THOMSON REUTERS ENDNOTE
[NC-Rase 18] ISSN 2348 – 8034
DOI: 10.5281/zenodo.1488739 Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

# PPE AND IDE ELECTRODES FOR NEXT GENERATION ENERGY HARVESTERS: A REVIEW

**Ms. S. G. Agrahari[*1] , Dr. C. M. Jadhao [2] & Mr. K. U. Pathak[3]**
[*1]Assistant Professor, Electronics and Telecommunication Department of Mauli Group Of Institution`s College of Engineering, India
[2]Principal, Electronics and Telecommunication Department of Mauli Group Of Institution`s College of Engineering, India
[3]Assistant Professor, Electronics and Telecommunication Department of Mauli Group Of Institution`s College of Engineering, India

## ABSTRACT

Piezoelectric effect helps to convert ambient vibrations into electrical energy that can be used to power any electronic circuits. Electrode is used as primary sensor to sense these environmental vibrations to harvest energy and convert it to mechanical vibrational energy to electrical energy due to piezoelectric phenomenon. Energy density per volume for Piezoelectric-type harvesters is very high. The proposed work is concentrated on recent energy harvester for self-powered Microsystems and proposes ZnO piezoelectric material for next generation harvesters. In this work simulation is carried out on interdigitated electrodes to sense the vibrations in the enviorenment for the frequencies of 170 to 350 Hz. Energy harvesters can be used in these wireless sensor networks as an alternate source of power. The vibration energy can be converted to electrical energy by the use of piezoelectric PZT, ZnO, AlN, GaAs cemented to micro cantilever. Piezoelectric electrodes play a vital role in energy extraction with higher efficiency. Piezoelectric-type harvesters have the highest reported energy density per volume. Furthermore, piezoelectric materials have an inherent capability of converting the mechanical energy into electrical energy, eliminating the need for external magnetic fields, complicated switching systems, and architectural design complexities. In this paper we have reviewed the work carried out by researchers during last few years. This review paper helps to new comers to decide best structure, material and approach to carry out their research work. Results obtained show a good scope for MEMS harvesters in numerous fields including medical field which was far away because of poisonous piezoelectric material.

***Keywords:*** *Piezoelectric Material, Energy Harvesting, MEMS*

## I. INTRODUCTION

In recent years wireless sensor network technology has been widely used in environmental monitoring, health care, urban temperature detection, agricultural production and other fields. The main power supply for these wireless sensor networks still majorly relies on chemical battery, which offers limited energy storage. These sensor networks are powered up by 0.2mW. Recent improvements in the microelectronic and micro-electromechanical system (MEMS) technologies enabled the fabrication of various sensors with remarkably small dimensions and low power requirements. These wireless sensor networks can monitor several parameters simultaneously. Although success of such systems heavily depends on the performance of the sensors, the major limiting factor is generally the power management using the simplicity of the design and fabrication batteries. Currently used batteries increase the cost and the size of these devices. It is not feasible to replace or manually recharge them. A possible solution to this problem is to apply a form of energy harvesting to convert the available ambient energy into electrical energy to recharge these batteries or substitute batteries. Interdigitated electrode can be used in these energy harvesters to sense the vibrations in environment. Energy harvester can be used effectively to power up wireless sensor networks.
Therefore, current interest is growing in utilizing harvested energy that is stored in on-chip capacitors and effectively eliminating the batteries. Although the ambient energy can be available in different forms, mechanical energy is widely preferred for energy harvesting applications because of Alternative sources of energy are solar,

magnetic field and wind. Mechanical vibrations (300 _W/cm$^3$) and air flow (360_W/cm$^3$) are the other most attractive alternatives. In addition to mechanical vibrations, stray magnetic fields that are generated by AC devices and propagate through earth, concrete, and most metals, including lead, can be the source of electric energy [1].

