Piezoelectric Energy Harvester Using MEMS Structures: A Review

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Abstract- *As the demand for wireless, miniature and low power devices are increasing day-by-day, so as the need for low cost, miniature size, very long lasting and environment-friendly sources of power is also increasing for implementing in those devices. Here, the Piezoelectric MEMS Energy Harvesters are fulfilling that need. In this paper, review works have been done on various Piezoelectric Materials and microstructures for energy harvesting applications. These materials are analyzed with a square shaped diaphragm which is subjected to a boundary load of 100 N/m^2. The simulations were done using ComsolMultiphysics software and the results for different materials were obtained in terms of output voltage. The study on results conclude that Rochelle Salt and Lithium Niobate are very useful materials for future energy harvesting applications. Some MEMS Structures were also reviewed and being presented here which can produce sufficient energy to power up such wireless devices.*

Keywords- Cantilever, COMSOL, MEMS, PEH, PZT, Energy

I. INTRODUCTION

Energy harvesting is the process of capturing the minutely available inexhaustible free energy from one or more naturally occurring energy sources such as thermal energy, mechanical energy, light energy and or electromagnetic energy etc. accumulating them and storing them for future use. Energy harvesting module is an electronic device that can perform all these functions to power a variety of sensors and control circuitry for intermittent duty applications. Until the recent development of modern high-end technologies, this process of capturing trace amounts of energy from the environment and converting it into electrical signals was not possible. Application of MEMS in energy harvesting has made a tremendous transformation in powering wireless sensor network systems such as ZigBee systems and wireless node deployed at a remote site where a wall plug or battery is unavailable or unreliable [1-3]. Multiple energy sources can be used to enhance the overall efficiency and reliability of any system[8,13].

Since MEMS structureslie in the range of µm to a few mm, implementing a power amplifier circuitry along with the energy generator is undesirable as it will increase the overall size of the device considerably. Therefore, it a hot topic for the researchers to find out which geometrical structure and which material will generate maximum power. This article is a review of various materials and or structures that have been implemented in MEMS structures for increasing the power efficiency of the energy harvester.

II. REVIEW WORK

This section discusses some research work carried out tilldate for enhancing the power efficiency of MEMS energy harvester.

A. Piezoelectric Material Selection

Piezoelectric materials are those which show the piezoelectric effect, which in essence, is the separation of charge within a material as a result of an applied strain. This charge separation effectively creates an electric field within the material and is known as the 'direct piezoelectric effect'. The 'converse piezoelectric effect' is the same process in reverse: the formation of stresses and strains in a material as a result of an applied electric field.

In recent years, energy harvesting using piezoelectric materials has become a very popular research topic. But it is difficult to compare power measurements as device fabrication and experimental methods vary from paper to paper. In an effort to standardize comparisons in spite of these changing parameters, the dependence of generator power output on various piezoelectric materials has been investigated.

After thoroughstudy,it is seen that PZT,ZnO,AlNand KNN-LS-CT are the most promising piezoelectric materials [1,5,7,28].

PZT material is often seen as the piezoelectric material in MEMS energy harvester. It has been reported to produce a maximum output voltage of 42mV[1-6], 0.4V[7-12] and 10.080V[13-18]. Moreover, the output voltage or power is decreased by a huge percentage with anincrease in input acceleration or temperature[20-25].

A comparative analysis is also done among all the piezoelectric materials available in COMSOL multiphysiscsby taking a basic square diaphragm sample (width=300µm x depth=300µm x height=50µm) with a boundary load of 100 N/m^2 on the surface and thefollowing result is observed:

Table 1: Comparison of Piezoelectric materials available in COMSOL Multiphysiscs

Sr. No.	Piezoelectric Materials	Output Voltage (in V)
1	Barium Sodium Niobate	0.0001910
2	Barium Titanate	0.0001590
3	Barium Titanate (poled)	0.0001400
4	Lithium Niobate	0.0011400
5	Lithium Tantalate	0.0005780
6	Lead ZirconateTitanate (PZT-2)	0.0004190
7	Lead ZirconateTitanate (PZT-4)	0.0003010
8	Lead ZirconateTitanate (PZT-4D)	0.0003020
9	Lead ZirconateTitanate (PZT-5A)	0.0003030
10	Lead ZirconateTitanate (PZT-5H)	0.0002170
11	Lead ZirconateTitanate (PZT-5J)	0.0002320
12	Lead ZirconateTitanate (PZT-7A)	0.0003790
13	Lead ZirconateTitanate (PZT-8)	0.0002350
14	Quartz	0.0006730
15	Rochelle Salt	0.0042600
16	Bismuth Germanate	0.0000207
17	Cadmium Sulfide	0.0003760
18	Gallium Arsenide	0.0000804
19	Tellurium Dioxide	0.0000577
20	Zinc Oxide	0.0002100
21	Zinc Sulfide	0.0000429
22	Ammonium Dihydrogen Phosphate	0.0002680
23	Aluminum Nitride	0.0000736

