COMSOL CONFERENCE
2014 BOSTON

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Zewail City of Science and Technology

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Simulation of a New PZT Energy Harvester with a Lower Resonance Frequency Using COMSOL Multiphysics®

Zewail City Staff

Sep, 2014

Outline

- Introduction.
- Theoretical Background of Piezoelectric Transducer.
- Use of COMSOL Multiphysics.
- Simulation Results.

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- **Introduction.**
- Theoretical Background of Piezoelectric Transducer.
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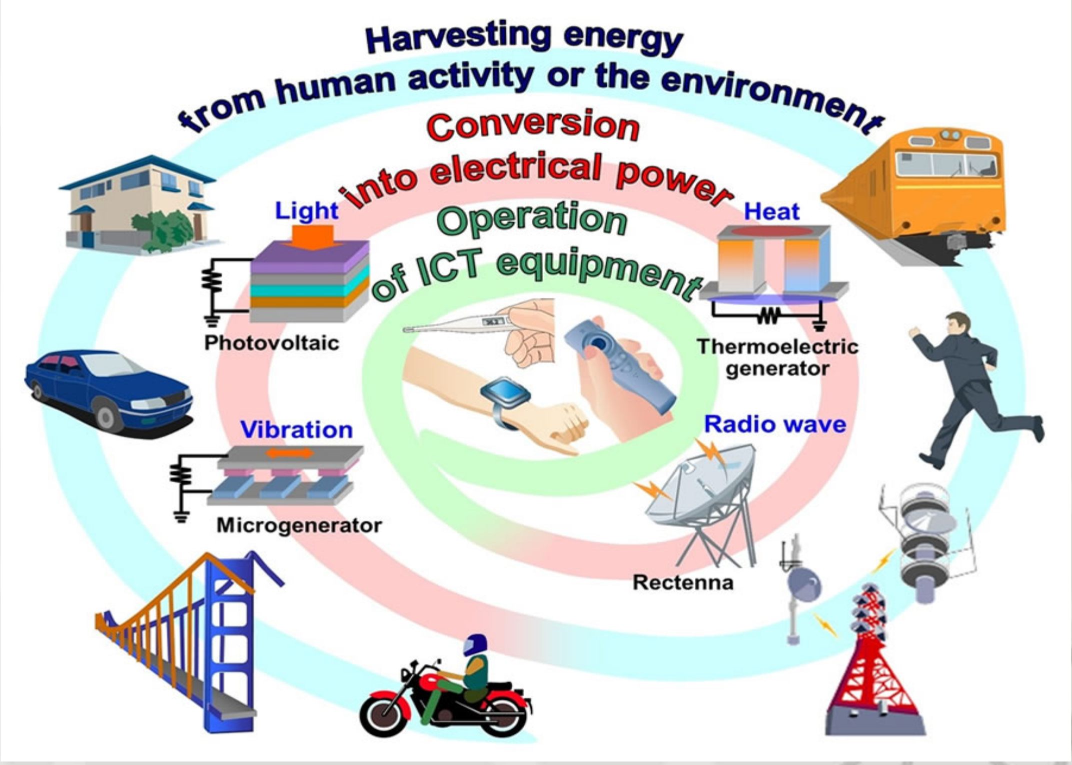
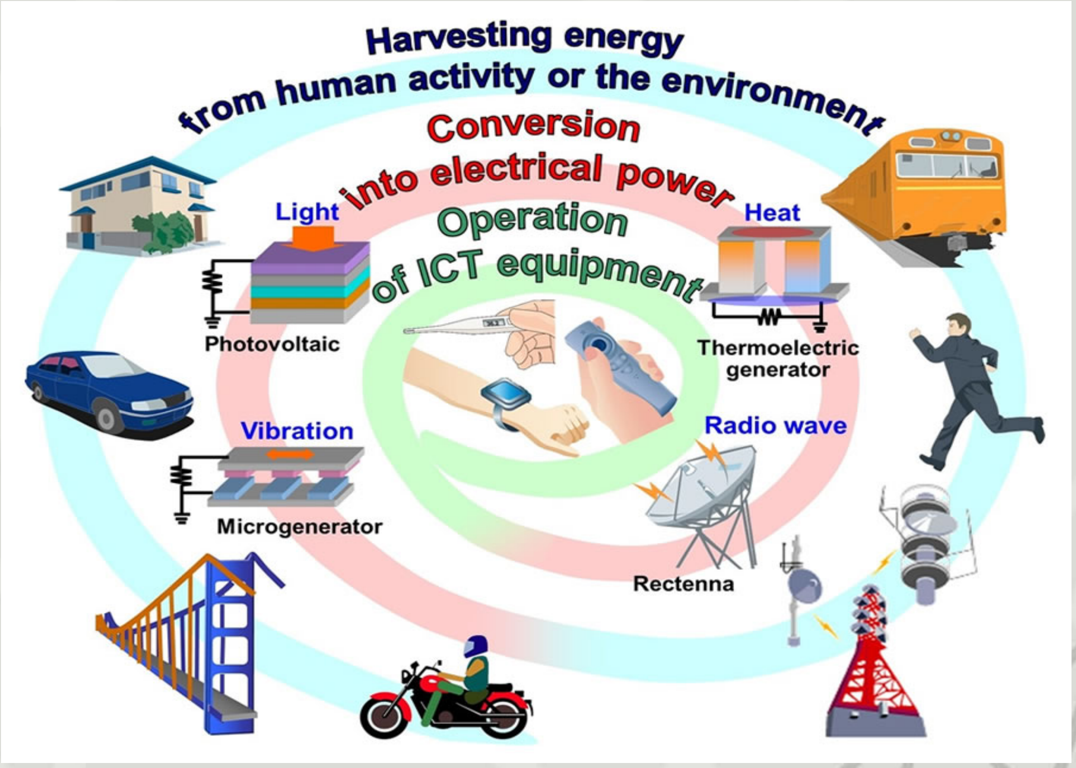
Introduction

- Energy harvesters became a good alternative for conventional batteries.