## II. MATERIAL SELECTION FOR HARVESTER

**Energy Harvester**

In MEMS cantilever based energy harvester, mechanical energy is extracted by damping the motion of suspension proof masses within the devices. There are three main types of Mechanical energy harvesters: 1) piezoelectric,2) electromagnetic, and 3) electrostatic Piezoelectric-type harvesters have the highest reported energy density per volume. Furthermore, piezoelectric materials have an inherent capability of converting the mechanical energy into electrical energy, eliminating the need for external magnetic fields, complicated switching systems, and architectural design complexities. Power can be generated from various environmental sources such as ambient heat, light, acoustic noise, radio waves, and vibration [2]. Vibration energy harvesting is the most suitable power generation method because vibrations are readily available in almost all cases. A highly efficient way to harvest vibrational energy is to use piezoelectric materials for the energy transformation [3]. When base of structure is accelerated due to vibrating source(s), pressure (stress) is exerted to a material. This creates a strain or deformation in the material. The capability of the piezoelectric thin film in generating an electrical output in response to mechanical energy or vibration has given a significant impact in our daily lives. Piezoelectric thin film has been widely used in various MEMS applications such as surface acoustic wave (SAW) resonators, pressure sensors, biomedical and energy harvesting. In energy harvesting application, a piezoelectric energy micro-generator typically harvests mechanical energy or vibrations and converts it to electrical energy through piezoelectric effect. Different piezoelectric materials can affect the performance of the energy harvester due to different piezoelectric constants. Some examples of piezoelectric materials include lead zirconatetitanate (PZT), zinc oxide (ZnO) and aluminum nitrate (AlN) [4]. These parameters affect the mechanical and electrical parameters of the device.

**Benefits of Energy Harvester Using Piezoelectric Phenomenon**

Mechanical energy in cantilever is generated due to stress and strains produced in beam as a result of acceleration of environmental vibrations. Two types of electrodes are used in this study as vibration sensing electrodes. These are parallel plate electrode and interdigitated electrode. Cantilever structure helps in mechanical to electrical transduction [9]. EH are popular and penetrating in various applications due to diverse benefits: Long lasting operability, No chemical disposal, Cost saving, Safety, Maintenance free, Inaccessible sites operability, Flexibility.It is observed that 90% of WSNs cannot be enabled without energy harvesting technologies (solar, thermal, vibrations).

**Electrodes**

Toprak et al.[2] worked to obtain optimized geometry of IDE and cantilever, including the piezoelectric and non-piezoelectric material for cantilever. Geometry with PZT thickness of 0.6 µm and an IDE consisting of 12 finger pairs gave Maximum output energy of 0.37 pJ for a 15-µN force. This energy is reduced to 1.5 **f**J for 5 µm PZT thickness with 2 electrode finger pairs. Chidambaram et al.[3] The leakage current density of the IDE structure was measured to be about 4 orders of magnitude lower than that of the PPE structure.

The best Figure.of merit (FOM) of the IDE structures was 20% superior to that of the PPE structures while also having a voltage response that was ten times higher (12.9 mV/µ strain). The IDE lowers power loss inside the PZT for this kind of electrode. Since IDE show better outputs it became part of interest due to better efficiency.

ISSN 2348 – 8034
Impact Factor- 5.070

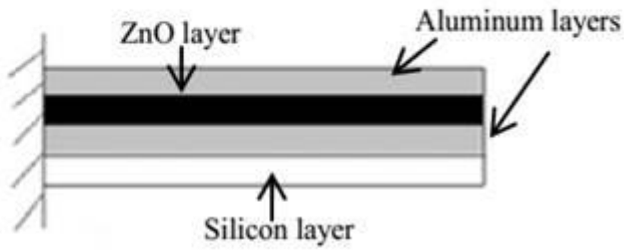


*Figure.1. Parallel plate Electrode*

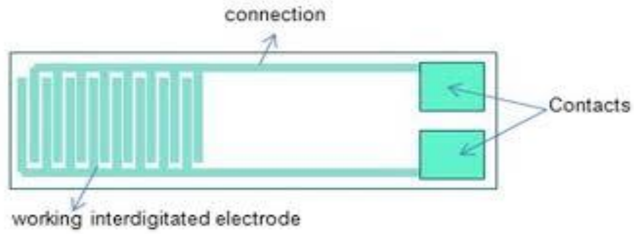


*Figure.2. Interdigitated Electrode*

**Operating mode of ZnO beam**

Mode selection is equally important to maximize conversion efficiency.d33 mode provides a higher electromechanical coupling when compared with d31 mode in typical piezoelectric materials[1].

