A COMPARISON BETWEEN QUARTZ AND PZT CERAMIC FOR SENSORIC APPLICATIONS

M.M.Mohammadi

Department of engineering, Abhar branch, Islamic Azad University, Abhar, Iran

Abstract

Today, piezoelectric sensors are widely used and very well known for industry. These sensors are characterized by their linearity and broad response frequency range. The main piezoelectric materials that are used for sensoric applications are single crystal quartz and PZT ceramics. This paper tries to clarify the advantages and disadvantages of these materials, especially related to sensor technology.

Keywords: piezoelectric, sensor, quartz, PZT.

1. Introduction

Piezoelectric sensors usually are self-generating devices characterized by an extended region of flat frequency response range, a large linear amplitude range and excellent durability. These inherent properties are due to the use of a piezoelectric material as the sensing element for the sensor. Piezoelectric materials are characterized by their ability to output a proportional electrical signal to the stress applied to the material. (Tichy et al, 2010)

The most famous piezoelectric materials for sensor technology are artificial quartz and PZT ceramics. For the proper selection of piezoelectric material in sensor technology, it is necessary to compare these materials in their properties which are related to sensor technology.

2. Single crystal quartz

Quartz chemical formula is SiO_2 (silica dioxide). Its structure is built by the tetrahedron of silica and oxide in the most of its modifications. (Tichy et al, 2010)

Quartz belongs to the trigonal point group 32 (D43 , P312). Three SiO_2 molecules build each unit cell. In the unit cell, there are three silicon atoms and six oxygen atoms. (Figure 1A) Oxygen is being lumped in pairs. Each silicon atom carries four positive charges and a pair of oxygen atoms carries four negative charges (two per atom). Therefore, a quartz cell is electrically neutral under the no-stress conditions. When an external force, F_x , is applied along the x-axis, the hexagonal lattice becomes deformed.

Figure 1b shows a compressing force which shifts atoms in a crystal in such a manner that a positive charge is built up at the silicon atom side and a negative charge at the oxygen pair side. Thus, the crystal develops an electric charge along the y-axis. If the crystal is stretched along the x-axis (Fig. 3C), a charge of opposite polarity is built along the y-axis, which is a result of a different deformation. This simple model illustrates that crystalline material can develop electric charge on its surface in response to a mechanical deformation. (Fraden, 2006)

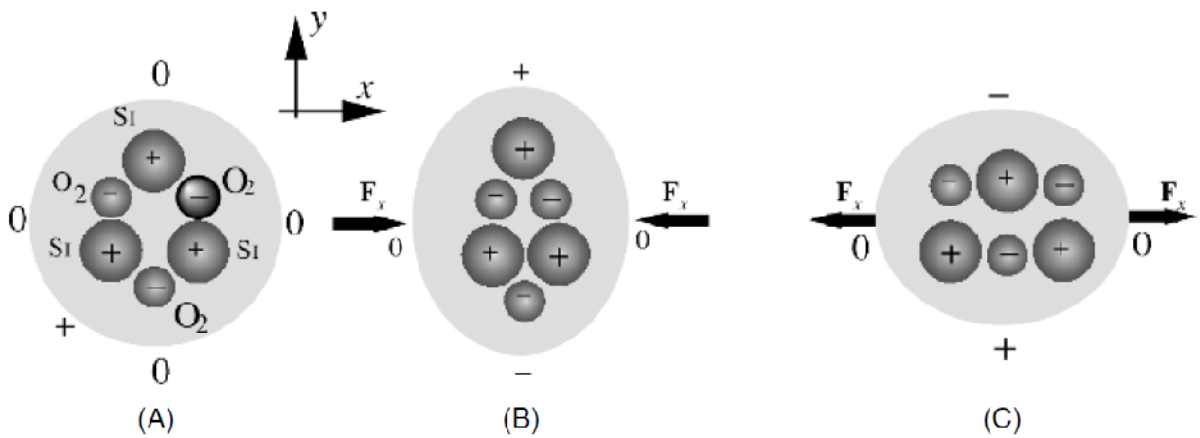

Figure 1. Piezoelectric effect in a quartz crystal.

