SMART MATERIAL TYPES

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Piezoelectric smart biomaterials

materials have been known to react to the surrounding environment producing some form of response. For instance, in 1824, Rochelle salt was discovered to become electrically polarized by the application of heat. That was the first discovery of the effect known as pyroelectricity. Since that time, numerous additional materials have been discovered having the inherent capability to convert one form of energy into another. Sensors are materials that respond to a physical stimulus, such as a change in temperature, pressure, or illumination, and transmit a resulting signal for monitoring or operating a control. Actuators are materials that respond to a stimulus in the form of a mechanical property change such as a dimensional or a viscosity change.

What is a Sensor?

Sensors are devices that we use to convert any physical characteristics or events into electric signals. In simple words, a sensor is a hardware device. It collects data input from its environment, converts it into electrical signals, and then gives it to the device/system.

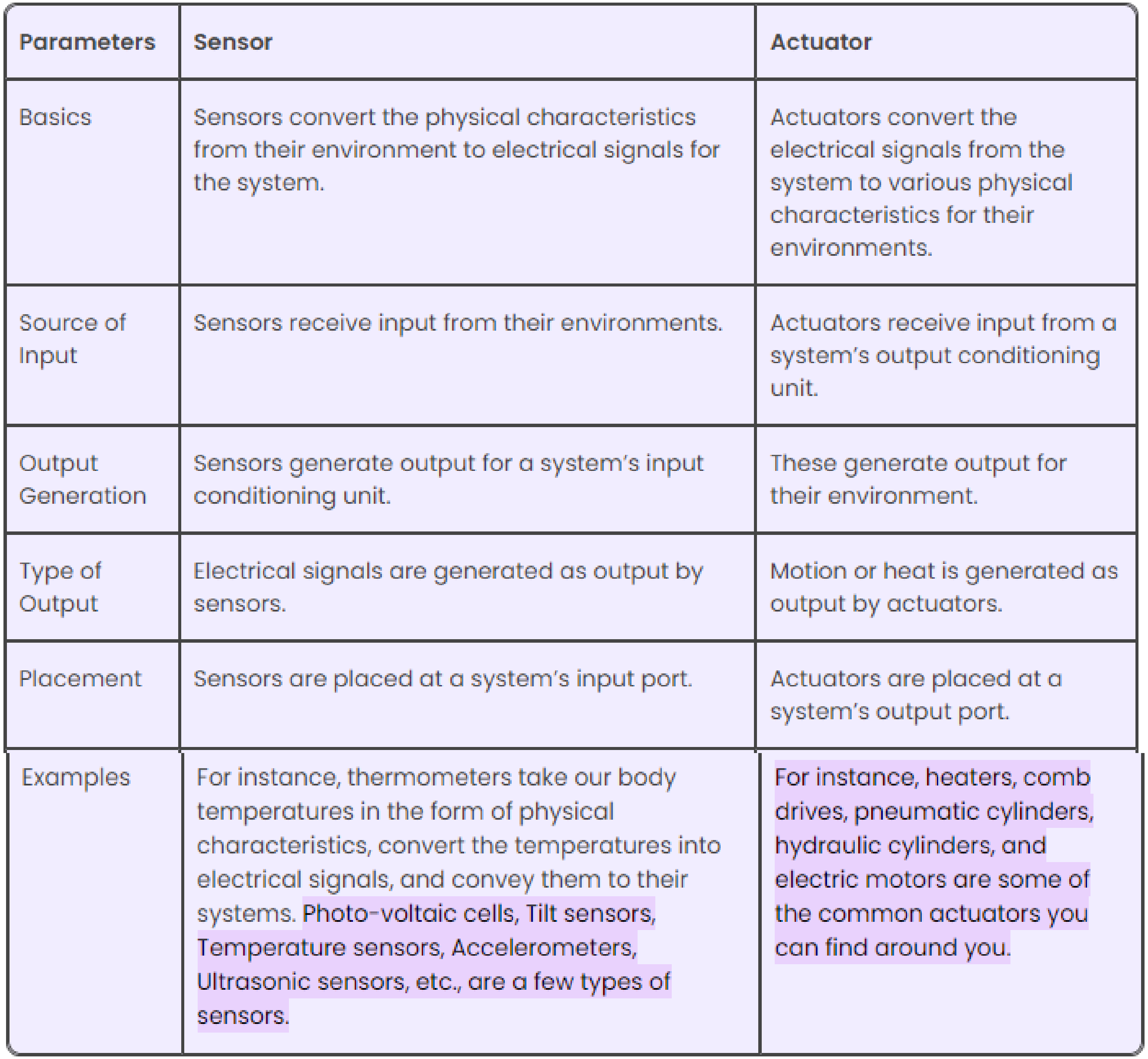
For instance, thermometers take our body temperatures in the form of physical characteristics, convert the temperatures into electrical signals, and convey them to their systems. Tilt sensors, Temperature sensors, Accelerometers, Ultrasonic sensors, etc., are a few types of sensors.

