

Simulation of Piezoelectric Nanofibers for Harvesting Energy Applications

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Abstract: Energy Harvesters are the devices that convert mechanical energy which is the vibration to electrical one. These systems are very promising, they may, for example, provide an essential energy in remote or inaccessible locations and even within the human body.

Energy harvesters provide a very small amount of power for low-energy electronics

In this work, we have taken a model which is simulated using COMSOL Multiphysics. It was used as a tool to design, characterize and to simulate an example which is nanofibers based piezoelectric energy generators. The results are compared with other available sources but using with another material.

The nanogenerator device consists of piezoelectric nanofibers which are deposited on the interdigitated electrodes of copper fine wires, which were assembled on a silicon substrate. Selected material of piezoelectric nanofibers is Lead Zirconate Titanate (PZT 5H) because of good benefit especially when it offers high sensitivity and good response. A soft and polymer Polyethylene high density (PEHD) was applied on top of the PZT nanofibers.

After applying a pressure on the top of nanogenerator, the output parameters (voltage and Strain) are studied according to the input one (frequency).

Keywords: piezoelectric, nanofibers, harvesting energy, Comsol multiphysics.

1. Introduction

Nowadays, Ferroelectric materials that form an important class of piezoelectric materials have become more and more used in many electronic applications such as: transducers [1], sensors [2], actuators [3] and energy harvesting [4]. In fact, they possess a spontaneous electrical polarization area that generates mechanical deformations. The coupling between the polarization and modulation of the deformation of the system due to the piezoelectricity in ferroelectric materials is characterized by significant changes in

polarization (or deformed) when a mechanical stress is applied to them (or electric field) and ferroelectrics have the strongest piezoelectric coefficients. Piezoelectric materials have the property of producing electrical charge when they strained which called direct piezoelectric effect that is the first effect. And the second one is converse piezoelectric effect where these materials undergo deformation when we applied an electric field. This property of piezoelectric materials is used in converting vibrational energy to electrical energy which may be stored [5].

During the last decade, one dimension nanomaterials such as: nanotubes [6], nanoribbons [7] and nanofibers [8], have attracted great attention because of their improved properties and potential applications in nanoscale devices [9]. The miniaturization of the sizes has been engineered the energy harvesting technologies. Energy harvesting is defined as capturing minute amounts of energy from one or more of the surrounding energy sources, accumulating them and storing them for later use. Energy harvesting is also called as power harvesting or energy scavenging.

2. Piezoelectric nanofibers structure

The nanofibers are constructed by the electrospinning [10] process using piezoelectric materials which are PZT and PVDF (Polyvinylidene fluoride), that have been demonstrated on [11]. After constructing the piezoelectric nanofibers, they deposited on the prepared interdigitated electrodes which were deposited on a silicon substrate (Figure 1) [12].

In this study, by replacing the PVDF, a soft and polymer PEHD was applied on top of the nanofibers.

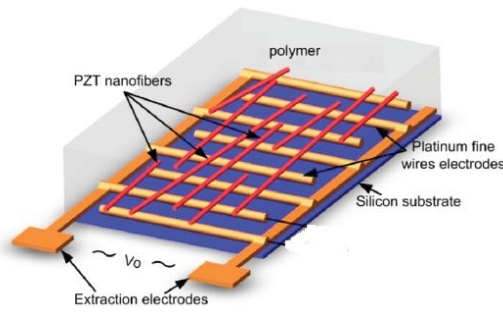


Figure 1. Schematic view of the model used of the PZT nanofibers generator.

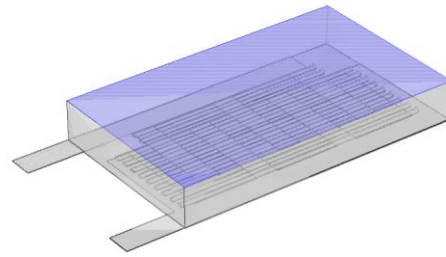


Figure 2. Schematic view of the model using Comsol multiphysics.

2.1 Constitutive equations

ΔV [11] is the potential generated from the PZT nanofibers between the interdigitated electrodes, is shown in the following equation:

$$\Delta V = \int G_{33} E_p / E_{11} (S_{xx} - S_{yy} * \nu - S_{zz} * \nu) dl$$

Table 1: Symbols of the equation

G_{33}	Piezoelectric voltage constant
E_p	Modulus of PZT nanofibers
E_{11}	Longitudinal modulus
S_{xx}	Stress along the direction x
S_{yy}	Stress along the direction y
S_{zz}	Stress along the direction z
l	length of the nanofibers
ν	Poisson's ratio

In this work, we apply the pressure on top of the piezoelectric nanofibers and we try to compare it using an electrical field.

3. COMSOL Multiphysics

In this work, Comsol Multiphysics is used as a tool to design our structure and extract the output parameters which are the voltage gain and the strain according to the input one (frequency). For simulating the piezoelectric nanofibers in Comsol, the "piezoelectric devices (pzd)" and "Electrical circuit" under structural mechanics are used. The type of study required for a frequency sweep is "Frequency domain".

3.1 Model simplification

The model chosen in this study is used with the component 3D. Figure 2 is the schematic view of our model.

The dimension of each part of our structure is given by the table 2.

