric energy harvesters used are designed in such a way that it can obtain the energy from the external mechanical impulse acted over the system. The piezo electric materials used are either Ceramics or crystalline materials**.** A numerous designs have been proposed earlier to achieve a relatively better potent output, since the power generated is closely associated with the morphological shape of the beams and several shapes are proposed to achieve a better vibration for a small disturbance. The comparative analyses carried out for the various beams like Triangular shape as proposed in (Power Processing Circuits 2008), response out of conventional rectangular beams as in (Vibration-based MEMS, 2003), T beam structures as in (Vibration-Based MEMS, 2001), and cantilever beams with Tip mass ideology as in (Integrated power harvesting system including a MEMS). In this article the cantilever beam with Hinge suspension is proposed with added mass at the end to have a better Degree Of Freedom, and PZT material of Grade 5A is specifically used for this system, to withstand the vibrations.

The each cantilever beam employed in the Harvester setup will experience three modes of vibrations and a complete cycle of vibrations leads to the 1 Resonance Cycle, and the vibrations achieved

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in the Beam will directly contribute to the Energy generation. The simulations of Stress distribution, Displacement profile are carried out in the ComsolMultiphysics tool and fabrication of the structure virtually carried out in Intellifab solver.

Harvester Setup:

The harvester setup is composed of array of laterally arranged beams suspended from the hinge suspension to have a better DOF. The Beams in the harvester setup is designed with Lead Titanium Zircon ate material of Specifically Grade 5A is used, since this specific material exhibits the maximum Density when compared with other piezo compatible material. The Density profile is concentrated more since the improper material selection and incompatible Density profile may leads to the deformation of entire structure because of narrowed hinge and analytical data based on Density profile is presented.

Table I: Material List based on Density Profile Analyses.

S.No	Material	Density
1	PZT 2	7600 Kg
2	PZT 4	7500 Kg
3	PZT 5A	7750 Kg
4	PZT 4 D	7500 Kg
5	Lithium Tantalite	7450 kg
6	Zinc Oxide	5680 Kg

The each beam in the harvester setup is added with a suitable tip mass to enable a continuous mode of vibration for a small disturbance. The each beam in the harvester setup will be approximately with aaspect ratio of 750*2000*400 microns. The tip mass added over the each beam will be approximately 750*300*150 microns, a dot pattern.

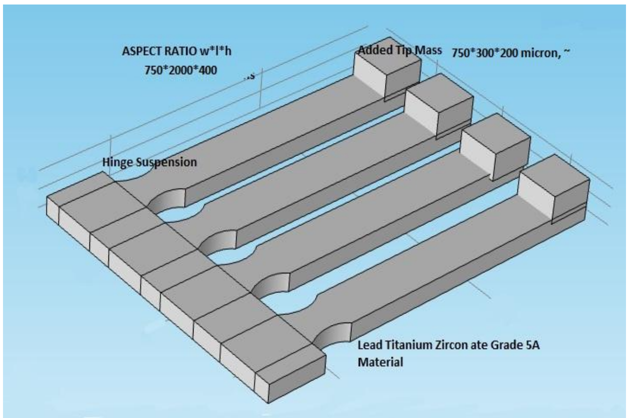


Fig. 1: Energy Harvester Setup.

Fabrication Process:

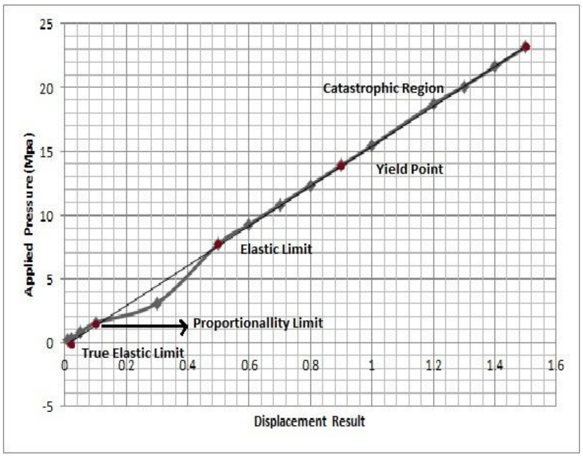
The entire virtual fabrication of the device carried out in the Intellifab module, the silicon substrate is used, with silicon nitride anchors are used for the beam suspension. The PZT material of 5A Grade is used for the Beam fabrication, the Virtual fabrication flow of the cantilever is as follows,thedevice modeling follows with basic process of substrate definition, Deposition of materials, patterning process followed by etching and Boding technique to ensure a proper packaging, the virtual fabrication process carried out in the Intellifab is as follows, the Silicon material of orientation 100 is used as a substrate, followed by substrate definition silicon nitride is deposited as a anchor material where Low Pressure Chemical Vapor Deposition(LPCVD) method is used where DichloroSilane material is used as Liquid state Precursor, The Photoresist material AZ5214 is used which has got a wall sloping profile of approximately 70 – 80%, which is deposited with Spin Coat mechanism.

Stress Strain Modeling:

The Stress originated in the end point of beam propagates in Uniaxial direction pattern and the maximum strain observed in the hinge, from where the entire beam is suspended freely and maximum stress is observed when the hinge experience the continual Resonance of vibration. The each cantilever beam subjected to vibrations will undergo modes of Resonance Cycle. The load applied in the tip of the cantilever beam where the load distribution will be in the negative Z axial point, stress propagation due to applied load will be propagating in the X, Y and even in its counter axial directions. The stress observed in the Hinge of the beam is given by

$\sigma = \rho l / h.$

The stress strain curve is a direct response of the beam extracted for various load conditions. The Stress Strain curve of the system as follows



Plot I: Stress Strain Graph Analysis.

Yield Point Analyses:

a. The true Elastic limit for any mechanical system is the point where it begins to respond due to applied load\Pressure, where for the proposed system with this aspect ratio the system begins to respond for a applied pressure of about 0.01Mpa.

b. The Proportionality limit for the system is the point till then the stress strain response is a linear one and the proportionality point for the system is exhibited at 0.1Mpa.

c.The Elastic limit is the point in the stress strain graph where the system undergoes a recoverable stress due to applied load, and the in this region the device response need not be a linear one and the maximum Point of Elasticity is for a applied pressure of 0.5Mpa.

d.Elastic point to Yield point region, where the phenomenon of plasticity is observed end in structural mechanics the beam undergoes a non-recoverable displacement and the region of plasticity is between 0.5Mpa to 0.8, 0.9Mpa.

e.The region above the Yield point is defined to be a region of Catastrophe region where the system or beam in structural mechanics once attained this region the system will undergo complete structural Deformation, i.e. above the point of 1Mpa

Stress Distribution:

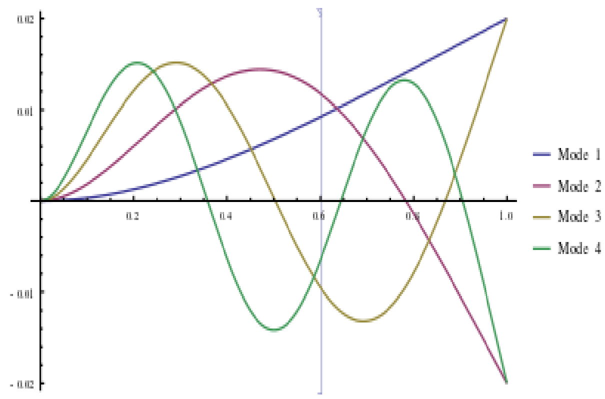
The stress exhibited in the cantilever beam is given by the integral form of

$ds = \int_0^{Z0} wl.$

Where integral limit ranging from 0 to Z_O, which Zobe the maximum displacement achieved by the cantilever beam during resonance and Lowerlimit function cannot be less than 0 since distance and displacement factors cannot be in Negative form. Area of stress propagation is given by the General Area formulae for applied limit.

