COMSOL CONFERENCE INDIA 2012

SIMULATION AND OPTIMIZATION OF MEMS PIEZOELECTRIC ENERGY HARVESTER WITH A NON-TRADITIONAL GEOMETRY

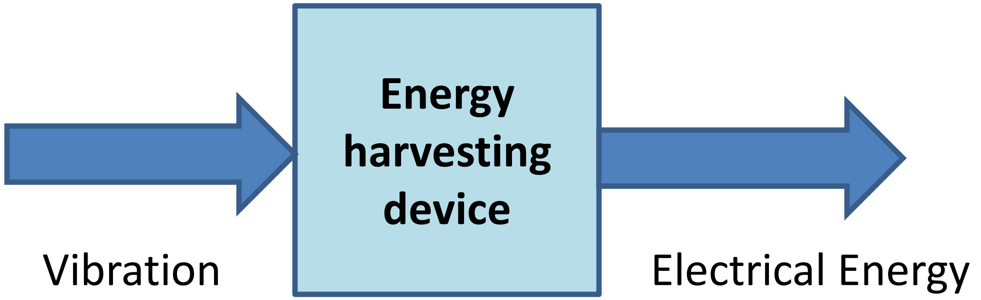
S. Sunithamani[1], P. Lakshmi[1], E. Eba Flora[1]
[1]Department of EEE, College of Engineering, Anna University, Chennai, India.

Excerpt from the Proceedings of the 2012 COMSOL Conference in Bangalore

Contents

Introduction

- The energy harvesting devices converts ambient energy into electrical energy .
- It is the concept by which energy is captured, stored and utilised.
- Ambient energy is available in the form of vibration, light, temperature gradient etc.
- Among these energy, mechanical vibration is the most widespread and wasted energy in the environment.



Theory

- Conversion of Mechanical vibration into electrical energy
  - -Electromagnetic
  - -Electrostatic
  - -Piezoelectric.
- Piezoelectric generators are mostly used because piezoelectric materials have the advantage of large power and ease of application.
- Direct piezoelectric effect: surface charge induced by a mechanical stress.
- The most studied energy harvesters are based on the piezoelectric effect and are made with MEMS technology.
- The geometry of piezoelectric cantilever beam greatly affects its vibration energy harvesting ability .
- In this paper MEMS based energy harvester with a non-traditional geometry is designed and simulated with COMSOL for the conversion of mechanical into electrical energy.
- Also the results are compared with other geometries such as rectangular and triangular.

Use of COMSOL

Geometry

The geometry consists of two subdomains,

1.substrate layer- stainless steel.

2. piezoelectric layer- active layer of unimorph .

