University Of Technology- Iraq
Department of Materials Engineering
General Materials Branch
Fourth class

Smart Materials

Lecture 11 : Electrostrictive Materials

Class Code on Google Classroom :2shhens

Electrostrictive materials

1. Electrostrictive materials are similar to piezoelectric materials inv that both are ferroelectric crystals, exhibit a dimensional change upon an applied electric field or an electric polarization upon an applied mechanical stress.
2. However, the electrostrictive actuators use a leadvmagnesiumniobate (PMN) crystal stack while piezoelectric actuators use lead-zirconate-titanate (PZT) based ceramics.
3. Unlike piezoelectric devices, PMN ceramics are not poled.

Electrostrictive materials

- Electrostriction is a property of all dielectric materials, and is caused by the presence of randomly aligned electrical domains within the material.
- When an electric field is applied to the dielectric, the opposite sides of the domains become differently charged and attract each other, reducing material thickness in the direction of the applied field (and increasing thickness in the orthogonal directions due to Poission's ratio).

- The resulting strain (ratio of deformation to the original dimension) is proportional to the square of the polarization.

- Reversal of the electric field does not reverse the direction of the deformation.

Discovery of PMN PT material

- First discovered in the late 1950s by Smolenskii *., Lead Magnesium Niobate PMN, which is the best* known and most widely studied relaxor ferroelectric.
- Characterized by interesting dielectric, electrostrictive, and piezoelectric properties in single crystal and bulk ceramic forms.

PMNPT

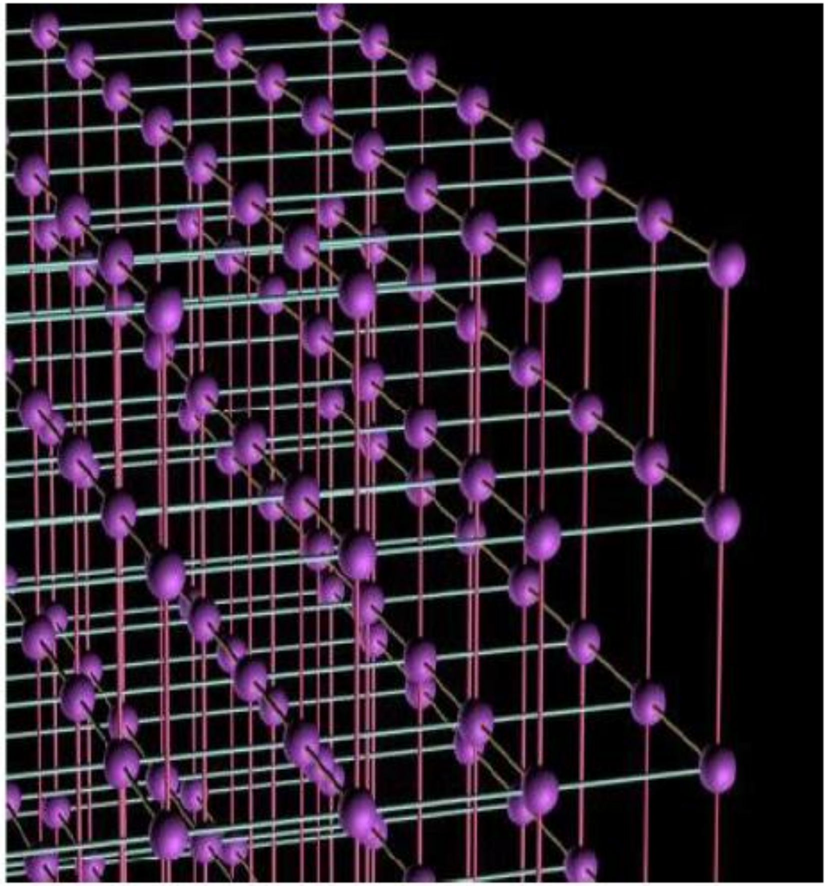
- PMNPT actually belongs to a family of piezoelectric materials called *ferroelectrics, a special kind of ferroelectric* called a *relaxor ferroelectric.*
- A crystal is said to be Ferroelectric when it possess a spontaneous polarization below a transition temperature.
- Above this temperature is the para electric phase .
- The temperature marks between ferroelectric and the para electric phase transition is called dielectric constant , peak.
- • The dielectric constant drops off rapidly with increasing frequency (hence the name “relaxor”) because it takes time for the polarization fluctuations to respond

Why Piezoelectric effects happens in PMN PT….

