

Piezoelectrics

I part: Polarization

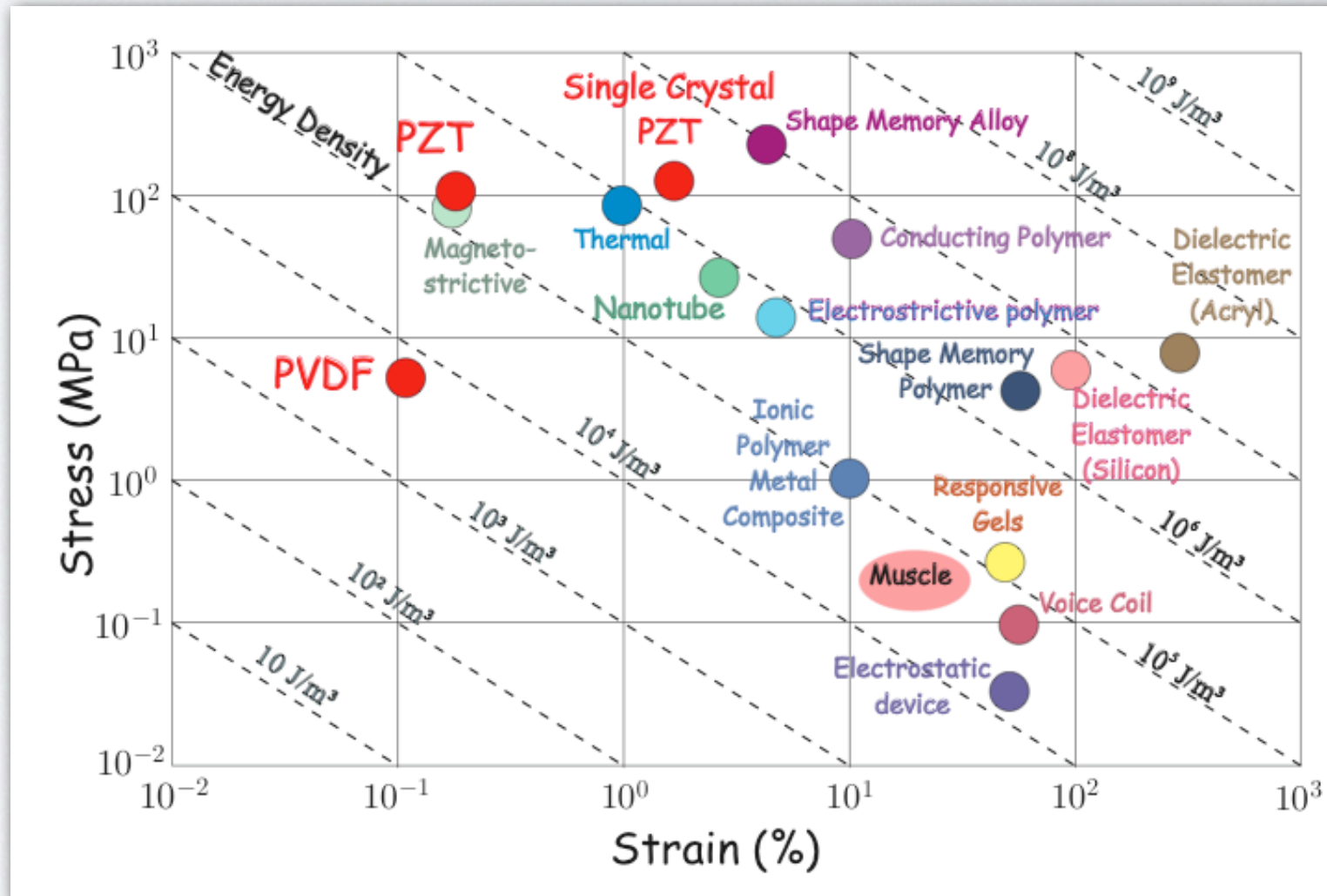
Luca Lutterotti

Stimulus-Response

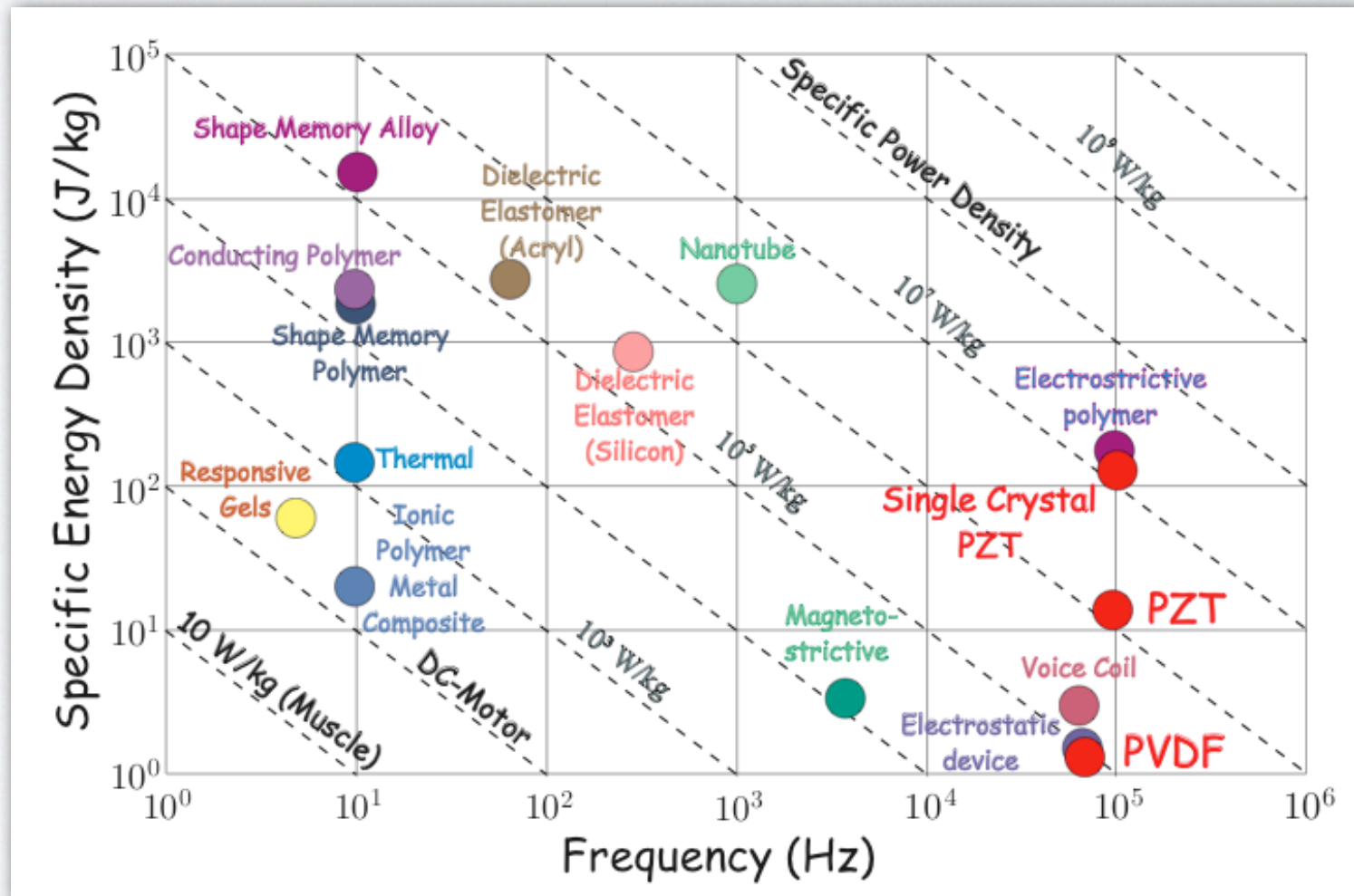
Output Input	Strain	Electric charge	Magnetic flux	Temperature	Light
Stress	Elasticity	Piezo-electricity	Magnetostriction		Photo-elasticity
Electric field	Piezo-electricity	Permittivity			Electro-optic effect
Magnetic field	Magnetostriction	Magneto-electric effect	Permeability		Magneto-optic
Heat	Thermal expansion	Pyro-electricity		Specific heat	
Light	Photostriction	Photo-voltaic effect			Refractive index

