Modeling and Simulation of MEMS Device Based on Epitaxial Piezoelectric Thin Film

Priyanka Gautam
Research scholar
Mewar University, Gangrar, Chittorgarh

Dr. Dheeraj Jain
Professor
Mewar University, Gangrar, Chittorgarh

ABSTARCT: Energy harvesting from environmental vibration nowadays is feasible because of natural oscillations like that caused by air or liquid flow and by exhalation or the heartbeat of a human body. This vibration frequency is typically low (in order of less than 1 kHz). Accordingly, low frequency vibration based energy harvesting systems are an important research topic; these systems can be used for wearable or implantable devices. Piezoelectric vibration based harvesters are not expensive and do not require external voltage sources Multiphysics 3.5 in 3D view to decrease operating frequency and improve output power. Unimorphs are designed with two different nonpiezoelectric materials as Aluminium and Gold. Eigen frequency analysis has been performed to obtain resonant frequency and generated voltage from the unimorphs with different piezoelectric epitaxial thin film. Unimorphs of dimension 100mm×30mm×4mm has been modelled with 2mm thin film epitaxial layer of piezoelectric material. From the simulation results Gold is preferred over Aluminium as about 100Hz less frequency response is observed. A Unimorph with gold and PZT-5A material is considered the best model with resonance frequency of about 160Hz with generated electric voltage of 107 volts is applied at the tip of unimorph.

Key words: MEMS. Aluminium nitride, Tellurium Dioxide, Gallium Arsenide,Lithium NiobatePZT-5APZT-5H

I INTRODUCTION

In recent years, harvesting ambient energy from the environment has been a growing interest area and major focus of many research groups [1]. Many ambient power sources such as thermal gradients, mechanical vibrations, fluid flow, solar, human-driven sources [2,3] etc. have been actively investigated in order to realize alternative power supplies. Ambient sources are potential candidates to replace existing Power sources such as batteries that have a limited energy storage capacity and lifetime for some applications [4]. In particular, mechanical vibration energy harvesting has drawn much attention as substantial advances have been achieved in integrated circuit technology, particularly in low power digital signal processors, reducing power requirements for wireless sensor nodes [5]. Energy harvesting from external mechanical excitation is made through conversion of nearly ubiquitous, ambient mechanical vibration energy using one of three transduction mechanisms: electrostatic, electromagnetic, or piezoelectric effects [1,7]. Although each transduction mechanism and corresponding application has advantages in different areas, energy conversion using piezoelectricity is regarded as one of the most promising technologies for MEMS devices. Piezoelectric materials [8] produce an electrical charge or voltage when subjected to a mechanical stress or strain, or vice versa. Vibration energy is directly converted to voltage with no need for complex geometries or additional components. This is in contrast with electrostatic devices where an input voltage is required. Perhaps most importantly, piezoelectric vibration energy harvesters (PVEHs) can generate high output voltages with enhanced efficiency

PIEZOELECTRIC VIBRATION ENERGY HARVESTING

Piezoelectric materials produce electrical charge or voltage across them when a mechanical stress or Strain is applied, or vice versa [8]. When subjected to mechanical strain, piezoelectric materials become electrically polarized and the degree of polarization is proportional to the applied strain. Conversely, these materials deform when exposed to an electrical field. This functionality enables the use of piezoelectric materials to convert mechanical energy into electrical energy. As previously reviewed, several methods exist for obtaining electrical energy from vibration sources including the use of electromagnetic induction, electrostatic conversion, and piezoelectric materials. Of these three vibration-based devices, PVEH devices have received the most attention because piezoelectric devices convert applied strain energy from vibration into usable electrical energy directly. There is no requirement for having complex geometries and numerous additional components and thus, PVEHs are the simplest type of generator to fabricate

II RELATE WORK

The knowledge gained supported the development of compatible microfabrication techniques and the design of the piezoelectric MEMS devices Investigate the degradation in ferroelectric and piezoelectric properties of epitaxial PZT thin films due to microfabrication processes and material used as a top electrode. The goal here is to acquire all the knowledge that is necessary to produce high quality and reproducible epitaxial piezoelectric MEMS devices with special attention on maintaining the superior properties of epitaxial PZT thin films in operating devices for better performance;

Investigate various micro fabrication processes for piezoelectric MEMS and apply the experience obtained to develop efficient micro patterning methods and process sequences for the microfabrication of the epitaxial piezoelectric MEMS devices

shailendra Kumar Dewangan : Energy harvesting is a process by which energy is originated and taken from external sources such as solar power, thermal energy, wind energy, salinity gradients, and kinetic energy etc. The sampled energy is captured, and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. In this work the piezoelectric material is used for this purpose. There are a number of methods available as the mean of energy harvesting techniques, but the mechanical energy harvesting can be considered to be the most prominent. This technique is based upon piezoelectric components where deformation is produced by different means are directly converted to electrical charge via piezoelectric effect. Then after the electrical energy can be regulated or stored for further use. This work proposes an innovative method using freewheel and reciprocating motion.

