DELHI TECHNOLOGICAL UNIVERSITY

“PIEZOELECTRIC SUBSTANCES”

APPLIED PHYSICS

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CANDIDATE'S DECLARATION

We, **Parth Johri** (2K20/B17/033), **Tushar Aggarwal** (2K20/B17/048) students of B.Tech Ist Year (Applied Physics) hereby declare that the project "PIEZOELECTRIC SUBSTANCES" which is submitted by us to the Department of Applied Physics, Delhi Technological University for — "APPLIED PHYSICS MID-TERM PROJECT 2021" in partial fulfilment of the requirement for the award of the degree of Bachelor of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi

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Date: 12/03/2021

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CERTIFICATE

I hereby certify that the project Dissertation titled “Piezoelectric Substances” which is submitted by Parth Johri , Tushar Aggarwal (2K20/B17/33, 2K20/B17/48) [Electronics and Communication Engineering & Mechanical Engineering], Delhi Technological University, Delhi in complete fulfilment of the requirement for the award of the degree of the Bachelor of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Dr. Pratibha Malik
(Assistant Professor)

Date: March’21

SUPERVISOR

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ABSTRACT

This report is made to highlight the importance of Piezoelectric substances , these substances generate electricity when they are subjected to pressure in such a way that there crystal lattice is affected ; we will not only discuss about these substances in detail but also tell about a number of applications of them in today's world. One of the applications is "**ENERGY HARVESTING**" i.e a method in which energy is derived from external sources, captured, and stored for small wireless autonomous devices like some used in electronics in the similar way the piezoelectric effect converts kinetic energy in the form of vibrations or shocks into electrical energy. Piezoelectric generators (energy harvesters) offer a robust and reliable solution by converting normally wasted vibration energy in the environment to usable electrical energy and what it holds for the future , this report is made to provide you with sufficient knowledge on this topic, we will cover all sorts of materials that are classified as piezoelectric substances as well as discuss about the ways in which piezoelectricity is being used in our daily life. The need for renewable sources of energy motivates us to dive into this topic and try to make models out of them which can be more efficient and affordable at the same time.

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ACKNOWLEDGEMENT

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CONTENTS

Introduction

Piezoelectric materials are materials that produce an electric current when they are placed under mechanical stress. the piezoelectric process is also reversible, so if you apply an electric current to these materials, they will actually change shape slightly... Piezoelectric substances produce Piezoelectricity Piezoelectricity is the electric charge that accumulates in certain solid materials in response to applied mechanical stress... Piezoelectricity is the creation of electric potential in certain materials when they are under mechanical stress, such as bending, stretching, or compressing. Physicists refer to this phenomenon as the piezoelectric effect. The materials that exhibit these characteristics are called piezoelectric materials.

The piezoelectric effect happens when the electric charge domains in the piezoelectric material are displaced under stress. Piezoelectric materials also exhibit the reverse property – called inverse piezoelectric effect – of changing shape in an electric field.

The Inverse property is due to the external electric field pushing the positive and negative charge crystals inside the material away from each other. Piezoelectric materials are used for making many household items such as inkjet printers and quartz watches, as well as industrial devices like sound generators and detectors.

Quartz and topaz are examples of naturally occurring piezoelectric materials. There are many other natural piezoelectric materials, but synthetic ferroelectric ceramics exhibit stronger piezoelectric effects and are far more affordable.

Hence, ceramic piezoelectric materials have been widely adopted by the industry.

Piezoelectricity is the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure and latent heat. Piezoelectric igniters are commonly used for butane lighters, gas grills, gas stoves, blowtorches, and improvised potato cannons.

Electricity Generation — Some applications require the harvesting of energy from pressure changes, vibrations, or mechanical impulses.

Piezoelectricity is the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, and biological matter such as bone, DNA and various proteins)in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure and latent heat. It is derived from the Greek word πιέζειν; piezein, which means to squeeze or press, and ἤλεκτρον ēlektron, which means amber, an ancient source of electric charge.

French physicists Jacques and Pierre Curie discovered piezoelectricity in 1880. The piezoelectric effect results from the linear electromechanical interaction between the mechanical and electrical states in crystalline materials with no inversion symmetry.

The piezoelectric effect is a reversible process: materials exhibiting the piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect, the internal generation of a mechanical strain resulting from an applied electrical field. For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension.

Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material. The inverse piezoelectric effect is used in the production of ultrasonic sound waves.

CHAPTER 1
ENERGY HARVESTING

Critical to self-charging power cell technology is the concept of energy harvesting, which is the collection of ―free‖ energy that a process generated.

This includes all sorts of processes, and the resulting energy could come in a variety of forms and from various sources. This power could come from inefficiencies in more conventional forms of power generation, for example. In 2013, we lost approximately 65 percent of the energy generated by natural gas, coal, nuclear and petroleum facilities. Six percent gets wasted during transmission and distribution.

We can also harvest energy from environmental sources, such as the sun and the wind. Smaller scale examples include heat from furnaces and mechanical energy created by walking or driving. Much of the work with energy harvesting has so far been done with smaller scale applications, such as batteries for small devices. When you use your smartphone, for instance, some of the energy gets wasted in the form of heat.
Energy harvesting, also known as energy scavenging, allows us to capture this energy, convert it to a usable form and direct it to a useful application.

CHAPTER 2
TYPES OF SELF-CHARGING POWER CELLS

Several different technologies for generating and storing energy within a single unit have emerged in recent years. They each are best suited to different kinds of devices and have unique challenges and benefits. Three prominent types are radio frequency, solar and piezoelectric power cells.

RADIO FREQUENCY

A startup called Nikola Labs has developed a smartphone case that plugs into the bottom of the phone and charges it by converting radio waves the phone receives from cell towers and wireless routers into energy the device can use to operate. Nikola says its charger can extend a smartphone‘s battery life by 25 to 30 percent. It works because it‘s located so close to the phone‘s radio transmitter and captures waves that the phone doesn‘t need for communication.

SOLAR

Researchers are also getting closer to creating a self-charging battery powered by light. Researchers at McGill University, in partnership with Hydro-Québec, incorporated photo-harvesting dye molecules into a lithium-ion battery cathode, which allowed the battery to use light to charge. The project is now moving into the second stage, which involves creating the storage portion of the cell. If they can succeed in creating a small, operational anode to store the solar energy, we could use it to charge smartphones and other small devices

PIEZOELECTRIC

One of the most promising methods for creating self-charging power cells uses piezoelectric material to convert mechanical energy directly into chemical energy. Researchers from the Georgia Institute of Technology recently published a study on a device that does just that.