1. *The piezoelectric effect happens in ferroelectrics such as PMNPT due to their unusual crystal structure.*
2. In most crystal structures, the atoms of the material are arranged in a regularly spaced lattice.

Electrostrictive materials

- In this picture the atoms are arranged in regular cubes, but in a real crystal they might be arranged in other ways.
- This small part is referred to as the *unit cell of* the lattice.



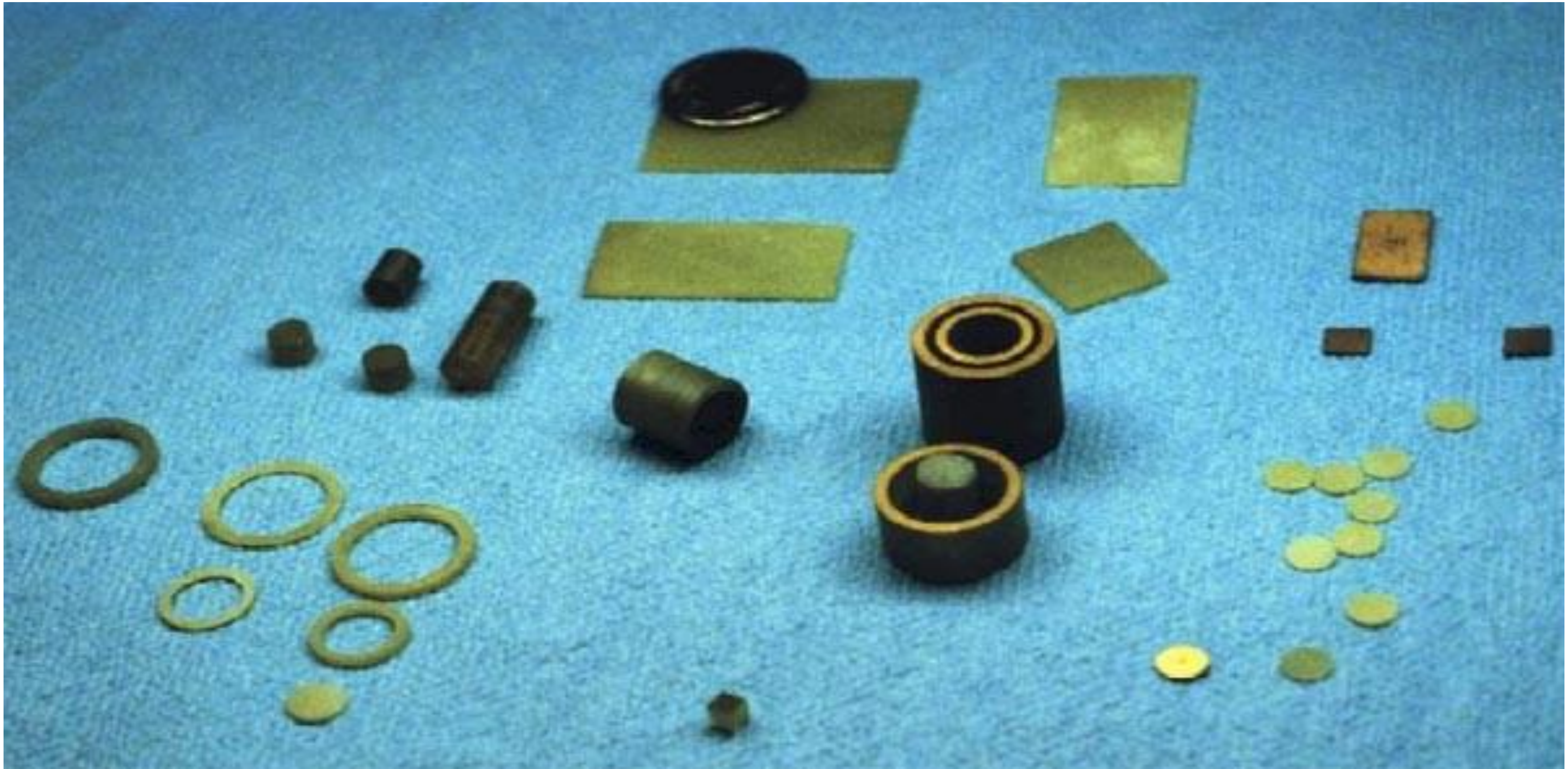
Electrostrictive actuators

- Electrostrictive actuators are made of a lead-magnesium- niobate (PMN) ceramic material.
- PMN is a non-poled ceramic with displacement proportional to the square of the applied voltage.
- The definition of the coupling constant for piezoelectric ceramics is straightforward and depends directly on the square of the piezoelectric constant and inversely on the compliance and dielectric constants appropriate for the boundary conditions.
- PMN unit cells are centro-symmetric