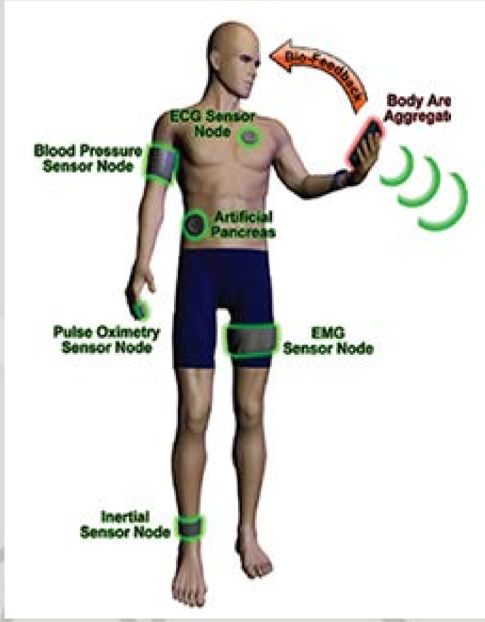
Introduction

- The most common sources of energy are solar radiation, vibration, and RF emissions.



Introduction

- The most important type is the environmental vibration because of natural oscillations like that caused by air or liquid flow and by exhalation or the heartbeat of a human body.



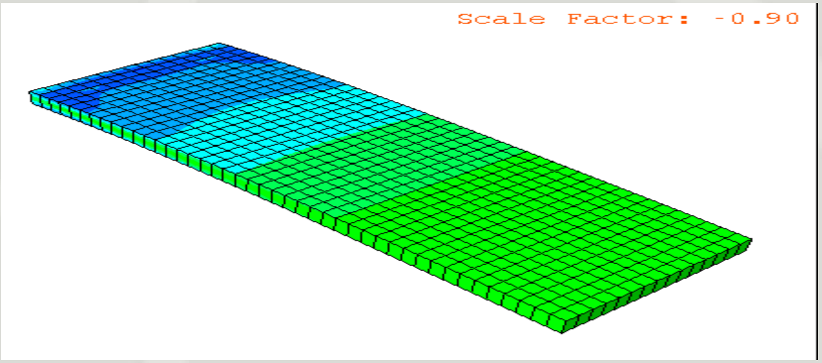
Introduction

- This vibration can be converted into electrical energy by three main harvesting mechanisms:
  - Electrostatic.
  - Electromagnetic.
  - Piezoelectric.

Introduction

- **Piezoelectric Energy Harvesters**

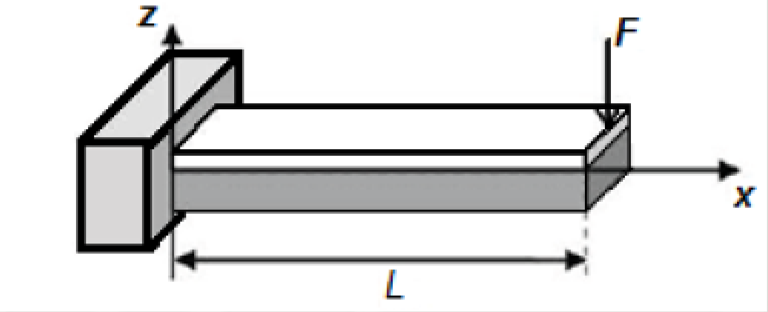
  The piezoelectric materials produce electric charges when strained.



  They are mostly used because they have a large power and are simple to use in applications.

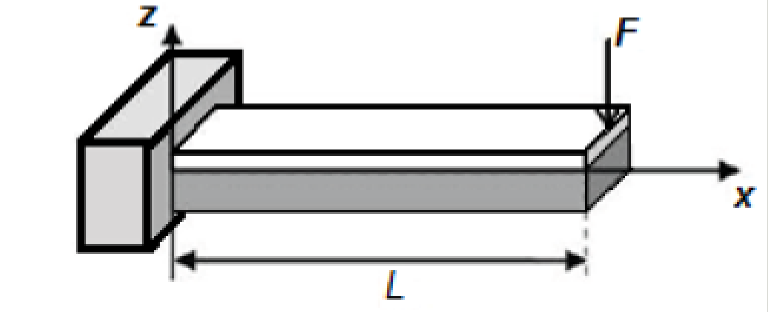
Introduction

- The most common structure used in PEH is the cantilever beam.



Introduction

- It is a beam with a support at one end, and is often referred to as a “fixed-free” beam.



Outline

- Introduction.
- **Theoretical Background of Piezoelectric Transducer.**
- Use of COMSOL Multiphysics.
- Simulation Results.

Theoretical Background of Piezoelectric Transducer

- The form used to describe the behavior of piezoelectric material is strain-charge form.

$$S = s^E T + d\overline{E}$$
$$D = dT + \varepsilon^T \overline{E}$$

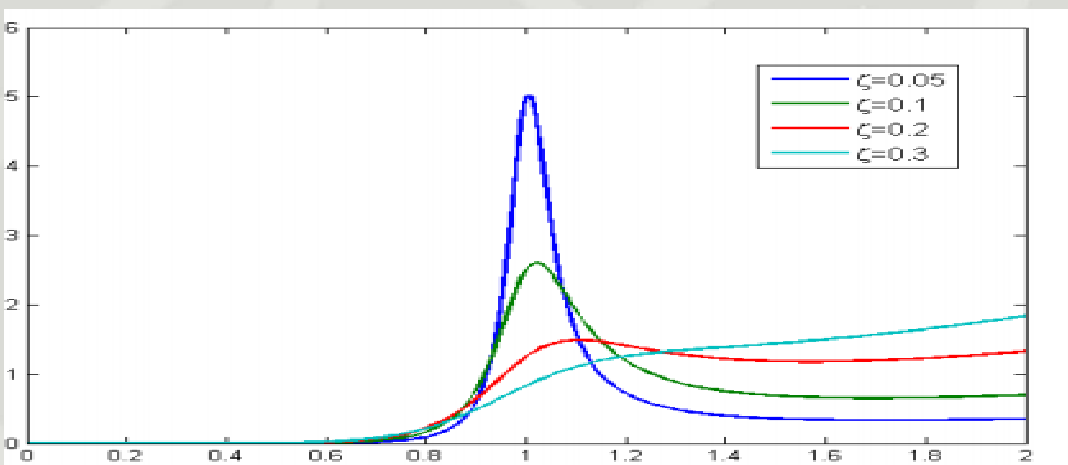
- The second term in the right side of first equation represents the piezoelectric coupling term, which provides the mechanism for energy conversion.