The project began with a coin-type Li-ion battery. The researchers replaced the polyethylene separator between the two electrodes within the battery with a polyvinylidene difluoride, or PVDF, film. Because of its piezoelectric properties, when the PVDF is under applied stress, it generates a charge that causes Li-ions to move from the cathode to the anode, charging the battery.

CHAPTER 3
CHALLENGES TO CREATING SELF-CHARGING POWER CELLS

- Natural and industrial processes like this have always created excess energy, but it occurred in small doses that we were not able to capture and put to use in the past. Because the energy typically occurs in small amounts, the technology used to capture it needs to be extremely efficient to get enough power to be useful. It also needs to store the energy for long enough so it's available when needed.

- Additionally, the energy needs to be converted correctly for the intended use but still be able to tolerate irregular input. It can be difficult to know exactly how much charge will be created.

- These irregularities have also made energy harvesting technologies a rather unreliable way to generate energy. Users could not depend on it, and this limited its use.

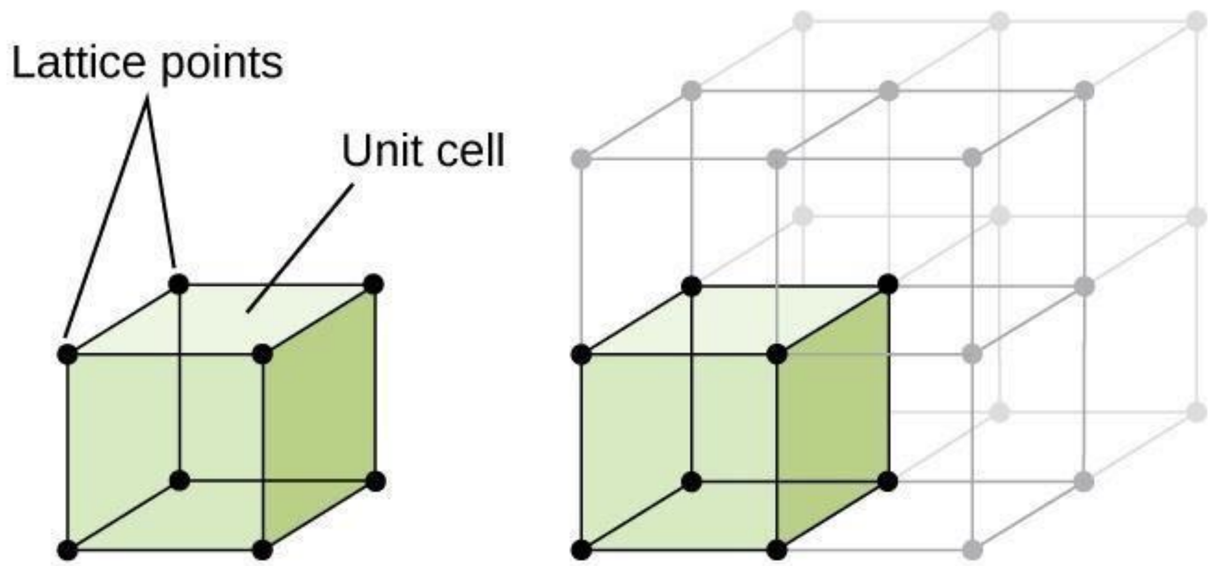
- Because the input is irregular, the energy-capturing device must be ready to generate power and provide an output of power whenever the user needs it to. Staying active in this way cannot take up too much energy because the energy comes in small doses, and that energy will be necessary to perform the desired function.

In short, *a self-charging* power cell must be able to generate, store and manage energy *highly* efficiently to work well enough to serve a useful function.

CHAPTER 4
HOW PIEZOELECTRICITY WORKS TO MAKE CRYSTALS CONDUCT ELECTRIC CURRENT

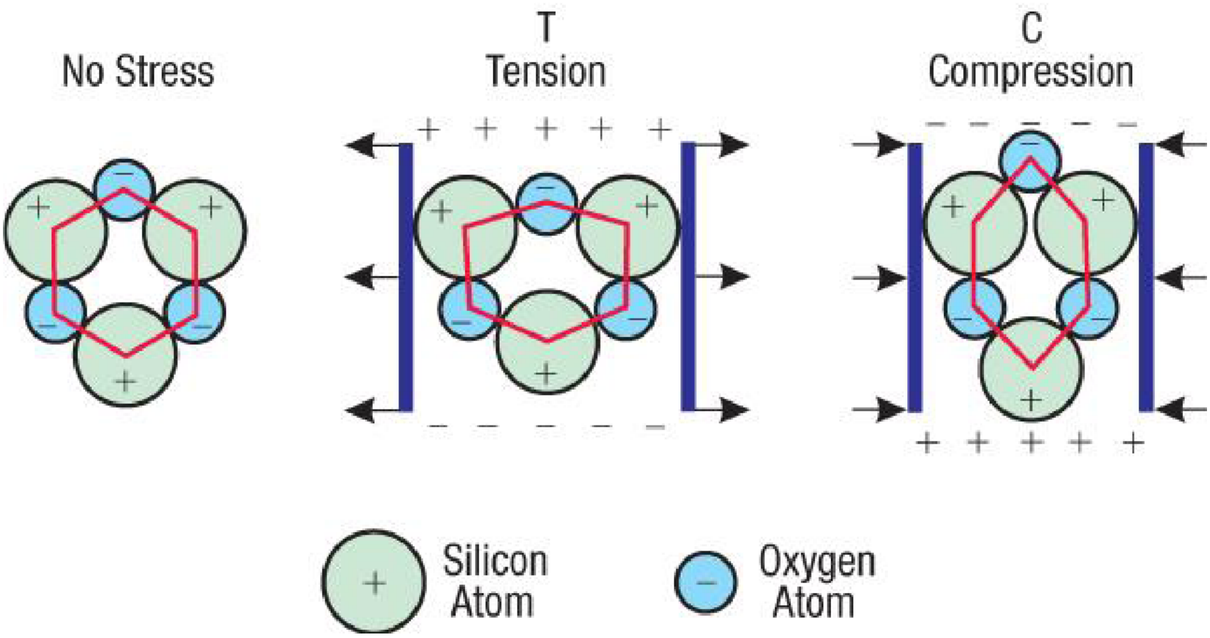
It sounds like a lot to take in, but it‘s simple to understand. The word piezoelectric originates from the Greek word piezein, which literally means to squeeze or press. Instead of squeezing grapes to make wine, we‘re squeezing crystals to make an electric current! Piezoelectricity is found in a ton of everyday electronic devices, from quartz watches to speakers and microphones. In a nutshell:

Piezoelectricity is the process of using crystals to convert mechanical energy into electrical energy, or vice versa. Regular crystals are defined by their organized and repeating structure of atoms that are held together by bonds, this is called a unit cell. Most crystals, such as iron have a symmetrical unit cell, which makes them.



