



Design of flexible Substrate based energy harvester for sensor nodes

Neha S Kadam¹, Prof. Suyog.S. Hirve²

^{1,2} Department of Electrical Engineering,
BVDUCOE, ,Pune, India

¹nehakadam1194@rediffmail.com , ²sshirve@bvucoep.edu.in

June 8, 2018

Abstract

"Energy saved is energy produced" this quote holds true in present day scenario of energy crisis. The potential is there to save the energy but it needs a dedicated approach and effective planning. Advent of Nano technology and advancement of material science one such potential area of energy saving is the wireless sensor network. Some materials exhibit the properties of piezoelectricity which is the charge that is collected in certain solid material in response to a given mechanical tension. A piezoelectric material generates visible piezoelectric energy when there uniform structure is deformed by about 0.2% of the original structure. The presented work tries to harness this property of piezoelectric material and analyzing the performance of piezoelectric energy harvester. The piezoelectric material which is used in the work is zinc oxide (ZnO), Copper (Cu) is used as electrode material which captures the charge generated & polyethylene terephthalate (PET) is used for cantilever structure. Two types of cantilever structure are studied in the work namely uni-morph & Bi-morph respectively. Eigen frequency analysis is done to get the resonance frequency for proposed energy harvester by using Comsol multi physics software. Comsol multi physics model is used to provide the readings on the Eigen frequency, resonance frequency,

tension and voltage output of all energy harvester based on piezoelectricity. The results were formulated in form of graph for clear understanding of effects of various parameters.

Key Words: Piezoelectric, Eigen frequency, Resonance Frequency, Cantilevers

1 INTRODUCTION

The human civilization is obsessed with the future prediction. Efforts have been implemented to predict a happening in its most accurate way. A simple example is the prediction of rainfall and its impact on agriculture. A prediction depends on the accuracy and interconnection of data. Wireless sensor networks measure environmental condition like temperature, sound, pollution level etc. Remote Sensor Network are an rising technology with lots of potential applications and opportunities. A significant amount of nodes with sensing and wireless communications capabilities, deployed in an area of interest, build a wireless sensor network. With the advent of Micro Electronics Mechanical Systems there is now possibility to realize tiny and cost effective devices, capable of wireless communication [10]. WSNs can be differentiated from other technologies because of a set of distinct requirements and unique feature, including for density, energy requirements, and computational capabilities. A renowned engineering body has classified the network technologies by characteristics. Usually the WSNs are has a data limit of 2Mbps of data rate and 1.5 km of wireless coverage. When it comes application part of wireless sensor networks 4 broad areas are covered by these networks namely area surveillance, health care, atmospheric sensing & industrial monitoring.

All wireless sensor networks primarily run on batteries. Batteries have a limited life cycle and other technological constraints. In wireless sensor networks (WSNs), demand of distinct applications and modest energy storage efficiency of sensor nodes makes it obligatory to increase sensor lifetime, circuit and protocols has to be energy efficient strategy has to be implemented. Energy harvesting from environmental vibrations provides a great solution for powering the energy to small-scale electronic devices. The presented work demonstrates the piezoelectric efficiency of some metal

substrate that can be used as source of harvesting energy for remote sensor networks. It is a process of converting environmental vibrational energy into electrical energy. The idea is to keep these metal substrate flexible so that they can be used in any environment and to adjust in extreme condition. Piezoelectricity as an electric charge that is collected in certain solid materials. For the presented work Zinc Oxide (ZnO) is used as piezoelectric material, Copper (Cu) act as a electrode which store the charge, polyethylene terephthalate is used as cantilever structure. The frequency domain analysis study is used to enumerate the reaction of a linear or liberalized model subjected to harmonic excitation for one or several frequencies. energy harvester simulation has been done in COMSOL Multiphysics tool. Analysis of frequency is conducted within the restricted condition to achieve the resonance frequency for proposed energy harvester.

Cantilever design is commonly used piezoelectric energy harvesters, in particular for vibrational forces, as greater mechanical tension can be produced, and construction of piezoelectric cantilevers is relatively easy [4]. a greater number of the piezoelectric energy devices used for harvesting uses a uni-morph or bi-morph cantilever design. In the presented work simulation of Uni-morph and Bi-morph structure is made in COMSOL Multiphysics model. The PET (polyethylene terephthalate) is used as cantilever which creates the mechanical stress due to vibration and when the mechanical stress is provided through vibration in cantilever structure, zinc oxide the piezoelectric material generates electric charge in the process which is stored in copper electrodes.