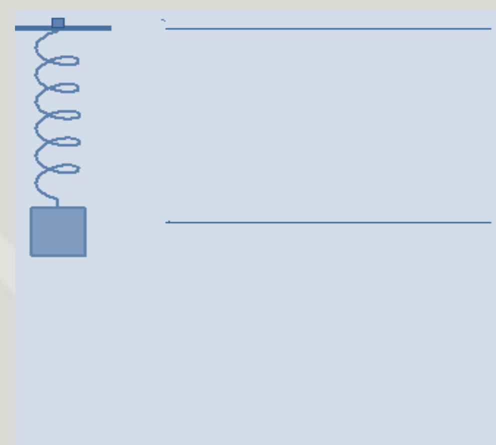
Theoretical Background of Piezoelectric Transducer

- One of the most important design parameters in designing a vibration energy harvesting device is the resonant frequency.

Theoretical Background of Piezoelectric Transducer

- Maximum energy occurs when the vibration frequency of the environment matches the resonant frequency of the cantilever .





Theoretical Background of Piezoelectric Transducer

- The variation of resonant frequency as follows

$$f_n \alpha \frac{1}{L^2} \sqrt{t_p} \sqrt{t_s}$$

where

L: length of cantilever.

t_p : thickness of piezoelectric material.

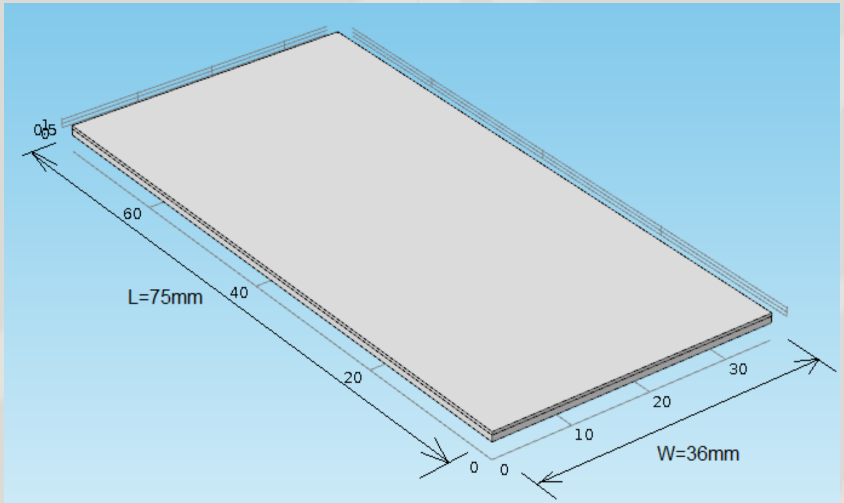
t_s : thickness of substrate material

Outline

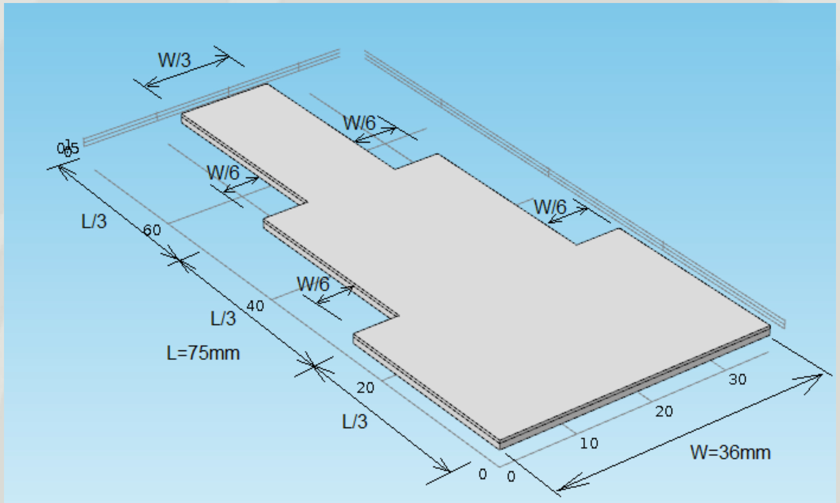
- Introduction.
- Theoretical Background of Piezoelectric Transducer.
- **Use of COMSOL Multiphysics.**
- Simulation Results.

Use of COMSOL Multiphysics

- The proposed and rectangular shapes were designed and simulated.