There are other crystals that get lumped together as piezoelectric materials. The structure in these crystals aren‘t symmetrical but they still exist in an electrically neutral balance.

However, if you apply mechanical pressure to a piezoelectric crystal, the structure deforms, atoms get pushed around, and suddenly you have a crystal that can conduct an electrical current. If you take the same piezoelectric crystal and apply an electric current to it, the crystal will expand and contract, converting electrical energy into mechanical energy



Piezoelectric Effect in Quartz

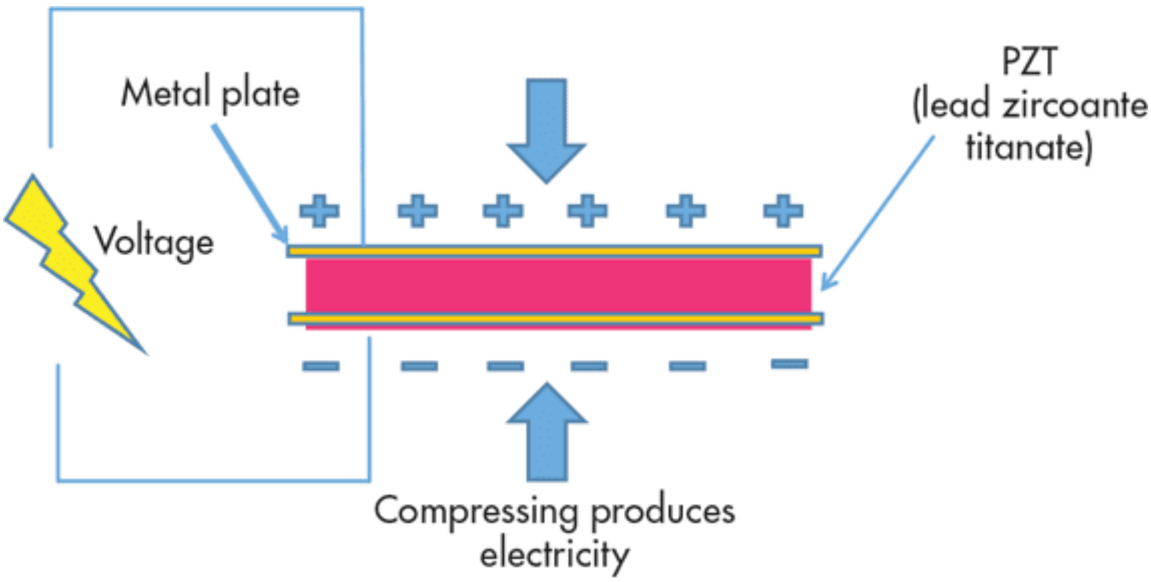
CHAPTER 5
WORKING OF PIEZOELECTRIC SUBSTANCES

We have specific materials that are suited for piezoelectricity applications, but how exactly does the process work?

With the Piezoelectric Effect the most unique trait of this effect is that it works two ways. You can apply mechanical energy or electrical energy to the same piezoelectric material and get an opposite result.

Applying mechanical energy to a crystal is called a **direct piezoelectric effect** and works like this:

1. A piezoelectric crystal is placed between two metal plates. At this point the material is in perfect balance and does not conduct an electric current.
2. Mechanical pressure is then applied to the material by the metal plates, which forces the electric charges within the crystal out of balance. Excess negative and positive charges appear on opposite sides of the crystal face.
3. The metal plate collects these charges, which can be used to produce a voltage and send an electrical current through a circuit.



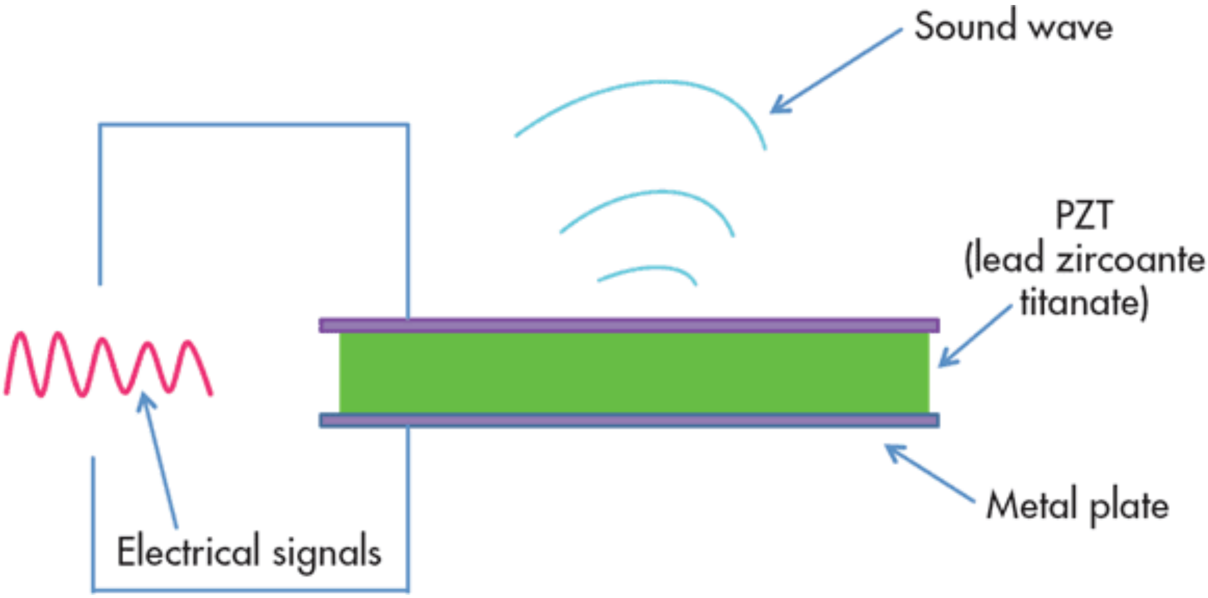
That's it, a simple application of mechanical pressure, the squeezing of a crystal and suddenly you have an electric current. You can also do the opposite, applying an electrical signal to a material as an **inverse piezoelectric effect.**