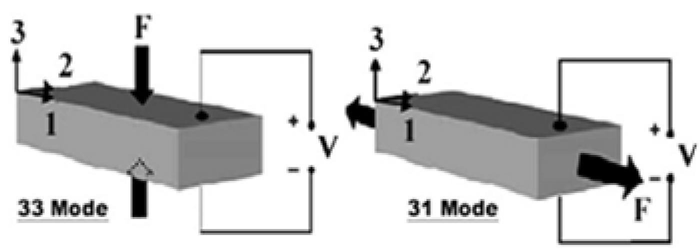


*Fig. 4. d33 and d31 coupling modes[4].*

Ralib et al.[5] simulated on The prototype cantilever structure consists of four layers namely: Si/ PZT/Pt interdigitated electrodes / Ni proof mass. The size of the
cantilever beam is 23µm x 71 µm with thickness 37 µm operating in d33 mode. The graph shows the expected sharp change in displacement as the frequency approaches the Mode 1 value that is 55MHz which shows the highest displacement shown in Figure 5. placing 24 Pa pressure at the end of the cantilever beam again provides the highest displacement with frequency of 53.7 MHz.Jinyu et al.[6] carried out simulations for 3x8.5x0.130 mm PPE electrode and obtained the figure of merit 59.98 for 165 Hz frequency, displacement approximately 550 µm at 1g. Output voltage is 7.70 $V.g^{-1}$ and power 174 µWatt $g^{-2}$.

Ryan et al.[7] The interdigitated beam utilizes the d33 piezoelectric constant. The d33 constant for PZT is commonly known to be approximately twice as large as the d31 constant. Therefore, designing a d33 structure properly could produce more energy and larger tuning range than a d31 structure.

ISSN 2348 – 8034
Impact Factor- 5.070

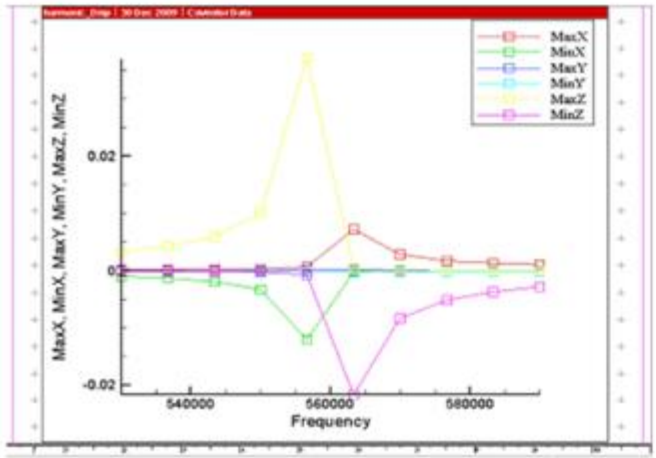


*Table 2. Device dimensions[8].*

| Material | Length (µm) | Width (µm) | Thickness (µm) |
|---|---|---|---|
| Silicon | 71 | 23 | 30 |
| BPSG | 71 | 23 | 18 |
| Zinc Oxide | 71 | 23 | 5 |
| Platinum (for one electrode) | 0.75 | 18 | 2 |
| Nickel | 10 | 23 | 10 |

The coupling coefficient of piezoelectric generators depends primarily on the piezoelectric material used, although the elastic properties of the other materials used in the generator structure may also influence the values. [12]

Hanim et al.[8] got the resonant frequency as 34.4 kHz at output voltage of 2.75V for device dimensions as shown in Table 2.

Rabbani et al.[10] used Si as proof mass (0.5592µg; dimensions:1000µm x 800µm x 300µm) at free end tip of cantilever to decrease the resonant frequency. The resonance frequencies for the cantilever having dimension 2000µm ×800µm ×20µm are 1427 Hz (first mode) and 15287 Hz (second mode). When excited with a mechanical vibration of 40 N/m2, the power generated at resonance is around 9µW.

The above discussionsshows that resonant frequency is very high as compared to frequency of vibration sources. Thus there is need of lowering this parameter. The length of cantilever is inversely proportional to resonant frequency. Dimensions should be chosen in such a way that resonant frequency of structure should be in the range of 10Hz-1Khz only. If the resonance is not taken place then vibration energy cannot be captured effectively. We propose the use of IDE for piezoelectric based energy harvester. Fabrication Process for IDE only is discussed below.

Andrea et al.[11] investigated the advantages of interdigitated electrode configurations (IDE) with respect to parallel-plate electrodes (PPE) in terms of output voltage and output power from the constitutive equations of piezoelectricity. A figure of merit for comparison has been proposed and calculated for both PPE and IDE structures. IDE has 2.12 times the figure of merit of PPE. The latter yielded higher energy densities and output voltages.