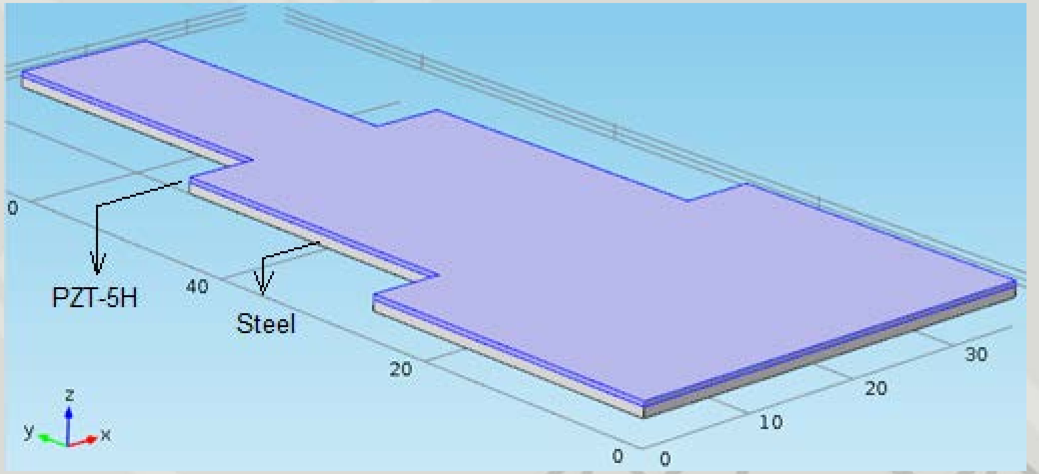
Rectangle Geometry



Proposed Geometry

Use of COMSOL Multiphysics

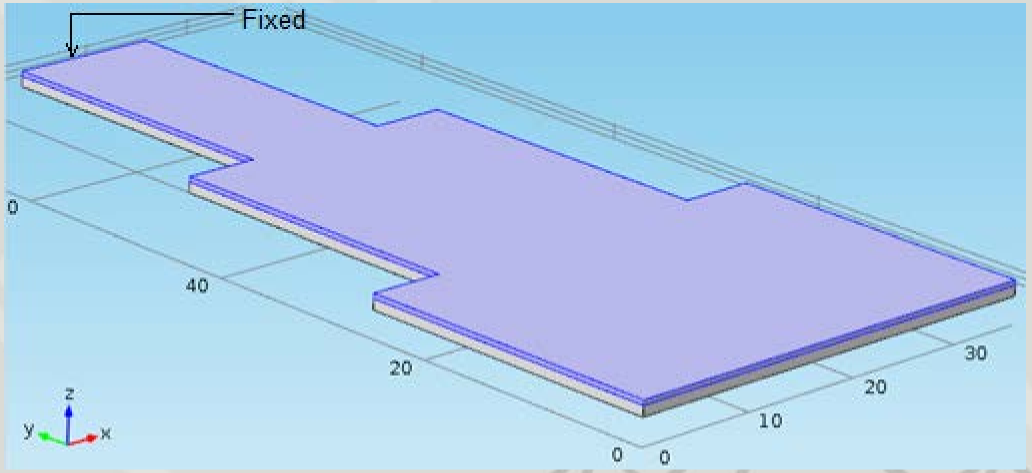
- The lower and upper layers are chosen to be steel and Lead Zirconate Titanate (PZT-5H).



Use of COMSOL Multiphysics

- **Boundary Conditions**

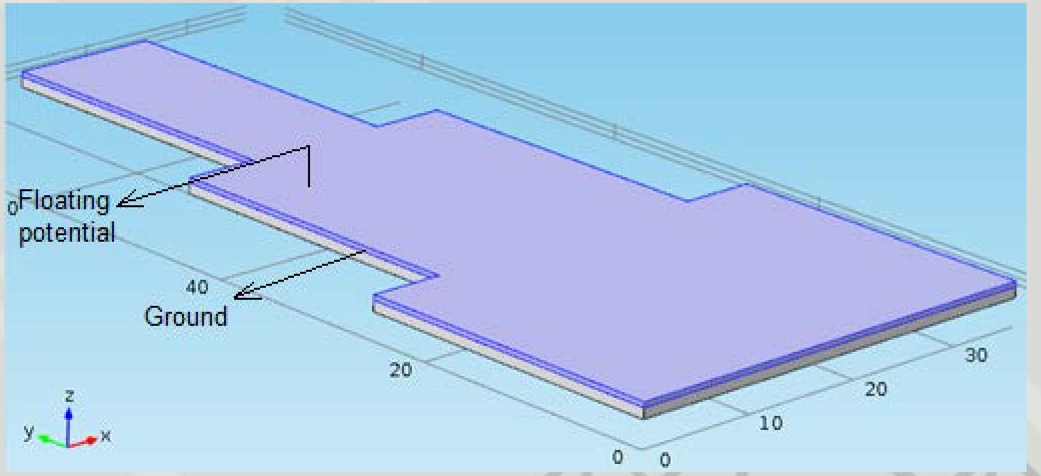
  - The narrow end of the unimorph cantilever is fixed while other is free to vibrate.



Use of COMSOL Multiphysics

- **Boundary Conditions**

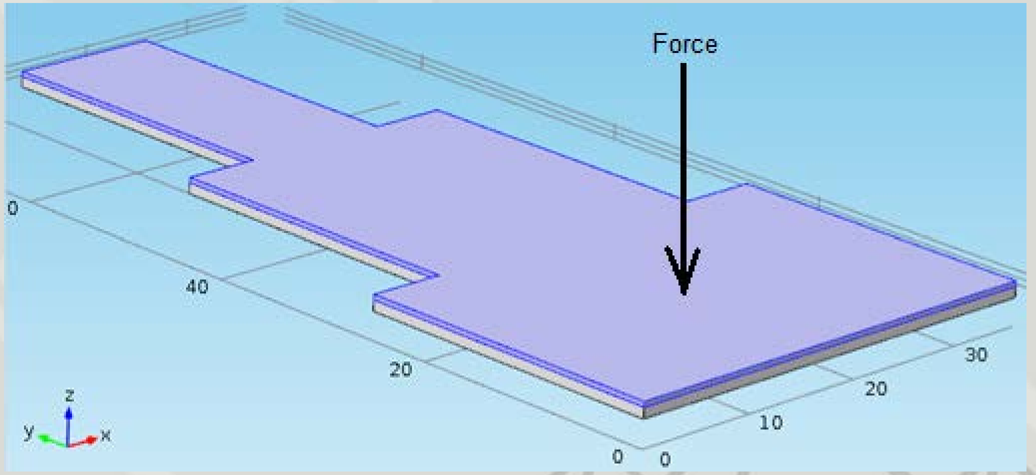
  - The floating potential and grounding are applied at the upper and the lower face of the piezoelectric layer respectively.



