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Analysis between Piezoelectric and Ferroelectric Materials

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Abstract:
The key distinction between piezoelectric, pyroelectric, and ferroelectric effects is that the piezoelectric effect is the generation of a surface charge in response to the application of external stress to a material, whereas the pyroelectric effect is the change in a material's spontaneous polarisation in response to a change in temperature. The ferroelectric effect, on the other hand, is a change in surface charge in response to a change in spontaneous polarisation.
Keywords:
Piezoelectricity and Ferroelectricity, Piezoelectric Materials, Ferroelectric Materials, Direct Piezoelectric Effect, Inverse Piezoelectric Effect.

I. Introduction:

Piezoelectric Materials

We can use piezoelectricity to convert electrical energy to mechanical energy and vice versa. When an electric field is applied to a substance, the electrons and nuclei assume new geometric positions, and the mechanical dimensions of the substance change. This is referred to as electrostriction. The reverse effect, i.e. the production of polarisation by mechanical stresses, can occur only if the lattice lacks a centre of symmetry; this phenomenon is known as piezoelectricity. Examples include Rochelle salt, quartz, and barium titanate.

Piezoelectric materials lack a crystallographic unit cell centre of symmetry. As a result, when a stress is applied to the crystal, the ions displace and the positive and negative charge centres separate. As a result, the material can convert mechanical energy (stress) to electrical energy (charge) in either direction. For improved piezoelectric performance, our team investigated aluminium nitride-based alloys. We are also investigating the ferroelectric response of high scandium content (Al,Sc)N and related materials. [1]

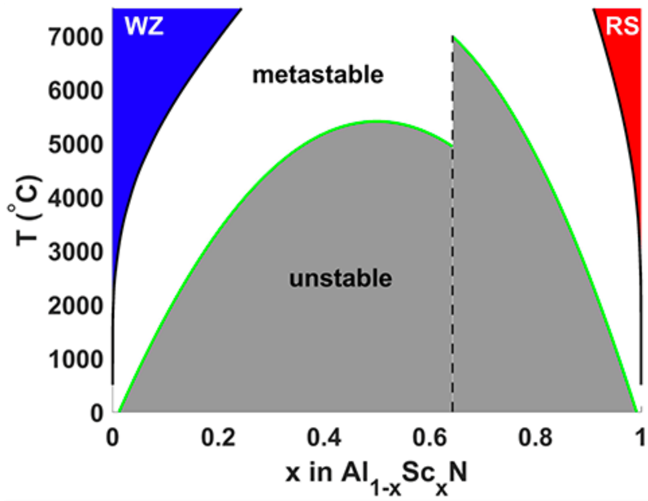

Figure 1: Piezoelectric Materials

Ferroelectric Materials

Ferroelectric materials have a high dielectric constant that is non-linear, meaning that it is highly dependent on the intensity of the electric field. These materials have hysterisis loops, which means that the polarisation is not a linear function of the applied electric field. An electric dipole moment exists when the centres of gravity of positive and negative charges in a body do not coincide in the absence of an applied electric field. As a result, the material is said to be spontaneously polarised and is known as ferroelectric material. This type of substance is known as ferroelectric. It has small regions called ferroelectric domains in which all dipoles are parallely oriented, but in the absence of an external electric field, different domains are randomly oriented. When the temperature rises above a certain threshold known as the Curie point, the substance loses its ferroelectric properties. Examples include Rochelle salt, potassium dihydrogen phosphate, and barium titanate. [2]

Ferroelectrics are a subset of piezoelectrics in that their unit cell has spontaneous polarisation (remains without applied field) that can be reoriented by applying an electric field. These are determined experimentally. Aside from (Al,Sc)N ferroelectric alloys, our team is also interested in the discovery and benchmarking of nitride perovskites. While oxide perovskites are well known for having useful piezoelectric and ferroelectric properties, nitride perovskites are relatively unknown.