It works like this:

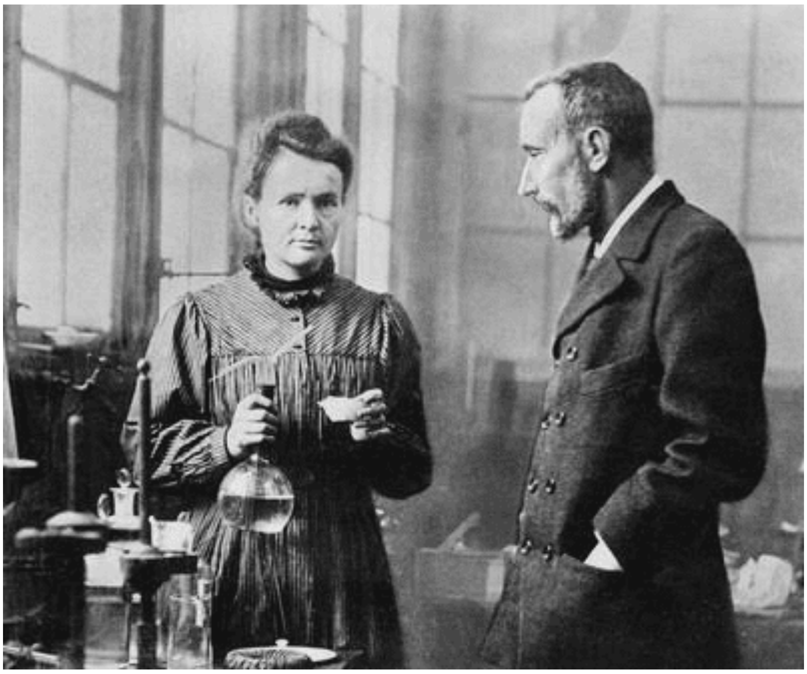
1. In the same situation as the example above, we have a piezoelectric crystal placed between two metal plates. The crystal‘s structure is in perfect balance.
2. Electrical energy is then applied to the crystal, which shrinks and expands the crystal‘s structure.
3. As the crystal‘s structure expands and contracts, it converts the received electrical energy and releases mechanical energy in the form of a sound wave.

The inverse piezoelectric effect is used in a variety of applications.

Take a speaker for example, which applies a voltage to a piezoelectric ceramic, causing the material to vibrate the air as sound waves.



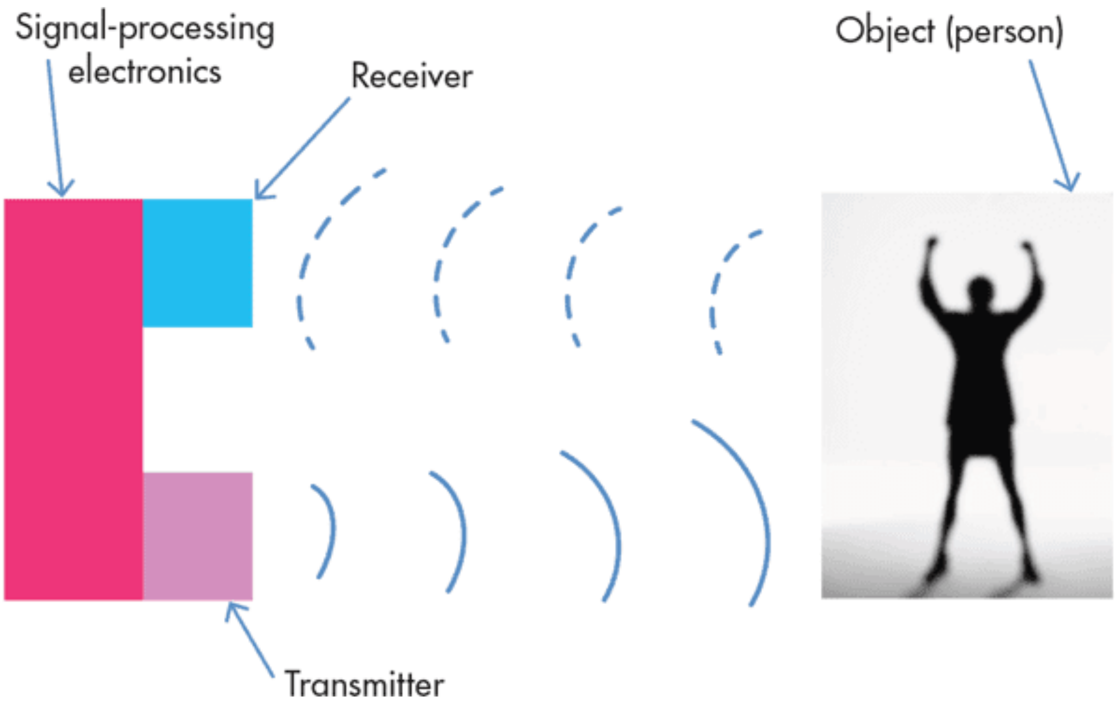
CHAPTER 6
THE DISCOVERY OF PIEZOELECTRIC SUBSTANCES



Piezoelectricity was first discovered in 1880 by two brothers and French scientists, Jacques and Pierre Curie. While experimenting with a variety of crystals, they discovered that applying mechanical pressure to specific crystals like quartz released an electrical charge. They called this the piezoelectric effect.

The next 30 years saw Piezoelectricity reserved largely for laboratory experiments and further refinement. It wasn‘t until World War I when piezoelectricity was used for practical applications in sonar.

Sonar works by connecting a voltage to a piezoelectric transmitter. This is the inverse piezoelectric effect in action, which converts electrical energy into mechanical sound waves.



