Ferroelectricity

The phenomenon of ferroelectricity was discovered in 1921 by J. Valasek who was investigating the dielectric properties of Rochelle salt ($NaKC_4H_4O_6.4H_2O$). Barium titanate ($BaTiO_3$) was discovered to be ferroelectric in 1944 by A von Hippel and is perhaps the most commonly thought of material when one thinks of ferroelectricity. While there are some 250+ materials that exhibit ferroelectric properties, some of the more common/significant materials include: Lead titanate, $PbTiO_3$, Lead zirconate titanate (PZT), Lead lanthanum zirconate titanate (PLZT)

What Properties do Ferroelectric Materials Possess?

Ferroelectric materials possess Pyroelectric Properties and Spontaneous Polarisation.

All ferroelectric materials are pyroelectric, however, not all pyroelectric materials are ferroelectric. Below a transition temperature called the Curie temperature ferroelectric and pyroelectric materials are polar and possess a spontaneous polarization or electric dipole moment. However, this polarity can be reoriented or reversed fully or in part through the application of an external electric field to the ferroelectric materials. Complete reversal of the spontaneous polarization is called "switching".

The non-polar phase encountered above the Curie Temperature is known as the para-electric phase.

The direction of the spontaneous polarization conforms to the crystal symmetry of the material, whereas the reorientation of the spontaneous polarization is a result of atomic displacements under the application of an external electric effect..

The magnitude of the spontaneous polarization is greatest at temperatures well below the Curie temperature and approaches zero as the Curie temperature is neared.

Piezoelectric Properties

Since all pyroelectric materials are piezoelectric, this means ferroelectric materials are inherently piezoelectric. This means that in response to an applied mechanical load, the material will produce an electric charge proportional to the load. Similarly, the material will produce a mechanical deformation in response to an applied voltage.

The piezoelectric properties, dielectric properties and electro optic coefficients may vary by several orders of magnitude in the narrow temperature band around the Curie temperature.

Applications of Ferroelectric Materials

- Capacitors
- Non-volatile memory
- Piezoelectrics for ultrasound imaging and actuators
- Electro-optic materials for data storage applications
- Thermistors
- Switches known as transchargers or transpolarizers
- Oscillators and filters
- Light deflectors, modulators and displays

Dielectric Materials

<u>Dielectrics</u> are insulating materials that exhibit the property of electrical polarization; thereby they modify the dielectric function of the vacuum.

<u>Understanding Dielectric:</u>

• Solids which have an energy gap of 3eV or more are termed as insulators.

• In these materials, it is almost not possible to excite the electrons from the valence band to conduction band by an applied field.

• Generally dielectrics are also called as insulators, thereby poor conductors of electricity. However they allow movement of some electrons at abnormally high temperatures, causing a small flow of current.

• Dielectrics are non-metallic materials of high specific resistance ρ, negative temperature coefficient of resistance ($-\alpha$), and large insulation resistance.

• Insulation resistance will be affected by moisture, temperature, applied electric field and age of dielectrics.

• Dielectric materials are electrically non-conducting materials such as glass, ebonite, mica, rubber, wood and paper.

• All dielectric materials are insulating materials.

• The difference between a dielectric and an insulator lies in their applications.

• If the main function of non-conducting material is to provide electrical insulation, then they are called as insulator. On the other hand, if the main function of non-conducting material is to store electrical charges then they are called as dielectrics.

Properties

• Generally, the dielectrics are non-metallic materials of high resistivity.

• They have a very large energy gap (more than 3eV).

• All the electrons in the dielectrics are tightly bound to their parent nucleus.

• As there are no free electrons to carry the current, the electrical conductivity of dielectrics is very low.

• They have negative temperature coefficient of resistance and high insulation resistance.

Classification of Dielectric materials

Dielectric materials can be classified into two major categories:

Linear (normal dielectric) materials and Non linear dielectric materials.

The linear dielectric materials can be again subdivided into three classes based on the mechanism of electric polarization as non polar, polar and dipolar materials.

Linear dielectric materials The dielectric materials which are exhibiting a linear relationship between the polarization and applied electric field are known as linear dielectrics. This class of materials gets polarized with the application of the field and gets depolarized on the removal of field. Based on the nature of the polarization mechanism, the linear dielectrics can be grouped as follows:

Non polar materials: In materials of this class, an electric field can cause only elastic displacement of the electron cloud (mainly the valence electron cloud). So they have only electronic polarization. Such materials are generally referred to as elemental materials.

Polar materials: In materials of this class an electric field can cause only elastic displacement of electron clouds as well as elastic displacement of the relative positions of ions. These materials have both electronic and ionic polarization. The material may be composed of molecules and each of the molecules is made of more than one kind of atom without any permanent dipole moment. Examples of such materials are ionic crystals; in this case the total polarizability is the sum of the ionic and electronic polarizabilities. $\alpha = \alpha_e + \alpha_i$.

Dipolar materials: The materials of this class have all three fundamental polarizations: electronic, ionic and orientation. Thus the total polarizbility for them is $\alpha = \alpha_e + \alpha_i + \alpha_o$.

Materials, whose molecules posses a permanent dipole moment, belong to this class examples are water, methyl alcohol.

<u>Non linear dielectric materials</u> The materials which have got a spontaneous polarization even in the absence of an external field are grouped into the class of non linear dielectrics. The spontaneous polarization appears in this class of materials due to its crystal structure. **A necessary condition for a solid to fall in the class of non linear dielectrics is the absence of a center of symmetry.** Among the 32 crystal classes, 11 of them have a center of symmetry and hence they won't exhibit spontaneous polarization. Out of the remaining 21 classes of crystals without a centre of symmetry, 20 of them are piezoelectric, ie these crystals can be polarized under the influence of an external stress. Ten out of the 20 pieozoelectric crystals exhibit the pyroelectric effect, ie the polarization of this class of materials can be changed with the change of temperature. The **ferroelectric materials** are a part of the spontaneously polarized pyroelectrics.