What is an Actuator?

An actuator is just opposite to a sensor. It converts an electric signal to a characteristic or a physical event. In simple words, an actuator would receive inputs from any system in the form of electrical signals and then generate an output for its environment.

For instance, heaters, comb drives, pneumatic cylinders, hydraulic cylinders, and electric motors are some of the common actuators you can find around you.

Difference between Sensor and Actuator



Parameters	Sensor	Actuator
Basics	Sensors convert the physical characteristics from their environment to electrical signals for the system.	Actuators convert the electrical signals from the system to various physical characteristics for their environments.
Source of Input	Sensors receive input from their environments.	Actuators receive input from a system's output conditioning unit.
Output Generation	Sensors generate output for a system's input conditioning unit.	These generate output for their environment.
Type of Output	Electrical signals are generated as output by sensors.	Motion or heat is generated as output by actuators.
Placement	Sensors are placed at a system's input port.	Actuators are placed at a system's output port.
Examples	For instance, thermometers take our body temperatures in the form of physical characteristics, convert the temperatures into electrical signals, and convey them to their systems. Photo-voltaic cells, Tilt sensors, Temperature sensors, Accelerometers, Ultrasonic sensors, etc., are a few types of sensors.	For instance, heaters, comb drives, pneumatic cylinders, hydraulic cylinders, and electric motors are some of the common actuators you can find around you.

Table 1. Sensor and Actuator Material Classes.

	Material Class	Stimulus	Response
Sensors	Pyroelectrics	Temperature Change	Electric Polarization
	Piezoelectrics	Mechanical Strain	Electric Polarization
	Electrostrictors	Mechanical Strain	Electric Polarization
	Magnetostrictors	Mechanical Strain	Change in Magnetic Field
	Electroactive Polymers	Mechanical Strain	Electric Polarization
	Electroluminescent Materials	Electric Field	Light Emission
	Photoluminescent Materials	Incident Light	Light Emission
	Electrochromic Materials	Electric Field	Color Change
Actuators	Piezoelectrics	Electric Current	Mechanical Strain
	Electrostrictors	Electric Current	Mechanical Strain
	Magnetostrictors	Magnetic/Electric Field	Mechanical Strain
	Shape Memory Alloys	Temperature Change	Mechanical Strain
	Electroactive Polymers	Electric Field/pH change	Mechanical Strain
	Electrorheological Fluids	Electric Field	Viscosity Change
	Magnetorheological Fluids	Magnetic Field	Viscosity Change

Pyroelectrics

Pyroelectrics, as previously mentioned, are materials that become electrically polarized upon an applied temperature change. Materials used as pyroelectrics include barium strontium titanate (Ba1-xSrx TiO3), lead zirconate titanate (PbZr1-x Tix O3), barium strontium niobate (Ba1-xSrx Nb2 O6), triglycine sulfates (TGS), lithium tantalate (LiTaO3) and polyvinylidene fluoride (PVDF). Ceramics are widely used due to their lower cost including availability and ease of processing, and good stability. Their weakness comes from their inherent brittleness. Polymers, PVDF and its copolymer with trifluoroethylene (PVDFTrFE), provide a non-brittle alternative but do not obtain the level of performance of ceramics. Pyroelectrics are widely used for infrared detection in surveillance and targeting applications. A pyroelectric infrared detector generally employs a thin film of pyroelectric material oriented with the electroded surfaces normal to its polarization direction. When infrared radiation is absorbed by the detector, the temperature of the pyroelectric material rises. This change in temperature alters the material’s polarization causing a change in surface charges across the material which produces an electrical signal via the electrodes. The resulting signal is proportional to the incoming radiation.