Use of COMSOL Multiphysics

- **Boundary Conditions**

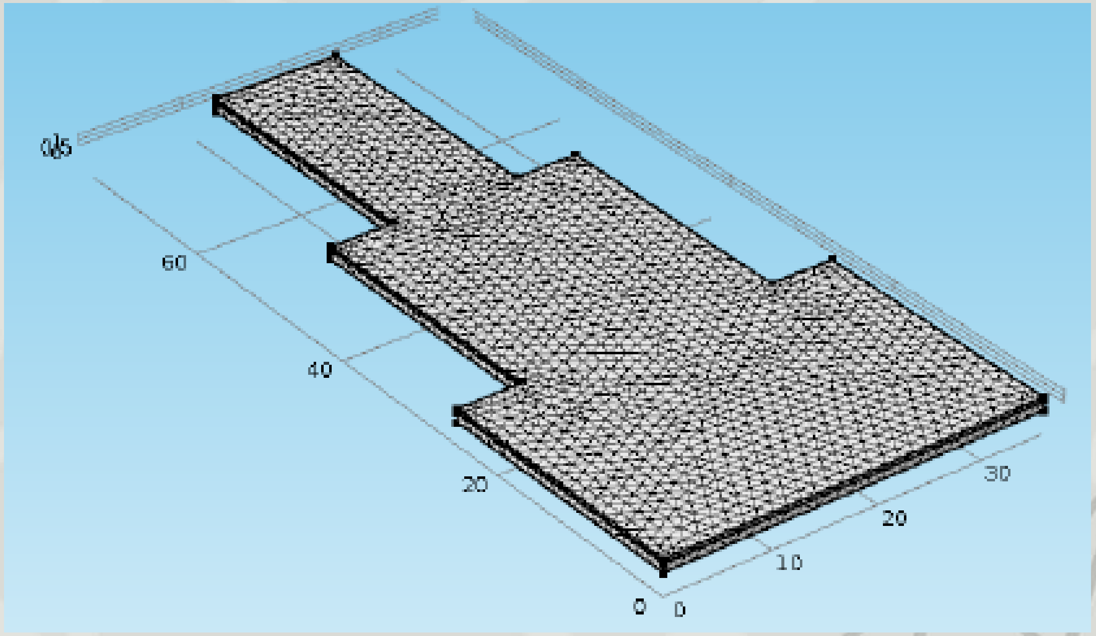
  - The body load F (0.1N) is applied as an input to the piezoelectric layer to induce a strain.



Use of COMSOL Multiphysics

- **Meshing**

  - The model is meshed in tetrahedral blocks with fine element size.



Outline

- Introduction.
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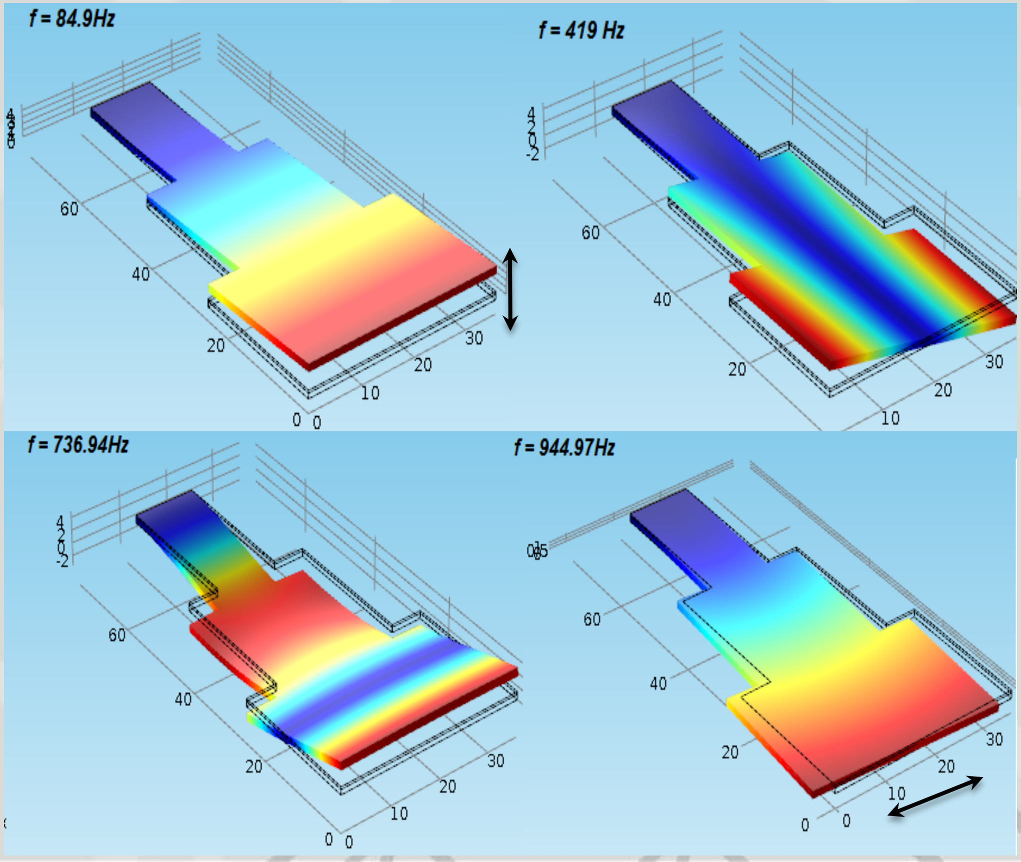
- **Simulation Results.**

