International Journal of Electrical and Computer Engineering (IJECE)
Vol. 3, No. 6, December 2013, pp. 857~862
ISSN: 2088-8708

Application of Piezoelectric Materials in Smart Roads and MEMS, PMPG Power Generation with Transverse Mode Thin Film PZT

Aqsa Abbasi
Department of Electronics Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan

Article Info

Article history:

Received Oct 3, 2013
Revised Nov 2, 2013
Accepted Nov 12, 2013

Keyword:

Piezoelectric effect
Piezoelectricity
Quarz crystal
Smart Roads
Ziconate Titanate

ABSTRACT

Due to the increase in electricity energy consumption and the fact that about 90 % of fuels being used now carbon dioxide pollutant and the crisis has been caused by greenhouse gases have made moving toward renewable energies unavoidable. At present, considering electricity crisis in Pakistan, although only 46% of the population of Pakistan have the facility of electricity and the remaining are still living in darkness but still we face a major power crisis. Modern technology needs a huge amount of electrical power for its various operations. In this paper, we have presented and reviewed a method to produce pollution free electricity by some techniques like Piezoelectric effect in pyroelectric crystal and power generation by thin film MEMS, PZT, PMPG and using them in piezoelectric roads, as congestion on roads is becoming inevitable with the fancy of masses towards personal transportation systems for their growing mobility. Accordingly, it is an object of the present invention to provide a method of electrical power generation that does not negatively impact the environment.

Corresponding Author:

Aqsa Abbasi
Departement of Electronics Engineering,
Mehran University of Engineering and Technology,
Jamshoro, Sindh, Pakistan.

1. INTRODUCTION

Energy harvesting is an area of active research. Many methods have been employed for harvesting energy from the environment. The most familiar ambient energy source is solar power. Other examples include electromagnetic fields (used in RF powered ID tags, inductively powered smart cards, etc.), thermal gradients, fluid flow, energy produced by the human body, and the action of gravitational fields. Finally, vibrational energy can be used as an ambient source. A power generator based on transducing mechanical vibrations can be enclosed to protect it from a harsh environment, and it functions in a constant temperature field. The most immediate applications for such a device is to power micro sensors and/or low power very large scale integration (VLSI) circuits. Aggressive power scaling trends over the last decade have resulted in power consumption in only the 10's to 100's of µW for low to medium throughput Digital Signal Processing (DSP) circuits and other digital VLSI circuits. As these power trends improve, energy harvesting devices become more viable as portable power sources over ordinary chemical batteries. Digital VLSI technology requires an "on" voltage of approximately 3V or more. In order to accomplish such a high voltage, the piezoelectric energy harvesting method is most useful, especially with the d33 piezoelectric mode.

From historical point of view, the first demonstration of the piezoelectric effect was given in 1880 by the brothers Pierre Curie and Jacques Curie using crystals of tourmaline, quartz, topaz, cane sugar, and Rochelle salt (sodium potassium tartrate tetra hydrate) [1]. While this was a scientific curiosity for the next third of a century, with the work of Langevin it produced one of the principal electromechanical transducer effects. Quartz, first used as a transducer, also received wide use in controlling oscillators and in selective wave filters. Quartz was soon replaced by Rochelle salt for transducers. This is a rather unstable crystal, which, however, was the first ferroelectric having an intrinsic polarization between its two Curie temperatures. In this paper, we have reviewed technique to generate electric power by using special crystal named as pyroelectric crystal. A material somewhat similar to a ferroelectric is electrets. These have become very useful in transmitters and receivers. Finally, thin films of piezoelectric crystals are useful for producing high frequencies in such devices as the acoustic microscope [2].

However the basic piezoelectricity deals with the ability of some materials - most notably crystals and certain ceramics, including bone - to generate an electric potential in response to applied pressure. Piezoelectric materials may include Quartz crystal, PZT (Lead Zirconate Titanate).

The Piezoelectric Micro Power Generator (PMPG) is a MEMS based device designed to harvest vibrational energy from the ambient source. It can generate a high open circuit voltage suitable for voltage rectification and for powering low power VLSI circuits. We envision that several PMPG devices could generate power on the order of 10 μW within an area of approximately 1 mm aquare. PZT thin films have attracted attention for many applications such as accelerometers, force sensors, actuators, gyroscopes, micro pumps, tunable optics, ferroelectric RAM, and display systems. PZT MEMS devices have many advantages such as fine resolution, large force generation, fast response time, zero magnetic fields, low power consumption, vacuum and clean room compatibility and operation at cryogenic temperatures. However, it is more difficult to fabricate a PZT MEMS device versus a similar beam-structured electrostatic device because PZT film is not a normal material for general silicon processing, often requiring many more mask steps [8]. Piezoelectric d31 type sensors and actuators have a cantilever beam structure that consists of a membrane film, bottom electrode, piezoelectric film, and top electrode. The d31 type devices require many mask steps (3~5 masks) for patterning of each layer while have very low induced voltage.