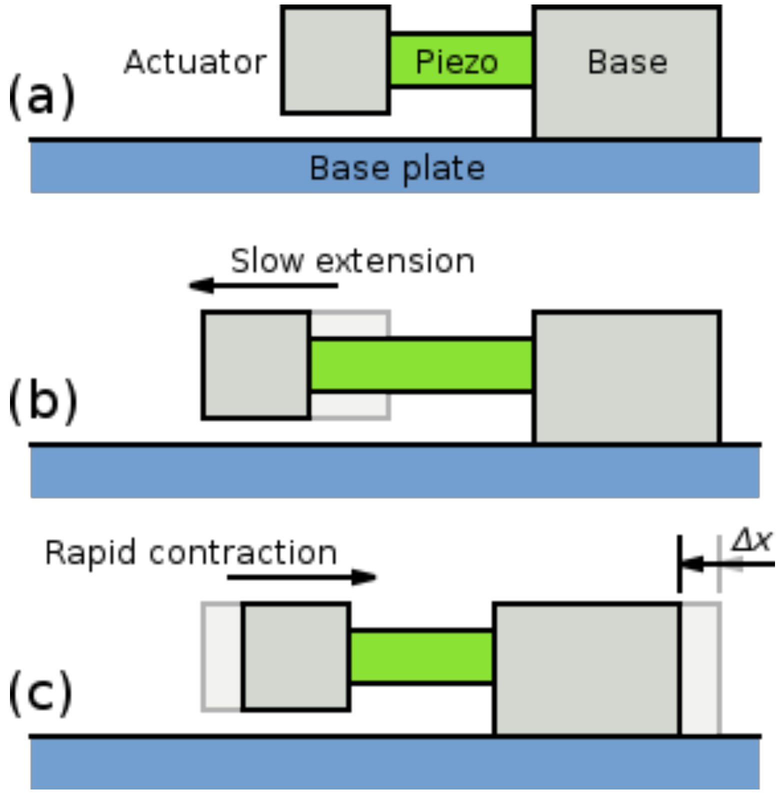
The sound waves travel through the water until they hit an object.
They then return back to a source receiver. This receiver uses the direct piezoelectric effect to convert sound waves into an electrical voltage, which can then be processed by a signal processing device. Using the time between when the signal left and when it returned, an object's distance can easily be calculated underwater.

With sonar, a success, piezoelectricity gained the eager eyes of the military.
World War II advanced the technology even further as researchers from the United States, Russia, and Japan worked to craft new man-made piezoelectric materials called ferroelectrics. This research led to two man-made materials that are used alongside natural quartz crystal, barium titanate and lead zirconate titanate.

CHAPTER 7
PIEZOELECTRICITY TODAY

In today's world of electronics piezoelectricity is used everywhere.
Asking Google for directions to a new restaurant uses piezoelectricity in the microphone.
There's even a subway in Tokyo that uses the power of human footsteps to power piezoelectric structures in the ground.
You'll find piezoelectricity being used in these electronic applications:

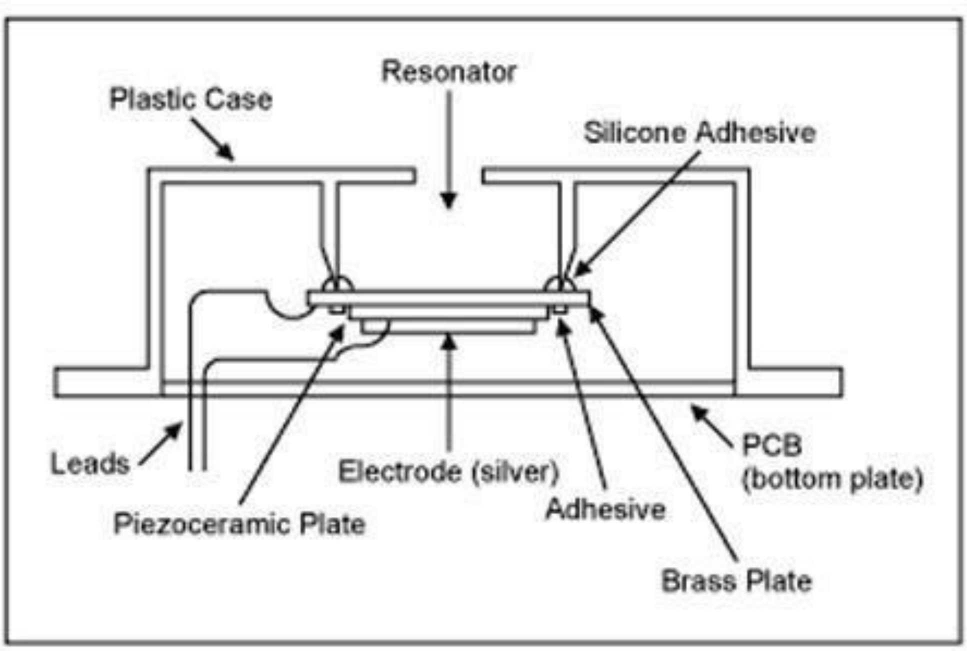
Actuators



Actuators use piezoelectricity to power devices like knitting and braille machinery, video cameras, and smartphones. In this system, a metal plate and an actuator device sandwiches together a piezoelectric material. Voltage is then applied to the piezoelectric material, which expands and contracts it. This movement causes the actuator to move as well.

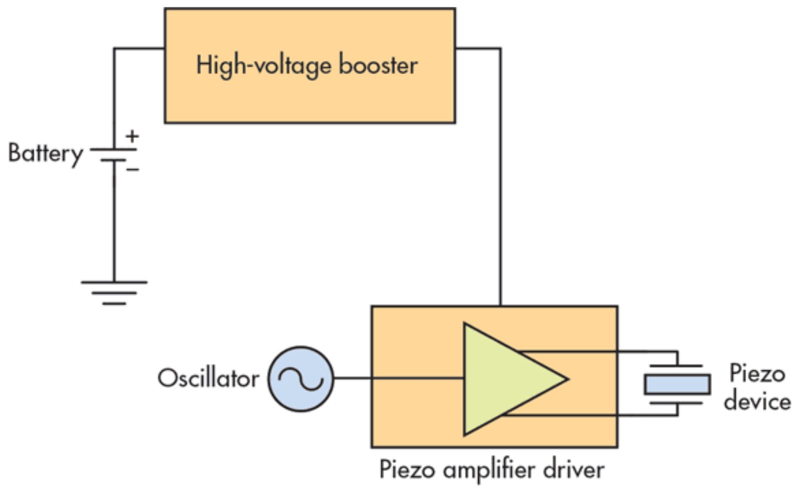
Speakers & Buzzers

Speakers use piezoelectricity to power devices like alarm clocks and other small mechanical devices that require high quality audio capabilities.
These systems take advantage of the inverse piezoelectric effect by converting an audio voltage signal into mechanical energy as sound waves.



