Smart Materials

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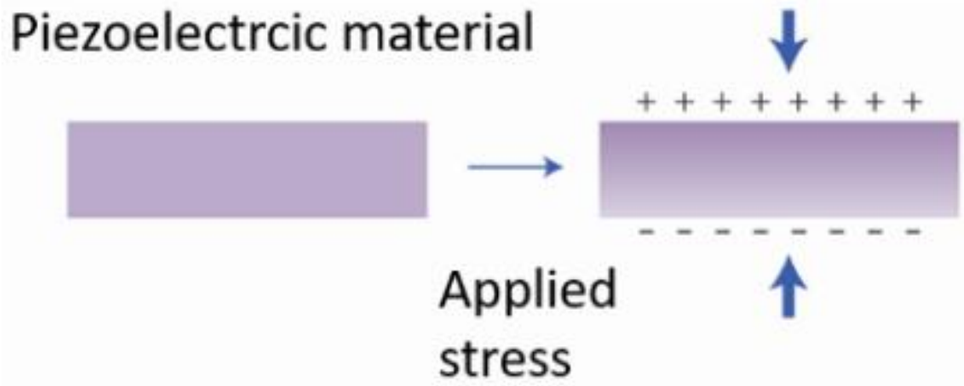
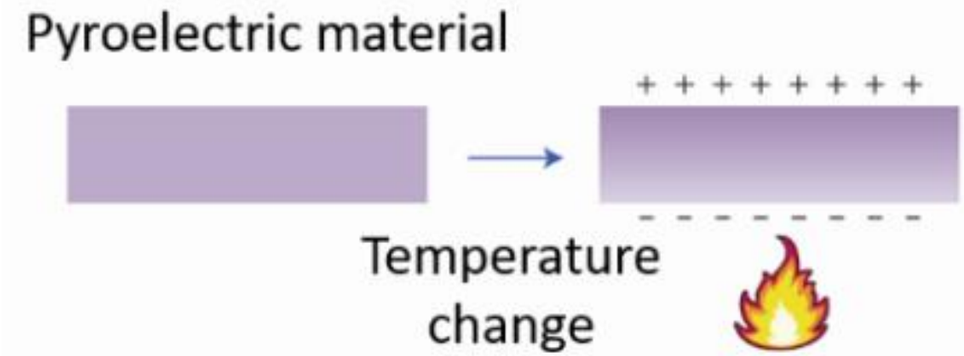
Classes of dielectric materials

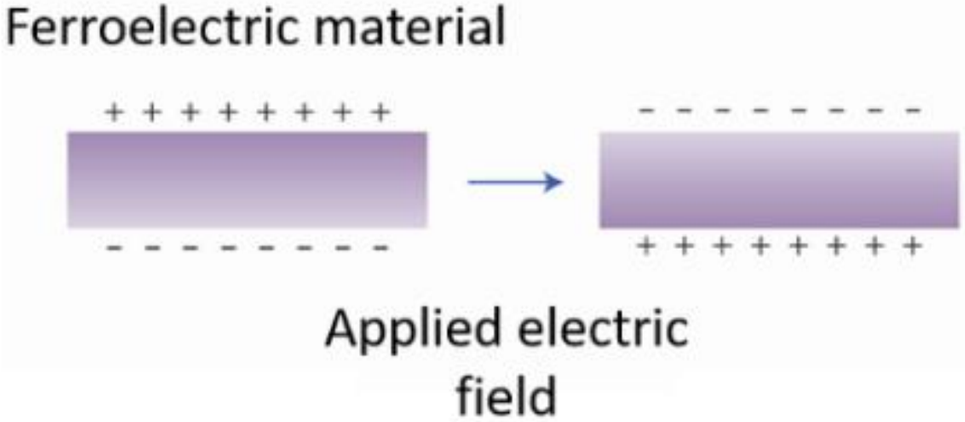
Piezoelectric: Spontaneous charge generation on application of stress or vice versa.



