MATERION

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TECHNICALTIDBITS

MATERION PERFORMANCE ALLOYS

I'm just a sweet transducer... – Many dielectrics have special properties that enable them to be used in sensors or other transducers.

- **Dielectric**
- **Ferroelectric**
- **Ferroelectric Domains**
- **Antiferroelectric**
- **Paraelectric**
- **Piezoelectric**
- **Pyroelectric**
- **Transducer**
- **Curie Temperature**

The next issue of Technical Tidbits will discuss the photoelectric effect and the work function of materials.

FERROELECTRIC AND PIEZOELECTRIC MATERIALS

As we discussed last August, dielectric materials polarize in response to externally applied electric fields. In September we talked about how **Ferroelectric** materials maintain polarization when the electric field is removed. Ferromagnetic materials behave similarly in the presence of magnetic fields, which is how the term ferroelectric came to be. (We will discuss the types of magnetic materials and their behavior later this year.)

While some dielectric materials only form dipoles when there is an applied electric field, ferroelectric materials always have electric dipoles. Nearby dipoles tend to spontaneously align with each other, creating **ferroelectric domains** within the material. (A domain is a region where all the dipoles are pointing in the same direction.) There may be multiple domains within a grain of metal, or a single domain may extend across several grains.

When a ferroelectric crystal forms, the domains will likely be pointing in random directions. When an electric filed is applied, the domains will align with field. When the field is removed, the domains (and the dipoles within them) will remain aligned in the direction of the now nonexistent field. This retained polarization makes these materials useful for computer memory, since you can use the polarization direction to represent a 1 or a 0, and it takes the application of another electric field in the opposite direction to change the polarization state. Thus, when the memory is written, it will remain that way as long as the domains remain stable, although random thermal noise will eventually cause the polarization to disappear. The longer it takes for the polarization to destabilize, the better the performance as memory.

As discussed in issue 117, ferroelectric materials experience hysteresis under the influence of cycling electric fields. Each cycle will result in some energy lost as heat, as dipoles and domains change direction.

Antiferroelectric materials also have dipoles. However, the dipoles alternate directions, so each one is pointing in the opposite direction of its closest neighbor. This means that there is no net polarization in the bulk material, as the individual polarizations of all the dipoles effectively sum to zero.

Paraelectric materials have no dipoles without the presence of an electric field. When an external electric field is applied, dipoles may form, and the material will show a weak polarization that will disappear when the field is removed.

Piezoelectric materials are another special class of dielectric materials. Most engineers will be familiar with their ability to convert strain energy to electric energy, and vice versa. Specifically, an applied voltage will cause strain in the crystalline matrix, and applied strain will result in a voltage across the crystal.

Pyroelectric materials are similar to piezoelectric materials, except that an applied voltage generates or consumes heat, while heating or cooling the crystal generates a voltage. This makes piezoelectric and pyroelectric materials useful for transducers.

A **transducer** is a device that converts one form of energy to another. A sensor is simply a transducer that converts an input (chemical composition, temperature, strain, light, pressure, etc.) into a voltage output which can be measured and interpreted. An actuator is the reverse process, as it uses a voltage input to generate mechanical motion. On a somewhat related tangent, temperature usually affects the relationship between the sensor input and the output voltage, leading to the old industry joke that all sensors are temperature sensors.

FERROELECTRIC AND PIEZOELECTRIC MATERIALS (CONTINUED)

What should also be noted is that the same material may show different behavior at different temperatures. Ferroelectric and antiferroelectric compounds will use polarization and become paraelectric when the temperature exceeds a certain minimum value. This threshold temperature is known as the **Curie temperature**, and is the ferroelectric equivalent of the Curie temperature in ferromagnetics (where a ferromagnetic material loses is magnetic polarization.)

For example, $PbTiO_3$ is ferroelectric below about 500°C, becoming paraelectric at higher temperatures. Similarly, $PbZrO_3$ is antiferroelectric when the temperature is less than about 233°C, and becomes paraelectric when the temperature exceeds this value.

Many piezoelectric materials and pyroelectric materials are also ferroelectric. Some materials may show all 3 behaviors, such as polyvinylidene fluoride. (See Table 1.)

		Ferroelectric	Piezoelectric	Pyroelectric	Antiferroelectric
AlN	Aluminum Nitride	N	Y	N	N
$BaTiO_3$ (BT)	Barium Titanate	Y	Y	N	N
$LiTaO_3$	Lithitum Titanate	N	Y	Y	N
GaAlN	Gallium Aluminum Nitrate	N	N	Y	N
$PbTiO_3$	Lead Titanate	Y	N	N	N
$PbZrO_3$	Lead Zirconate	N	N	N	Y
$PbZrTiO_3$ (PZT)	Lead Zirconate Titanate	Y	Y	N	N
PVDF	Polyvinylidene fluoride	Y	Y	Y	N
SrBaNbO (SBN)	Strontium Barium Niobate	Y	N	N	N

Table 1 – Room Temperature Behavior of Some Common Specialty Dielectrics.
Note that many of these materials fit into more than one behavioral category, and a significant number of them are titanates.

As Technical Tidbits has discussed many times, you can change the property of a pure metal by alloying it with other metals. In the same way, you can change the properties of one of these special dielectric materials by mixing it with other dielectrics. By making such compound materials, you can control the bulk properties of the new material such as conductivity, dielectric constant, Curie temperature, etc. Note that PZT (lead zirconium titanate, or $PbZrTiO_3$) is not a single compound, but a mixture of 3 separate oxides, namely PbO, ZrO_2, and TiO_2).

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