Mariem Saida : Piezoelectric energy harvesting from vibrations of the human body has become an interesting topic to supply medical devices. The output power of the piezoelectric energy harvesting system depends on the geometry of the device and the material used. The paper presents a study about piezoelectric system which converts the human breathing movement into electrical energy. We propose a new parametric study of piezoelectric cantilever based on a study of the dimensions” influence of the device and the material used on the optimization of the recovered energy. We obtain simulations for different dimensions based on the finite element method (FEM).

Levent Beke; This paper presents a piezoelectric energy harvester (PEH) to convert vibrations to electrical power. A unimorph cantilever beam is used to generate voltage on piezoelectric material bonded close to the anchor of the cantilever beam. A 4.85 × 1 × 0.04 cm structural layer with piezoelectric material yields peak-to-peak voltage of 64 V at the resonance frequency of the structure. The empirically confirmed maximum power output is close to 0.5 mW. The results from validation data on the observed structure has been correlated to the simulations in finite element method (FEM) program using piezoelectric analysis tools

G. Yesner :A novel bridge transducer based on the cymbal design has been developed for energy harvesting from impact loading by vehicle-induced deformations in pavement. The bridge transducer consists of a 2 mm thick 32×32 mm square soft PZT ceramic and hardened steel end caps. A novel electrode design is used to polarize the piezoelectric ceramic along its length, effectively utilizing d^{33} mode for enhanced energy generation. A prototype module with 64 bridge transducers were fabricated and loaded repeatedly to simulate vehicle traffic on a highway. When compared to the conventional transducer design, horizontal poling increases energy and voltage considerably.

PIEZOELECTRICEFFECT: Piezoelectric materials consist of ferroelectric materials, such as $Pb(Zr,Ti)O_3$, $BaTiO_3$, and $LiNbO_3$, and non-ferroelectric materials, such as AlN and ZnO [33, 34]. One of the defining traits of a piezoelectric material is that the molecular structure is oriented such that the material exhibits a local charge separation, known as an electric dipole. Throughout the material composition, the electric dipoles are oriented randomly, and for ferroelectrics, the dipoles can be oriented such as when the material is heated slightly below the Curie temperature and/or a very strong field is applied, the electric dipoles reorient themselves relative to the electric field; this process is termed poling. Once the material is cooled, the dipoles maintain their orientation and the material is then said to be poled. After the poling process is completed, the material will exhibit a relatively high piezoelectric effect. Thus, poled ferroelectrics are very effective and attractive piezoelectrics. Energy conversion using piezoelectric materials is possible because mechanical strain in a piezoelectric material induces deformation of electric dipoles, forming electrical charges that can be removed from the material and used to power various devices. Such mechanical and electrical behavior of piezoelectric materials can be described using linear piezoelectric constitutive equations that contain relevant material property constants, constant strain

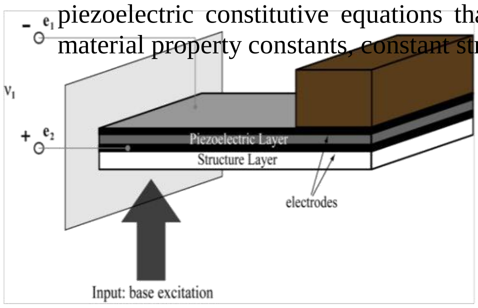

Figure 1.4 Unimorph cantilevered piezoelectric energy harvester device in {3-1} mode of operation with standard electrode configuration. Note asymmetric layers and the need for a "structural" layer

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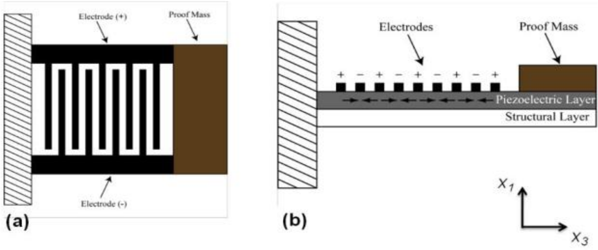

Figure 1.5 interdigitated electrode (IDTE) configurations in cantilevered piezoelectric energy harvesting {3-3} mode devices: (a) top-view and (b) side-view