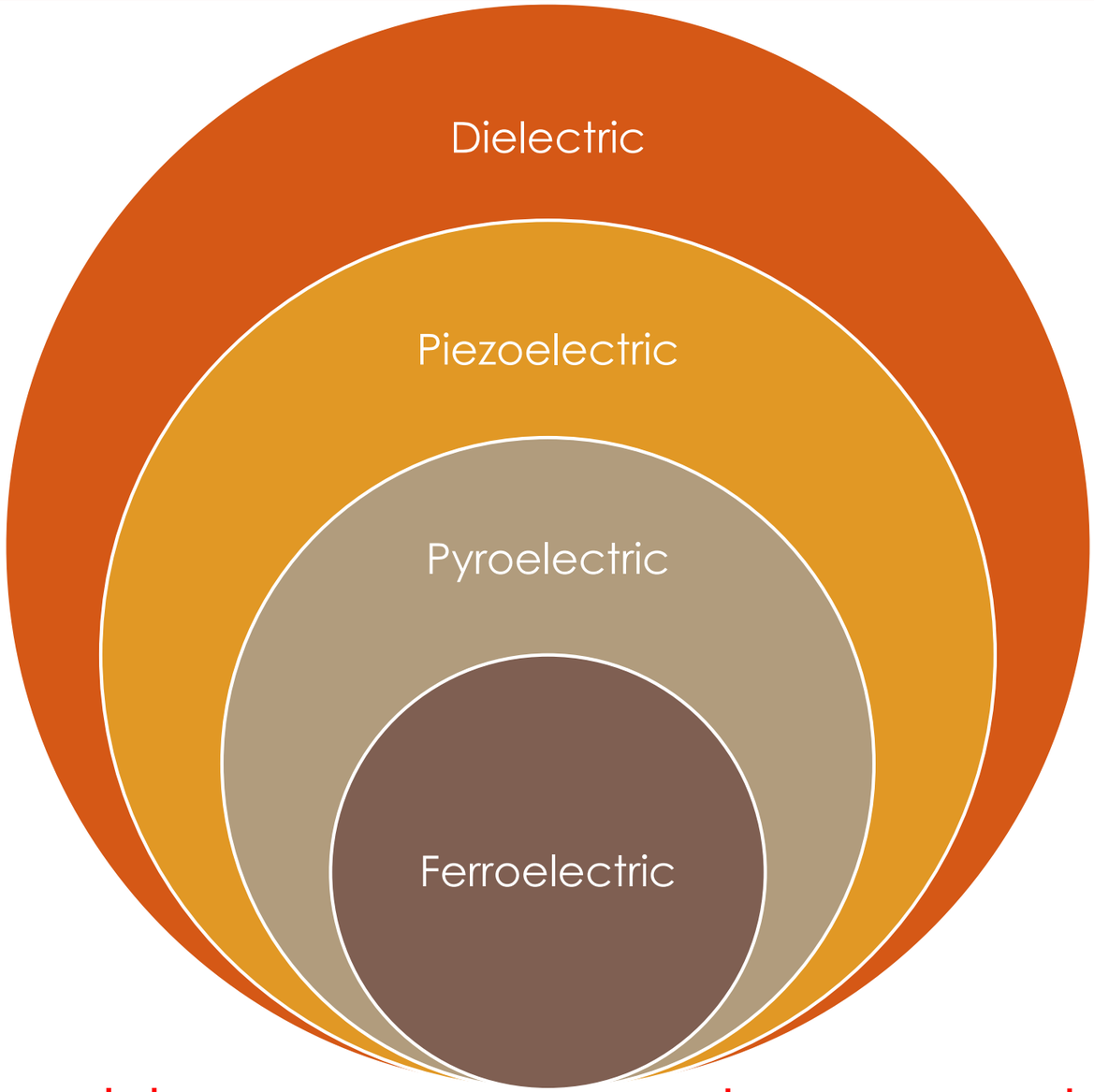
Pyroelectric: Spontaneous charge generation on application of heat.



Ferroelectric: Spontaneous charge generation on application of electric field.



Classes of dielectric materials



The materials should possess non centro symmetry to produce charges.

Ferroelectric materials

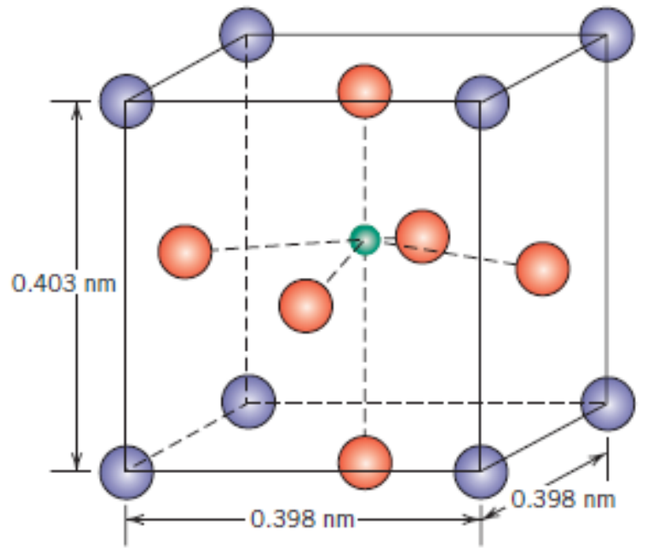
1. Exhibit spontaneous polarization - that is, polarization in the absence of an electric field.
2. There must exist in ferroelectric materials permanent electric dipoles
3. Have extremely high dielectric constants at relatively low applied field frequencies; for example, at room temperature, ε_r for barium titanate may be as high as 5000.
4. Consequently, capacitors made from these materials can be significantly smaller than capacitors made from other dielectric materials.

