A Review: Piezoelectric Materials

Tushar Kumar Mohanta
Assistant Professor
Department of Physics, St. Columba's College, VBU, Hazaribag

Abstract: Merely a small percentage of the ferroelectric and piezoelectric materials created in the last ten years are now being used in sensor applications. Transducers, actuators, and sensors have been able to be made from synthetic piezoelectric crystals (like quartz, as opposed to natural quartz), ceramics, polymer sheets, and thin and thick films in recent years. Transistors, solar cells, and light-emitting diodes are popular semiconductor devices; however, co-integration of additional active materials and component classes is sometimes required due to application requirements. Over the past few years, piezoelectric materials have become widely used in a number of science and technology disciplines, including health, electronics, the military, and the oil industry, thanks to a number of fascinating properties.

INTRODUCTION

Nobel laureates Pierre and Jacques Curie discovered piezoelectricity, or pressure electricity, in 1880 [1] while investigating how pressure affected the way crystals like quartz, tourmaline, and Rochelle salt generated electrical charge. In actuality, the term "piezoelectric effect" refers to the formation of an electrical charge in response to mechanical pressure or vice versa. The primary disadvantage of natural piezoelectric materials is their low piezo-electricity. The discovery of PZT and BaTiO3 in the 1950s [2, 3] was a significant advancement, and the family of these materials showed extremely strong dielectric and piezoelectric capabilities. With a permanent presence in the field of material science and engineering, PZT is currently one of the most extensively used and exploited piezoelectric materials. With a global market estimated to be worth tens of billions of dollars, they are frequently employed as hydrophones, multilayered capacitors, sensor and actuator devices [4–7], and more. Lead oxide, a component of PZT, is extremely hazardous, and this toxicity is increased when it volatilizes at high temperatures, especially during calcination and sintering, which pollutes the environment [8]. Because materials technology has had such a significant impact on the development of human society, history has been split into various historical periods (e.g., the Stone, Bronze, and Iron Ages) based on the materials that dominated during these eras. The usage of plastic, composites, and other well-designed, man-made engineering materials that outperform traditional materials characterizes the so-called Engineering Materials Age, often referred to as the Synthetic Materials Age, which is currently in effect. However, because these engineering materials and structures are usually preprocessed and designed to react to a limited set of external stimuli, they have acquired the reputation of being "dumb." These reactions are designed to accommodate the broadest variety of probable contexts in which a structure or substance might be used, but they are typically not the most efficient option in a given set of conditions. Recent developments in a number of emerging technologies, such as biotechnology, biomimetics, nanotechnology, and information technology, will usher in the Smart Materials Age at the start of the twenty-first century.

Piezoelectric Effect

The ability of an object to generate an electrical field in response to strain or stress is known as piezoelectricity. Many solid materials, such as crystals, ceramics, and biological components like bones, proteins, and DNA, accumulate electric charge. The electrical charge increases when these materials are heated or put under mechanical stress. The name "piezoelectric" originates from the Greek words "piezein" and "piezo," which mean "to press or squeeze something" and "push," respectively. Piezoelectricity is generated as a result of the piezoelectric effect. In crystals having piezoelectric properties, mechanical quantities like stress or strain are related to electrical parameters like electric field and electric displacement. The phenomena known as "electromechanical coupling" is described.