Table 2: dimensions of the structure

Silicon substrate	L= 0.005 mm (length) H=0.003 mm (width) e= 10^{-5} mm (thickness)
Nanofibers	r= 50 nm (radius of nanofiber) l= 4.5 μ m (length of nanofiber)
The Polymer rectangular	L _p = 5 μ m (length) H _p =3 μ m (width) e _p = 0.7 μ m (thickness)

3.2 Material parameters

The piezoelectric material parameters of the nanofibers are derived from PZT 5H (Lead Zirconate Titanate) which are shown as following [13].

Table 3: Piezoelectric material parameters of PZT-5H

Density ρ (Kg/m ³)	7500
Piezoelectric coupling d (*10 ⁻¹² C/N)	$\begin{pmatrix} 0 & 0 & 0 & 0 & 741 & 0 \\ 0 & 0 & 0 & 741 & 0 & 0 \\ -247 & -247 & 593 & 0 & 0 & 0 \end{pmatrix}$

Compliance S_E (*10 ⁻¹²) m ² /N)	16.5	-4.78	-8.45	0	0	0
	-4.78	16.5	-8.45	0	0	0
	-8.45	-8.45	20.7	0	0	0
	0	0	0	43.5	0	0
	0	0	0	0	43.5	0
	0	0	0	0	0	42.6

In this work, we have chosen the copper for electrodes where we extract the voltage. The PEHD was applied to the top of piezoelectric nanofibers.

Table 4: PEHD material parameters.

Density ρ (Kg/m ³)	960
Relative permittivity ϵ_r	2.25
Poisson's ratio	0.46

The table 4 shows the material PEHD parameters which is extracted from [14].

3.3 Polarizations

Before having the deformation and the voltage gain, we should apply a pressure on the surface of the polymer.

The value of the pressure is about 50 N/m². We define it using the “Boundary load” system in the Piezoelectric Devices PZD.

3.4 Electrode boundary conditions

To simulate and extract the voltage gain, we must connect the electrodes together by using the “Floating potential” for the high face of this one. The ground (GND) electrodes are set by the “Ground” condition under the face. In the floating potential selection, we modified the electric charge to “circuit”.

3.5 Mesh

The model is meshed with physics controlled mesh and element size extra coarse. The meshed model looks as follows:

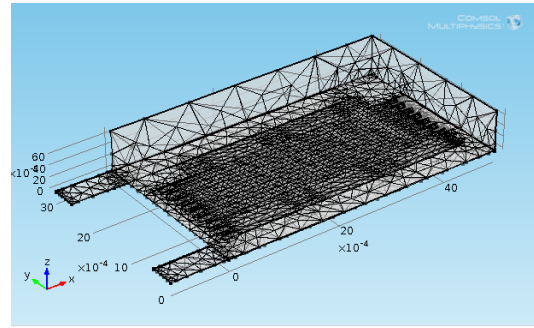


Figure 3. Meshed model

4. Results

This work is performed in the frequency domain, and the results are shown on figure 4 and 5.

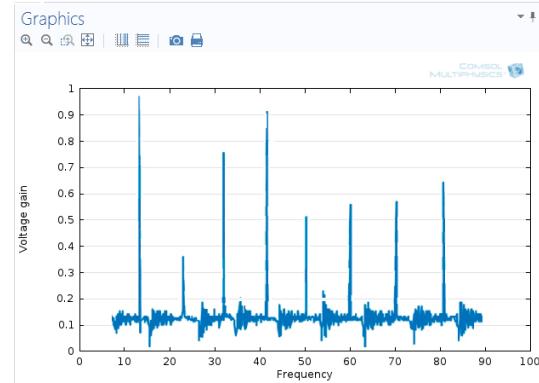


Figure 4. Output voltage from piezoelectric nanofibers

The output voltage was measured when a pressure $p=50\text{N/m}^2$ is applied, we can see the resonance plot with different frequencies and with a high number of voltage.

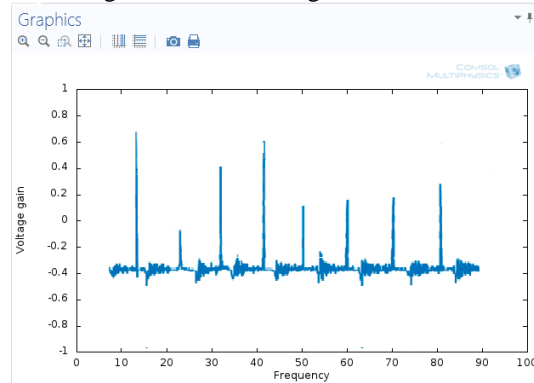


Figure 5. Output voltage by decreasing the value of the pressure to 10N/m²

When we increase the value to 10 N/m^2 , we see that the resonance plot increases too and the value of the output voltage increases.

5. Conclusions

The piezoelectric nanofibers are simulated using Comsol Multiphysics software, which is very useful for this study.

After the simulation, we have tried to compare the results with other available experimental works but using with another materials. The output voltage from piezoelectric nanofibers generators were measured when we have applied the pressure to the top of the generator, it was very high compared against the experimental.

We have demonstrated a piezoelectric nanogenerator based on lead zircon ate titan ate nanofibers that the piezoelectric voltage is high and powerful for energy harvesting.

6. References

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