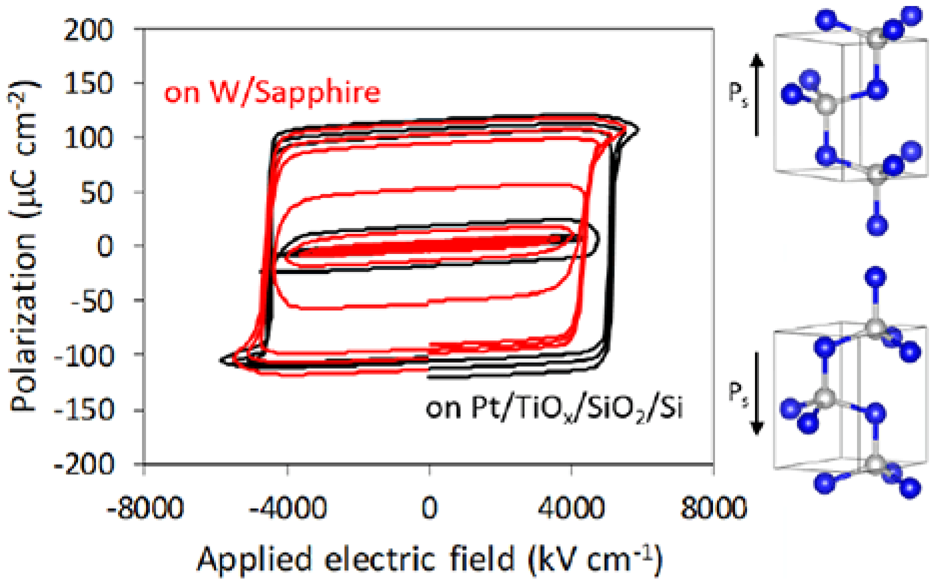

Figure 2: Ferroelectric Materials

Objectives:

1. Explain Piezoelectric Materials
2. Explain Ferroelectric Materials
3. Difference Between Piezoelectricity and Ferroelectricity.
4. Difference Between Ferroelectric and Piezoelectric Materials.

II. Result and discussion:

This study compares Piezoelectricity vs Ferroelectricity and discusses the differences between the two.
Piezoelectricity:

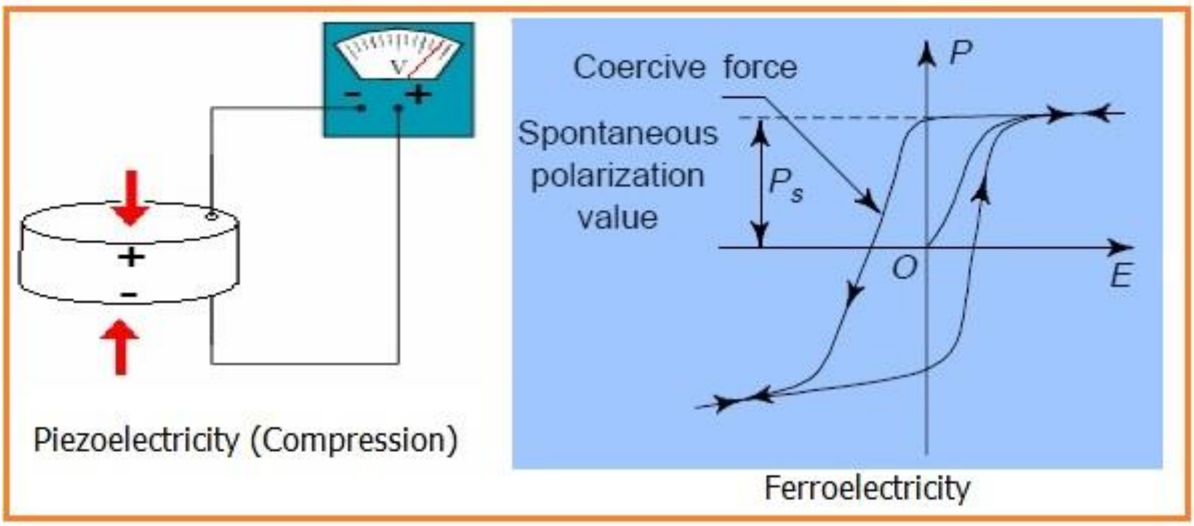

Figure 3: Piezoelectricity Vs Ferroelectricity effect of Compression.

Definition:
The term "piezoelectricity" refers to electricity generated through the application of pressure. Piezoelectricity, in other words, is the electric charge that accumulates in certain solid materials when mechanical stress is applied. Crystals, ceramics, and biological materials such as DNA and bone are among the materials used. Figure 1 depicts the effect of compression.

Direct Piezoelectric Effect:
When mechanical stress is applied to this material, it generates electric potential. Compression reduces volume and produces voltage with the same polarity as the material. The figure depicts this. When tension is applied, the volume increases and a voltage with polarity opposite to the material is produced.