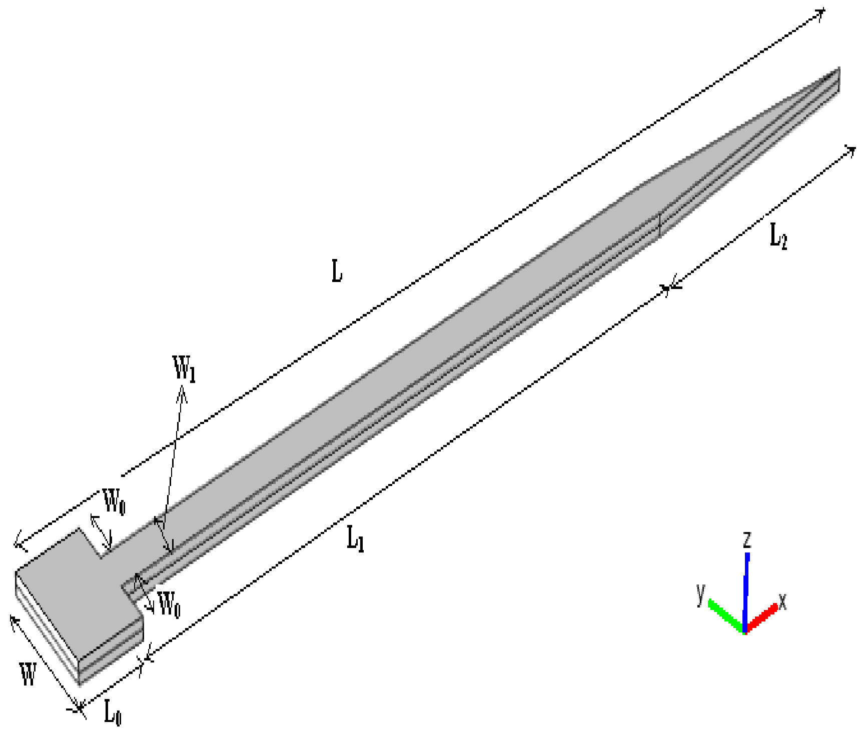


Figure 1. Structure of piezoelectric energy harvester with non-traditional geometry. L=27000µm, L_0=2000µm, L_1=18000µm, L_2=7000µm, W=3000µm, W_0=W_1=1000µm, T_0=200µm, T_1=210 µm.

Meshing and Governing Equations

Meshing

- The mesh consists of 238 quad elements for a total number of degrees of freedom 10639.
- The swept mesh tool is used .

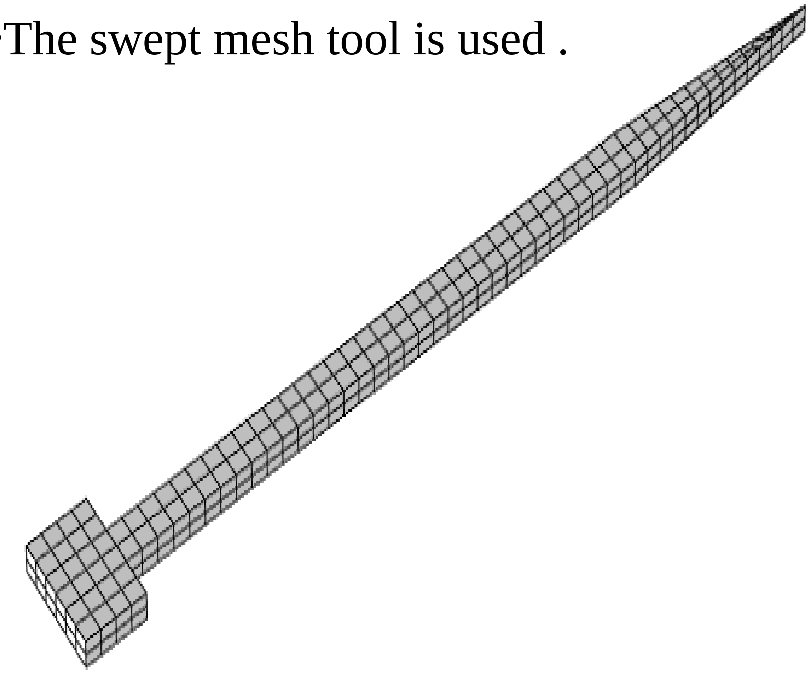


Figure 2. Piezoelectric Energy Harvester mesh.

Piezoelectric Equations

$$\boldsymbol{S = s^E\, T + d\, E} \qquad \textbf{(1)}$$

$$\boldsymbol{D = \varepsilon^T\, E + d\, T}$$

Where

S - the mechanical strain vector

s^E -elastic compliance tensor (Pa^{-1})

T- mechanical stress vector (Nm^{-2})

D -elastic displacement vector (Cm^{-2})

ε^T -the dielectric permittivity tensor (Fm^{-1})

E- the electric field vector (Vm^{-1})

d- the transverse piezoelectric coefficient tensor (CN^{-1}).

For the **substrate layer** only mechanical behaviour is considered using stress-strain relationship.

$$\boldsymbol{S = sT} \qquad \textbf{(2)}$$

s is the compliance of stainless steel substrate.

Subdomain settings

- The material parameters of the substrate are as follows: its density ρ=7850 kg/m^3,Young's modulus E=200 x 10^9 Pa,Poisson's ratio μ=0.33.
- The active layer of unimorph is modelled using the following set of properties.