Simulation Results

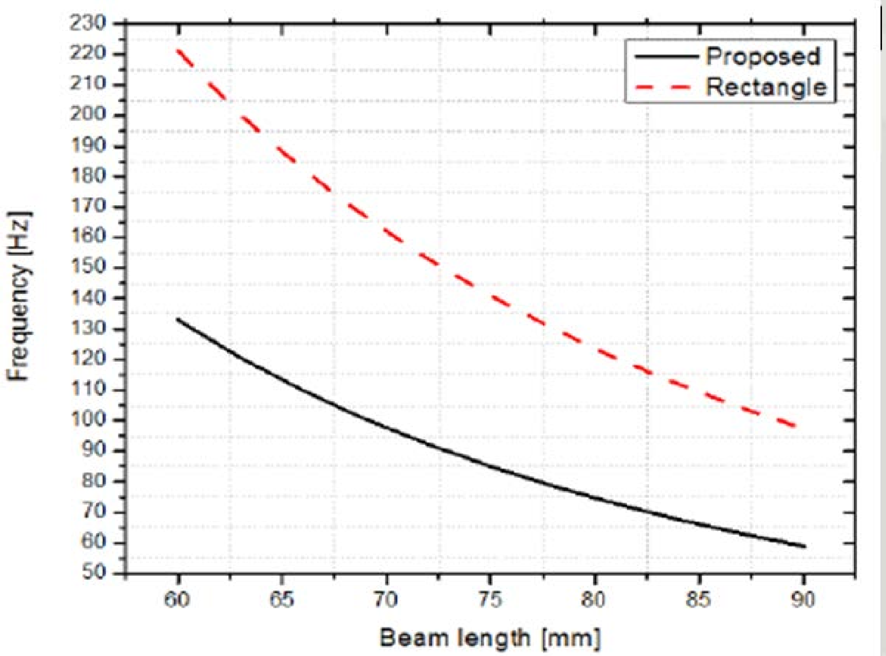
- **Eigenfrequency Analysis**
  The first four resonance frequencies of proposed geometry.



Simulation Results

- **Eigenfrequency Analysis**

The resonant frequency decreases with increasing the cantilever length.

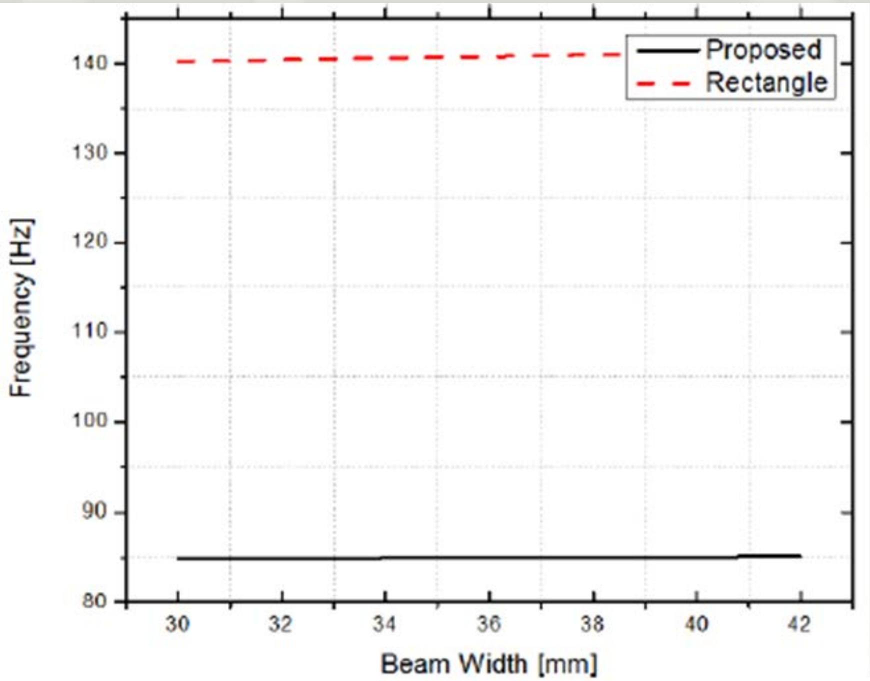


Resonance Freq. versus beam length at W=36mm, t_p=0.4mm

Simulation Results

- **Eigen frequency Analysis**

The resonant frequency is slightly invariant to the width of cantilever.

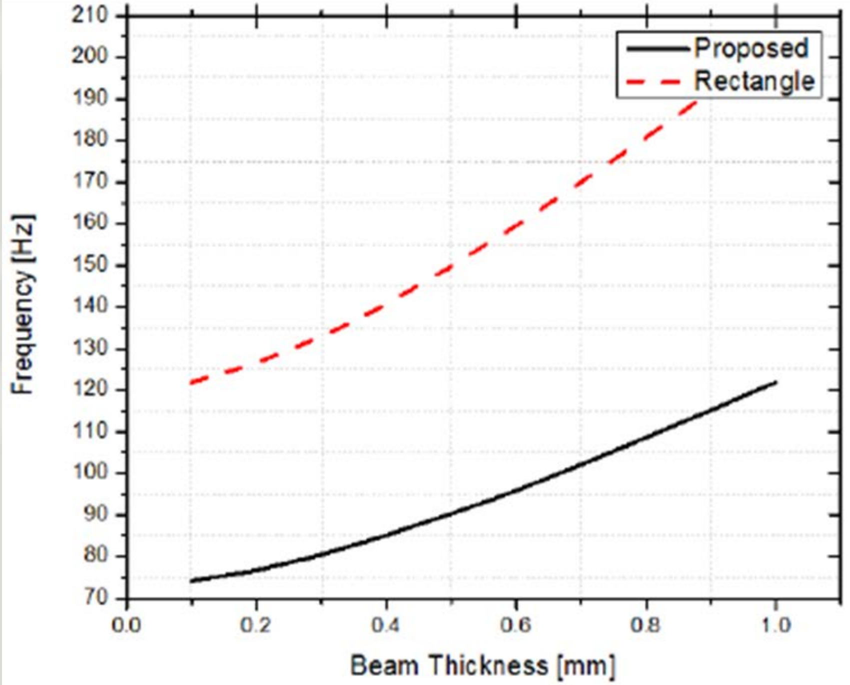


Resonance Freq. versus beam width at L=75mm , t_v=0.4mm

Simulation Results

- **Eigen frequency Analysis**

The resonant frequency increases with increasing the cantilever thickness.