2 Comparison and Results

Unimorph Piezoelectric Energy Harvester



Fig.1. Unimorph Cantilever

A lean piezoelectric structure can be constructed into a cantilever, fixing it with a non-piezoelectric layer usually a metal act-

ing as a conductor of the generated charge, Such a configuration is called a "unimorph" as only one active layer the piezoelectric layer is used in this structure.

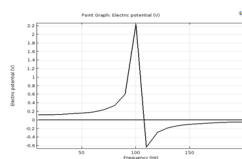


Fig.2. Electric Potential with maximum value of 2.4 V for uni-morph structure

For a uni-morph structure electric potential of 2.4 V was observed at resonance frequency 100 Hz.

Since we are using cantilevers for our demonstration von mises stress test was conducted to check whether cantilever will withstand for given load condition.

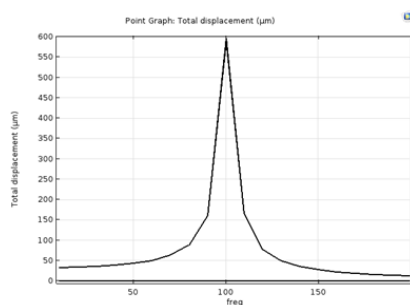


Fig.3.Total Displacement with Frequency

As in fig.3. shows total displacement 600 m was observed at a resonance frequency 100 Hz. On the tip of cantilever we obtained maximum displacement.

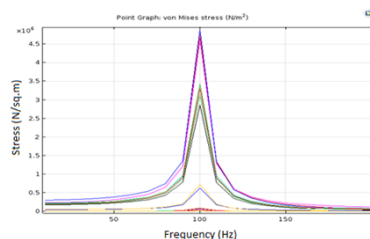


Fig.4. Von Mises graph for Uni-Morph structure

For PET material yield stress value is 5 Mpa against maximum value Von Mises Stress is of 4.5 Mpa.

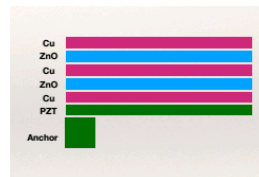


Fig.5. Bimorph Cantilever

A cantilever can also be made by creating two lean layers of piezoelectric structure into the same metal layer to increase the power output of the unit, it is called a bimorph structure as two active layers are used. Bi-morph structure possesses the capability of increasing the output of the energy harvester in spite of any considerable rise in the device volume.

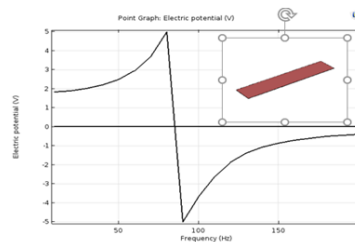


Fig.6. Electric Potential with maximum value of 5 V for Bi-morph structure

As in fig.7 shows total displacement 600 μm was observed at a resonance frequency 100 Hz. On the tip of cantilever we obtained maximum displacement.

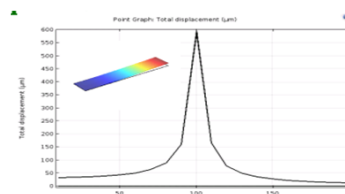
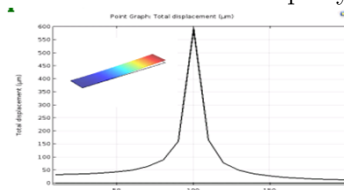


Fig.8. Von Mises graph for Bi-Morph structure

For PET material yield stress value is 1.6 Mpa against maximum value Von Mises Stress is of 1.4 Mpa.

The metal substrate are used as cantilevers in the presented work. Two types of structure was used in the presented work namely uni-morph and Bi-morph. In uni-morph structure one layer of substrate was piezoelectric layer and the other one was a non-piezoelectric layer while in case of Bi-Morph structure the metallic layer is sandwiched between two piezoelectric layers.

Table 1. Material Property



The piezoelectric material have defined parameters. stress T_p as input, the strain coefficient d_{ip} gives the relationship between the applied stress and the electric induction Di (therefore, current density is $\int_p = dD/dt$), while the voltage coefficient g_{ip} gives the voltage Equation

$$V = T_p g_{ip} l$$

Table 2. Number of layers per electric potential

Properties	Material		
	ZnO	Cu	PZT
Young's Modulus (pa)	81×109	120×109	4×109
Density, Q ($Kg \cdot m^{-3}$)	5690	8970	1360
Poisson's Ratio	0.3	0.36	0.37

The comparison for uni-morph and bi-morph structure is presented in form of graph.

