# Design and Simulation of Various Shapes of Cantilever for Piezoelectric Power Generator by Using Comsol

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**Abstract:** The environs vibration-based Micro electromechanical systems (MEMS) piezoelectric harvester provides a green and virtually infinite alternative power source over traditional energy sources. Here we are using the application in power generator by the help of Micro electromechanical systems (MEMS) which can be refer to devices that have characteristic length of less than 1 mm but more than 1 micron, that combine electrical and mechanical components. By using the structural mechanics module of Comsol Multiphysics 4.4, we make the various geometries of the cantilever beam in order to compare displacement and electric potential and hence to calculate the generated power. A layer of piezoelectric material (PZT-5H) is added to the cantilever of specified thickness 0.5 µm and base material as silicon of thickness 1.5 µm and using the piezoelectric devices module of Comsol Multiphysics. The prototype of E shaped cantilever shows greatest deflection of 0.6078 µm and the power as 49.05 µW, whereas the T and pie shaped cantilever gives a less piezoelectric voltage of 0.0386 V and 0.0426 V with displacement of 0.5288 µm and 0.3517 µm respectively and the power which generated is as 29.2 µW and 36.29 µW.

**Keywords:** Micro electromechanical systems (MEMS), Energy harvester, Cantilever.

## 1. Introduction

The ambient vibrations can be of great promise for harvesting energy initially at small scale to use for micro and nano scale devices. Such vibrations converted to electrical energy by piezoelectric transducer due to their major significance. Various research journals have introduced the phenomenon of energy optimization to increase the generated power and used directly for application like sensors or storage devices. The energy can be available in various forms like vibration, light, temperature gradient energy harvester does not require an external energy source and compatible with MEMS technology. Piezoelectric material shows the piezoelectric effect which says that a change in electrical charge will be there if the material is strained. Such material give high potential as compared to other hence can be a choice to work on. We have selected piezoelectric material as compared to the other material because it has high piezoelectric coefficient. So power requirement of micro devices like as of wireless sensors or storage devices is less than the 100 microwatt and that can be accomplished by the help of the designs mentioned in this paper [10]. Piezoelectric as a power generators are mostly used because these materials have the advantage of large power and ease of application. This paper represents the analysis and simulated MEMS based piezoelectric cantilever beams as the geometry of the shape designed will have effect on the produced vibration [9]. We proposed the various piezoelectric cantilever beams (T, pi, E) using the Structural mechanics module in COMSOL Multiphysics to convert mechanical energy into electrical energy. This electrical energy can be used as an alternative power source for portable electronics. We compared their properties by changing the various materials and then chosen the one with well defined outcomes at lower commercial values along with ease of availability as described in the later sections.

## 2. Design Parameters

### 2.1 Geometry

E shaped cantilever is a beam anchored at only one end and having greater length as compare to its width and thickness. In this research paper we prescribed the equations to understand the behavior and geometry of E shape cantilever as shown in figure1.

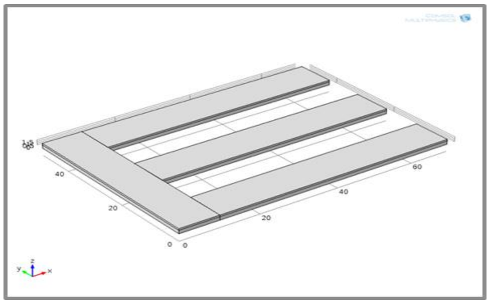

Figure 1: Geometry of E shaped cantilever

To calculate the deflection in the cantilever beam is described in equation 1, which is also known to be as Stoney’s formula. As it relates cantilever end deflection ‘δ’ to applied stress ‘σ’.

$$\partial = \frac{3\sigma(1-V)}{E}\frac{L^2}{t^2} \qquad (1)$$

Where ‘v’ 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. The cantilever spring constant ‘k’ relates to the cantilever dimensions and material constants are given by:

$$k = \frac{F}{\delta} = \frac{Ewt^3}{4L^3\,k} \qquad (2)$$

Where ‘F’ is the applied force and ‘δ’ is the applied stress, E is young modulus, ‘t’ is the thickness of the cantilever beam, ‘L’ is the total length, ‘w’ is the width and ‘k’ is the rotational stiffness. The movement of the cantilever is effected by its length, width, thickness and various properties of the material used to make the structure. The geometric shape, as well as the material used to build the cantilever determines the cantilever’s stiffness. The mechanical and electrical behaviour can be modeled by two constitutive equations.