Piezoelectrics

Piezoelectrics are materials that exhibit an electrical polarization with an applied mechanical stress (direct effect), or a dimensional change with an applied electric field (converse effect). They are used for both sensing and actuating devices. Lead zirconate titanate (PbZr1-xTix O3) is the premier piezoelectric material as it may be doped to produce an n-type or p-type material with a range of dielectric constants to meet the requirements of numerous applications. Other piezoelectric materials that may be used are barium titanate (BaTiO3), lead titanate (PbTiO3), lead metaniobate (PbNb2 O6), and PVDF. Polymers are generally favored for sensing applications while ceramics are favored for actuating. Figure 1 depicts the piezoelectric effect observed in lead zirconate titanate upon the application of compressive forces relative to the crystal structure.Piezoelectrics is a mature technology with numerous applications throughout the military and commercial sectors. Devices using piezoelectrics include: adaptive optics, hydrophones and sonobuoys, fuse devices, depth sounders, thickness gauging, flaw detection, level indicators, alarm systems, strain gauges, airplane beacon locators, fetal heart detectors, and tire pressure indicators among many others.

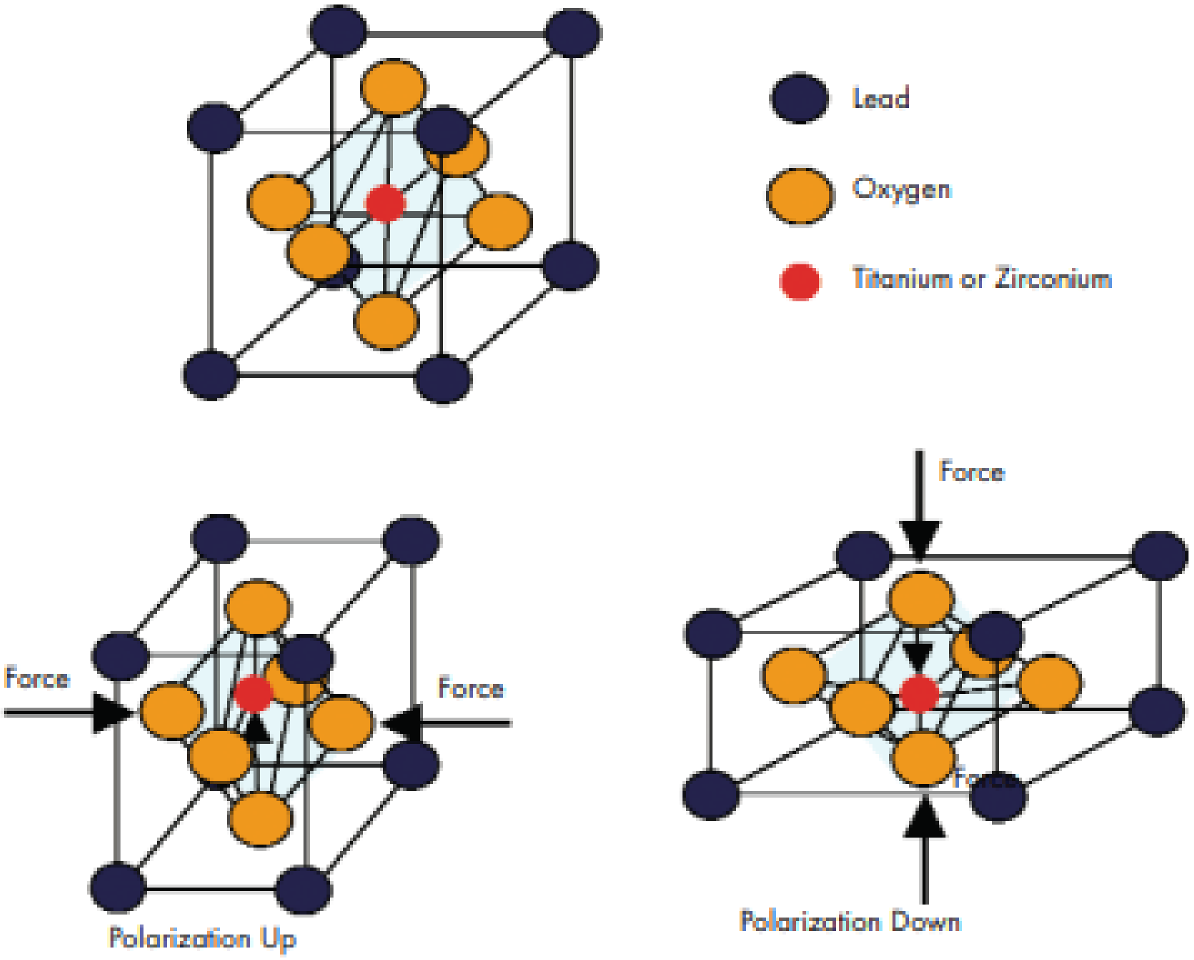


Figure 1. The Piezoelectric Effect

What is the Piezoelectric Effect?

Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word Piezoelectric is derived from the Greek piezein, which means to squeeze or press, and piezo, which is Greek for “push”.

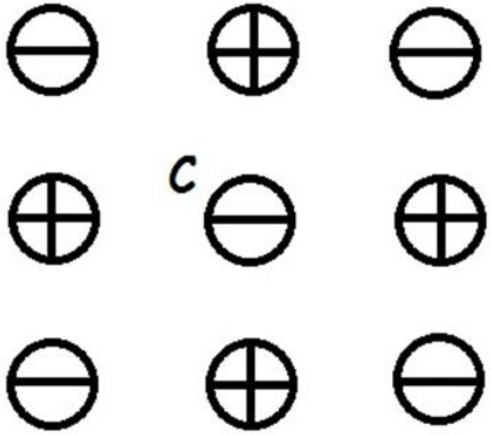
One of the unique characteristics of the piezoelectric effect is that it is reversible, meaning that materials exhibiting the direct piezoelectric effect (the generation of electricity when stress is applied) also exhibit the converse piezoelectric effect (the generation of stress when an electric field is applied).

Piezoelectricity

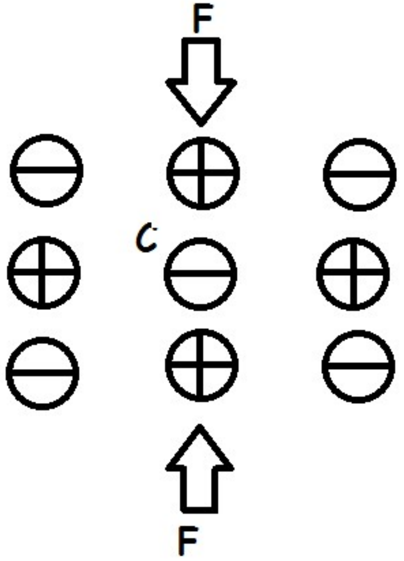
Piezoelectricity is the effect of mechanical strain and electric fields on a material; mechanical strain on piezoelectric materials will produce a polarity in the material, and applying an electric field to a piezoelectric material will create strain within the material. When pressure is applied to a piezoelectric material, a dipole and net polarization are produced in the direction of the applied stress. Piezoelectricity has many applications in regards to electrical transducers and signal devices.

Center of Symmetry

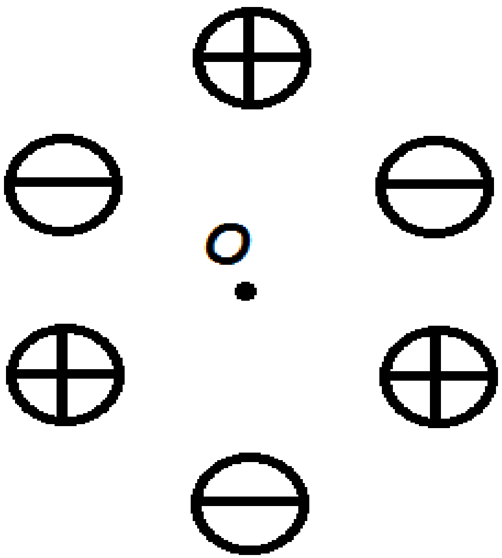
Materials must not have a center of symmetry in order to act as piezoelectric materials. In a material with a center of symmetry, the center of masses of the positive and negative charges coincide at the center of symmetry with or without mechanical strain, keeping zero net polarization. In the case of piezoelectric materials, when stress is applied, the center of masses of the positive and negative ions change depending on the direction the stress is applied; a net polarization is produced, creating a voltage difference between the two surfaces of the crystal the stress is being applied on.



- A non-piezoelectric material with a center of symmetry.
- In Figure , no force is applied to the non-piezoelectric material; no polarization is induced, as the centers of mass for both the positive and negative ions coincide at point C.