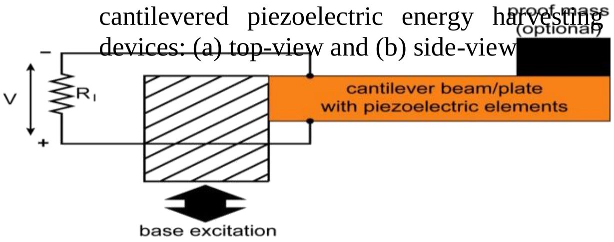

Figure 1.6 Schematic of a cantilevered piezoelectric energy harvesting system with simple electrical resistance loading, *R*$_l$

PIEZOELECTRIC MATERIALS: Polycrystalline ceramics are the most extensively explored as piezoelectric energy harvesting materials along with polymers [1, , 34]. Piezoelectric ceramic materials include ferroelectric materials with perovskite crystal structures such as barium titanate (BaTiO3), lead titanate ($PbTiO_3$, PCT), lead zirconate titanate ($PbZr_xTi_{1-x}O_3$, PZT) and non-ferroelectric materials with wurtzite crystal structures such as ZnO and AlN. Among all, lead zirconate titanate (PZT), a solid solution of ferroelectric $PbTiO_3$ and ant ferroelectric $PbZrO_3$, is the most common type of piezoelectric used in energy harvesting applications due to its high piezoelectric coupling. The dielectric and piezoelectric cons tants of PZT depend strongly on materials

PIEZOELECTRICITY

Piezoelectricity is a coupling between the mechanical and electrical behaviors of a material. The piezoelectric effect in quartz was discovered in 1880 by the brothers J. Curie and P. Curie. When certain types of crystals are subjected to tensile or compressive forces,

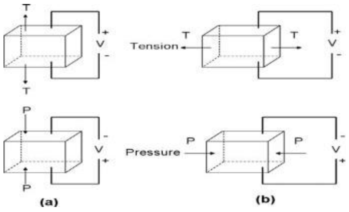

Figure 1.7 The piezoelectric effect: when a pressure (P) or a tension (T) is applied to a crystal, a voltage (V) develops across the material. (a) When the deformation and voltage are collinear, this is the d33 mode (longitudinal effect). (b) In the case of perpendicular deformation and voltage, the mode is d31 (transverse mode

The resulting strain causes a polarized state in the crystal, and an electric field is created. This phenomenon is called direct piezoelectric effect. Conversely, if a crystal is polarized by an electric field, strains along with resulting stresses are created, which was called converse piezoelectric effect. In crystals that show piezoelectric properties, electrical quantities such as electric field or polarization, and mechanical quantities such as stress or strain, are interrelated. This phenomenon is called electromechanical coupling. In piezoelectric materials, the transverse (d31 mode) and longitudinal (d33 mode) effects are very important. In d33 mode, the direction of applied stress (force) and generated charge is the same, while in d31 mode the stress is applied in one axial direction but the charge is obtained from the perpendicular direction.In general, a piezoelectric material has a polycrystalline structure consisting of many domains. Each domain has a polarization, one end is more negatively charged and the other end is positively charged. Let us assume the polarization is an imaginary line that runs through the center of both charges on the domain as shown in figure 1.2. In order to obtain a net polarization in piezoelectric materials, the polarization of all domains must lie in one direction. The process so-called poling must be performed on a multidomain piezoelectric material in order to produce the piezoelectric effect. Poling is the process by which electric field is applied to a piezoelectric material (figure 1.2). At a certain voltage, the polarization in all domains lines up and face in nearly the same direction. The piezoelectric effect can now be observed in the piezoelectric material.

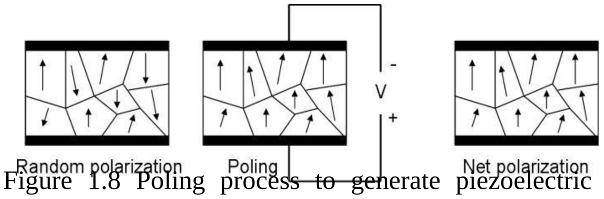

Figure 1.8 Poling process to generate piezoelectric effect.

The piezoelecic effect provides the ability to use piezoelectric materials as both a sensor and an actuator. Piezoelectric materials are therefore widely used in many areas of technology and science. It should be noted that the poling process is not necessary for the epitaxial piezoelectric films since they are naturally polarized.