Piezoelectric materials

A class of materials known as piezoelectric materials has the unusual ability to deform in the presence of an electric field or to produce an electric charge in response to mechanical stress. They are employed in many different applications where it is necessary to convert mechanical energy into electrical energy and vice versa because of this feature. Quartz, piezoceramics, piezoelectric polymers, gallium phosphate, potassium sodium tartrate, or Rochelle salt are a few typical examples of piezoelectric materials. Piezoelectric materials find use in many fields, such as nanotechnology, acoustics and audio, automotive, medical, energy harvesting, aerospace, defense, mechanical engineering, consumer electronics, robotics, environmental monitoring, civil engineering, and infrastructure monitoring. The mechanism whereby these materials produce an electric charge in proportion to the applied mechanical stress is known as the "direct piezoelectric effect." On the other hand, they undergo strain proportionate to the applied field when exposed to an electric field; this phenomenon is referred to as the inverse piezoelectric effect. Piezoelectric materials have been widely used in commercial applications for the past fifty years, including energy-harvesting devices, actuators, and sensors [9]. They are useful for sensing and measuring physical variables like pressure, tension, and acceleration because of their inherent capacity to transform mechanical energy into electrical impulses and vice versa. Due to its remarkable qualities and affordability, lead zirconate titanate (PZT) is regarded as one of the best options among many classes of piezoelectric materials and is the material of choice for many applications in a variety of industries [10]. With greater piezoelectric constants, PZT and La-doped PZT have both shown exceptional piezoelectric performance. as d33 and d31, which improve the device's overall performance and sensitivity [11]. Lead-based materials have also attracted a lot of attention in the field of ultrasonic imaging because of their exceptional sensitivity, which makes it possible to accurately detect and analyze high-frequency sound waves. This attribute has been crucial in raising the general standard and accuracy of ultrasonic imaging methods. Its potential to revolutionize non-invasive imaging of numerous organs and tissues also extends to the realm of medical diagnostics.

Fundamentals of Piezoelectricity and Ferroelectricity:

A material exhibiting piezoelectricity has a non-centrosymmetric crystal structure. One of the most widely used natural crystals with a non-centrosymmetric structure in piezoelectric devices is quartz. An electric charge develops on the surface of such a crystal when pressure is applied. We call this effect the direct piezoelectric effect. An electric field causes the crystal to become distorted. The term "inverse piezoelectric field" refers to this phenomenon (Fig.1). After several decades after its discovery, the phenomenon of piezoelectricity was exploited commercially for the first time in ultrasonic submarine detectors developed during World War I. Later, scientists manufactured ceramics made of barium titanate (BaTiO3) as a piezoelectric ceramic material. As with other piezoelectric ceramics, BaTiO3 (BT) displays spontaneous polarization due to non-uniform shifting of the negative ion center relative to the positive ion center in the crystallographic unit cell. This results in a non-centrosymmetric structure, as illustrated in Fig. 2.

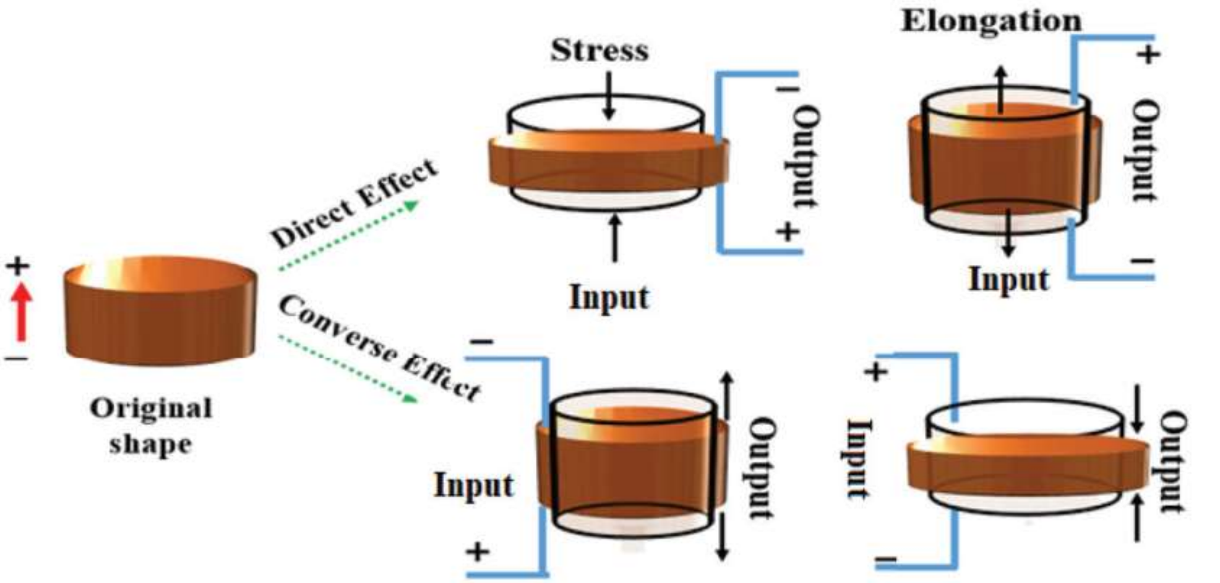

Fig.1. Direct and converse piezoelectric effect.