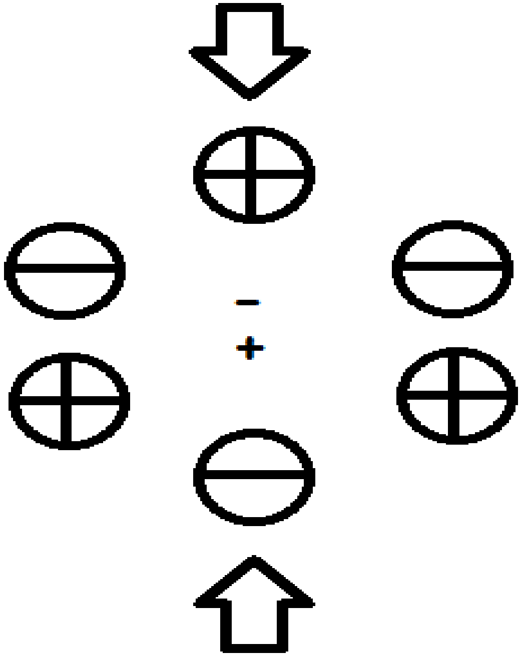


- A force is applied on a non-piezoelectric material with a center of symmetry.
- in Figure, a force is applied to the non-piezoelectric material; no polarization is induced, as the centers of mass for both the positive and negative ions still coincide at point C.



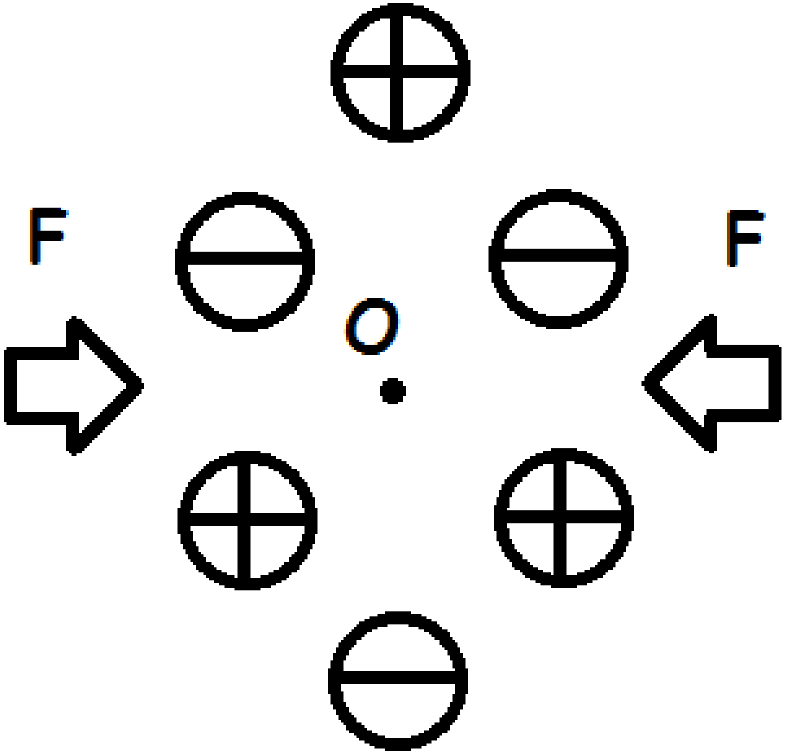
- A piezoelectric material with no center of symmetry.

- In Figure , a piezoelectric material is shown with no force applied to it. The centers of mass for both the positive and negative ions coincide at point O.



- A piezoelectric material compressed on the top and bottom

- In Figure , when a vertical force is applied, the centers of mass for both the positive and negative ions shift, creating a net polarization as shown in the middle of the material. This process cancels out within the material until the ends of the material's surface.



- A piezoelectric material compressed on the sides.
- when a horizontal force is applied, the centers of mass for both the positive and negative ions still coincide with each other, producing no net polarization; a net polarization will be induced depending on the crystal structure, the direction the force is applied onto the material, and the material's Poisson ratio.

Mechanism

When a stress is applied to a piezoelectric material, the dimensions of the material changes. Depending on the direction the stress is applied, the resulting change in dimensions can shift the centers of mass for the positive and negative ions; this produces a dipole throughout the material. The dipoles inside the material cancel each other out, but on the surface of the material the dipoles are not canceled out, producing a polarity given by.

$$P = d\,T = d\frac{F}{A}$$

where T is the mechanical stress, P is the induced polarization, and d is the piezoelectric coefficient