The main object is to investigate the role of PMPG, MEMS power generation in piezoelectric network for smart roads. The remainder of the paper is arranged as follows. Section-2 provides the origin of piezoelectric effect in crystal. The detail of the proposed technique has been discussed in section-4. Simulation parameters and results have been given in section-5. Based upon the simulation results, conclusions have been drawn and some recommendations for future work have been proposed in section-6.

2. ORIGIN OF PIEZOELECTRIC EFFECT IN CRYSTAL

The origin of the piezoelectric effect was, in general, clear from the very beginning. The displacement of ions from their equilibrium positions caused by a mechanical stress in crystals that lack a centre of symmetry must result in the generation of an electric moment, i.e., in electric polarization. Attempts to calculate the piezo constants of a crystal based on this model were first undertaken by the brothers Curie as shown in following Figure 1.

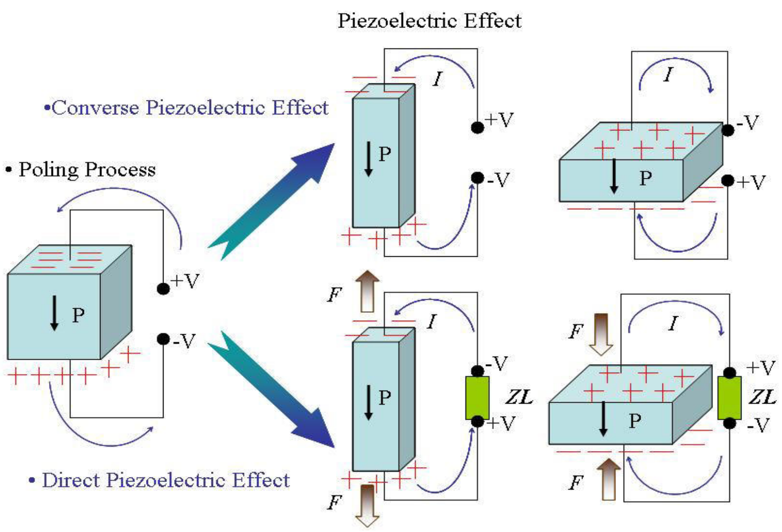

Figure 1. Origin of piezoelectric effect and polarization

We assume that some crystals have spontaneous polarization. Thus, only some crystals like pyroelectric crystals that have an unique polar axis, along which the spontaneous polarization exists, are considered. These are the crystals of classes 6mm, 4mm, mm2, 6, 4, 3m, 3, 2, m, and 1. For reasons that are obvious, crystals of class 1 will not be considered further. The special polar axis—crystallophysical axis X3—coincides with the axes L6, L4, L3, and L2 of the crystals or lies in the unique plane P (class “m”).

Thus, all considered crystals have spontaneous polarization Ps = P3. We believe that the piezoelectric effect in pyroelectric crystals arises as a result of changes in their spontaneous polarization under external effects (electric fields, mechanical stresses). Moreover, we believe this mechanism can be regarded as the governing factor. Let us demonstrate, in general terms, that the piezoelectric effect in these crystals is really a result of changes in Ps caused by the applied electric field or mechanical stress [3].

For example, if one starts to deform such a crystal, its constituent particles will be slightly displaced from their equilibrium positions as shown in following Figure 2.

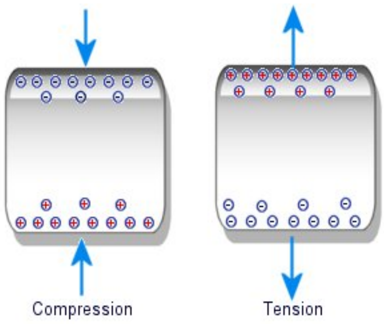

Figure 2. Deformation of crystal.

Accordingly, this results in the displacement of the electric centres of positive and negative charges of an elementary cell from equilibrium positions, i.e., the spontaneous polarization of the crystal changes. Generally, this change will have the components along all three axes of ΔPs = (ΔP1, ΔP2, ΔP3) [4]. Let us suppose that a first approximation, ΔPs = (ΔP1, ΔP2, ΔP3) is proportional to the mechanical stresses causing it, i.e., ΔPi = dikl Tkl where Tkl represents the mechanical stress and dikl represents the piezoelectric modules. If one accepts their values in the absence of mechanical stresses or an electric field as a reference point for the polarization state and for the electric induction, then ΔPi or ΔDi can just be substituted by Pi or Di, and the piezoelectric effect equations keep their conventional form.