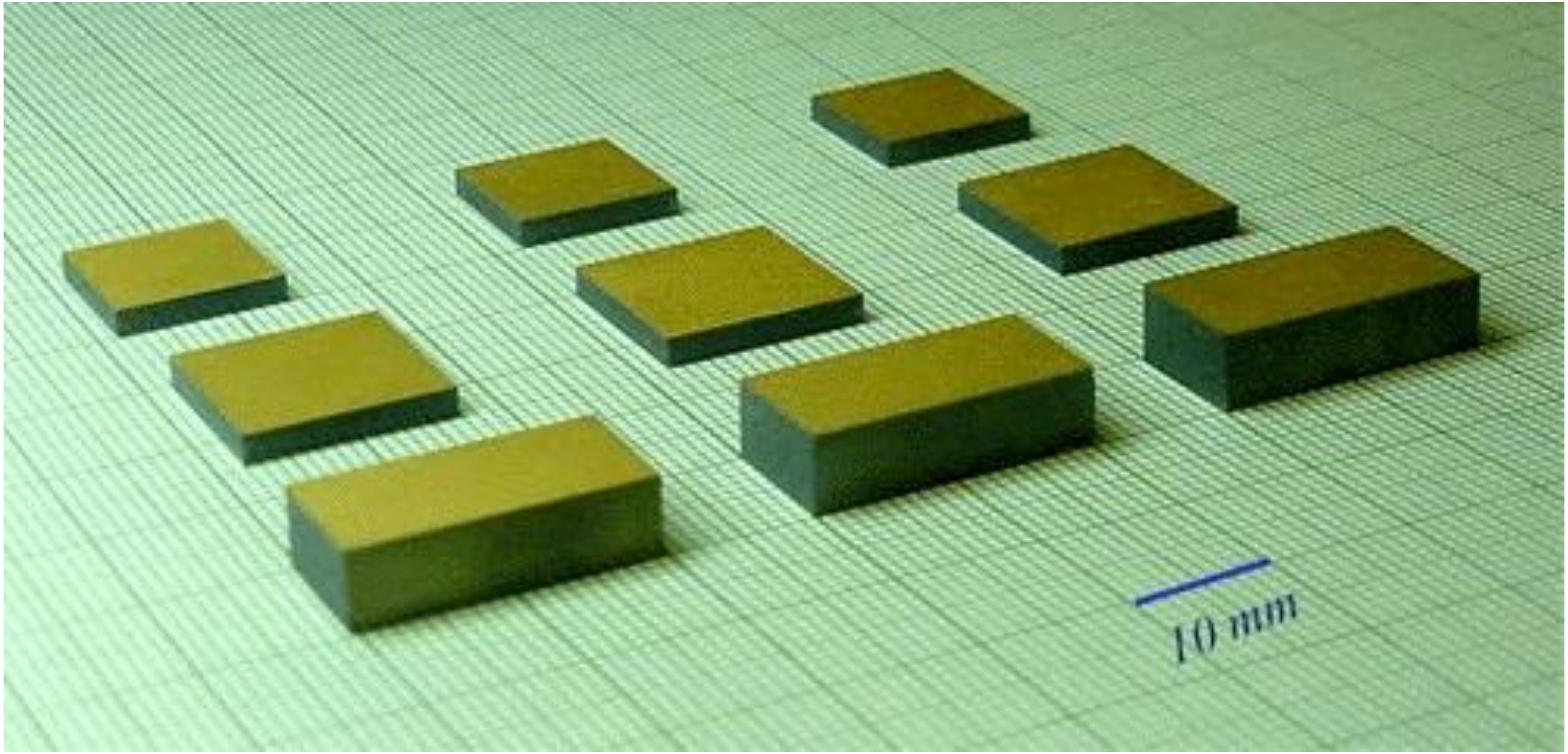
Electrostrictive actuators

- An electrical field separates the positively and negatively charged ions, changing the Dimensions of the cell and resulting in an expansion.
- Electrostrictive actuators are operated above the Curie temperature which is typically very low when compared to Piezo materials.