Ferroelectric materials

Case study: $BaTiO_3$

Ba^{2+} ions : at corners of tetragonal unit cell

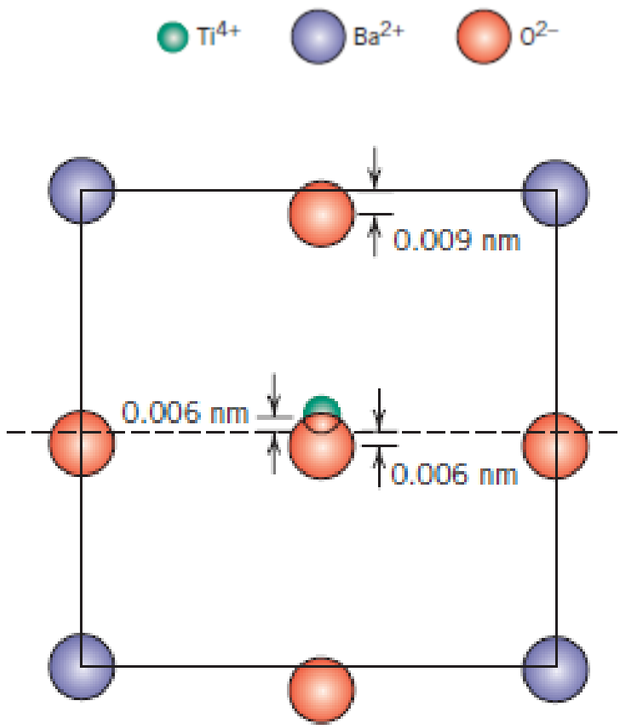
Dipole moment results from the relative displacements of the O^{2-} and Ti^{4+} ions from their symmetrical positions.



O^{2-} ions are located near, but slightly below, the centers of each of the six faces,

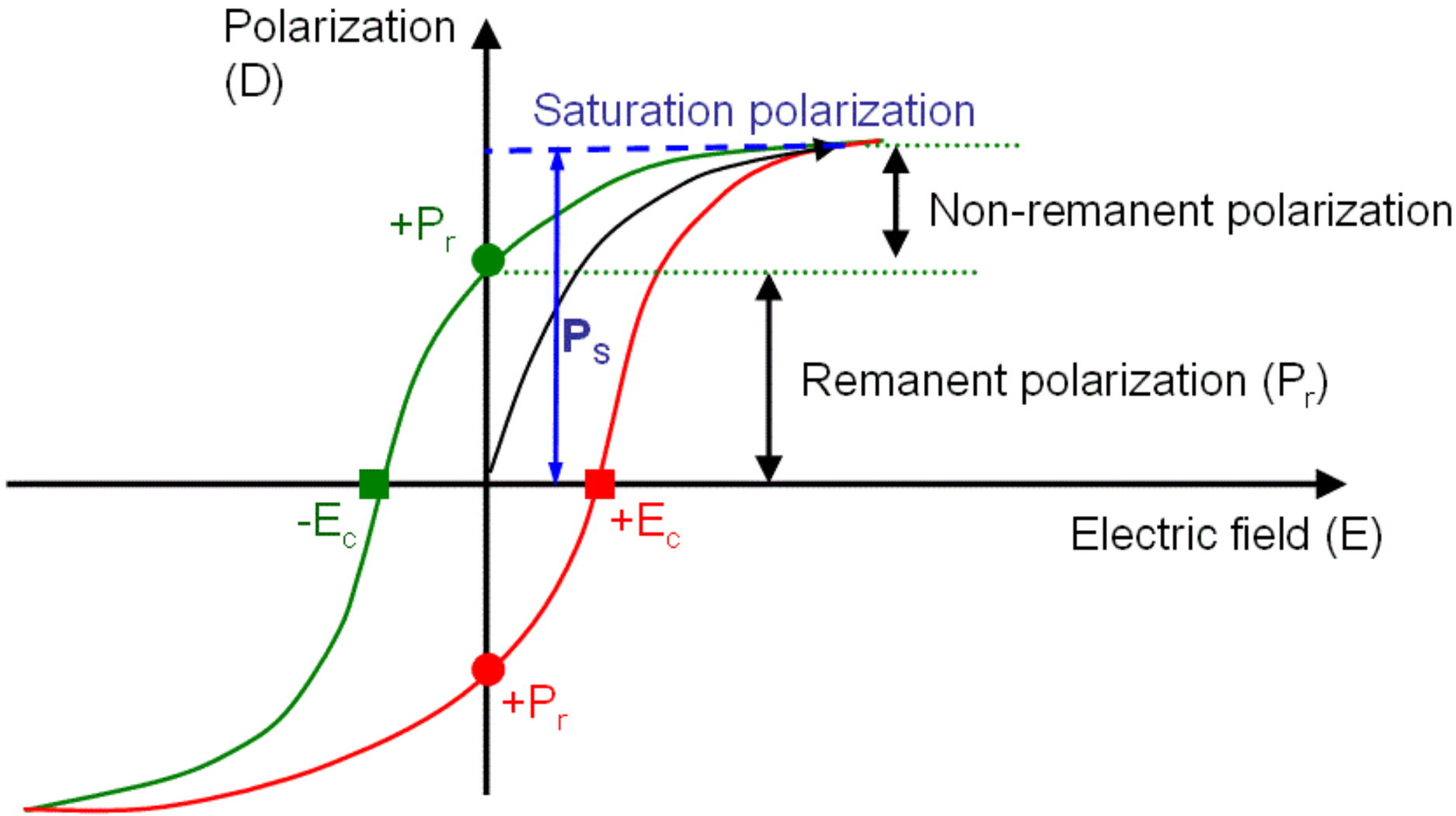
Ti^{4+} ion is displaced upward from the unit cell center.