Inverse Piezoelectric Effect: When an E-field is applied to this type of material, it shortens or lengthens proportionally to the voltage applied.
The basic equations for piezoelectricity are as follows. [3]
P =D x Stress ... Equation-1
E = Strain/D ... Equation-2
Where,
P = Polarization
E = Generated Electric Field
D = Piezoelectric coefficent (in meters/volt)

Ferroelectricity:
"Ferroelectricity" refers to the property of certain nonconducting crystals or dielectrics that exhibit spontaneous electric polarisation. By applying an appropriate electric field, this polarisation can be reversed. This is depicted in figure-4.
For more information on the material types used in Piezoelectricity and Ferroelectricity, see Ferroelectric vs Piezoelectric.
This Ferroelectric vs Piezoelectric study discusses the differences between ferroelectric and piezoelectric materials. [4-5]
The properties of ferroelectric and piezoelectric materials are derived from a combination of structural and electrical properties. Both types of materials, as the name implies, have electric properties.
Piezoelectric substance
The piezoelectric material has the ability to convert mechanical energy into electric energy and vice versa. The piezoelectric materials are classified into two types: crystals and ceramics. [6]

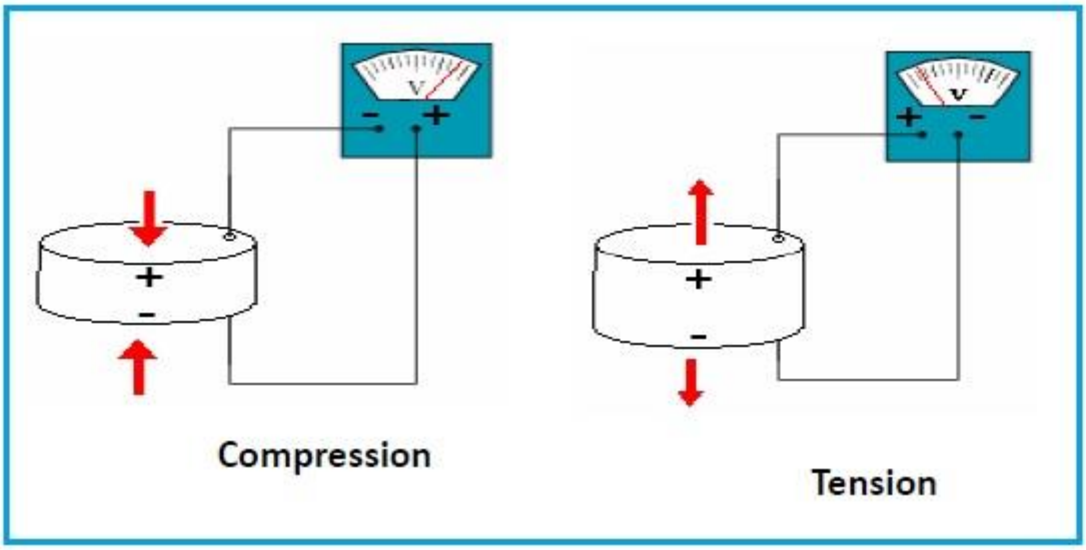

Figure 4: Direct Piezoelectric Effect

When piezoelectric materials are subjected to mechanical stress, they produce electrical potential. This direct piezoelectric effect can be found in strain sensors, petrol lighters, microphones, ultrasonic detectors, and other devices. [7]

Figure 4 depicts the direct piezoelectric effects of compression and tension.
Compression Effect: When volume is reduced, voltage with the same polarity as the material appears.
Tension Effect: As volume is increased, voltage with opposite polarity as material appears.