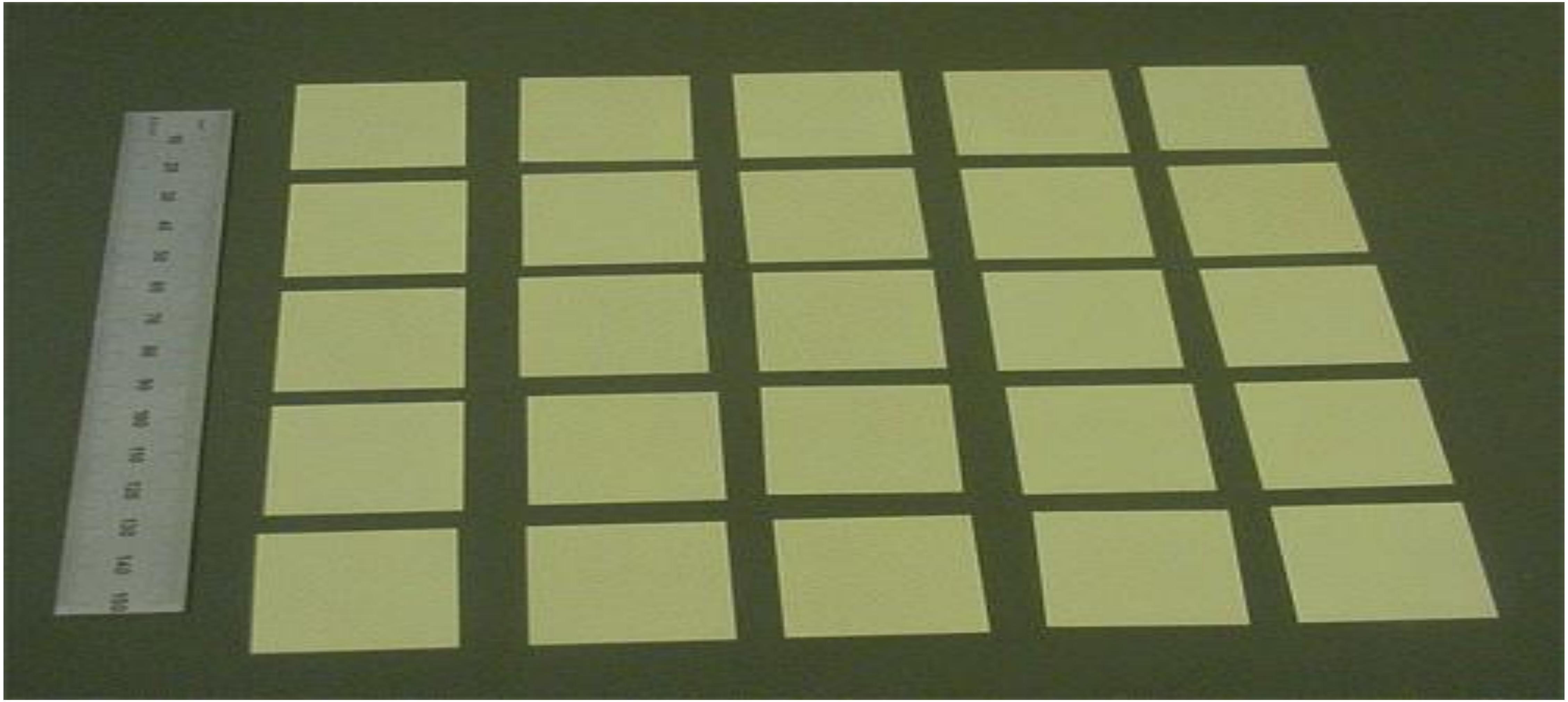
PMNPT Crystal Shapes



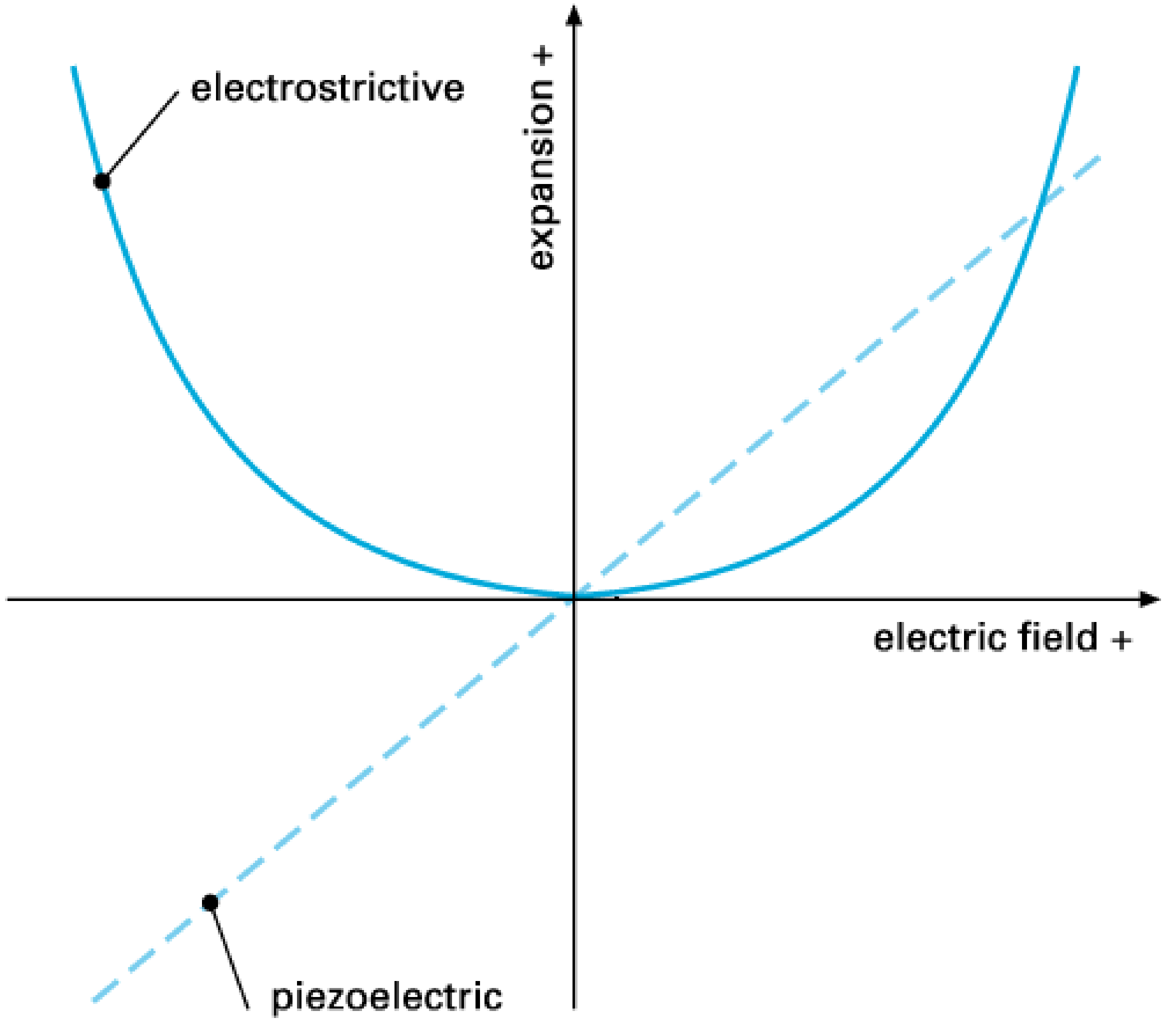
PMNPT Crystal Slabs and Plates



2 inch PMNPT Crystal Plates and wafers



Displacement Vs. voltage behavior of Piezo and PMN actuators (generalized)



Comparison of PMN with PZT and PZN