To pick up an electric charge, conductive electrodes must be applied to the crystal at the opposite sides of the cut. As a result, a piezoelectric sensor becomes a capacitor with a dielectric material which is a piezoelectric crystal. The dielectric acts as a generator of electric charge, resulting in voltage V across the capacitor.

By applying the external forces and loads to quartz, it can act as an electromechanical sensor which makes a linear charge or voltage output relative to the applied load.

3. PZT ceramics

Piezoelectric ceramics, discovered in the 1950's, experience much stronger piezoelectric effect. The piezoelectric ceramics must undergo a polarizing process for the piezoelectric phenomenon to occur, while crystal materials are naturally piezoelectric. The most commonly used piezoelectric ceramic is lead zirconate titanate (PbZrO3-PbTiO3) or PZT.

Piezoelectric ceramics are ferroelectric materials. Above a certain temperature, called the Curie temperature, the crystal structure have a centre of symmetry and therefore no electric dipole moment. Below the Curie temperature, the crystal structure undergoes a phase change into the ferroelectric state where the structure is not symmetric and has spontaneous polarization. These molecular dipoles align within small areas and forms electrical domains.The domains are randomly oriented and therefore, the net external electric dipole is zero, as shown in Figure 2. If the piezoelectric ceramics is subjected even once to a large electric field (poling), the domain dipoles align in the direction closest to the field. Because of the random original orientation of domains, it is not possible to get perfect dipole alignment with the field. However, each domain can have several allowed directions and therefore, a reasonable degree of alignment can be achieved. Due to the alignment of the domains, the material elongates in the same direction, as shown in Figure 2b. When the voltage is removed, the domains do not entirely return to their original positions, and the material remains partially polarized. The strain resulted from the partial polarization is called a remanent strain. Due to the poling, the material has become permanently piezoelectric and can convert mechanical energy into electrical and vice versa. After poling, if electric field is applied, the material elongates in the direction of the field as illustrated in Figure 2c. (Marek et al, 2006)

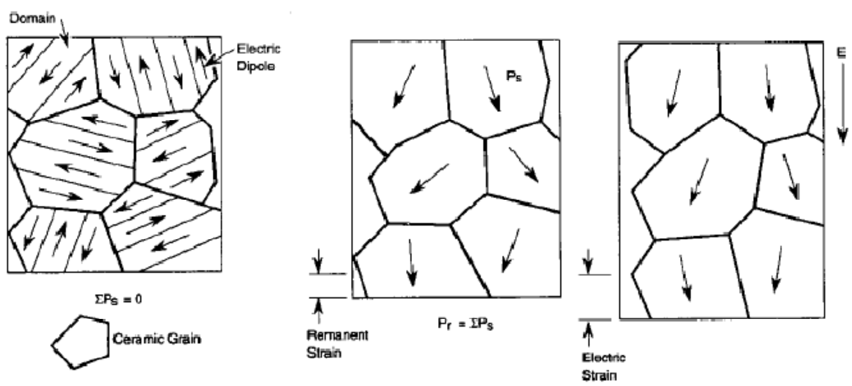

Figure 2. Behaviour of piezoceramic material. a) Non-polarized state, b) polarized state,

c) electric applied after poling.

3. Main piezoelectric material properties related to sensor technology

Before comparison of the two materials, a list of piezoelectric material properties which are related to sensor technology is given:

3.1 Charge and voltage sensitivity

A piezoelectric accelerometer can be regarded as either a charge source or a voltage source with high impedance. Consequently, charge sensitivity and voltage sensitivity are used to describe the relationship between input and output. Charge and voltage sensitivity equals the amount of charge or voltage produced by piezoelectric material divided by the input parameter that can be acceleration, force and etc. charge is the main output of piezoelectric materials and should be given by manufacturer but voltage sensitivity can be easily obtained by deviding charge sensitivity with sensor capacitance. (Gustav., 2002)

3.2 Amount of Linearity

The relation between input and output of sensing element can have a degree of linearity over a definite range of frequency. This property can state the accuracy of sensing element.