$$S = s_E.T + d^t.E \qquad (3)$$

$$D = d.T + \epsilon_T.E \qquad (4)$$

Where, piezoelectric material's stress (**T**), strain (**S**), charge-density displacement (**D**), and electric field (**E**) interact. The matrix **d** contains the piezoelectric coefficients for the material, and it appears twice in the constitutive equation (the superscript *t* stands for matrix-transpose. The power is calculated from equation 5.

$$P_{ave} = {V^2}/{R_{load}} \qquad (5)$$

Where ‘$P_{ave}$’ is the average power generated and ‘V’ is the electric potential found via the simulation of the cantilever beams and $R_{load}$ is the resistive load or impedance [11].

## 3. Use of COMSOL Multiphysics

### 3.1 Energy Harvesting Model

Cantilever beam consists of two layers, base layer as silicon and upper layer is made up of PZT-5H material. The one end of the beam is fixed and another end is suspended freely. When the beam gets the force [2] from the produced vibrations the cantilever will deflect in up and down direction. This mechanical energy of the beam will get converted into electrical energy by the process shown in Figure 2.

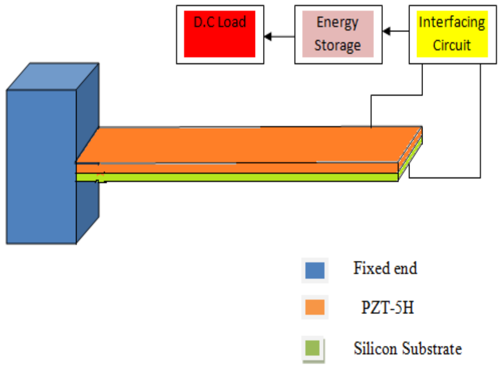

**Figure 2**: Model of energy harvesting system

It includes an external energy source that is force produced from the various vibrations in the studied environment. The interfacing circuit includes a transducer to convert mechanical energy produced as a result of deflection from cantilever beam to electric power and also consists of harvesting circuit which is used to optimize the harvesting efficiency [3]. At the end a storage battery or a load circuit has been used in order to store the harvested energy. Much research has been focused on harvesting electric power from the different body parts like finger tapping and motion produced by walking. Figure

3 describes the flow chart about the steps involved in the designing of cantilever geometry. All the mentioned steps will be explicated in detail in the upcoming sections.

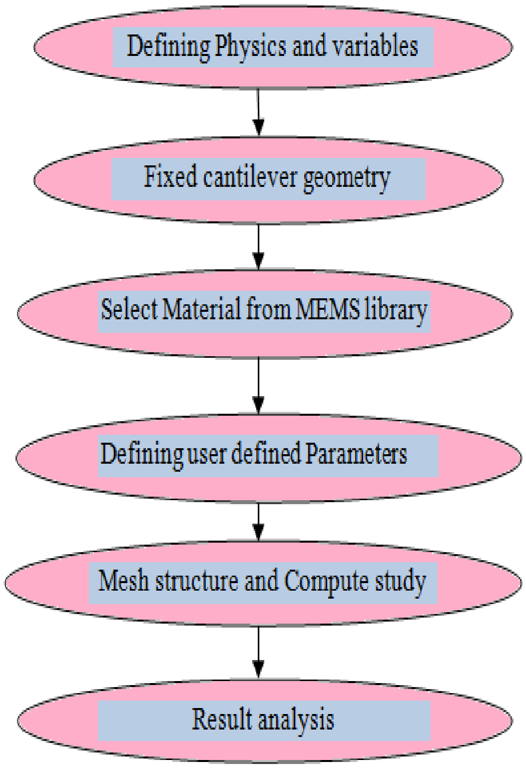

**Figure 3**: Modeling Process steps for energy harvesting system

### 3.2 Materials Properties

Five materials have been used in this design such as lead zirconium titanate (PZT-5H), Zinc oxide (ZnO), Aluminium nitride (AlN), Barium titanate (BaTiO$_3$), Silicon (Si). The bottom layer and top layer are made up of Silicon and piezoelectric material respectively. Some materials were already defined previously can be found in the materials database folder of the program, where as some materials could be filled by the users. Two focused materials which have been used throughout all processes namely, PZT-5H [4] and Silicon though their significant properties are described in Table1.