Mechanism type	PZT (TRS 200 HD)	PZN-4.5% PT	PMN-32%PT
Actuator displacement (μm)	6.3	22.8	26.3
Mechanism without fractional loss of motion (μm)	37.8	138	159
Measured displacement (μm)	33.1	101	104
Measured fractional loss (%)	12.5	26.9	34.0
Theoretical fractional loss (%)	15.9	27.9	22.5

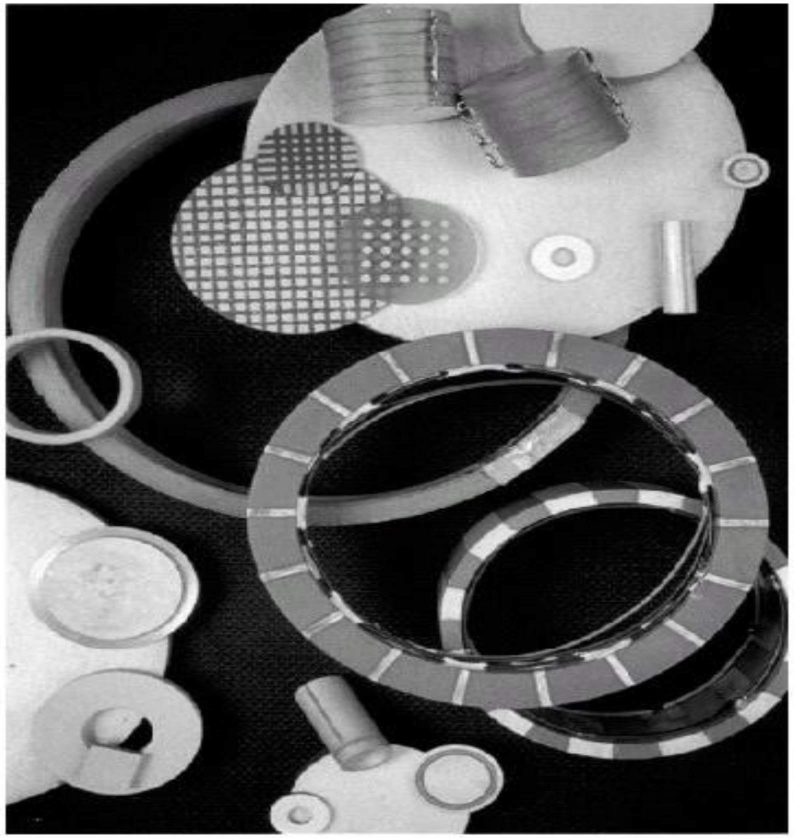
BM600 - Lead Magnesium Niobate (PMN)

Piezoelectric Materials

Overview

The large electrostrictive effect in the BM600 material appears near the broad maxima of the dielectric permittivity. The characteristics of this material are summarized below.