Beam Vibrational Modes:

The cantilever beams subjected to the mechanical vibrations undergoes up to ‘n’ modes of vibrations. Under each applied stressthe beam will undergo different vibrational cycles. The three different modes of vibrations are displayed in figure II. The change in resonant frequency under each mode is due to the varying Stress propagation for a same (single point) loads.



Model Plot I: Resonant Frequency Cycle.

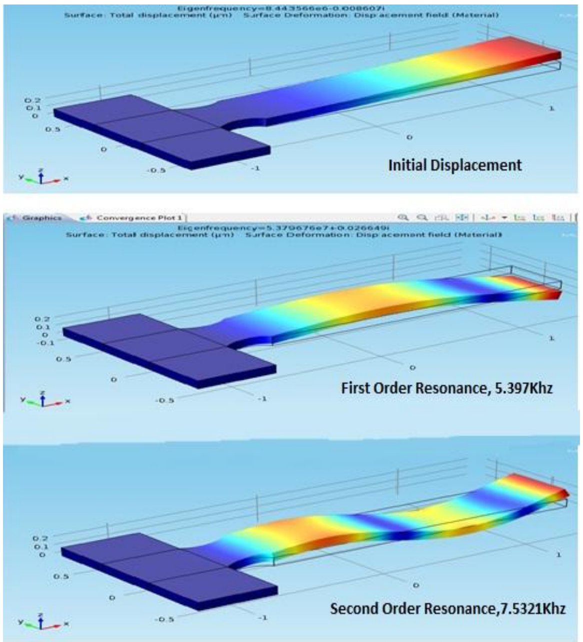


Fig. 2: Resonant Frequency Simulation model.

The beams in the harvester system when subjected to the applied load it undergoes two modes of resonance vibration at two different frequencies, where the two modes of vibrations are as follows,

Simulation Analyses:

The Simulation of the Harvester setup of Potential estimation generated out of beam during vibrations and stress profile analyses and strain, displacement analyses are carried out in COMSOL Multiphysics Simulation Software, the Stress analyses of the beams due to the applied pressure of 10 Pascal's is simulated and analyzed as shown, the maximum stress of about 15507 N/m^2 is experienced by the hinges due to the structural impact. The maximum stress withstander by the hinges is directly proportional to the applied load which includes self-added tip mass, Material Density and the stress which is formulated by the

$$\sigma h = \frac{(Load + Mt)*MaterialDensity\rho}{AspectRatio}.$$

Where σhrepresents the Stress exhibited on Hinges, Load be applied load and self-added weight because of tip mass (m_t).

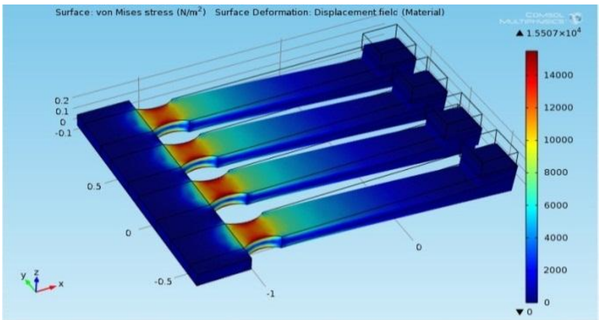


Fig. 3: Stress Profile Analyses, Maximum of 15507 N/m^2.

The displacement simulation profile is analyzed and a comparative analyses showing the maximum displacement achieved in the hinged structure for a uniform applied load of 10 Pascal's, the figure shows the displacement profile analyses of a conventional rectangular beam without hinges and a displacement of about 2.14μm is achieved, and in figure , displacement analyses of Hinged structure is analyzed where a maximum displacement of about 7.16μm is achieved for a applied load, and these ensures the maximum Degree of freedom is achieved in the Hinged Structure a uniform applied load.