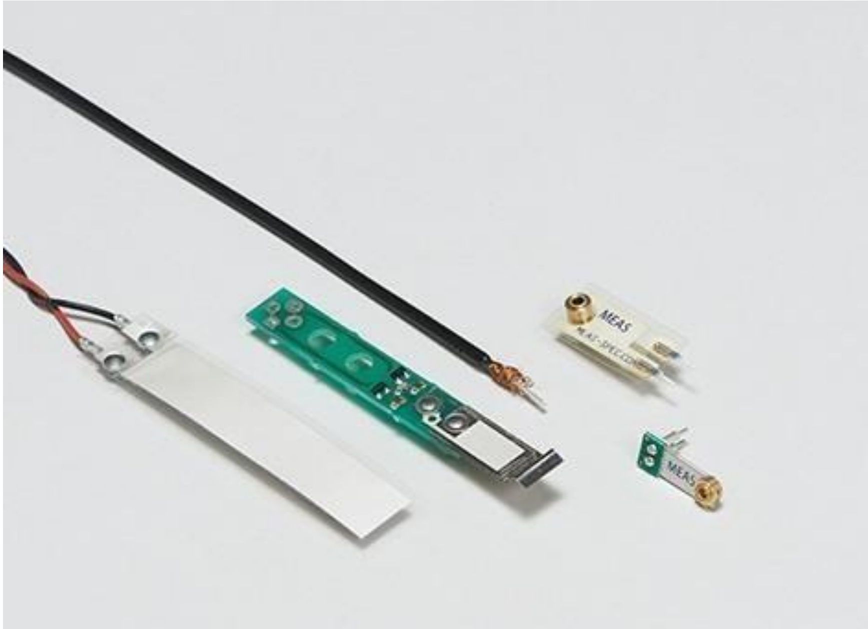
Drivers

Drivers convert a low voltage battery into a higher voltage which can then be used to drive a piezo device. This amplification process begins with an oscillator which outputs smaller sine waves. These sine waves are then amplified with a piezo amplifier.



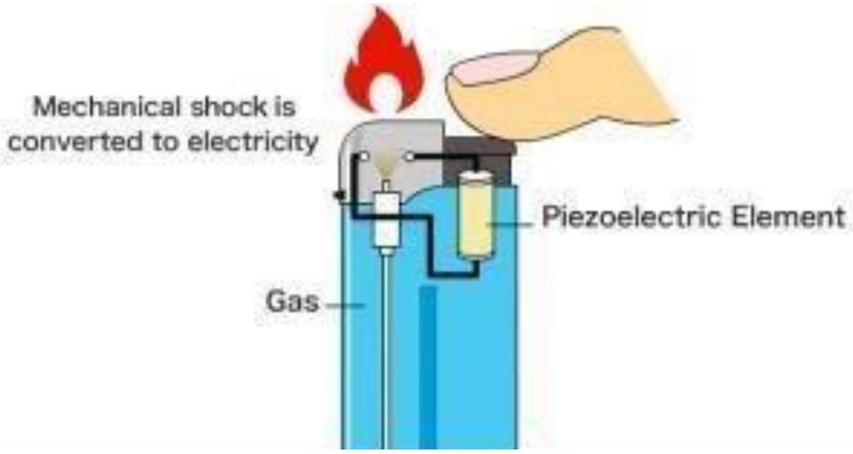
Sensors

Sensors are used in a variety of applications such as microphones, amplified guitars, and medical imaging equipment. A piezoelectric microphone is used in these devices to detect pressure variations in sound waves, which can then be converted to an electrical signal for processing.



Power

One of the simplest applications for piezoelectricity is the electric cigarette lighter. Pressing the button of the lighter releases a spring-loaded hammer into a piezoelectric crystal. This produces an electrical current that crosses a spark gap to heat and ignite gas. This same piezoelectric power system is used in larger gas burners and oven ranges



Motors

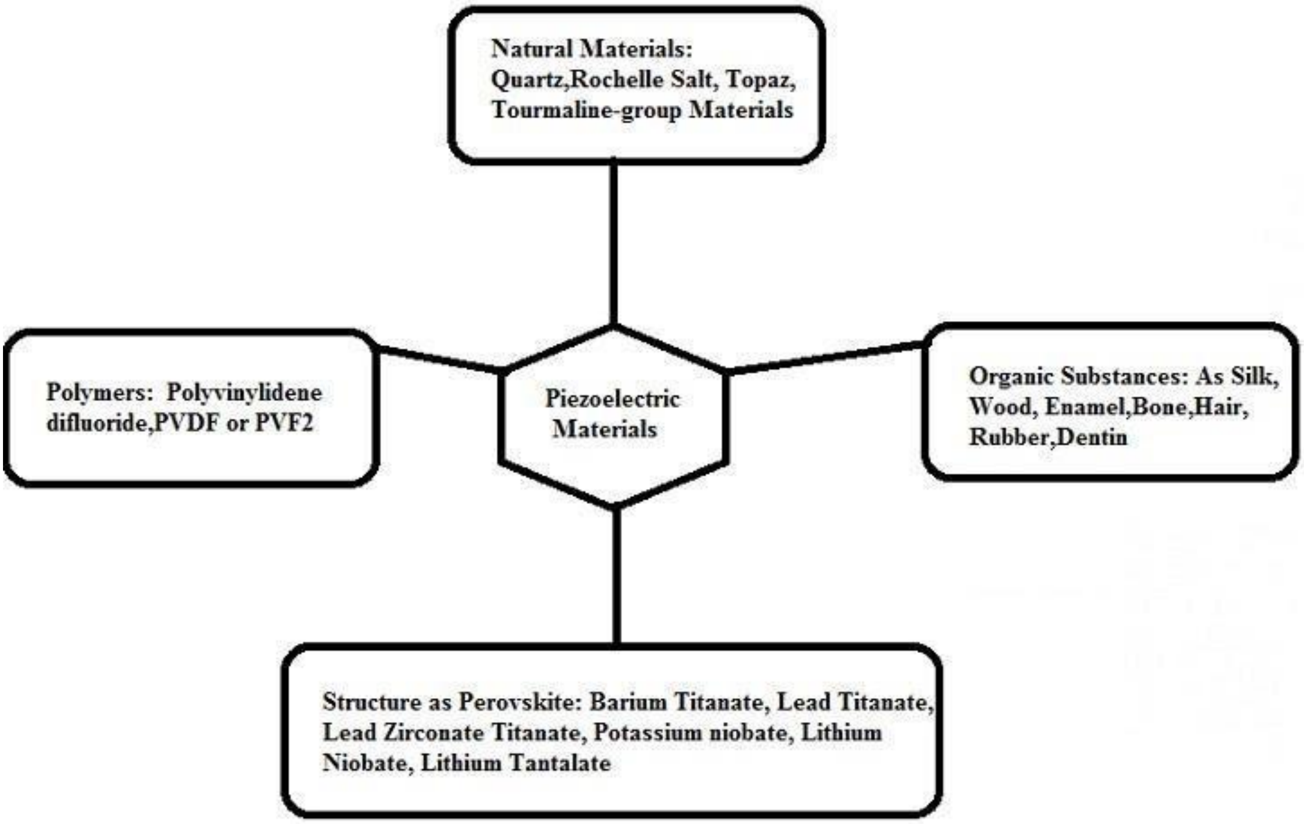
Piezoelectric crystals are perfect for applications that require precise accuracy, such as the movement of a motor. In these devices, the piezoelectric material receives an electric signal, which is then converted into mechanical energy to force a ceramic plate to move.