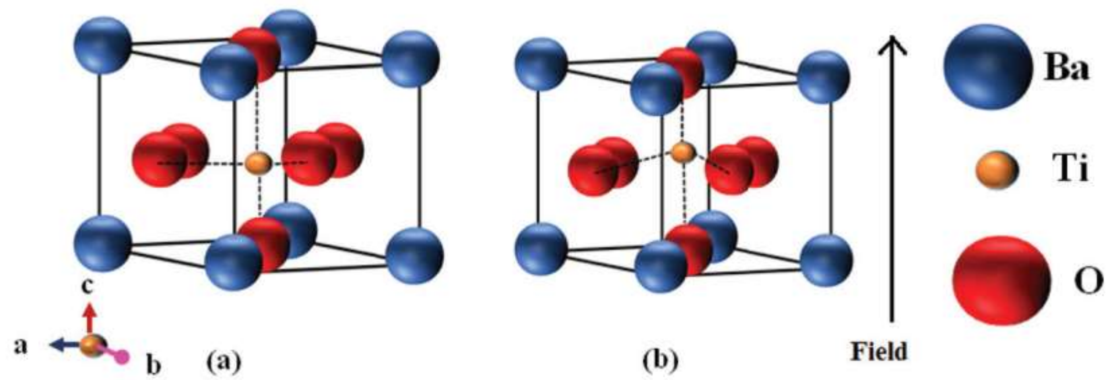

Fig.2.(a) Centrosymmetric and (b) non-centrosymmetric representation of the ABO_3 perovskite structure

Barium titanate is a member of the perovskite structure ABO3, where B-cations (O3) are found at the unit cell's face centers and A-cations (Ba) occupy the A-site. At high temperatures, BT exhibits a centrosymmetric cubic phase. Upon cooling, it experiences a sequence of phase transitions, including tetragonal, rhombohedral, orthorhombic, and monoclinic phases. Curie temperature is consistent with the location of the first non-centrosymmetric structural transition upon cooling. Different areas of the material from higher symmetry of the crystal structure experience a crystallographic orientation when cooling through the Curie temperature; these regions are referred to as the domain. realm walls are distinct areas that divide each realm.

The phenomenon known as ferroelectricity occurs when an electric field acts upon a material and causes its spontaneous polarization to change directions. The coercive field, which is connected to the motion of ferroelectric domain walls, is the electric field required for the directional change to happen. At the macroscopic length scale, polycrystalline ceramics show no net spontaneous polarization or piezoelectricity after cooling from the high manufacturing temperatures.

Use of direct piezo effect

- ✓ The world's first piezoelectric floor was constructed at a London nightclub in 2008. It produces electricity when people dance on it, which may be used to power lightbulbs.
- ✓ Piezoelectric effect finds application in bulk and surface acoustical wave equipment, mechanical frequency filters, etc.
- ✓ Ultrasonic imaging, speakers and microphones for sound and ultrasound, hydrophones.
- ✓ Piezoelectric guitar pickups and biosensors are powered by Pacemaker.
- ✓ Piezoelectric components find application in single and dual-axis tilt sensing, as well as in the creation and detection of sonar waves.

Uses of converse piezoelectric effect

- ✓ Miniature motors,
- ✓ printer needle drivers,
- ✓ Motors and actuators
- ✓ microscope lens positioning,
- ✓ Fuel valves for automobiles with injecting mechanisms
- ✓ Actuators with numerous layers for accurate positioning in optics; etc.

Advantages of Piezoelectric Materials

- Piezoelectric materials are the best alternative to fossil fuels since they can work in any temperature range,
- Best capturing energy
- Recycled
- Produce green energy.

Limitations of Piezoelectric Materials

- Resistance and durability limit
- Discrepancy in stiffness between pavement and piezoelectric materials.