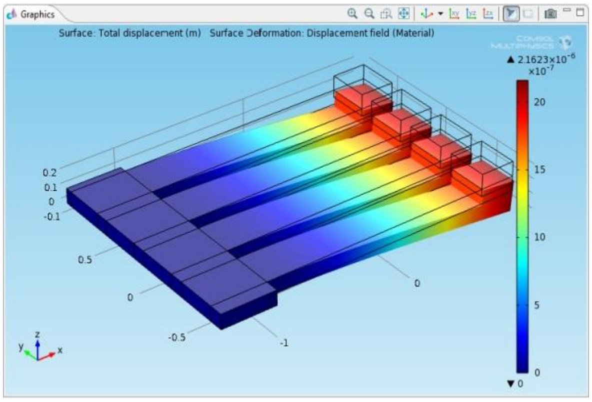


Fig.4: Displacement Profile analyses of Beam, where a maximum of 2.162µm is achieved(lower DOF).

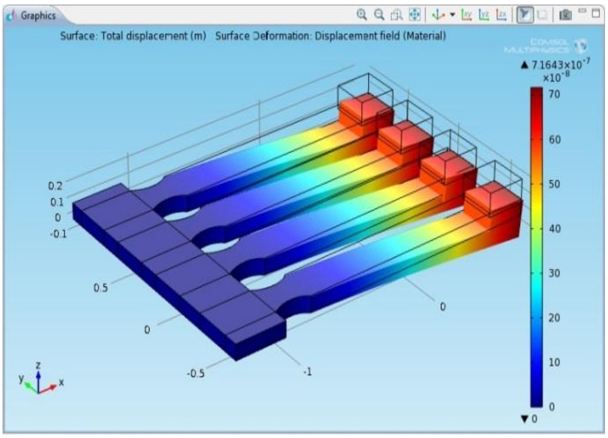


Fig.5: Displacement Profile analyses of Beam, where a maximum of 7.164µm is achieved(Higher DOF).

Potential Analyses for PZT 5A grade material is simulated, and for the hinged structure potential of about 1.29v is generated out of the individual beam during vibration.

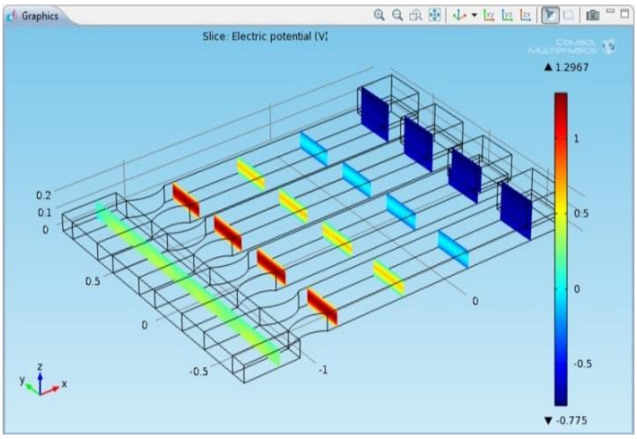


Fig. 6: Potential Distribution Profile, Maximum potential of 1.29v generated for 10pa pressure.

Conclusion:

A potential is generated out of the individual beams made of PZT material of Grade 5A where it possess a Density 7750kg/m^3 suitable for the Hinge shape. The Degree of freedom is observed more in the structure with Hinges, which results in the maximum displacement, and vibrations which contributes maximum power generated out of the individual beams. The Yield point graph analysis is carried out where the device's True E Limit and Catastrophic points are analyzed.The beam designed can with stand up to a pressure of about 0.9Mpa pressure, and system attains the region of catastrophe above the pressure of about 1Mpa since undergoes structural deformations.

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