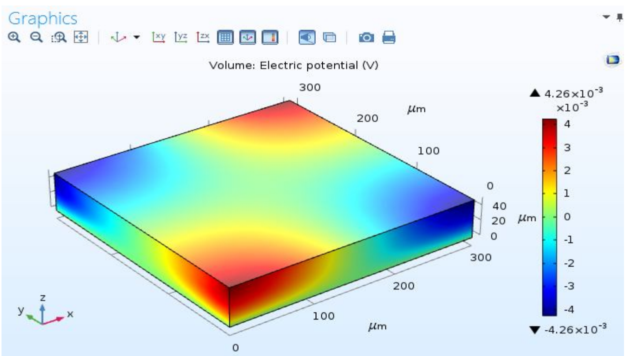


Fig.1: Simulation Result using Rochelle Salt as the material giving maximum output

From Fig.2above, it is observed that Rochelle Salt produces the maximum output voltage of 4.26 mV.

B. Structural Analysis

Apart from the importance of the piezoelectric material, the mode and MEMS structure also play a very important role. In real-time applications of these devices, the structure is the most critical part. It must be designed as per the system requirement along with to produce amaximum output voltage or power.

In structure designing, the geometry, as well as the number of layers in the structure, plays a vital role in the generation of themaximum output voltage.

Numerous compound structures have been reported by many researchers and are still an ongoing hot research topic in MEMS energy harvesting. Few of them worth mentioning are:

i. Cantilever Beam Structure:

A cantilever beam is a rigid structural element anchored at only one end to a support (usually vertical) from which it is protruding. As reported in [7], the output voltage increases as we increase the beam length and conversely the output voltage decreases as we increase the beam thickness. A maximum output voltage of about0.4V is obtained as reported with a beam length of 10cm, beam width of 1.3 cm and beam thickness of 0.1 cm with Silicon and PZT-5H material.

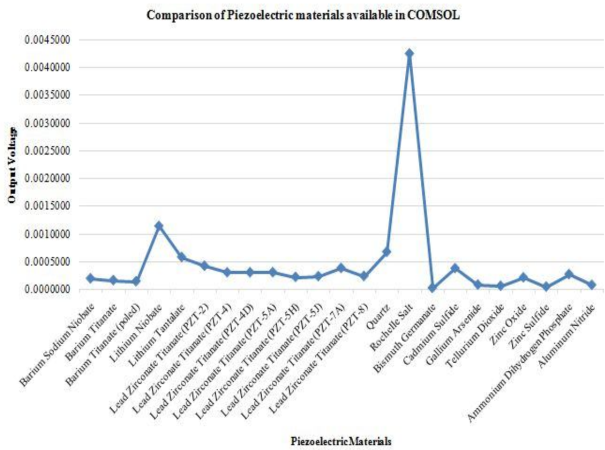
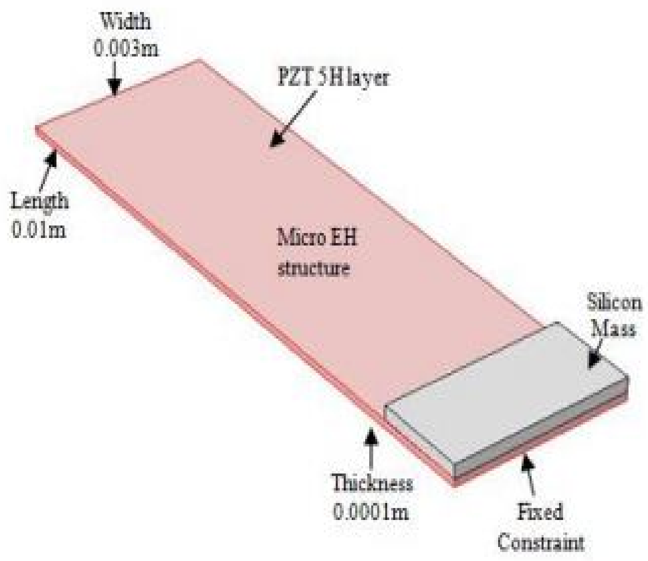
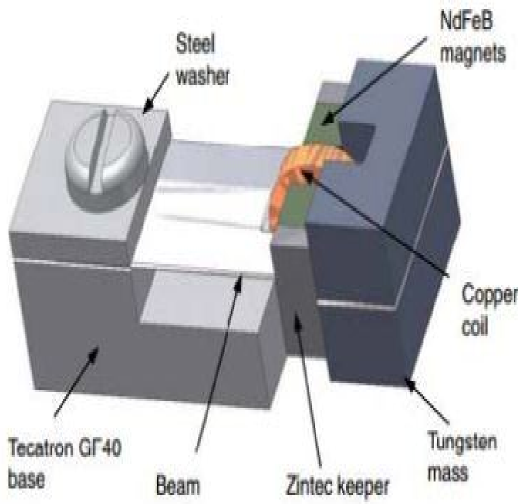


