Design and Simulation of Microcantilever Based Piezoelectric Energy Harvesters of Various Shapes Using COMSOL Multiphysics®

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Introduction: Energy harvesting is an emerging area of research where wasted ambient energy is converted into useful electrical power thus providing a promising solution to the environmental and replacement issues associated with battery powered systems The recent advancement of microfabrication technology has led to increasing interest in developing micro-energy harvesters in the form of MEMS (Micro Electro-Mechanical Systems) devices.

Problem: Various cantilever geometries (conventional rectangular, pi, T and triangular) are simulated using the structural mechanics module of Comsol Multiphysics to compare their spring constants. A layer of piezoelectric material (ZnO, AlN and PZT are modelled) is added to the cantilever and using the piezoelectric devices module of Comsol Multiphysics, we determine the piezoelectric voltage that is generated in each of these cases.

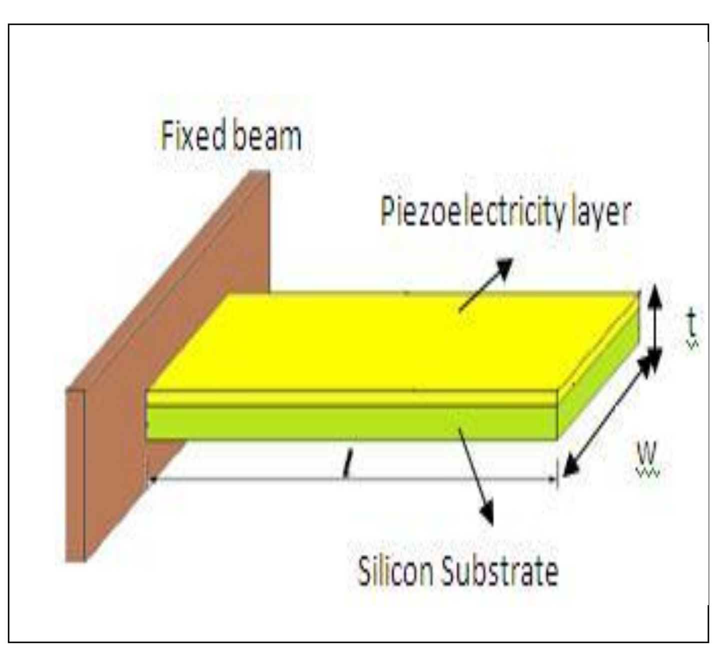

Figure 1: Device Structure

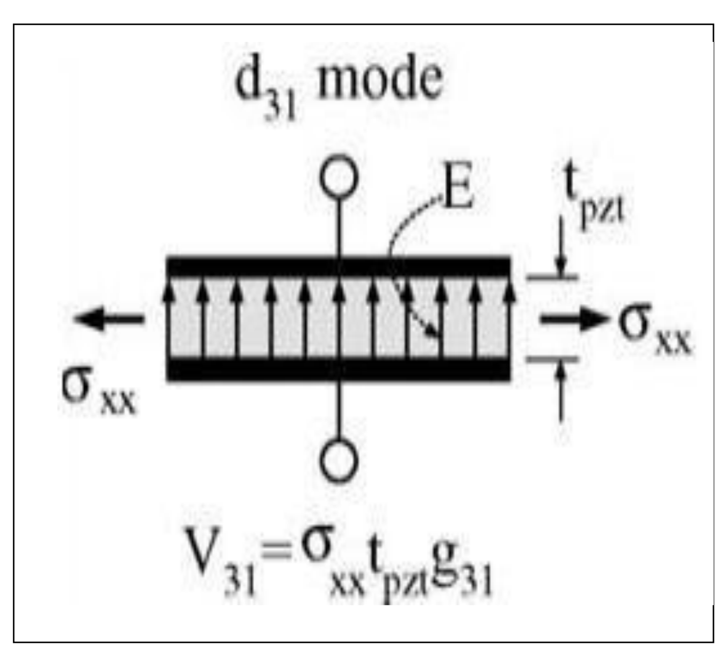

Figure 2: d31 mode

Theory: A cantilever (figure 1) consists of a beam fixed at one end and free at the other. Two equations are commonly used to analyze a cantilever. The first one is Stoney's formula which relates the cantilever deflection (δ) to the applied stress (σ)

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

Where, v is Poisson's ration, E is the Young's modulus, L is the length of the cantilever and t is the thickness.

The second equation relates cantilever spring constant k to the applied force

$$k = \frac{E}{\delta}$$

For a conventional rectangular geometry cantilever, the expression for spring constant is given by

$$k = \frac{Ew}{4}\left(\frac{t}{L}\right)^3$$

Where, E is Young's modulus, w is the width of the cantilever, t is the thickness and L is the length.

There are various modes in which we can operate a piezoelectric device for energy harvesting. Here, we consider the most common one, the d31 mode where the applied stress and generated voltage are perpendicular to each other (figure 2).

The voltage generated in d31 is given by

$$V_{31} = \sigma_{xx} t_{pzt} g_{31}$$

where V31 is the open circuit voltage, σxx is the stress, tPzt is the thickness of the piezoelectric layer and g31 is the piezoelectric constant.

Use of Comsol Multiphysics: Our structure (figure 1) consists of silicon cantilevers with a piezoelectric layer on top. The length of the cantilevers is fixed at 60 µm and the width is fixed at 10µm. We have taken a Si layer of thickness 1.5 µm and a piezoelectric layer of thickness 0.5 µm.

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 piezoelectric layer. In this study, we study four geometries namely, conventional rectangular cantilever, pi shaped cantilever, T shaped cantilever and finally a triangular cantilever. Properties of Si and the piezoelectric layer (ZnO, AlN and PZT are modeled) are taken from the Comsol material library.