Thus, a permanent ionic dipole moment is associated with each unit cell.



Ferroelectric materials

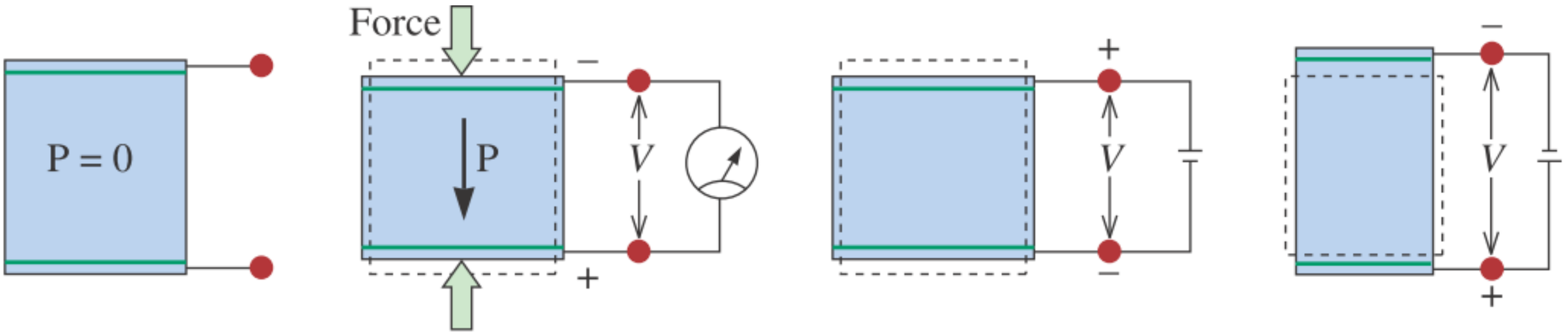
Hysteresis loop



Piezoelectric materials

Polarization is induced and an electric field is established across a specimen by the application of external forces.

Reversing the sign of an external force (i.e., from tension to compression) reverses the direction of the field.



Piezoelectric materials

Piezoelectric materials are used in transducers, which are devices that convert electrical energy into mechanical strains, or vice versa.

Candidates:

1. Titanates of barium and Lead,
2. Lead zirconate ($PbZrO_3$),
3. Ammonium dihydrogen phosphate ($NH_4H_2PO_4$),
4. Quartz.

Pyroelectric materials

Pyroelectricity is the ability of certain materials to generate a temporary voltage when they are heated or cooled.

The change in temperature modifies the positions of the atoms slightly within the crystal structure, such that the polarization of the material changes.

This polarization change gives rise to a voltage across the crystal.

Pyroelectric materials

If the temperature stays constant at its new value, the pyroelectric voltage gradually decreases due to

1. Leakage current (the leakage can be due to electrons moving through the crystal,
2. Ions moving through the air from the porosity,
3. Leakage current leaking through a voltmeter attached across the crystal.

Example: Lithium tantalate ($LiTaO_3$)

All pyroelectric materials are also piezoelectric, the two properties being closely related. However, note that some piezoelectric materials have a crystal symmetry that does not allow pyroelectricity.

Summary

1. Ferroelectric, piezoelectric and pyroelectric materials are a subclass of dielectric materials.
2. Ferroelectric materials produces charge on the application of electric field.
3. The ferroelectric materials retains the produced charge even in the absence of electric field.
4. Piezoelectric materials produces charge on the application of stress/force or vice versa.
5. Pyroelectric materials produces charge on the application of heat.