-Elastic compliance tensor

$$S^E = \begin{bmatrix} 50 & -20 & -20 & 0 & 0 & 0 \\ -20 & 50 & -20 & 0 & 0 & 0 \\ -20 & -20 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 70 & 0 & 0 \\ 0 & 0 & 0 & 0 & 70 & 0 \\ 0 & 0 & 0 & 0 & 0 & 70 \end{bmatrix} \text{ x } 10^{-12}\ Pa^{-1}$$

-Piezoelectric tensor

$$d = \begin{bmatrix} 0 & 0 & 0 & 0 & 11 & 0 \\ 0 & 0 & 0 & 11 & 0 & 0 \\ -2.5 & -2.5 & 5 & 0 & 0 & 0 \end{bmatrix} \text{ x } 10^{-12}\ CN^{-1}$$

-Relative permittivity matrix

$$\varepsilon^T = \begin{bmatrix} 50 & 0 & 0 \\ 0 & 50 & 0 \\ 0 & 0 & 50 \end{bmatrix} \text{ x } \varepsilon^0$$

-Density ρ = 3000 kg m^{-3}

Boundary conditions

- **Vertical acceleration :**

  - body load $F_Z = a\rho$ in each subdomain, a =0.1g and ρ is the density of the material .
- One end of the unimorph cantilever is fixed while other is free for vibration.

  -fixed constraint condition is applied for the vertical faces of both the layers.

  -while all other faces are free of displacement.
- **Electrostatic boundary conditions :**

  -upper and lower face of PZT layer are selected as floating and ground potentials respectively .

  -while all other faces of piezoelectric layer are kept as zero charge.
- **Mesh boundary conditions:**

  -to optimize the thickness of the PZT layer, Moving mesh application mode is used.

  - bottom face: clamped,

  - vertical faces: clamped along thickness,

  -upper surface: tangentially constrained and displaced in the normal direction to the surface by a given displacement (deltathickness).

  -*deltaThickness* is changed from 10μm to 400μm obtaining parameterized moving mesh.

Modelling and Optimization

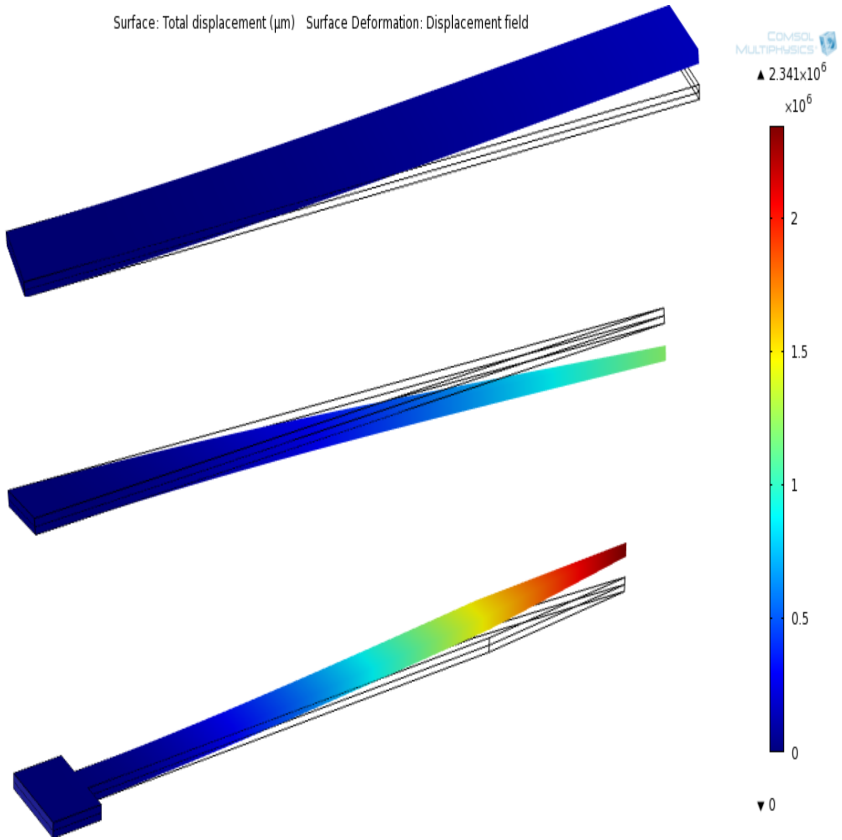


Figure 3 FEM modelling of rectangular, triangular and non-traditional geometries.