Smart and functional materials are out of the diagonal

Actuators and stress/strain



Actuators and frequency

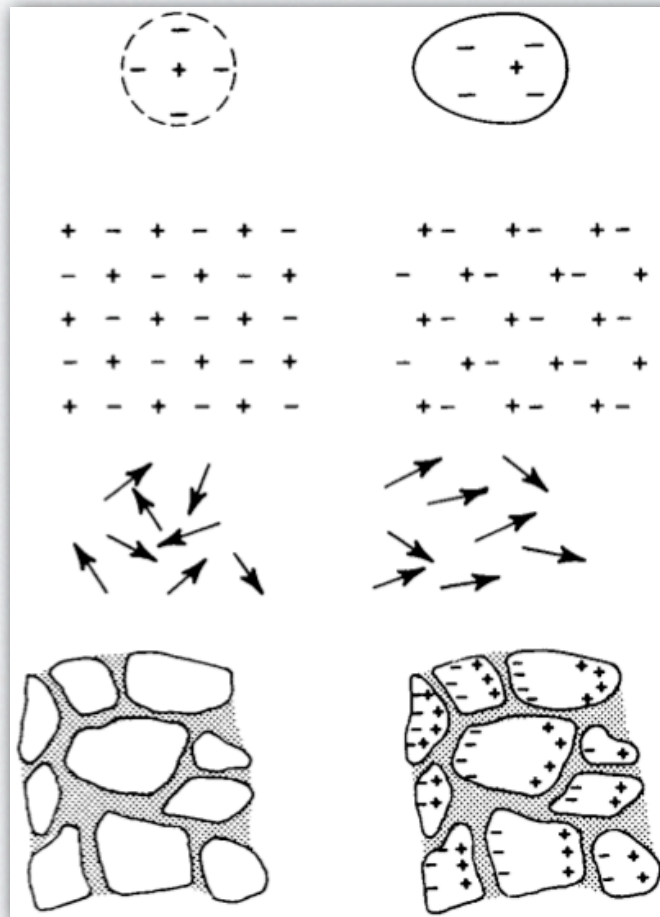


Polarization processes

Non polarized

Polarized

Polarization process



Atomic

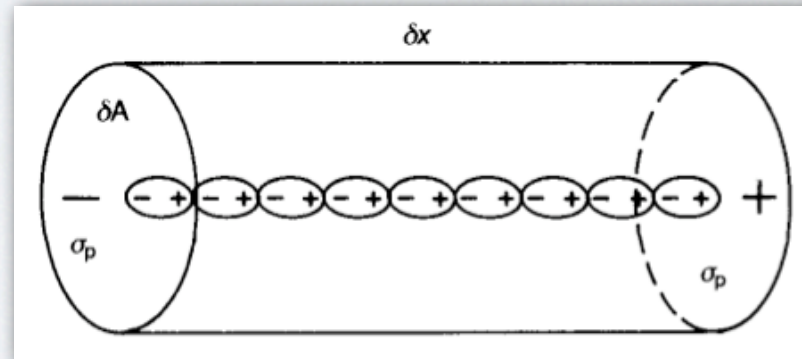
Ionic

Dipolar

Space charge
or
diffusional

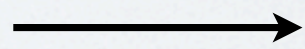
$E \longrightarrow$

Polarization



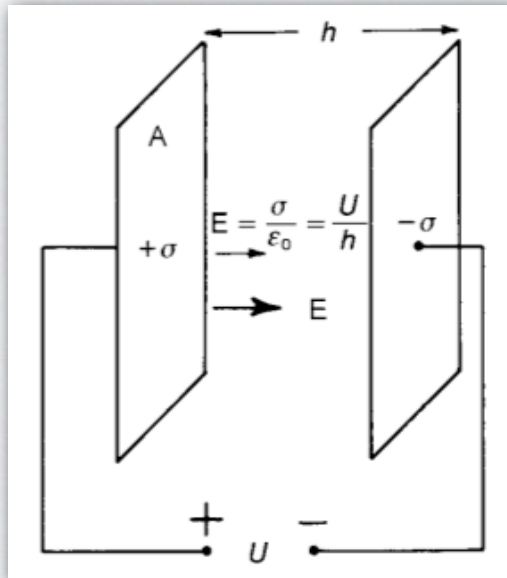
$$p = Q\delta x$$

$$\delta p = \sigma_p \delta A \delta x = \sigma_p \delta V$$



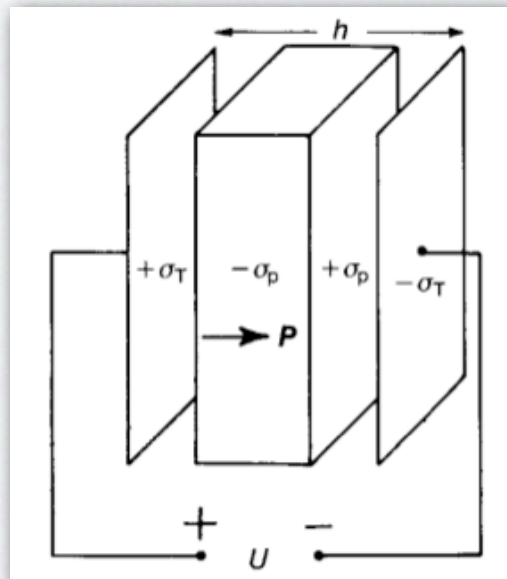
$$\frac{\delta p}{\delta V} = P = \sigma_p$$