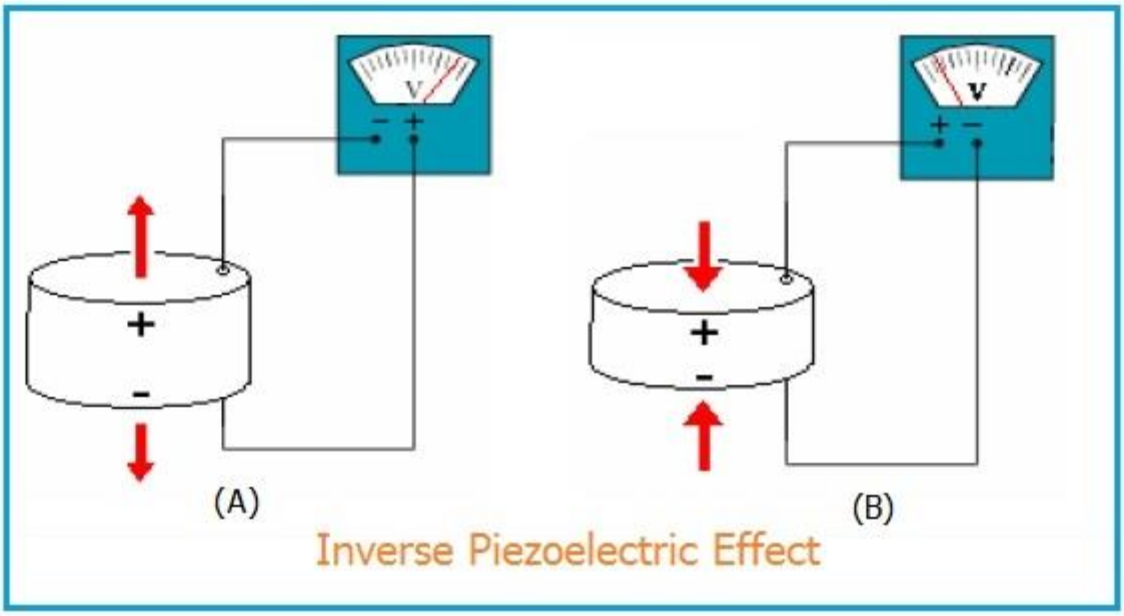

Figure 5: **Inverse Piezoelectric Effect**

When the Piezoelectric material is exposed to an electric field (i.e. voltage), it lengthens or shortens proportionally to the voltage. This inverse piezoelectric effect can be found in crystal speakers, crystal oscillators, actuators, record player pick ups, and other electronic devices.

- As shown in Figure 5(A), if the applied voltage has the same polarity, the material expands.
- As shown in Figure 5(B), if the applied voltage has the opposite polarity, the material contracts.

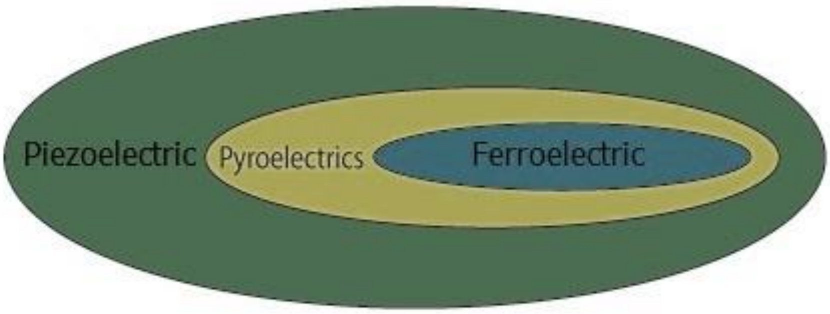

Figure 6: Ferroelectric vs Piezoelectric

A large number of ferroelectric materials are also piezoelectric. However, the opposite is not true. [9]
The table below summarises the differences between piezoelectric and ferroelectric materials. [10]

Table 1: Comparison Between Piezoelectric and Ferroelectric Material

Features	Piezoelectric	Ferroelectric
Characteristics	Generates electric potential when subjected to mechanical energy (viz. compression or tension) is applied.	Polarization can be changed and reversed with the applied external electric field.
Material classes	Organic, Ceramic, single crystal	Organic, Ceramic
Examples of materials	PVF2, PZT, PLZT, Quartz, LiNbO3	PVF2, Liquid Crystals, PZT (Lead [Pb], Zirconate, Titanate) thin film
Applications	actuator, transducer, optical, frequency control, SAW devices, ultrasonic receiver	non-volatile memory, displays

III. Conclusion:

While all ferroelectric materials are piezoelectric as well, not all piezoelectric materials are ferroelectric. Mechanical energy is converted into electric energy by a piezoelectric material. When piezoelectric materials are subjected to physical stress, such as stretching, bending, or compression, they develop electric potential due to the reorganisation of charge domains within the material. An inverse effect occurs as well: when exposed to an external electric field, piezoelectric materials change shape.

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