We have plotted the resultant displacement (figure 3) and stress generated (figure 4) for various geometries.

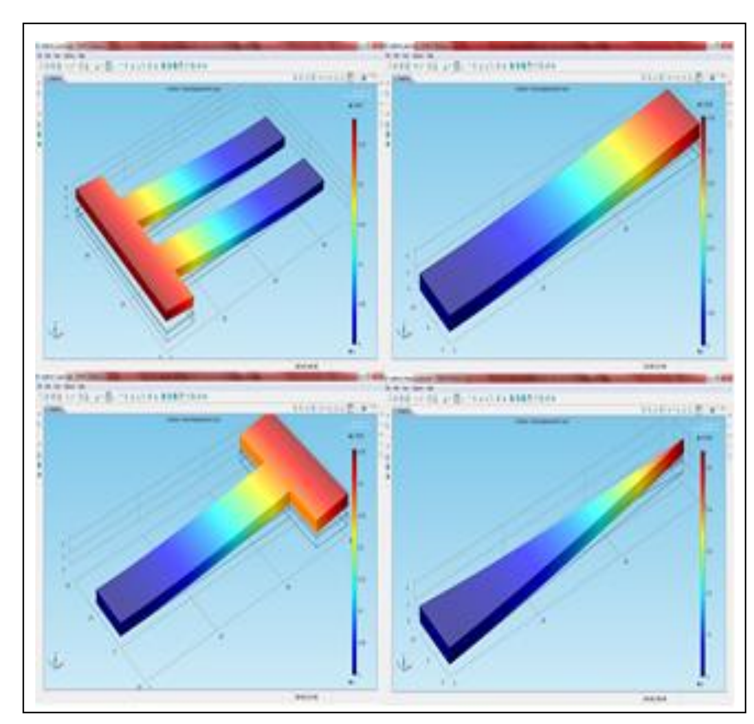

Figure 3: Displacement of various cantilevers

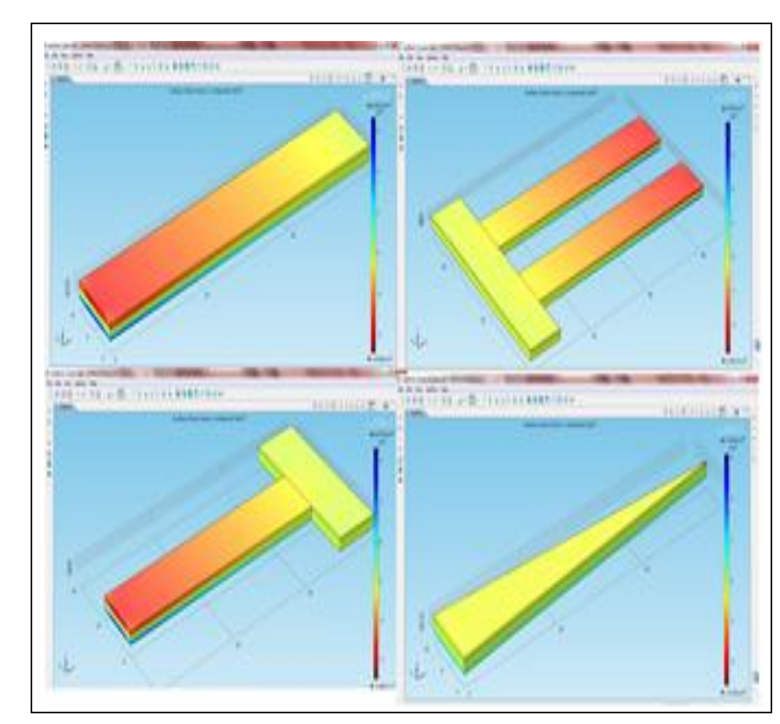

Figure 4: Stress generated in the piezoelectric layer for various cantilever geometries

Table 1: ZnO piezo layer

Geometry	Displacement (µm)	Spring Constant k	Stress (Nm^{-2})	Voltage (V)
Rectangular	0.3532	1.415	6.75e7	0.4287
Pi	0.2817	1.774	3.65e7	0.2095
T	0.3535	1.414	6.14e7	0.3279
Triangular	**0.5392**	**0.927**	**2.41e8**	**0.8519**

Table 2: AlN piezo layer

Geometry	Displacement (µm)	Spring Constant k	Stress (Nm^{-2})	Voltage (V)
Rectangular	0.4115	1.215	4.09e7	0.1112
Pi	0.3287	1.521	2.83e7	0.0542
T	0.4133	1.209	4.96e7	0.0848
Triangular	**0.6268**	**0.797**	**2.57e8**	**0.7497**

Table 3: PZT piezo layer

Geometry	Displacement (µm)	Spring Constant k	Stress (Nm^{-2})	Voltage (V)
Rectangular	0.2323	2.152	-7.18e7	0.2024
Pi	0.185	2.702	-4.07e7	0.0996
T	0.2322	2.153	-6.97e7	0.1561
Triangular	**0.3541**	**1.412**	**-2.73e8**	**0.4034**

Results: We observe that the pi geometry has a greater stiffness and spring constant as compared to the conventional cantilever. T and triangular geometries have lower stiffness and spring constant as compared to conventional cantilevers. Thus we observe a greater deflection in the triangular and T shaped cantilevers as compared to the conventional cantilever. The greater deflection results in a greater stress and strain in the piezoelectric layer resulting in greater generated piezoelectric voltage. Our results for various piezoelectric layers are summarised in tables 1-3.Thus we observe that the triangular is most suitable for piezoelectric based energy harvesting cantilevers followed by T shaped cantilevers.

References:

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