Capacitor



In vacuum

$$E = \sigma / \epsilon_0$$



In dielectric

$$E = \frac{\sigma_T - \sigma_p}{\epsilon_0}$$

$$\frac{Q_T}{A} = (1 + \chi_e) \epsilon_0 \frac{U}{h}$$

$$C = \frac{Q_T}{U} = (1 + \chi_e) \epsilon_0 \frac{A}{h}$$

Permittivity of vacuum
↓
Electric displacement: $D = \epsilon_0 E + P$

Polarization: $P = \chi_e \epsilon_0 E$

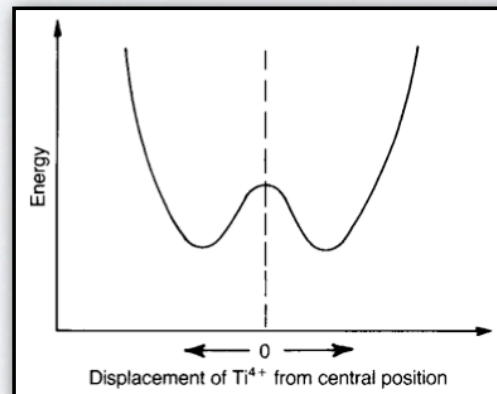
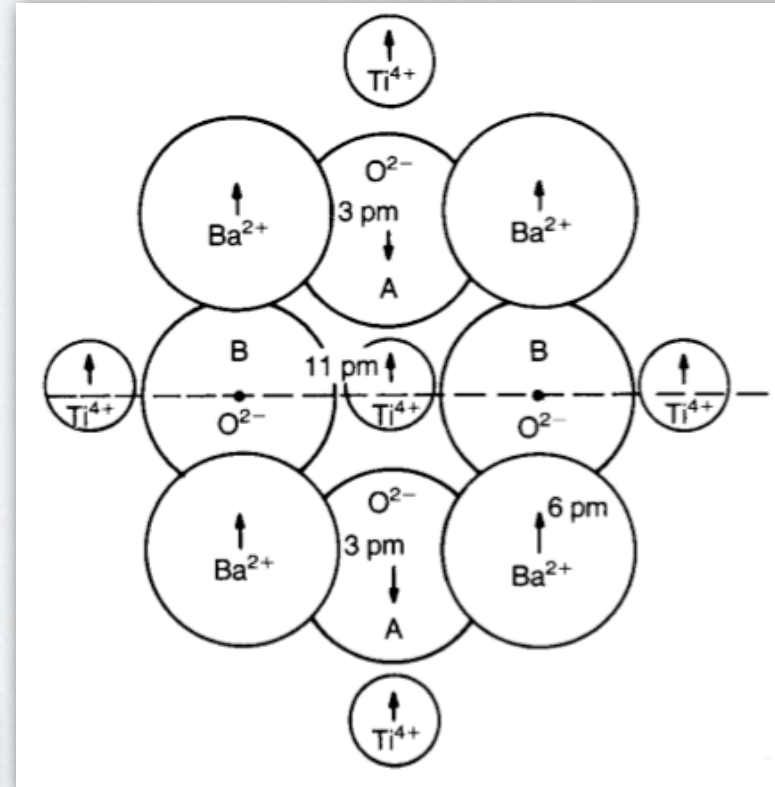
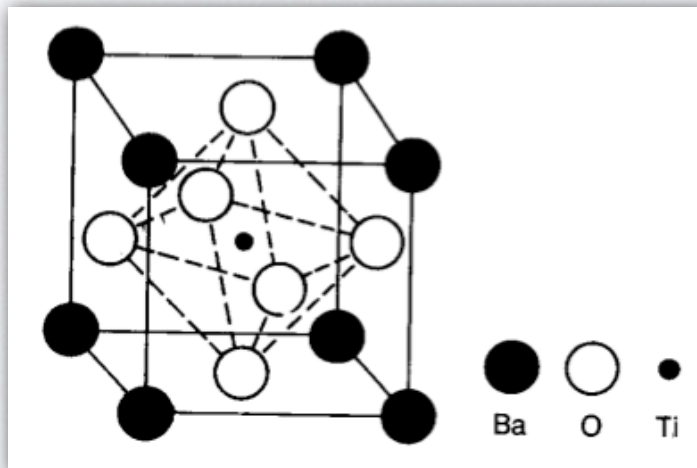
$$D = \epsilon_0 E + \chi_e \epsilon_0 E = (1 + \chi_e) \epsilon_0 E$$