Resonance Freq. versus beam thickness at W=36mm and L=75mm

Simulation Results

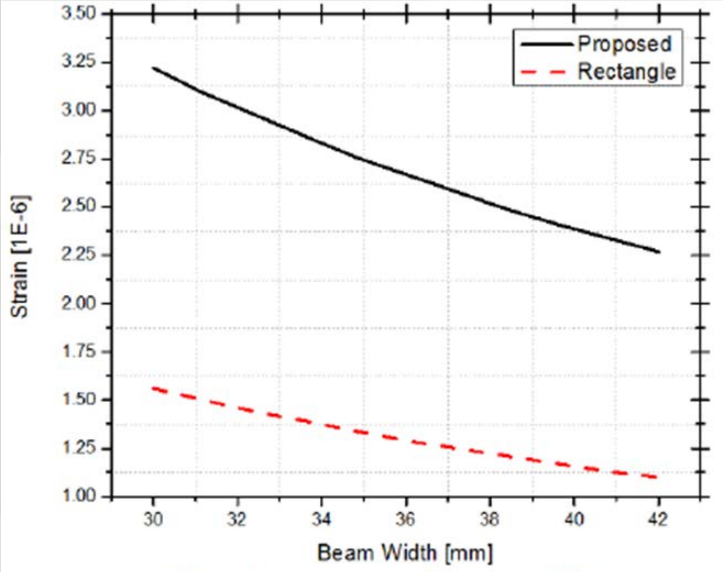
- **Eigen frequency Analysis**

It is clear that with the same width, length, and thickness the proposed geometry has a lower resonant frequency than generated from the rectangle one which make this proposed geometry is more suitable for human applications.

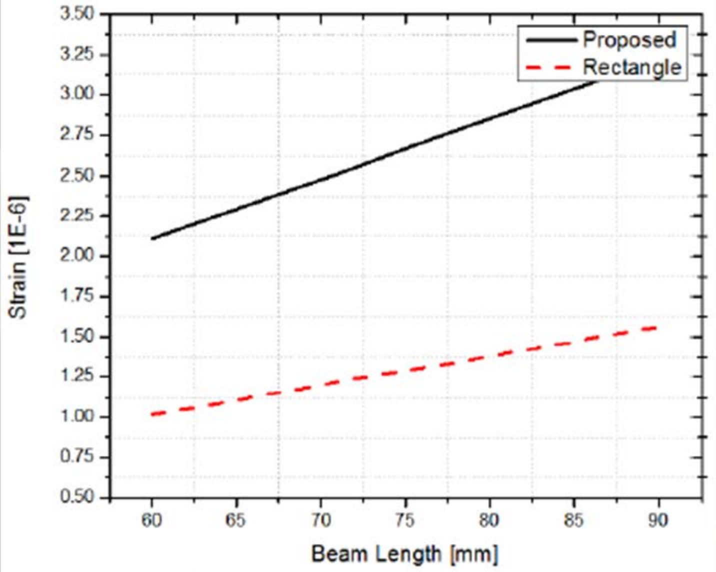
Simulation Results

- **Stationary Analysis**

the proposed geometry has a larger strain than obtained from the rectangle shape.



The strain versus beam width at L=75mm , t_p=0.4mm

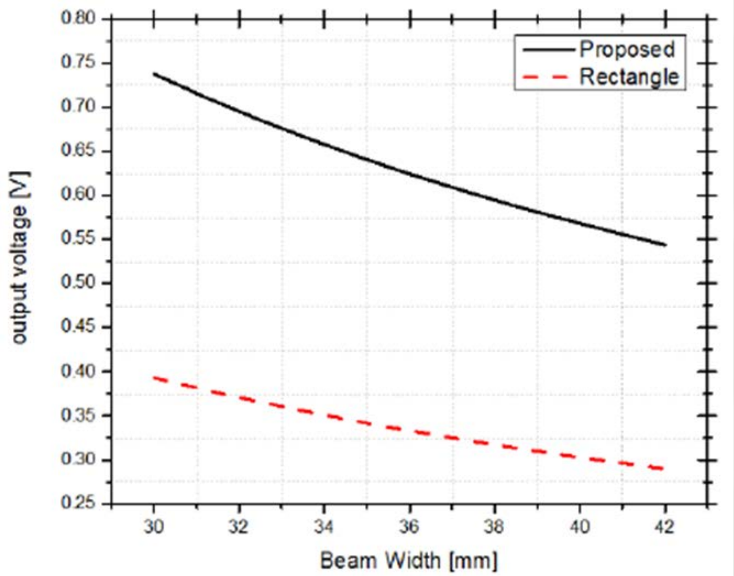


The strain versus beam length at W=36mm , t_p=0.4mm

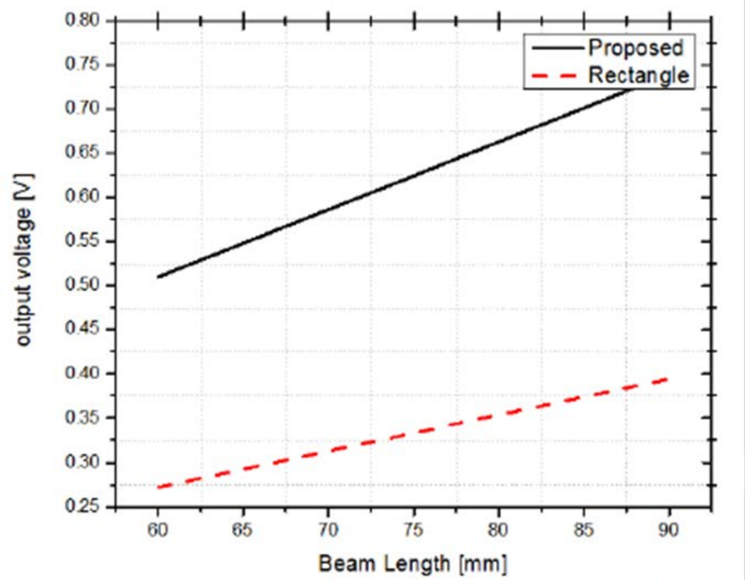
Simulation Results

- **Stationary Analysis**

the proposed geometry has a larger output voltage than obtained from the rectangle shape.