3. PIEZOELECTRICITY AND POWER GENERATION USING TRANSVERSE MODE THIN FILM PZT AND MEMS, PMPG

As piezoelectric effect converts mechanical strain into electric current or voltage and generates electric energy from weight, motion, vibration and temperature changes. Considering piezoelectric effect in thin film lead zirconate titanate, Pb(Zr,Ti)O3 (PZT), MEMS power generating device is developed [5]. It is designed to resonate at specific frequencies from an external vibration energy source, thereby creating electrical energy via the piezoelectric effect using electromechanical damped mass as shown in following Figure 3.

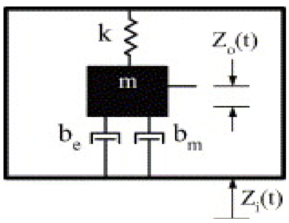

Figure 3. Schematic of generating vibration convertor

PMPG devices should be designed so that they mechanically resonate at a frequency tuned to the ambientvibration source in order to generate maximum electrical power as shown in the following Figure 4.

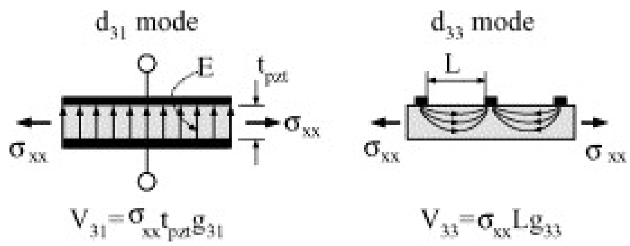

Figure 4. Two modes of piezoelectric conversion from input mechanical stress

4. PIEZOELECTRIC SENSORS NETWORK FOR SMART ROAD

The present invention relates generally to methods of electrical power generation, and more particularly is a method and device to generate electricity by using traffic on existing roadways to drive an electrical generator [6]. This paper provides technical review for the production of electric power using PZT, MEMS, PMPG in piezoelectric roads-Harvest traffic energy to generate electricity as shown in following Figure 5.

Figure 5. Network for smart roads and generation of electric voltage

Since Energy demand and heavy traffic correlation motivate to dream about a device in the road that would harvest the energy from the vehicles driving over it. For this, embed piezoelectric material beneath a road can provide the magic of converting pressure exerted by the moving vehicles into electric current. The method uses an electrical generation device installed beneath the roadbed. The electrical generation device includes a pressure plate covered with one or more protection layers which lie beneath the surface of the road.

In this process, piezoelectric material is embedded beneath the road with the electrical generating device. For a road with embedded piezoelectric generators, part of the energy the vehicle expands on roads deformation is transformed into electric energy (via direct piezoelectric effect) instead of being wasted as thermal energy (heat).

This electrical generating device includes pressure plates that are covered with protection layer or asphalt as shown in following Figure 6.

 ISSN: 2088-8708

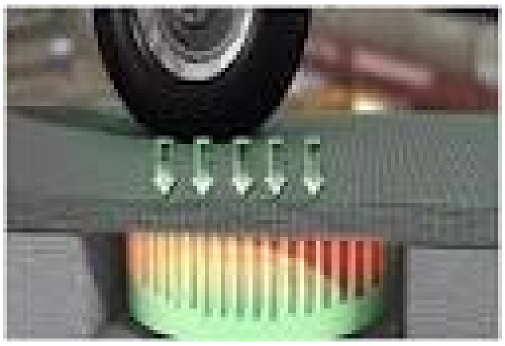

Figure 6. Wheels pushing protected plates.

The piezoelectric effect converts mechanical strain into electrical current or voltage and the system is expected to scale up to 400 kilowatts from a 1-kilometre stretch of dual carriageway. The mechanical force is provided by the wheel of automobile vehicle, in which gravitational forces (weight) is normal to the surface of road that causes compression as shown in the following Figure 7.

