Electrostrictors and Relaxor Ferroelectrics

$$\begin{Bmatrix} D \\ T \end{Bmatrix} = \left[\begin{array}{c|c} \varepsilon^S & e \\ \hline -e_t & c^E \end{array}\right] \begin{Bmatrix} E \\ S \end{Bmatrix}$$

Transpose

❖ Electrostrictors and Relaxor Ferroelectrics

Ref. : The one given out.

Blackwood & Ealey ‘Electrostrictive Bias in PMN Actuators” Smart Material & Structures 2(1993) pg. 124-133

Electrostriction Effect

Strain $\propto$ $(\text{Polarization})^2$

What is Polarization?

$D = \text{electrical displacement}$

$D = \varepsilon_o E + P$

$\quad = \varepsilon_o E + \varepsilon_r \varepsilon_o E$

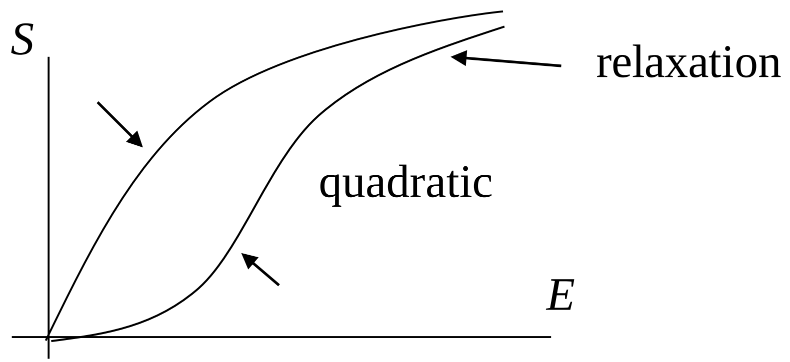
$D \simeq P$

Electrostrictors and Relaxor Ferroelectrics

Relaxor Ferroelectric - Class of crystal

- exhibits dispersive phase transition
- exhibits large electro effect

- Behavior
  - Large strain
  - High stiffness
  - require no poling (sym.)
    - Little hysteresis
    - Long stability
    - Low thermal expansion
    - High sensitivity of coupling ← to temperature
    - High sensitivity of dielectric permittivity
    - Nonlinear
    - Brittle
    - Very high permittivity



Electrostrictors and Relaxor Ferroelectrics

- Low temperature
  - ferroelectric (like piezo)
  - hysteresis ↗

High temperature
  - hysteresis ↘
  - strain ↘

- Applications
  - Little hysteresis → high frequency
    → micro positioning
  - Long term stability → remote application

- Constitutive Equation

$$D_m = \varepsilon_{mn}{}^{T} E_n + 2\,m_{mnij} E_n T_{ij}$$

$$S_{ij} = m_{pgij} E_p E_g + s_{ijkl}^{E} T_{kl}$$

Electrostrictors and Relaxor Ferroelectrics

$$\begin{Bmatrix} \vec{D} \\ \vec{S} \end{Bmatrix} = \begin{Bmatrix} D_1 \\ D_2 \\ D_3 \\ S_1 \\ S_2 \\ \vdots \\ S_6 \end{Bmatrix} = \begin{Bmatrix} \vdots \\ S_{11} \\ S_{22} \\ S_{33} \\ 2S_{23} \\ 2S_{31} \\ 2S_{12} \end{Bmatrix} = \begin{bmatrix} \varepsilon^T & 2m^* \\ m_t^* & s^E \end{bmatrix} \begin{Bmatrix} E \\ T \end{Bmatrix}$$

$$m^* = \begin{bmatrix} m_{11}E_1 & m_{12}E_1 & m_{12}E_1 & 0 & \underline{m_{44}E_3} & m_{44}E_2 \\ m_{12}E_2 & m_{11}E_2 & m_{12}E_2 & \underline{m_{44}E_3} & 0 & m_{44}E_1 \\ m_{12}E_3 & \underline{m_{12}E_3} & \underline{m_{11}E_3} & m_{44}E_2 & m_{44}E_1 & 0 \end{bmatrix}$$

If $\bar{E} = \begin{Bmatrix} 0 \\ 0 \\ E_3 \end{Bmatrix}$ then $\underset{\sim}{m}$ looks like $\underline{d}$

Electrostrictors and Relaxor Ferroelectrics

$$\varepsilon^T = \begin{bmatrix} \varepsilon^T{}_{11} & 0 & 0 \\ 0 & \varepsilon_{11}{}^T & \varepsilon_{11}{}^T \end{bmatrix}$$

$$s^E = \begin{bmatrix} s_{11}{}^E & s_{12}{}^E & s_{12}^E & 0 & 0 & 0 \\ s_{12}{}^E & s_{11}{}^E & s_{12}^E & 0 & 0 & 0 \\ s_{12}{}^E & s_{12}{}^E & s_{12}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{44}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{44}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & s_{44}^E \end{bmatrix}$$

quadratic $S \propto E^2$ is good low E

$$S \propto \tanh^2(kE)$$

$$S_{ij} = \frac{1}{k^2} m_{mnij} \tanh^2(k|E|) \; \frac{E_m E_n}{|E|^2}$$

relaxation parameter

as $E \rightarrow$ small

$$\tanh^2(k|E|) \rightarrow k^2 E^2$$

$$S \rightarrow mE^2$$

Electrostrictors and Relaxor Ferroelectrics

- Hyperbolic Constitutive Relation

$$D_m = \varepsilon_{mn}{}^T E_n + \frac{2}{k} m_{mnij} T_{ij} \sinh(k|E|) / \cosh^3(k|E|) \cdot \frac{E_n}{|E|}$$

$$S_{ij} = s_{ijkl} T_{kl} + \frac{1}{k^2} m_{mnij} \tanh^2(k|E|) \frac{E_m E_n}{|E|^2}$$

- Polarization

$$S \propto P^2,\ P(E) = \varepsilon_r \varepsilon_o E$$

$$P_n = P^2 \tanh(kE_n)$$

Saturation polarization = constant

- Material Properties @ room temperature for 0.9 PMN-0.1PT

$$C_{1111} = 120\,GPa$$

$$v_{1111} = 0.38$$

$$\varepsilon_{33} = 17000\,\varepsilon_0 \leftarrow \mathrm{max.}$$