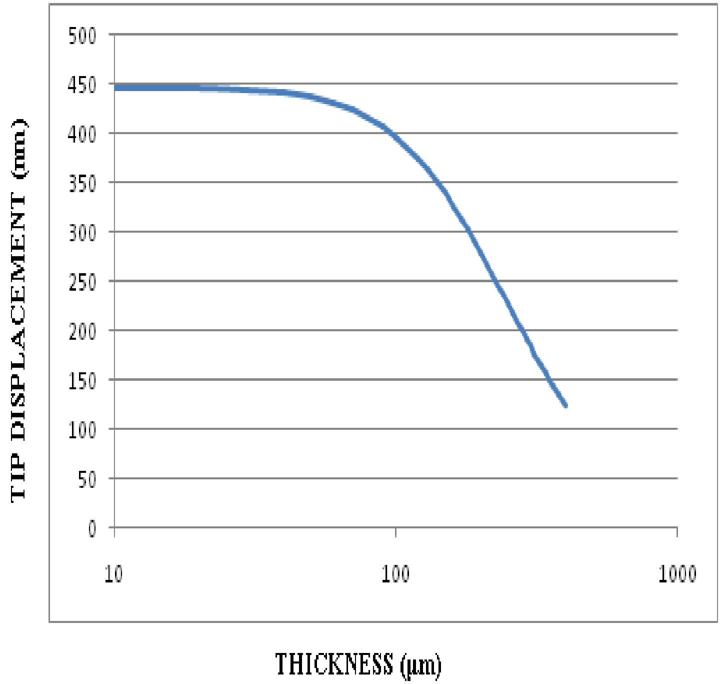


Figure 4 Tip displacement (nm) Vs Thickness(μm).