Particulars	Uni-Morph	Bi-Morph
Electric Potential	2.4 V	5.0 V
No. of layers	4	6

Fig 9. Frequency vs. Electric Potential comparison

3 Conclusion

Energy harvesting systems based on piezoelectric concept provides excellent solution of renewable source of power to supplement traditional batteries in sensor nodes. The great potential of remote sensor node has created a demand for harvesting energy from the surrounding environment for wireless devices. Wireless remote monitoring of mechanical structures and biomedical sensors are such energy harvesting applications where piezoelectric energy can be used. Energy harvesting through piezoelectric technique has provided a greater advantage over other techniques: Excellence power density and amenity of applications and efficiency to construct the piezoelectric material in order to capture the vibrating energy into distinct scales.

Acknowledgement The authors are thankful to Dr Gopal Gawande (hod_extc@ssgmce.ac.in) and Prof. M.L Bhaiyya (bhaiyya.manish@gmail.com) for there valuable suggestion in this presented work.

References

- [1] Roundy, S., Wright, P.K and Rabaey, J., A study of low level vibrations as apower source for wireless nodes,Computer Communications, Vol.26, pp.1131-1144,2003
- [2] Roundy, S. and Wright, P.K., A piezoelectric vibration based generator for wireless electronics, Smart Materials and structures,Vol 13, N0.%,pp.1131-1142,2004
- [3] Shen, D., Park,J.H., Noh,J.H., Choe,S.Y., Kim S.H., Wikle., H.C. and Kim,D.J., Micromachined PZT cantilever based on SOI structure for low frequency vibration energy harvesting, Sensors and actuators A:physical,Vol 154,No.1,pp.103-108,2009
- [4] Choi,W.J ., Jeon, Y., Jeong, J.H., Sood, R. and Kim S.G.,Energy harvesting MEMS device based on thin film piezoelectric cantilevers, Journal of Electroceramics,Vol.17,N0.2-4,pp.543-548,2006.

- [5] Xiaotong Gao,¹ Wei-Heng Shih,^{1,a} and Wan Y. Shih² Vibration energy harvesting using piezoelectric unimorph cantilevers with unequal piezoelectric and non-piezoelectric lengths Applied physics letters 97 233503,2010
- [6] He Qing a, Yan Zhen b, Fei Likai, Song Bo Modelling and analysis of piezoelectric vibrating generator of cantilever, Applied mechanics and materials vols, 148- 149, pp 1327-1330 ,2012
- [7] R.Ambrosio,A.Jimenez,J.Mireles,M.Moreno,K.Monfil & H.Heredia Study of piezoelectric energy harvesting based on PZT, Integrated Ferroelectrics,126:1,77- 86
- [8] Hu Cao ,V. Hugo Schmidt,Rui Zhang ,Wenwu Cao,Haosu Luo,Elastic, piezoelectric, and dielectric properties of 0.58Pb Mg $\frac{1}{3}$ Nb $\frac{2}{3}$ O $\frac{3}{2}$ -0.42PbTiO $\frac{3}{2}$ single crystal,Journal of applied physics,vol 96,No 1,July 2004.
- [9] Shashank Priya and Daniel J. Inman, Energy Harvesting Technologies, Springer Science & Business Media publication, chapters 1-4 & 6 , pp 3-16,21- 33, 107-126,165-192,2009
- [10] Toprak, A.,Tigli, O., Interdigitated-Electrode-Based MEMS-Scale Piezoelectric Energy Harvester Modeling and Optimization Using Finite Element Method,IEEE transaction on ultrasonic, ferroelectronics, and frequency control, vol.60, no. 10, October 2013.
- [11] Jamain,U.M., Ibrahim,N.H., Rahim, R.A,Performance Analysis of Zinc Oxide Piezoelectric MEMS Energy Harvester IEEE-ICSE2014.
- [12] Yi Chiu, Ming Hsuan Lee, Wei-Hung Hsu, Flexible Electret Energy Harvester with Copper Mesh Electrodes, Journal of Physics, IOP Publishing, Power MEMS, 2014.
- [13] Hong-JieTseng , Wei-Cheng Tian ^{2,3,4}, and Wen-Jong Wu Flexible PZT Thin Film Tactile Sensor for Biomedical Monitoring, SENSORS, ISSN, 2013.
- [14] Junjun Ding, Vinod R. Challa, M. G. Prasad and Frank T. Fishe, Vibration Energy Harvesting and Its Application

for Nano- and Microrobotics, Selected Topics in Micro/Nano-Robotics for Biomedical Applications chapter 5 New York, 2013.

- [15] Jiashi Yang, Member, IEEE, Ziguang Chen, and Yuntai Hu, An Exact Analysis of a Rectangular Plate Piezoelectric Generator, IEEE transactions on ultrasonics, ferroelectrics, and frequency control, vol. 54, no. 1, January 2007.