Piezoelectric Materials are necessary for the Sensor

The optimum materials for transduction components in sensors should possess the following qualities:

- ➢ Strong piezoelectric sensitivity.
- ➢ High stiffness
- ➢ Electrically good insulation strength
- ➢ Few hygroscopic properties
- ➢ Hysteresis is absent
- ➢ All properties are highly stable
- ➢ Good machinability
- ➢ Cheap manufacture

Quartz

Quartz is the most important single crystal that is still utilized as a transducer in piezoelectric sensors. It appears in a number of forms and has the chemical formula SiO_2. Every piezoelectric crystal has one or more polar axes, which is a common feature. A polar axis in crystallography is distinguished by having non-equivalent front and rear ends, meaning that a rotation of an axis perpendicular to the polar axis by an angle of 180° does not return the respective crystal to its initial position [12]. It is composed of oxygen tetrahedrons with silicon centers. Quartz is altered at temperatures below 573°C in order to be used in piezoelectric applications. It belongs to the 32-symmetry original-trapezoid trigonal (original) crystalline method and is commonly called α-quartz [13]. Quartz has a density of 2649.10^3 kg/m and a Mohs hardness of 7. It is resistant to most acids and alkalis and essentially dissolves in water. It melts quartz at 1710°C.

Lead Zirconate Titanate (PZT)

PZT, an acronym for solid solutions with nominal compositions of 52–54 moles percent lead zirconate (PbZrO3) and 46–48 moles percent lead titanate (PbTiO3), is the foundation for a significant number of piezoelectric ceramic sensor formulations. PZT is the official trademark licensed by Clevite Corporation. PZT is a significant ferroelectric substance that forms perovskites. The unit cell's face centers are made up of oxygen atoms, while its corners are made up of lead atoms. The radius of Pb and O2 ions is approximately 1.4 Å. Together, they form a face-centered, four-dimensional cubic pattern. The center of the whole cell is home to octahedral titanium or zirconium ions.

Applications of Piezoelectric Materials

- For hydrophone
- Sensing devices
- Ultrasonic sensors
- Transducers
- Thermistors.

Conclusion:

This article gives the basic idea about piezoelectric effect, piezoelectric material (PZT), advantage of piezoelectric material. All these characteristics informed that it can be applicable for sensor.

References:

1. Curie J, Curie P (1880) Bulletin de la Societe Mineralogique de France 3:90.
2. Jaffe B, Jaffe H, Cook WR (1971) Piezoelectric ceramics, 1st edn. Academic Press, London.
3. Haertling GH (1991) In: Buchanan RC (ed) Piezoelectric and electro-optic ceramics in ceramic materials for electronics, 2nd edn. Marcel Dekker, New York.
4. Uchino K (1993) Mater Res Bull 18:42.
5. Newnham RE (1998) Functional composites for sensors and actuators: smart materials. The Pennsylvania Academy of Science, PA, USA.
6. Sahoo B, Jaleel VA, Panda PK (2006) Mater Sci Eng B 126:80.
7. Sahoo B, Panda PK (2007) J Mater Sci 42:4270. doi:https://doi.org/10.1007/s10853-006-0687-2.
8. Yugong W, Zhang H, Zhang Y, Jinyi M, Daohua X (2003) J Mater Sci 38:987.

9. Kang M G, Jung W S, Kang C Y, Yoon S J. Recent progress on PZT based piezoelectric energy harvesting technologies, Actuators **5**(5), 1–17,2016.

10. Vacca M, Graziano M, Chiolerio A, Lamberti *A.* Electric clock for NanoMagnet Logic Circuits, Field-Coupled Nanocomputing, Paradigms,Progress, and Perspectives, Springer, Italy, **1**(1), 73–110, 2014.

11. Thakur O P, Prakash C. Structural, dielectric and piezoelectric properties of PLZT (x/60/40) ceramics, Integrated Ferroelectrics: An International Journal **122**(1), 100–107, 2010.

12. W. Raith, L. Bergmann, C. Schaefer, Lehrbuch der Experimentalphysik, Bd. 2: Elektromagnetismus, 9th ed., Berlin, Walter de Gruyter, 2006.

13. M. Okrusch, S. Matthes, Mineralogie: Eine Einf¨uhrung in die spezielle Mineralogie, Petrologie und Lagerst¨attenkunde, 7th ed., Berlin, Springer, 2005