Results-output voltage

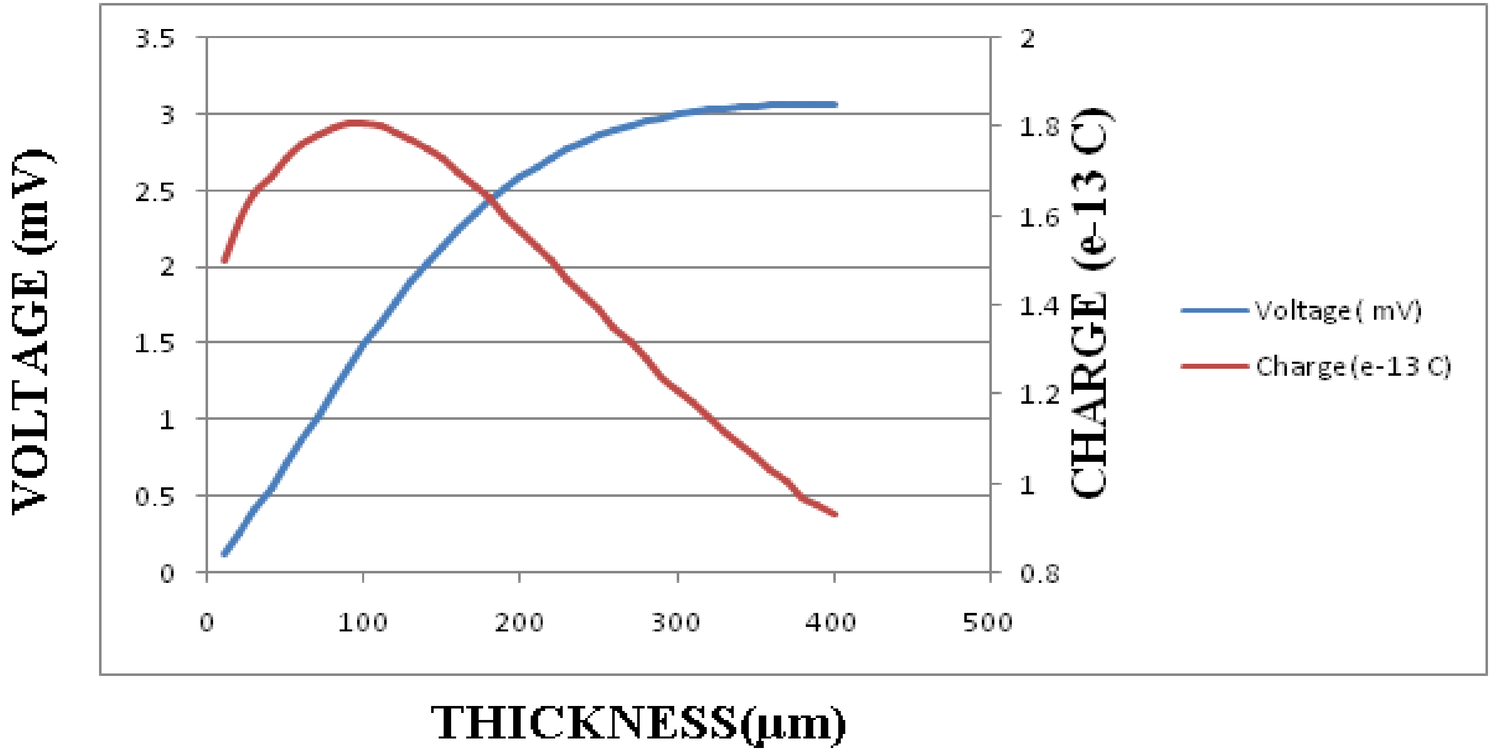


Figure 5 voltage (mV) Vs thickness (µm) and charge (e-13) Vs thickness (µm).

Results-Stored energy

Stored electrical energy

$$E = \frac{1}{2} QV$$

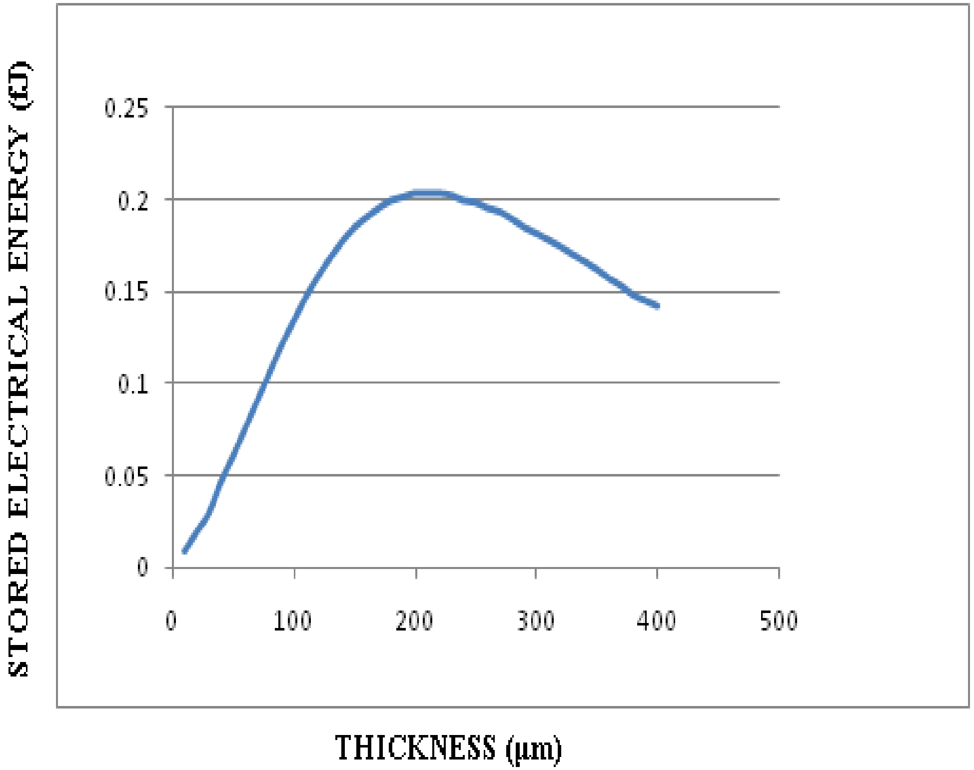


Figure 6 Stored electrical energy (fJ) Vs thickness (µm).