**Table1**: Material properties

| **Material Properties** | **Material used in cantilever** | | | | |
|---|---|---|---|---|---|
| | **PZT -5H** | **ZnO** | **AlN** | **BaTiO$_3$** | **Si** |
| **Young's Modulus (GPa)** | 63 | 170 | 344 | 67 | 165 |
| **Density (kg/m$^{3}$)** | 7500 | 5606 | 3260 | 5800 | 2330 |
| **Poisons Ratio** | 0.31 | 0.30 | 0.22 | 0.36 | 0.3 |

### 3.3 Simulation Setup

Comsol Multiphysics a finite element method (FEM) based partial differential equation (PDE) solver is used to simulate our devices. The geometries consist of silicon cantilevers with a layer on top as the piezoelectric layer with their specific device dimensions are shown in table 2. The length of the cantilevers is fixed as 60 µm and the width is fixed at 10 µm. We have taken a Si layer of thickness 1.5 µm and an upper layer of thickness 0.5 µm.

**Table 2**: Device specification

| **Layer** | **Length (µm)** | **Width (µm)** | **Thickness (µm)** |
|---|---|---|---|
| **Silicon** | **60** | **10** | **1.5** |
| **PZT-5H** | **60** | **10** | **0.5** |

We used the structural mechanics module of Comsol Multiphysics to simulate the mechanical domains and the piezoelectric devices module to simulate the piezoelectric properties of the PZT-5H layer [5]. In this we study four geometries namely conventional pi shaped cantilever, T shaped cantilever and finally an E shaped cantilever. One of the cantilever ends is assigned a fixed boundary condition and the other ends are given a free boundary condition. We keep the bottom of the piezoelectric layer as ground and assign a floating potential condition to the top surface of the piezoelectric layer. A constant force of 0.5 µN is applied on all the cantilevers.

## 4. Result and Discussion

In the figure 4(a), 4(b) and so far up to 6(b) depicts the result related the displacement and generated piezoelectric voltages for various geometries simulated. As per theoretical criteria, we observed an increase in deflection with a decrease and hike in electric potential which leads to the increase in the generated power [6]. The E shape from the all other traditional geometries will have maximum displacement. It is well in case of PZT-5H but not of same extremity with other materials, as explicated in the material section. The force for simulation of various geometries will kept the same in all cases but provide us with different values. [7]. The displacement and generated piezoelectric voltage and the generated power of different geometries has been compared in Table 3 on the basis of simulated geometries in the Comsol Multiphysics. From the following comparison we can lead towards the best suited geometry for the harvesting application which gives us the maximum power at the generator end as discussed in the later section [8].

