Problem set #1: Piezoelectric Materials

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Contents

1 Problem 1

A square disc with sides 7 mm is made out of a piezoelectric material having a strain coefficient of $550 \times 10^{-12}\,\mathrm{m\,V^{-1}}$ and a mechanical compliance of $20 \times 10^{-12}\,\mathrm{m^2\,N^{-1}}$. Compute (a) the strain produced by a force of 50 N applied to the face of the material when the applied electric field is zero, and (b) the electric field required to produce an equivalent amount of strain when the applied stress is equal to zero.

a) To compute the strain produce by a given force we can use the mechanical compliance and the following relation,

$$S = \frac{1}{\xi}T,$$

where S is the elongation, T the applied force and $1/\xi$ is the mechanical compliance. Hence, replacing with numeric values,

$$\begin{aligned} S &= 20 \times 10^{-12}\,\frac{\mathrm{m}^2}{\mathrm{N}} 50\,\mathrm{N} \\ &= 1 \times 10^{-9}\,\mathrm{m}^2. \end{aligned}$$

Since the strain is a dimensionless quantity, we need to take the ratio between the deform area and the origina area,

$$\begin{aligned} S &= \frac{1 \times 10^{-9}\,\mathrm{m}^2}{49 \times 10^{-6}\,\mathrm{m}^2} \\ &= \frac{1}{49} \times 10^{-3}. \end{aligned}$$

b) Finally, in order to compute the required electric field to produce a previous strain when the applied stress is zero, we can use the following coupling relation,

$$S = \frac{1}{\xi}T + gE,$$

where S is the strain, $1/\xi$ is the mechanical compliance, T is the stress, g is the strain coefficient and E the electric field. Since the applied stress is zero, the relation simplifies to,

$$S = gE.$$

Solving for the electric field and replacing by the numeric values we get,

$$\begin{aligned} E &= \frac{S}{g} \\ &= \frac{550 \times 10^{12}\,\mathrm{V\,m^{-1}}}{49 \times 10^3} \\ &= \frac{550}{49} \times 10^9\,\frac{\mathrm{V}}{\mathrm{m}} \\ &\approx 11.224 \times 10^9\,\frac{\mathrm{V}}{\mathrm{m}}, \end{aligned}$$

2 Problem 2

Find out the dielectric permittivity of the above-mentioned sample if the piezoelectric coupling coefficient of the material is k = 0.7.

Finding ϵ In order to compute the dielectric permittivity we use the following relation between the piezoelectric coupling coefficient (k), piezoelectric constant (d) and mechanical compliance ($1/\xi$),

$$\begin{aligned} k^2 &= \frac{d^2}{1/\xi\epsilon} \\ \epsilon &= \frac{d^2}{1/\xi k^2} \end{aligned}$$

replacing the numeric values,

$$\begin{aligned} \epsilon &= \frac{(550 \times 10^{-12}\,\mathrm{m\,V^{-1}})^2}{20 \times 10^{-12}\,\mathrm{m^2\,N^{-1}}(0.7)^2} \\ &\approx 3.086 \times 10^{-8}\,\mathrm{N\,V^{-2}}, \end{aligned}$$

Recalling that $\mathrm{V} = \mathrm{N\,m\,C^{-1}}$, we get,

$$\epsilon \approx 3.086 \times 10^{-8}\,\frac{\mathrm{C^2}}{\mathrm{N\,m^2}}$$

3 Problem 3

Compute the stress required to produce 100 microstrain in APC 856 when the applied electric field is held constant at zero. Assume that the material APC 856 has a compliance at constant electric field $s^E = 15.3 \times 10^{-12}\,\mathrm{m^2\,N^{-1}}$

Finding strain This case is similar to problem1. Hence, we can applied the same constitutive equation for small deformations and compute the stress,