PROPERTY	BM600
Physical Properties	
Density	7.8 g/cm^3
Grain Size	3 - 6 microns
Young's Modulus (0 Field)	100 GPa
Modulus Rupture	70 MPa
Dielectric Properties	
T_m	38°C
Maximum K (1 kHz)	30,000
K @ 25°C (1 kHz)	22,000
Loss Tangent @ 25°C	0.08
Maximum Piezoelectric Charge Coefficients	
Static* d_{33} @ 25°C (4.0 kV/cm)	1800 pC/N
Dynamic d_{33} @ 38°C (4.5 kV/cm)	650 pC/N
Dynamic d_{31} @ 38°C (4.0 kV/cm)	290 pC/N
Maximum Dynamic Coupling Coefficients @ 38°C	
k_{33} (@ 6 kV/cm)	0.55
k_{31} (@ 5 kV/cm)	0.25
k_p (@ 5 kV/cm)	0.41
k_t (@ 6 kV/cm)	0.47
Dynamic Coupling Coefficients @ Peak d_{33}	
k_{33}	0.53
k_{31}	0.25
k_p	0.38
k_t	0.42



***Note:**
Static charge coefficient and coupling coefficient values are expected to be 10-20% higher than those obtained from dynamic measurements at the same temperature.

Features

- Large field-induced strain
- Low hysteresis
- Available in a wide variety of configurations

Applications

- High-power sonar transducers
- Micro-positioners
- Adaptive systems
- Actuators

ELECTROSTRICTIVE ACTUATION MATERIALS

1. **Electrical Breakdown** may happen when an electric field applied in the poling direction exceed the dielectric strength of the material, resulting in electrical arcing through the material and shortcircuit. Electrical breakdown also destroys the piezoelectric properties of the material.
2. **Depoling** may happens when an electric field is applied opposite to the poling direction, resulting in degradation of the piezoelectric properties or even polarization in the opposite direction. The depoling field (coercive field) may be as low as half of the electrical breakdown field.

ELECTROSTRICTIVE ACTUATION MATERIALS

3. **Curie Temperature**. At temperatures close to the Curie temperature, depoling is facilitated, aging and creep are accelerated, and the maximum safe mechanical stress decreases.

- For typical PZT materials, the Curie temperature is about 350°C. The operating temperature should generally be atleast 500°C lower than the Curie temperature.

4. **Non-linearity and Hysteresis**. Real-life piezoceramics are non-linear and hysteretic.Hysteresis is due to internal sliding events in the polycrystalline piezoelectric material. Upon removal of the electric field, remnant mechanical strain is observed.

- Hysteresis of common piezoelectric may range from 1 to 10%. Under high frequency operation, hysteresis may generate excessive heat, and loss of performance may occur if the Curie temperature is exceeded.

ADVANTAGES of ELECTROSTRICTIVE ACTUATION MATERIALS

1. The main advantage of electrostrictive materials over piezoelectric materials is their very low hysteresis. This could be especially beneficial in high-frequency dynamic applications, which could involve considerable hysteresisassociated heat dissipation.
2. The another advantage of electrostrictive materials over piezoelectrics are that they have almost, a quick response time, and higher displacements with good reproducibility. These properties are desired for micropositioner and adaptive optic actuation applications.
3. Their one more advantage is their greater strain capability. However, they lose a large percentage of this strain, unless operated within a very small range of temperatures. They are therefore not suitable for rotor control.

LIMITATIONS OF ELECTROSTRICTIVE ACTUATION MATERIALS

1. The main disadvantage of electrostrictive materials is the temperature dependence of their properties.
2. Another disadvantage of available electrostrictors is their higher cost compared with piezoelectrics. Ceramic materials that are used in electrostrictive devices are in a class called “relaxor ferroelectrics.” The term “relaxor” refers to the significant decrease in dielectric constant with increasing frequency