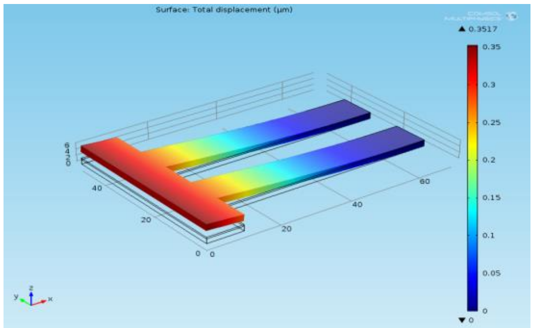

**Figure 4(a)** Displacement of pi shaped Cantilever

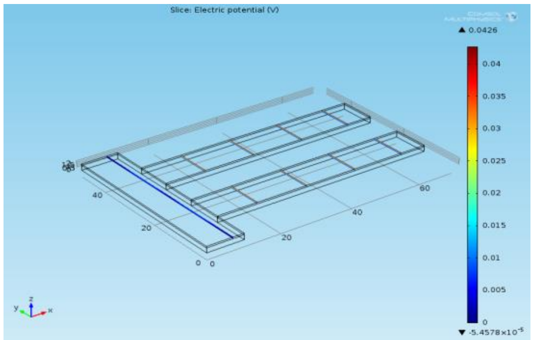

**Figure 4(b)** Generated piezoelectric voltage in pi shaped cantilever.

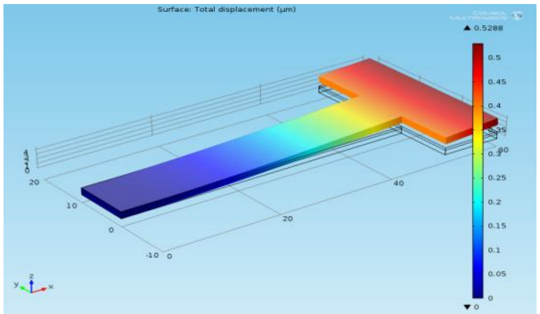

**Figure 5(a)** Displacement of T shaped Cantilever

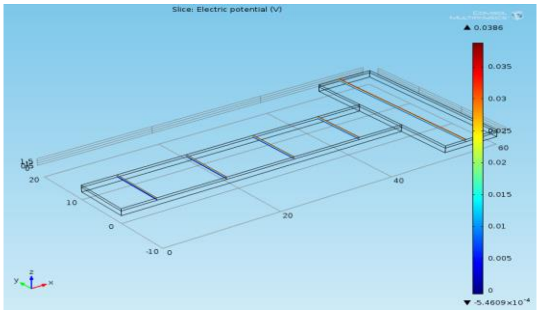

**Figure5 (b)** Generated piezoelectric voltage in T shaped cantilever

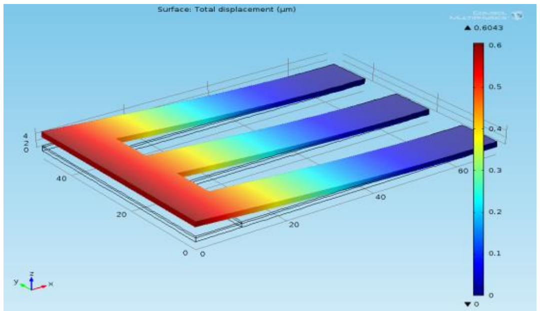

**Figure 6(a)** Displacement of E shaped Cantilever

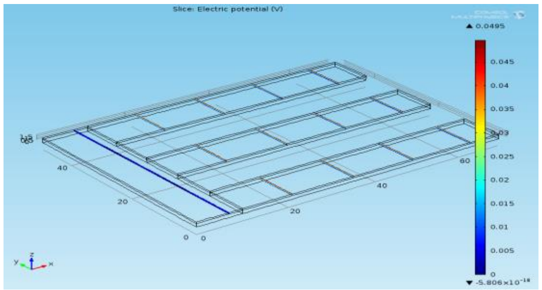

**Figure 6 (b)** Generated piezoelectric voltages in E shaped Cantilever

**Table 3**: Comparison of deflection, generated piezoelectric voltages and power for various geometries

| Geometry | Displacement (µm) | Piezoelectric Voltage (V) | Power Generated (µW) |
|---|---|---|---|
| **II shaped** | 0.3517 | 0.0426 | 36.29 |
| **E shaped** | 0.6078 | 0.0495 | 49.05 |
| **T shaped** | 0.5288 | 0.0386 | 29.2 |

The various geometries of the cantilever beam has been simulated in order to compare displacement and electric potential and hence to calculate the generated power. A layer of piezoelectric material (PZT-5H) is added to the cantilever of specified thickness 0.5 µm and base material as silicon of thickness 1.5 µm by using the piezoelectric devices module of Comsol Multiphysics. The prototype of E shaped cantilever shows greatest deflection of 0.6078 µm and the power as 49.05 µW, whereas the T and pie shaped cantilever gives a less piezoelectric voltage of 0.0386 V and 0.0426 V with displacement of 0.5288 µm and 0.3517 µm respectively and the power which is generated as 29.2 µW and 36.29 µW. Hence we can say that all the designed shapes with PZT-5H shows ambient deflection but out of them E shaped cantilever shows best deflection of 0.6078 µm and generates the maximum amount of power which is 49.05 µW, it is maximum as compare to the rest of the two geometries. So, E shaped beam can be best implemented in energy harvesting devices and proven to be the best mean of power generation for the Micro and nanodevices.

## 5. Conclusion

A huge part of the world economy in terms of money lost as a waste heat from industrial processes and many other sources, with the help of the vibrations sense by the various designed cantilever beams can be converted into electricity. The various shapes discussed above can be the best source of energy harvesting. It can be of great promise for the future of the upcoming generation by developing such MEMS based smart devices which can be used for the micro scale as well on the major scale if the durability and efficiency will seems well after fabrication of the designs as mentioned in the paper.

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## 7. Acknowledgements

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