$$\epsilon = \epsilon_0 (1 + \chi_e)$$

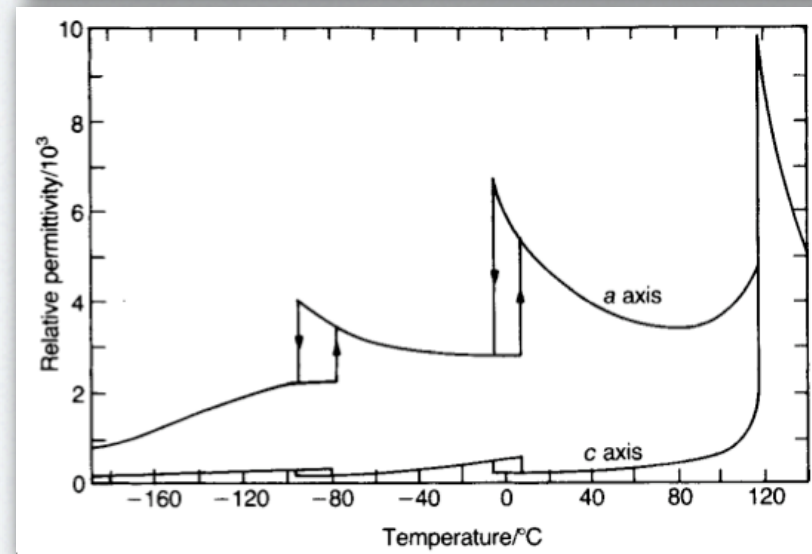
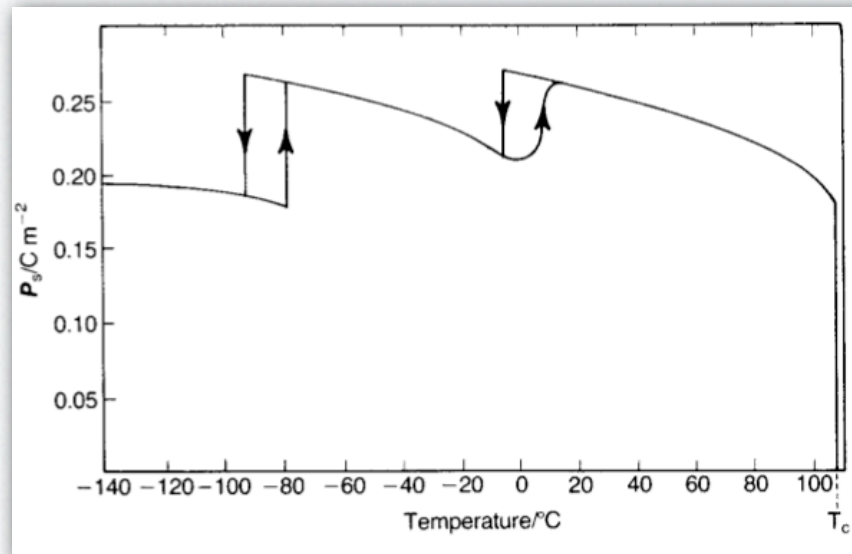