Results-Frequency analysis

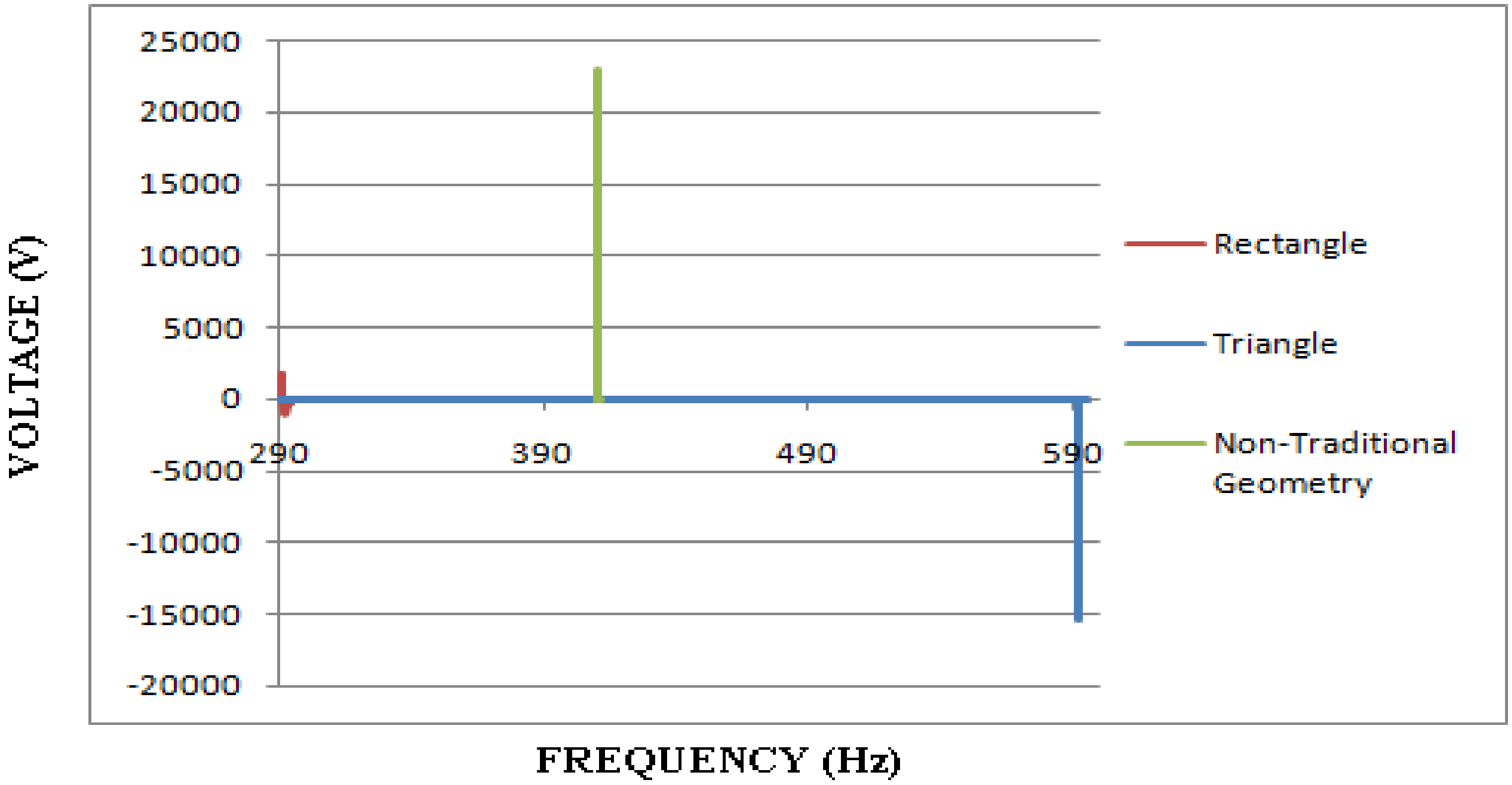


Figure 7 Voltage (V) Vs Frequency (Hz) for three different geometries.