ISSN 2348 – 8034
Impact Factor- 5.070

Ankita et al. [13] The cantilever of E shaped is being designed and simulated with dimensions of 6.832mm x 2.180mm. The materials play a vital role in sensitivity of sensor and PZT 5H is selected on the basis of material analysis carried out. The Z displacement of 5.3 µm to 46.14 µm has been recorded.

Ankita et al.[14] The cantilever of E shaped has been designed and simulated with dimensions of 3.332mm x 1.180mm for loading on bridges. The materials play a vital role in sensitivity of device and PZT 5H is selected on the basis of materials analysis carried out.

The voltage generation of about 3.12 mV and Z-displacement of 4.03µm has been recorded at 100 Hz of frequency.

The tuning of the resonant frequency and electrical damping force is needful to keep an optimum output power, especially when the vibration amplitude and frequency is susceptible to change over time. In this paper, we have first presented the different key issues for VEH[15].

It was found that the thinner the beam, i.e. the lower the spring constant of the cantilever, the lower the untunedresonant frequency and the larger the tuning range. For this generator, a 120 m thick beam was chosen to give a predicted untuned resonant frequency of 45.2 Hz and a tuning range from 66.4 to 108.8 Hz[16].

The EH device has a wideband and steadily increased power generation from 19.4 nW to 51.3 nW within the operation frequency bandwidth ranging from 30 Hz to 47 Hz at 1.0 g. Based on theoretical estimation, a potential output power of 0.53 $\mu W$ could be harvested from low and irregular frequency vibrations by adjusting the PZT pattern and spacer thickness to achieve an optimal design[17].

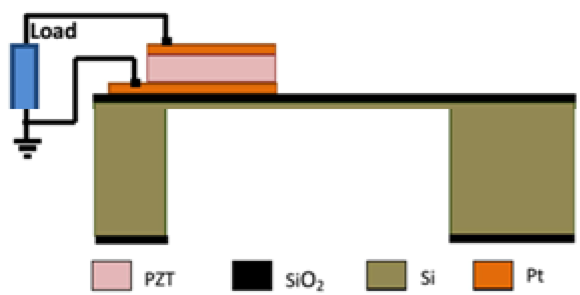


*Fig. 6. Lateral view of MEMS structure[10].*

## III. FABRICATION PROCESS

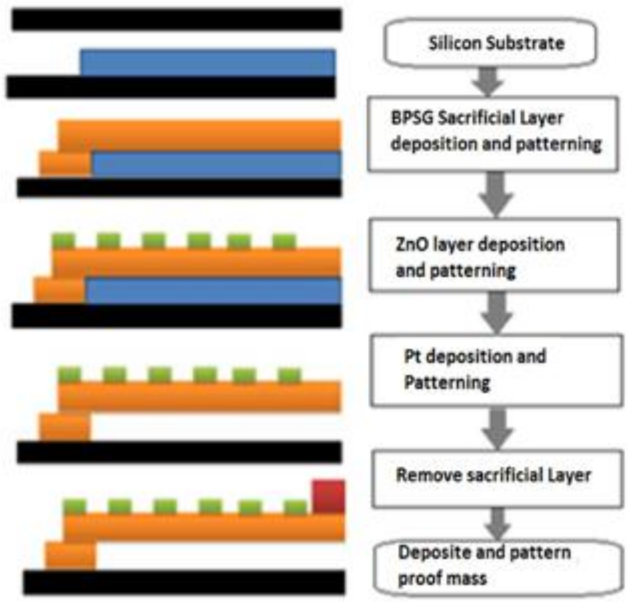


*Fig. 7. Fabrication Flow for IDE.*

Environmental Monitoring

light, temperature, humidity– Integrated Biology

Structural Monitoring

Building, Automation Interactive and Control

RFID, Real Time Locator, TAGS Transport Tracking, Cars sensors

Surveillance

Intrusion Detection

Interactive museum exhibits Medical remote sensing

Emergency medical response

Monitoring, pacemaker, defibrillators Military and Aerospaceapplications

Not limited above all

## IV. CONCLUSION

Designs of ID for energy Harvester are reviewed in this paper. On comparing IDE and PPE electrodes in this paper we noticed that IDE has four times better performance as compared to PPE. It is also observed that IDE has better Figure of merit. Device geometry, modes, piezoelectric materialand design has a crucial role in giving high output voltages at resonant frequency. Zinc oxide material fornext generationharvester is proposed as piezoelectric layer because of its excellence bonding to substrate material such silicon and high piezoelectric coupling coefficient. Choosing the proper interdigitated electrode layout and beam dimensions can nearly double the performance. Thus, designing a proper d33 unimorph or bimorph device will increase energy harvesting performance. These structures are being used forwireless sensor networks still there is scope for further optimization to obtain power which will be enough to drive portable devices.