Hysteresis:

Hysteresis is the maximum difference in output at any measurand value within the specific range, when the value approached first with increasing and then with decreasing the measerund. (Gustav., 2002)

4. The comparison between the two materials

PZT is the most widely used piezoelectric ceramics and is commercially available. It has very high piezoelectric coupling coefficients and relatively low maximum operating temperature (200C). pzt has some advantages over quartz like lower cost and versatility in design by changing the composition and properties.

It has higher availability and has higher piezoelectric charge sensitivity (coefficients up to 100 times higher than values observed in quartz) but it has some disadvantages like lower stability, loss of polarization, aging and fatigue, and it has strong temperature dependence of electromechanical properties like sensitivity, low Curie temperature, pyroelectricity (temperature changes create mechanical response) and brittleness.

As mentioned above ferroelectric materials have a domain structure, as shown in Fig. 2. The dipole moment in each domain is oriented in the same direction and causes spontaneous polarization. If a varying electric field E is applied to it, the overall variation of polarization draws a hysteresis loop, as shown in Fig. 3. Once the material has an electric field applied to it, it does not return to the original domain structure when the electric field is removed, resulting in remanent polarization Pr. To cancel Pr, a certain strength of reverse electric field must be applied. The field strength Ec required to cancel the remanent polarization is called a coercive field.

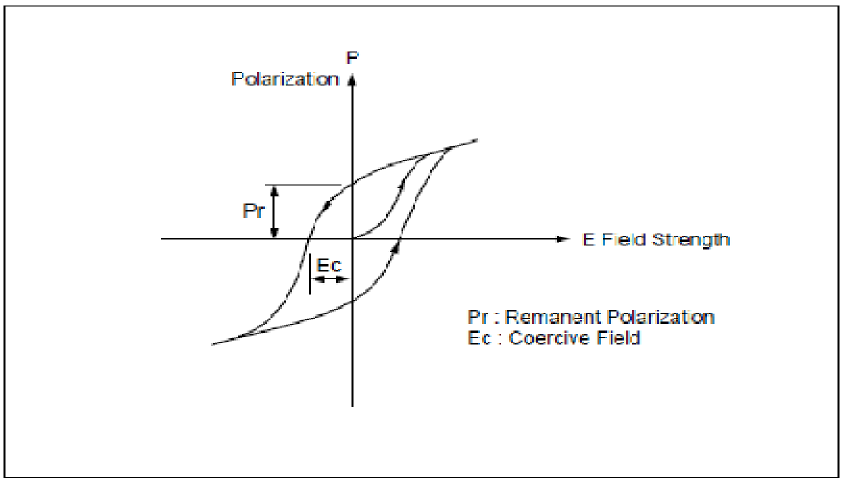

Figure 3. Hysteresis Curve of a Ferroelectric Material

The technological prominence of α-quartz stems largely from the presence of piezoelectricity, combined with extremely low acoustic loss. Quartz piezoelectric properties depend directly on cutting orientation. In a definite cut orientation, quartz properties are independent of temperature. Quartz has a high voltage sensitivity but low charge sensitivity. It has a linear response over abroad range of frequency. It is not pyroelectric. Acousto-optic devices are often fabricated from lithium niobate and quartz, because acoustic waves can effectively propagate through these crystal over a frequency range from tens of megahertz to several gigahertz. (Fraden, 2006)

5. Conclusions

Quartz has higher cost than PZT ceramics but is more precise especially in applications that temperature changes can lower the accuracy of measurements. It has a very high acoustic quality and has a very low acoustic loss. Quartz charge sensitivity is very lower than PZT and it limits the resolution of quartz charge mode sensors.

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