Results- Strain analysis

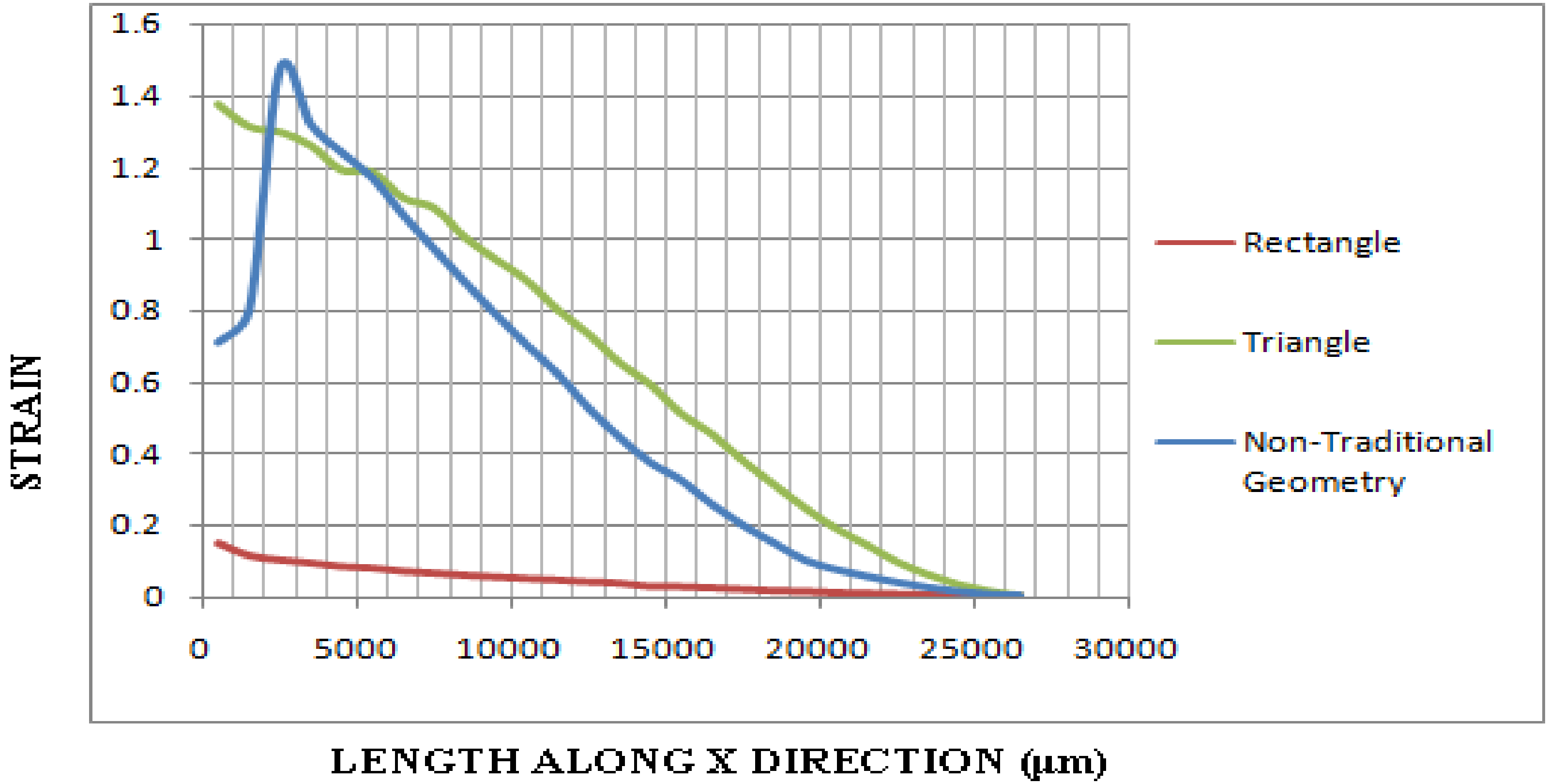
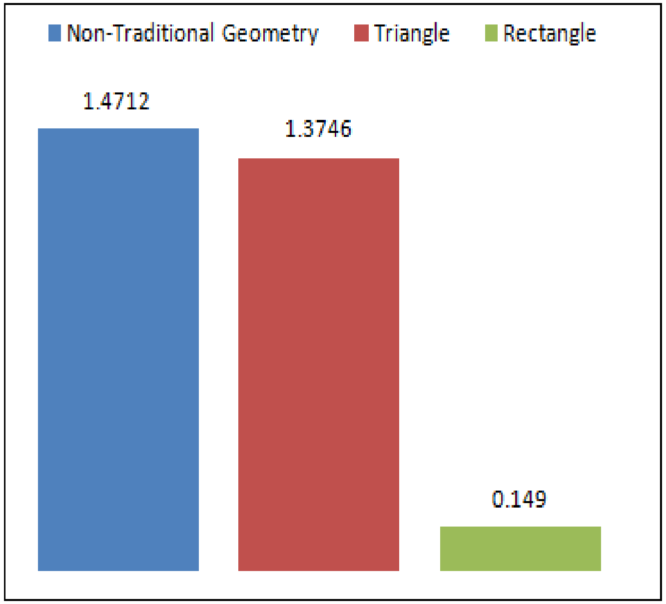
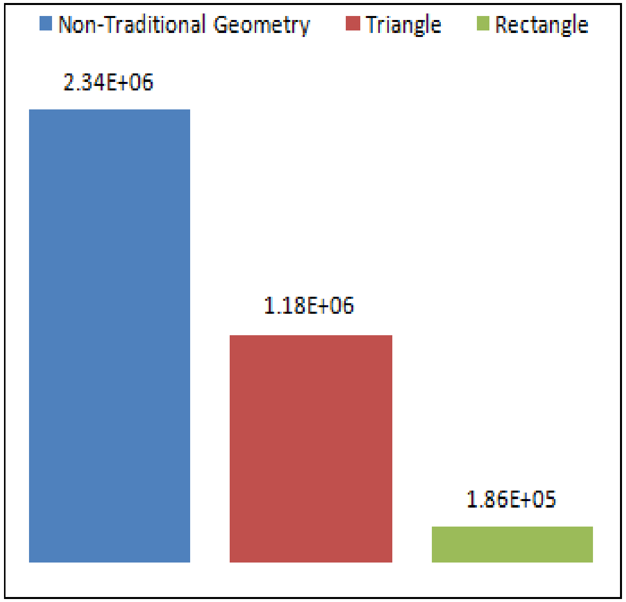