Fig. 2: Comparison of Piezoelectric materials available in COMSOL Multiphysics.



(a)



(b)

Fig. 3 :(a) Cantilever Beam Structure (b) cantilever beam based PEH [ref.28]

ii. An array of Cantilever Beams:

In this, an array of cantilever beams is used and each beam has its own resonant frequency.The modal analysis was done by selecting the number of modes in the analyzer solver to 5 modes of frequency from 67 Hz to 70 Hz depending upon the excitation frequency band affecting the harvester behavior. This is an optimization technique for power, current and voltage of the harvester which is greatly dependent on the alignment of the layers of thecantilever as well as the thickness of the supporting layer provided that, this thickness should be more than the PZT thickness, which is used as the material [26].

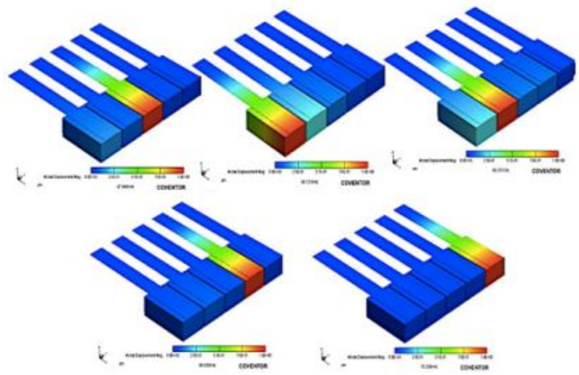


Fig. 4: Array of Cantilever Beams

iii. Rectangular Cantilever with Trapezoidal Cross Section:

Different cantilever structures like rectangular cantilever with rectangular cross-section (RCRC), rectangular cantilever with trapezoidal cross section (RCTC), trapezoidal cantilever with rectangular cross-section (TPCRC), trapezoidal cantilever with trapezoidal cross section (TPCTC), triangular cantilever with rectangular cross-section (TACRC) and triangular cantilever with trapezoidal cross section (TACTC) are reported in [19]where the output is optimized by the geometry of the structure. Finite element analysis and frequency analysis are carried out for all six geometries and their results are compared and out of which the Rectangular Cantilever with Trapezoidal Cross Section (RCTC) shows the maximum output voltage.From this paper, we can conclude that the geometry of the piezoelectric energy harvester greatly affects its energy harvesting ability.

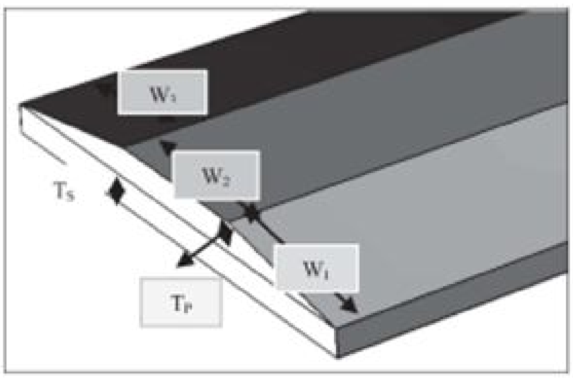


Fig. 5: Trapezoidal Cross-Sectional Cantilever Beam Structure

iv. Double Clamped with Segmented Electrodes:

A doubly clamped piezoelectric energy harvester with segmented electrodes is reported in [27].Here, the authors tried to study the electromagnetic coupling in the proposed structure, considering the strain nodes formation and charge cancellation issues. The single-mode power and voltage outputs of each of the PZT segments are obtained and are connected in series across a resistive load for the total outputs. Galerkindiscretization along with Euler-Bernoulli beam assumptions has been implemented here. This compound structure is also capable of producing a remarkable output voltage.