CHAPTER 8
TYPES OF PIEZOELECTRIC MATERIALS – PROPERTIES AND CHARACTERISTICS

With their amazing characteristic to produce electricity from unused vibrations of the devices, piezoelectric materials are emerging as revolutionary power harvesters. Owing to the research done on these materials, today there is a wide range of piezoelectric materials to choose from. Different specifications characterize these materials. But, how to choose a material for our requirement? What to look for? What are the types of piezoelectric materials? In this article, we look into different types of piezoelectric materials along with their properties. The article describes the five basic merits to look for while choosing a piezoelectric material for the product.

Types of Piezoelectric Materials

The different types of piezoelectric materials include the following:



8.1 TYPES OF PIEZOELECTRIC MATERIALS – PROPERTIES AND CHARACTERISTICS

1) **Natural Existing**
   These crystals are anisotropic dielectrics with non-centrosymmetric crystal lattice. Crystal materials like Quartz, Rochelle salt, Topaz, Tourmaline-group minerals, and some organic substances such as silk, wood, enamel, bone, hair, rubber, dentin come under this category.

2) **Man-Made Synthetic Materials**

   Materials with ferroelectric properties are used to prepare piezoelectric materials. Manmade materials are grouped into five main categories – Quartz analogs, Ceramics, Polymers, Composites, and Thin Films.

- Polymers: Polyvinylidene difluoride, PVDF or PVF2.

- Composites: Piezocomposites are the upgrade of piezopolymers.

  They can be of two types

  a) Piezo polymer in which piezoelectric material is immersed in an electrically passive matrix.
  b) Piezo composites that are made by using two different ceramics, example $BaTiO_3$ fibers reinforcing a PZT matrix.

- Manmade piezoelectric with crystal structure as perovskite: Barium titanate, Lead titanate, Lead zirconate titanate (PZT), Potassium niobate, Lithium niobate, Lithium tantalate, and other lead-free piezoelectric ceramics.

There are a variety of piezoelectric materials that can conduct an electric current, both man-made and natural.

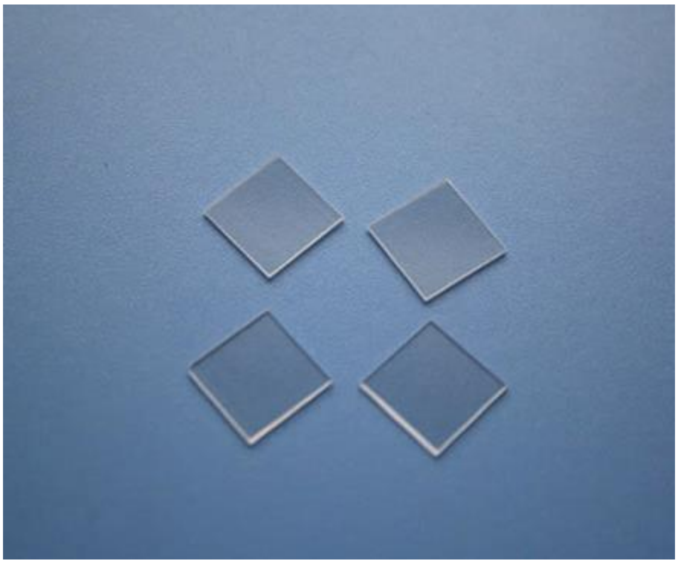
The most well known, and the first piezoelectric material used in electronic devices is the quartz crystal. Other naturally occurring piezoelectric materials include cane sugar, Rochelle salt, topaz, tourmaline, and even bone.

Quartz crystal.

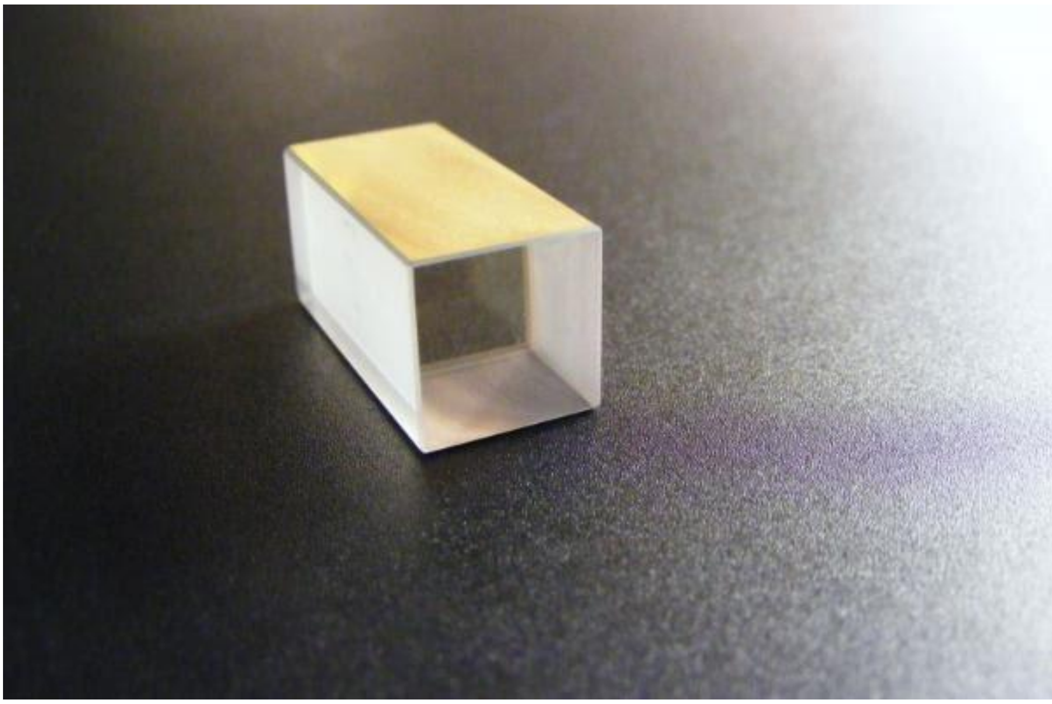
As piezoelectric technology started to take off after World War I we began developing man-made materials to rival the performance of quartz. Man- made piezoelectric materials include:

PZT is made from lead zirconate titanate and can produce more voltage than quartz with the same amount of mechanical pressure.
PZT piezo ceramics used in ultrasonic sensors.