Figure 8 Strain curves of three different geometries along X direction.

Performance comparison





a)Strain.

b) Deformation.

Summary

- A piezoelectric energy harvester with non-traditional geometry was designed and simulated in COMSOL Multiphysics.
- The thickness of PZT layer was optimized to give maximum stored electrical energy.
- Frequency analysis and strain analysis were carried out for the optimized thickness of 210μm.
- Simulation results demonstrate that the piezoelectric energy harvester with non-traditional geometry improves strain and generate more voltage at resonant frequency than the rectangular and triangular piezoelectric energy harvester.
- The simulation results suggest that such structures can be used for energy generation in wireless sensor networks.

References

[1] Z.S.Chen, Y.M.Yang and G.Q.Deng, "Analytical and Experimental Study on Vibration Energy Harvesting Behaviors of Piezoelectric Cantilevers with Different Geometries" International conference on sustainable power generation and supply, 1 - 6 (2009).

[2] M.Guizzetti, V.Ferrari, D.Marioli and T.Zawada, "Thickness optimization of a piezoelectric converter for energy harvesting," *Proceedings of the COMSOL Conference*, 2009.

[3] Suyog N Jagtap and Roy Paily, "Geometry Optimization of a MEMS-based Energy Harvesting Device" Proceeding of the 2011 IEEE Students' Technology Symposium, 265 - 269 (2011), IIT Kharagpur.

Thank You !

Questions???