## V. ACKNOWLEDGMENTS

Authors would like to thank Dr.S.S.Sadistap,Head, CEERI Pilani, Principal Dr. R.S. Pande and head of the department,Electronics Engineering, SRCOEM, Nagpur, Mr.Deepak Khushlani for the needful support and guidance

## REFERENCES

1. *Toprak, A.,Tigli, O., 2013, "Interdigitated-Electrode-Based MEMS-Scale Piezoelectric Energy Harvester Modeling and Optimization Using Finite Element Method",IEEE.*
2. *Kim, H., Tadesse, Y., Priya, S., 2009, "Energy Harvesting Technologies", S. Priya, D.J. Inman*
3. *(eds.),SpringerScience+Business Media.*
4. *Mazzalai, A., Chidambaram,N.,Balma,D.,Muralt, P., August 2013, "Comparison of Lead ZirconateTitanate Thin Films for Microelectromechanical Energy Harvester With Interdigitated and Parallel Plate Electrodes", IEEE.*
5. *Saadon,S., Sidek,O., 2010, "A review of vibration-based MEMS piezoelectric energy harvesters", Elsevier.*
6. *Ralib, A.A., Nordin,A.N. , Salleh, H., 2010, "Theoretical Modeling And Simulation Of MEMS Piezoelectric Energy Harvester", ICCCE.*
7. *Ruan, J.J., Lockhart, R.A., Janphuang, P., Quintero, A., Briand,D., and Rooij,N., 2013, " An Automatic Test Bench for Complete Characterization of Vibration-Energy Harvesters", IEEE.*
8. *Knight, R.R., &Changki Mo &Clark.W.W., 2011, "MEMS interdigitated electrode pattern optimization for a unimorph piezoelectric beam".*
9. *Ralib,A.A., Nordin,A.N., Salleh,H., 2010, "Simulation of MEMS Piezoelectric Harvester".*
10. *Jamain,U.M., Ibrahim,N.H., Rahim, R.A, IEEE-ICSE2014 , "Performance Analysis of Zinc Oxide Piezoelectric MEMS Energy Harvester".*
11. *Rabbani, S., Rathore, P., Ghosh, G., and Panwar, B. S., 2010, "Mems structure for energy harvesting",COMSOL Conference 2010 India.*
12. *Beeby, S.P., Tudor, M.J., and White, N.M., "Energy harvesting vibration sources for microsystems applications" Measurement Science And Technology, Institute Of Physics Publishing , Meas. Sci. Technol. 17 (2006) R175–R195*
13. *Balpande, S.S. ; Lande, S.B. ; Akare, U. ; Thakre, L., 2009, " Modeling of Cantilever Based Power Harvester as an Innovative Power Source for RFID Tag" 2nd IEEE International Conference onEmerging Trends in Engineering and Technology (ICETET), pp. 13 – 18.*
14. *Kumar, A., S.S.Balpande, Oct, 2014, "MEMS Based Bridge Health Monitoring System" International Journal of Advances in Science, Engineering and Technology, Volume-2,Issue-4.*
15. *Kumar, A., Balpande, S.S., 2014,"Energy Scavenging From Ambient Vibrations Using MEMS Device" International Journal Of Scientific Progress And Research (IJSPR) ,**05**, Number-01, ISSN: 2349 – 4689*
16. *Seddika,B.A., Despessea,G., Defaya,E., September 9-12, 2012 "Improved Wideband Mechanical Energy Harvester Based on Longitudinal Piezoelectric Mode".*
17. *Dibin Zhu, Stephen Roberts, Michael J. Tudor , Stephen P. zeeby ,2010, "Design And Experimental Characterization Of A Tunable Vibration-BasedElectromagnetic Micro-Generator".*
18. *Liu, H., Tay, C.J., Quan, C., Kobayashi, T., and Lee, C., IEEE, "Piezoelectric MEMS Energy* Harvester forLow-Frequency Vibrations with Wideband OperationRange and Steadily Increased Output Power".