Barium Titanate is a ceramic piezoelectric material that was discovered during World War II and is known for its long lasting durability.



Lithium Niobate is a material that combines oxygen, lithium, and niobium together in a ceramic material that performs similar to barium titanate.



8.2 PROPERTIES OF DIFFERENT PIEZOELECTRIC MATERIALS

The properties of different piezoelectric materials include the following.

<u>Quartz</u>

- Quartz is the most popular single crystal piezoelectric material. Single crystal materials exhibit different material properties depending on the cut and direction of the bulk wave propagation. Quartz oscillators operated in thickness shear mode of the AT-cut are used in computers, TV's and VCR's.

- In S.A.W. devices ST-cut quartz with X-propagation is used. Quartz has extremely high mechanical quality factor QM > 105.

<u>Lithium Niobate and Lithium Tantalate</u>

- These materials are composed of oxygen octahedrons.

- Curies temperature of these materials is 1210 and 6600c respectively.

- These materials have a high electromechanical coupling coefficient for surface acoustic waves.

<u>Barium Titanate</u>

- These materials with dopants such as Pb or Ca ions can stabilize the tetragonal phase over a wider temperature range.

- These are initially used for Langevin -type piezoelectric vibrators.

<u>PZT</u>

- Doping PZT with donor ions such as Nb5+ or Tr5+ provides soft PZT like PZT-5.
- Doping PZT with acceptor ions such as Fe3+ or Sc3+ provides hard PZT's like PZT-8.

<u>Lead Titanate Ceramic</u>

- These can produce clear ultrasonic imaging because of their extremely low planar coupling.
- Recently, for ultrasonic transducers and electromechanical actuators single

crystal relaxor ferroelectrics with morphotropic phase boundary (MPB) are being developed.

Piezoelectric Polymers

Piezoelectric polymers have certain common characteristics as

- Small piezoelectric d constant which makes them a good choice for the actuator.
- Large g constant which makes them a good choice as sensors.
- These materials have good acoustic impedance matching with water or the human body due to their lightweight and soft elasticity.
- Broad resonance bandwidth due to low QM.
- These materials are highly-opted for directional microphones and ultrasonic hydrophones.

Piezoelectric Composites

- Piezoelectric composites made up of piezoelectric ceramic and polymer phases form excellent piezoelectric materials
- High coupling factor, low acoustic impedance, mechanical flexibility characterizes these materials.
- These materials are especially used for underwater sonar and medical diagnostic ultrasonic transducer applications.

Thin films

- For bulk acoustic and surface acoustic wave devices thin films of ZnO are widely used because of their large piezoelectric coupling.

8.3 WHICH IS THE BEST PIEZOELECTRIC MATERIAL?

Piezoelectric materials are chosen based on the requirement of our applications. The material that could easily meet our requirement can be considered the best. There are a few factors to be considered while choosing piezoelectric materials.

The *five* important merits of piezoelectric are :

1. **The electromechanical coupling factor**

   k2=(Stored mechanical energy/ Input electrical energy)/
   k2=(Stored electrical energy / Input mechanical energy)

2. **Piezoelectric strain constant d**
   Describes the relation of magnitude of induced strain x to the electric field E as

   $$x = d.E.$$

3. **Piezoelectric voltage constant g**
   g defines the relation between the external stress X and induced electric field E as

   $$E= g.X.$$

   Using the relation P = d.X. we can state $g = d/\varepsilon_0 .\varepsilon$. where ε = permittivity.

4. **Mechanical quality factor QM**
   This parameter characterizes the sharpness of the electromechanical resonance system.

   $$QM= \omega_0/2\omega.$$

5. **Acoustic Impedance Z**
   This parameter evaluates the acoustic energy transfer between two materials. This is defined as

   $$Z2 = (\text{pressure/volume velocity}).$$

   In solid materials $Z = \sqrt{\rho}. \sqrt{c}$ where ρ is the density and c is the elastic stiffness of the material.

8.4 CHARACTERISTICS OF PIEZOELECTRIC SUBSTANCES

- Polymers have low piezoelectric constants compared to ceramics.

- Shape change of ceramic-based materials is more than that of polymer-based materials when the same amount of voltage is applied.

- Piezoelectric voltage coefficient of PVDF makes it a better material for sensor applications.

- Due to the larger electromechanical coupling coefficient, PZT is used in an application where mechanical stress has to be converted to electrical energy.

- Three parameters to be considered for selecting piezoelectric materials for applications working under mechanical resonance are the mechanical quality factor, electromechanical coupling factor, and dielectric constant.

  Higher the magnitude of these parameters best is the material for the application.

- Materials with large piezoelectric strain coefficient, large non-hysteretic strain levels are best for an actuator.

- Materials with high electromechanical coupling factor and high dielectric permittivity are best as transducers.

- Low dielectric loss is important for materials used in off-resonance frequency applications accounting for low heat generation.

Based on these physical, material, electromechanical properties we can easily distinguish between piezoelectric materials.

These properties helps us to choose the best piezoelectric material for our Application.

CHAPTER 9
PIEZOELECTRICITY AND THE FUTURE

What does the future hold for piezoelectricity?

The possibilities abound.
One popular idea that inventors are throwing around is using piezoelectricity for "**Energy Harvesting**"
(already discussed in chapter no 1).
Imagine having piezoelectric devices in your smartphone that could be activated from the simple movement of your body to keep them charged.

Thinking a bit bigger, you could also embed a piezoelectric system underneath highway pavement that can be activated by the wheels of traveling cars.

This energy could then be used in stop lights and other nearby devices.

In few years when a road will be filled with electric cars and you'd find yourself in a net positive energy situation.

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