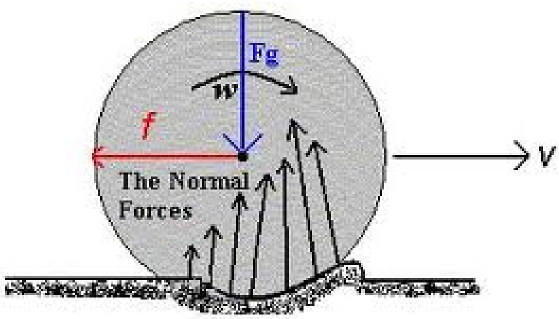

Figure 7. Deformation (compression) in the road due to friction and weight

5. RESULTS AND ANALYSIS

The present invention relates generally to methods of electrical power generation, and more particularly is a method and device to generate electricity by using traffic on existing roadways to drive an electrical generator. Energy demand and heavy traffic correlation motivate to dream about a device in the road that would harvest the energy from the vehicles driving over it. For this, embed piezoelectric material beneath a road can provide the magic of converting pressure exerted by the moving vehicles into electric current. The method uses an electrical generation device installed beneath the roadbed. The electrical generation device includes a pressure plate covered with one or more protection layers which lie beneath the surface of the road.

The generators are embedded between the superstructure layers, and usually covered with an asphalt layer. When a car drives over the box, it takes the vertical force and compresses the piezoelectric material, thereby generating electricity. The energy-80 kilowatt-hours per kilometre of road for car traffic can be stored in a nearby battery or super capacitor, depending on the application, or sent directly to streetlights and other roadside devices. The energy being converted into electricity through piezoelectric effect is coming from motion of vehicle which will otherwise be wasted by heat when the road deforms under the weight of the car. The layer of piezoelectric material is stiffer than the road material it replaces, so it even saves a tiny amount of energy. Its displacement to voltage graph for automobile can be analyzed by the following simulated graph in Figure 8.

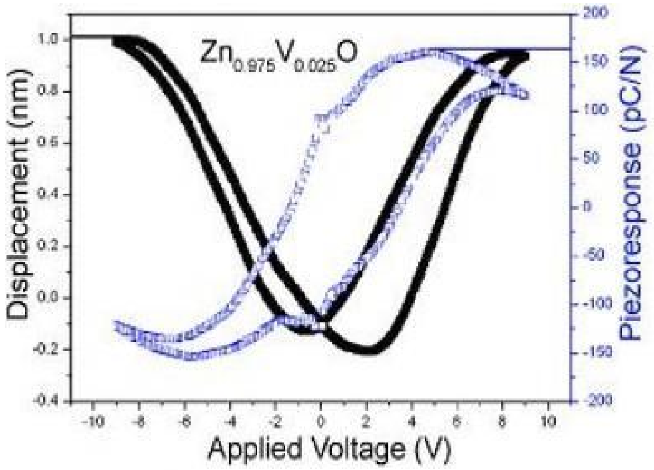

Figure 8. Displacement VS Applied voltage graph

6. CONCLUSION

At the time when governments are finding it hard to make land available for new power plants, extracting energy while using the vast spread of highways all over the world seems no less lucrative proposition. However, this idea has not yet gained enough ground among the policy makers even though researchers have shown that energy could be extracted from highways by fitting them with piezoelectric devices. The energy generating road designs could become a starting point for a self-sustaining future. We thus conclude that this thought will be a revolution in power production and curb down the energy costs thereby improving our country's economy. This energy is produced by consumers' participation without requiring any kind of input energy. In future, we will continue the work investigating the Energy Harvesting MEMS Devices that would results in the better production of without any useful input.

REFERENCES

[1] Jacques and Pierre Curie. "Développement par compression de l'électricité polaire dans les cristaux hémièdres à faces inclinées*". Development, via compression, of electric polarization in hemihedral crystals with inclined faces, Bulletin de la Société minérologique de France*. 1880; 3.
[2] Damjanovic, Dragan. "Ferroelectric, dielectric and piezoelectric properties of ferroelectric thin films and ceramics". *Reports on Progress in Physics*. 1998; 61(9): 1267.
[3] F Yi, SJ Dyke, JM Caicedo, JD Carlson. "Experimental verification of multi-input seismic control strategies for smart dampers".
[4] Sergey V. Bogdanov. "The origin of Piezoelectric effect on Pyroelectric crystal". IEEE transactions on ultrasonics, ferroelectrics, and frequency control. 2002; 49(11).
[5] Fang, Hua-Bin, et al. "Fabrication and performance of MEMS-based piezoelectric power generator for vibration energy harvesting". *Microelectronics Journal*. 2006; 37(11): 1280-1284.
[6] AKAI Y. WIPO Patent No. 2004077652. Geneva, Switzerland: World Intellectual Property Organization, 2004.
[7] Crawley, Edward F and Javier De Luis. "Embedded piezoelectric structure and control". U.S. Patent No. 4,849,668. 18 Jul. 1989.
[8] Jeon, Yongbae, et al. "Energy harvesting MEMS devices based on d33 mode piezoelectric Pb (Zr, Ti) O3 thin film cantilever". *CIRP Seminar on Micro and Nano Technology*, Copenhagen, Denmark. 2003.