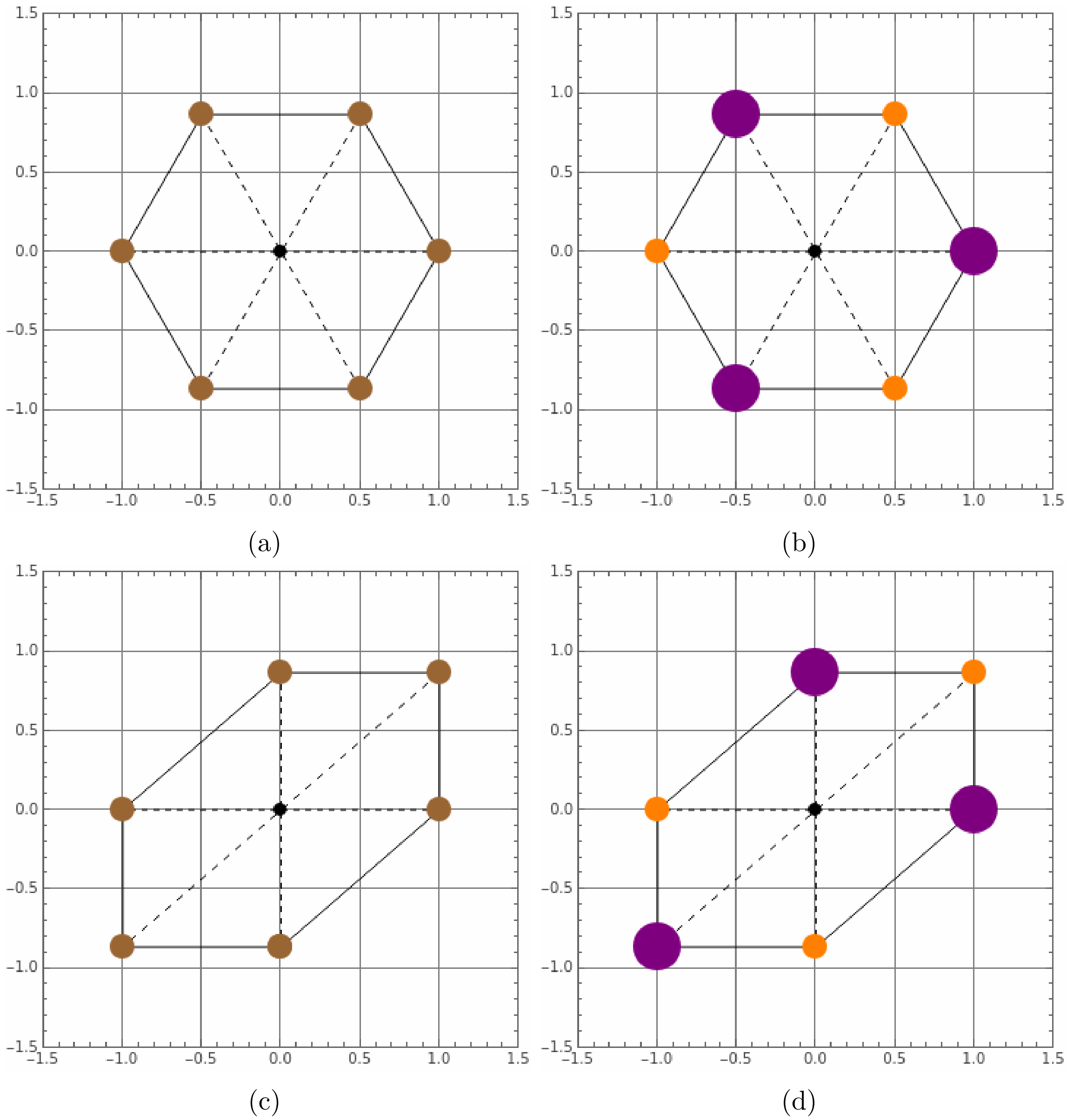
$$\begin{aligned} S &= \frac{1}{\xi}T + \cancelto{0}{gE} \\ T &= \xi S \\ &= \frac{1}{15.3 \times 10^{-12}\,\mathrm{m^2\,N^{-1}}} 100 \times 10^{-6} \\ &= 6.535 \times 10^{6}\,\frac{\mathrm{N}}{\mathrm{m^2}} \end{aligned}$$

4 Problem 4

(a) What do you understand by centrosymmetric crystal? (b) Explain with suitable diagram/s why piezoelectricity is not observed in all types of crystals while electrostriction is observed in all crystals.

Centrosymmetric crystals The representation of a crystal material as a lattice allows to understand the "centrosymmetric" as a symmetry in the lattice. This is an inversion center type of symmetry. Therefore, if each point's coordinates are inverted, $(x, y, z) \rightarrow (-x, -y, -z)$, the point remains unchanged.

Connection with electrostriction and piezoelectricity On the other hand, electrostriction is an effect observe when an electric field is applied to a crystal and induces a deformation (strain) in the material. When the crystal is represented by a centrosymmetric lattice and introduce a uniform deformation, the inversion symmetry cause that each atom position has an identical partern (fig 1c). However, a piezoelectric material is represented by a lattice lacking of centrosymmetry. This absecense of symmetry cause the creation of a dipole that can be measure as a voltage (fig 1d). Although in figure 1 it is shown a hexagonal lattice, the detail of adding different type of particles it is crutial to break the symmetry.



(a) (b) (c) (d)

Figure 1: Representation of centrosymmetry lattice under deformation. Figures1a and 1c represent electrostriction is a non-piezoelectric material and figures1b and 1d represent electrostriction is a piezoelectric material

5 Problem 5

Do a survey and find out 5 companies that sell piezoelectric ceramics and piezoelectric polymers. List the specifications including the piezoelectric constants and unit price of these materials. You will need these materials for your final project so also find out which company will deliver the products here and what is the lead time.

Company	Product Types	Key Piezoelectric Constants	Unit Price Range (USD)	Delivery to Monterrey, Mexico
APC International	Ceramic discs, rings, plates	d33 ~ 300-750 pC/N; d31 ~ -170 to -300 pC/N	Varies by size and shape; approx. $10-$100 per piece	Yes, upon inquiry
FBelec	Customized piezo ceramics and rings	Specs available on request (d31, d33)	Custom pricing based on specs	Yes, ships internationally, including Mexico
TAIMI	Discs, plates, rings, tubes	Diameters 1-150mm; d33 typical range 400-750 pC/N	Quotes provided upon request	Yes, ships internationally
Alibaba Suppliers	Various piezoelectric ceramics	Varies widely: d33 200-750 pC/N commonly	From a few USD to hundreds depending on order size	Yes, many suppliers ship to Monterrey
PiezoHannas.com	Piezo ceramics discs and plates	Soft PZT: d33 up to 750 pC/N	Price offers on inquiry	Possible to arrange delivery to Mexico