GOVERNING EQUATIONS OF PIEZOELECTRICITY

Piezoelectricity that combines electrical and mechanical components described by Gauss's Law and Hooke's Law can be expressed by the following relations:

$D=\varepsilon 0E+P$ (1.1)
$S = sT$ (1.2)

Where D is the electric charge density displacement, or the electric displacement [C m-2], ε is the permittivity [F m-1], E is the electric field strength [V m-1], P is the polarization, S is the mechanical strain, s is the compliance [m N-1], and T is the applied mechanical stress [N m-2].

III PROPOSED SYSTEM

Energy harvesting devices are attractive as an energy source for powering micro-devices, such as small wireless sensor networks, biomedical implants, environmental condition monitoring systems and structural health monitoring systems .The development of devices able to convert kinetic energy from vibrations, forces or displacements into electric output has advanced rapidly during the past few years because such energy can be found in numerous applications, including industrial machines, transportations, household goods, civil engineering structures, and portable and wearable electronics .Several transduction methods can be used for energy harvesters including electromagnetic induction, electrostatic generation and piezoelectric materials. The choice of the transduction methods depends mainly on the applications since there is no clear evidence with respect to the preferred transduction methods .Nevertheless, among these methods, piezoelectric materials have received the most attention due to directly convert vibration energy into electrical energy with a high power density and ease of integration into a system and thus they are well suited to miniaturization. Moreover, harvesters based on piezoelectric materials have a wider operating range at low frequency than the other transduction methods, which can be efficiently utilized to harvest energy from common environmental vibrations. The fabrication throughput, reproducibility and device miniaturization seem to be limited. While the growth of epitaxial piezoelectric thin films on silicon is promising for MEMS based energy harvesters, several challenges still remain for the development of high performance devices based on the epitaxial PZT thin films. The realization and characterization of vibration energy harvesting MEMS devices based on an epitaxial $Pb(Zr_{0.2}Ti_{0.8})O_3$ thin film having a high piezoelectric coefficient and a low dielectric constant. The analytical power model and finite element model used to design and optimize the devices, and the choice of the actual PZT stoichiometry for energy harvesting applications. The results on the fabrication and characterization of the epitaxial PZT cantilevers with and without a Si proof mass are presented. Different characteristics of the fabricated epitaxial PZT harvester's .their dynamic behavior, electromechanical coupling coefficient and energetic performances. The electrical characteristics of the harvesters, i.e. power, voltage, current were experimentally investigated and the results obtained are in good agreement with the analytical model. The performances of the epitaxial PZT harvesters are also compared with other demonstrated energy harvesters The vast majority of piezoelectric energy harvesting devices uses a cantilever beam structure. A cantilever beam, by definition, is a beam with a support only one end, and is often referred to as a "fixed-free" beam. When the generator is subjected to vibrations in the vertical direction, the support structure will move up and down in sync with the external acceleration. The vibration of the beam is induced by its own inertia, since the beam is not perfectly rigid, it tends to deflect when the base support is moving up and down Typically, a proof mass is added to the free end of the beam to increase that deflection amount. This lowers the resonant frequency of the beam and increases the deflection of the beam as it vibrates. The larger deflection leads to more stress, strain, and consequently a higher output voltage and power .Electrodes covering a portion of the cantilever beam are used to conduct the electric charges produced to an electrical circuit, where they can be utilized to charge a capacitor or drive a load.

Use of COMSOL Multiphysics The piezoelectric energy harvester with proposed and rectangular shapes were designed and simulated in COMSOL Metaphysics 4.4 using piezoelectric devices module as 3D configuration as shown in Figure 2a and Figure 2b. The goal is to study the deformation, strain generated voltage, and charge distribution of piezoelectric energy harvesters with the two shapes and compare them

IV CONCLUSION

The design of piezoelectric cantilevers to effectively convert ambient vibrations and flows into electricity. Such devices provide affordable, sustainable and maintenance-free power solutions for low power wireless and portable devices Then providing it boundary conditions as one side fixed and other side free constraints. A force of 20N/m2 along Y direction is made on the top side. Table 1 shows the results of analysis 1 to analysis 6. This analysis has been done with three different piezoelectric materials PZT-5, PZT-5A and PZT-5H with Aluminum as base material for obtaining modal analysis from these three models with same dimensions as 100mm × 30mm × 4 mm. Modal analyses is done for five modes in. Upon review of published literature in this field, it was found the current design of the piezoelectric cantilevers needs to be modified with an effective way of converting mechanical energy into electricity, from piezoelectric cantilevers. From Analysis 1 to 6 it can be concluded that for designing a unimorph with low resonant frequency the preference should be given to Tellurium Dioxide, Aluminum Gallium Arsenide, PZT materials respectively.. As gold is much costly than Aluminum therefore when cost doesn't matters much with the results Aluminum can be preferred over gold.

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