The output voltage versus beam width at L=75mm , t_p=0.4mm



The output voltage versus beam length at W=36mm , t_p=0.4mm

Simulation Results

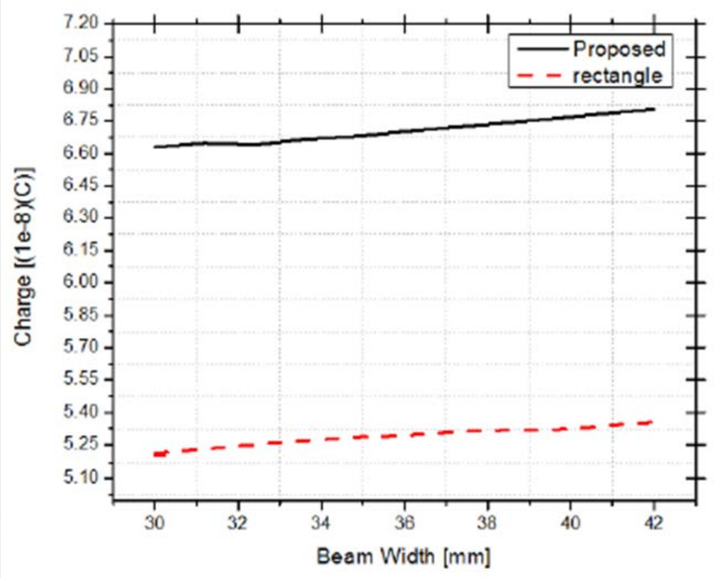
- **Stationary Analysis**

After integrating the surface charge density over the piezoelectric surface, the total stored charge was calculated.

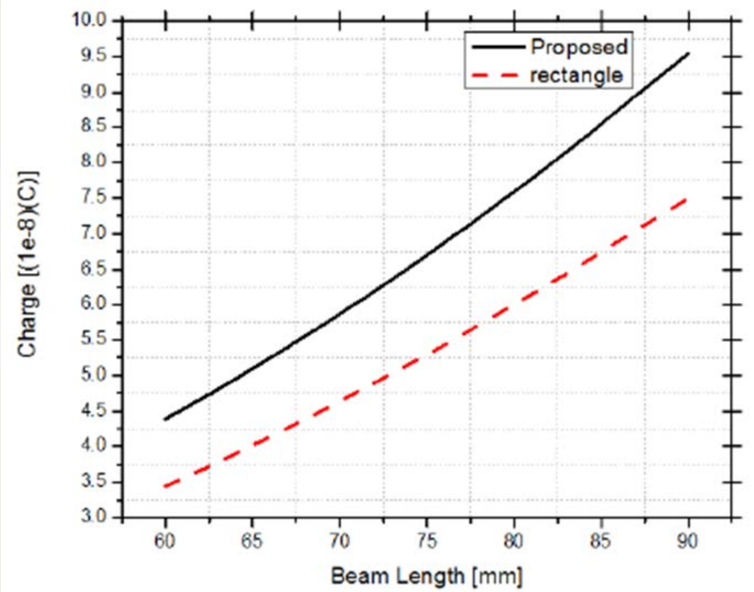
Simulation Results

- **Stationary Analysis**

Increasing the beam length and width increases the total charge.



The generated charge versus beam width at L=75mm , t_p=0.4mm

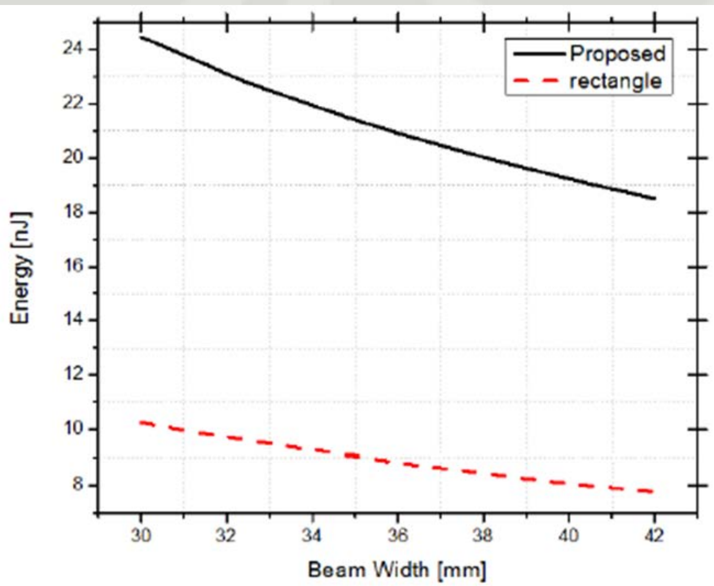


The generated charge versus beam length at W=36mm , t_p=0.4mm

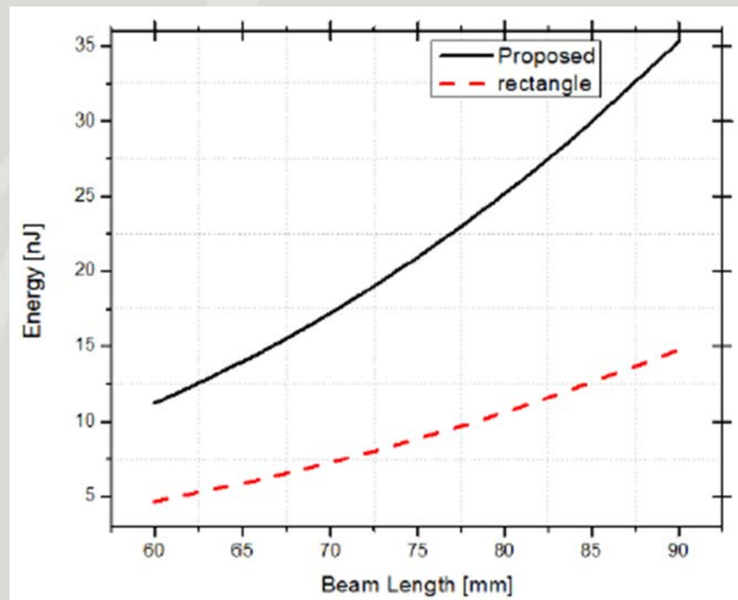
Simulation Results

- **Stationary Analysis**

The total stored energy was calculated using this equation $E = \frac{1}{2} QV$



Energy versus beam width at L**=75mm ,** t_p**=0.4mm**



Energy versus beam length at W**=36mm ,** t_p**=0.4mm**

Thank You