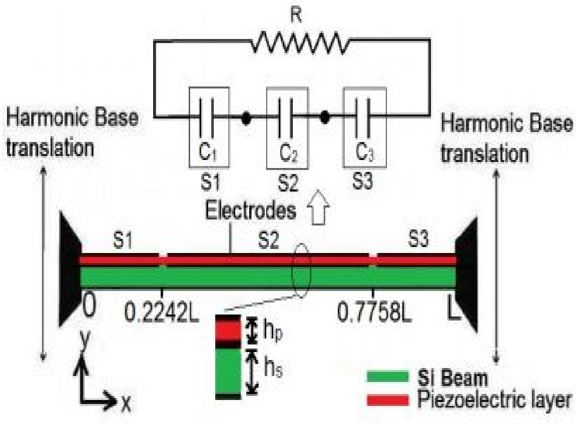


Fig. 6: Doubly clamped piezoelectric energy harvester with segmented electrodes

III. CONCLUSION

In this article, various piezoelectric materials and structures have been studied. Since the numbers of piezoelectric materials are very large and infinite compound structures could be designed, therefore, intensive research is demanded in this field for generating maximum output voltage or power so that its applications could extend up to even high power devices. This paper certainly provides latest update to the researchers about materials and microstructures being used for PEH.

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REFERENCES

[1] Huicong Liu, ChenggenQuan, Cho JuiTay, Takeshi Kobayashi, Chengkuo Lee, “A MEMS-based piezoelectric cantilever patterned with PZT thin film array for harvesting energy from low-frequency vibrations”, in Physics Procedia, Volume 19, 2011, Pages 129-133, ISSN 1875-3892.

[2] J. A. Paradiso and T. Starner, “Energy scavenging for mobile and wireless electronics,” IEEE Pervasive Comput.,vol. 4, no. 1, pp. 18-27, 2005

[3] S. P. Beeby, M. J. Tudor,and N. M. White, “Energy harvesting vibration sources for microsystems applications,”Meas. Sci. Technol., vol. 17, no. 12, pp. 175-195, 2006

[4] P. D. Mitcheson, E. M. Yeatman, G. K. Rao, A. S. Holmes and T. C. Green, “Energy harvesting from human and machine motion for wireless electronic devices,” Proc. IEEE, vol. 96, no. 9, pp. 1457-1486, 2008

[5] S. Tadigadapa and K. Mateti, “Piezoelectric MEMS sensors: state-of-the-art and perspectives,” Meas. Sci.Technol., vol. 20, no. 9, pp. 092001-1 – 092001-30, 2009

[6] P. D. Mitcheson, E. K. Reilly, T. Toh, P. K. Wright and E. M. Yeatman, “Performance limits of the three MEMS inertial energy generator transduction types,” J. Micromech. Microeng., vol. 17, no. 9, pp. S211-S216, 2007

[7] Mahidur R. Sarker, Azah Mohamed, Ramizi Mohamed, “Develop a Vibration Based MEMS Piezoelectric Energy Harvester using Micro Cantilever Beam”, IJAER, Volume 11, Number 5(2016), Pages 3421-3426, ISSN 0973-4562.

[8] C. B. Thangammal, P. Rangarajan, J. R. Perinbam, “Maximization of wireless sensor network’s lifetime using losningen cross-layer approach,”Asian J. Sci. Res. vol.5, pp.133-142, 2012.

[9] D. Christin, P. S. Mogre,andM. Hollick,“Survey on wireless sensor network technologies for industrial automation: the security and quality of service perspectives,”Future Internet.,vol.2, pp.96-125, 2010.

[10] M. R. Sarker, R. Mohamed, A. Mohamed, “A batteryless low Input Voltage micro-scale Thermoelectric based Energy Harvesting Interface Circuit with 100mV Start-up Voltage,”PezegladElektrotechniczny., vol. 90, no. 4, pp.49–52, 2014.

[11] G. Park, T. Rosing,M. D. Todd, C. R. Farrar andW. Hodgkiss, “Energy harvesting for structural health monitoring sensor networks,”Journal of Infrastructure Systems.,vol.14, pp.64-79, 2008.

[12] J. Ko, C. Lu, M. B. Srivastava, J. A. Stankovic, A. Terzis and M. Welsh, “Wireless sensor networks for healthcare,”Proceedings of the IEEE.,vol.98,pp.1947-1960, 2010.

[13] K. ViswanathAllamraju, K. Srikanth, “Design and Experimental Study of Novel Piezoelectric Vibration Energy Impact Mass Harvester”, in Procedia Engineering, Volume 144, 2016, Pages 560-567, ISSN 1877-7058.

[14] L. Zhou, J. Sun, X.J. Zheng, S.F. Deng, J.H. Zhao, S.T. Peng, Y. Zhang, X.Y. Wang, H.B. Cheng, “A model for

the energy harvesting performance of shear mode piezoelectric cantilever," Sensors and Actuators, Vol. 179, pp. 185–192,(2012).

[15] N.H. Diyana, Asan G.A. Muthalif, M.N. Fakhzan, A.N.Nordin, "Vibration Energy harvesting using single and comb-shaped piezoelectric beam structures: Modeling and Simulation", Procedia Engineering, Vol.41, pp. 1228–1234,(2012).

[16] Marco Ferrari, Vitoria Ferrari, Michele Guizzetti, Bruno Andò, Salvatore Baglio, Carlo Trigona"Improved Energy Harvesting from Wideband Vibrations by Nonlinear Piezoelectric Converters,"Procedia Chemistry, Vol. 1, pp.1203–1206,(2009).

[17] Yuantai Hu, Ting Hu, Qing Jiang, "Coupled analysis for the harvesting structure and the modulating circuit in a piezoelectric bimorph energy harvester",ActaMechanicaSolidaSinica, Vol. 20, pp. 134-145, (2007).

[18] XianzhiDaia, Yumei Wen, Ping Li, Jin Yang, Ming Li, "Energy harvesting from mechanical vibrations using multiple Magneto strictive / piezoelectric composite transducers", Sensors and Actuators, Vol. 66, pp. 94–101,(2011).

[19] E. Eba Flora, P. Lakshmi and S. Sunithamani, "Simulation of MEMS energy harvester with different geometries and cross sections," 2013 IEEE Conference on Information & Communication Technologies, JeJu Island, 2013, pp. 120-123.

[20] E. Arroyo, Y. Jia, S. Du, S. T. Chen and A. A. Seshia, "Experimental and Theoretical Study of a Piezoelectric Vibration Energy Harvester Under High Temperature,"in Journal of Microelectromechanical Systems, vol. PP, no. 99, pp. 1-10.

[21] S. R. Anton and H. A. Sodano, "A review of power harvesting using piezoelectric materials (2003–2006)," Smart Mater. Struct., vol. 16,no. 3, pp. R1–R21, Jun. 2007.

[22] B. R. Tittmann, D. A. Parks, and S. O. Zhang, "High temperaturepiezoelectrics—A comparison," in Proc. 13th Int. Symp. Nondestruct. Characterization Mater. (NDCM-XIII), Le Mans, France, 2013,pp. 1–17.

[23] D. Darnjanovic, "Materials for high temperature pyroelectric transducers," Current Opinion Solid State Mater. Sci., vol. 3, pp. 469–473,Sep. 1998.

[24] E. Arroyo, Y. Jia, S. Du, S. T. Chen, and A. Seshia, "High temperature performance of a piezoelectric micro cantilever for vibration energy harvesting," J. Phys. Conf. Ser., vol. 773, no. 1, p. 012001, 2016.

[25] E. Arroyo, A. Badel, F. Formosa, Y. Wu, and J. Qiu, "Comparison of electromagnetic and piezoelectric vibration energy harvesters: Model and experiments," Sens. Actuators A, Phys., vol. 183, pp. 148–156,May 2012.

[26] Salem Saadon, Othman Sidek, "Micro-Electro-Mechanical System (MEMS)-Based Piezoelectric Energy Harvester for Ambient Vibrations", in Procedia - Social and Behavioral Sciences, Volume 195, 2015, Pages 2353-2362, ISSN 1877-0428.

[27] R. Kashyap, T. R. Lenka and S. Baishya, "A Model for Doubly Clamped Piezoelectric Energy Harvesters With Segmented Electrodes,"in IEEE Electron Device Letters, vol. 36, no. 12, pp. 1369-1372, Dec. 2015.

[28] Yushan Tan, Ying Dong, and Xiaohao Wang,"Review of MEMS Electromagnetic Vibration Energy Harvester"JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 26, NO. 1, FEBRUARY 2017

[29] Kurmendra& Kumar, R.," Design analysis, modeling and simulation of novel rectangular cantilever beam for MEMS sensors and energy harvesting applications" Int. j. inf. tecnol. (2017) 9: 295. https://doi.org/10.1007/s41870-017-0035-6.