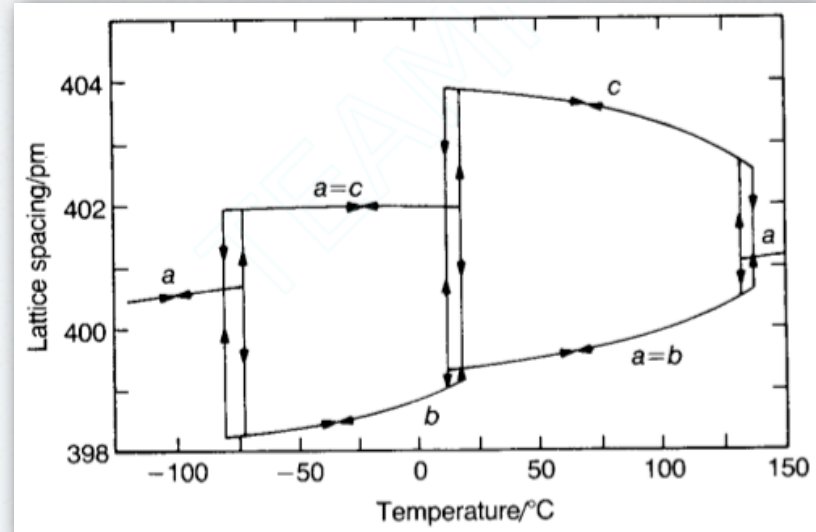
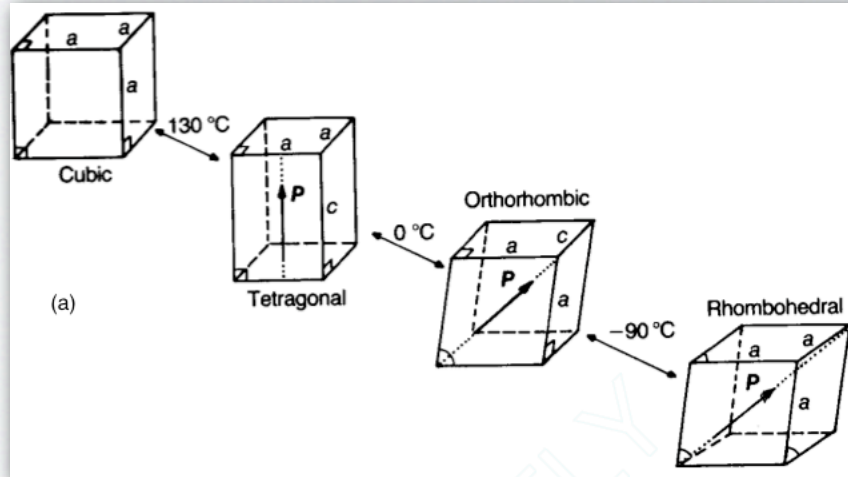
$$\frac{\epsilon}{\epsilon_0} = 1 + \chi_e = \epsilon_r$$

$$C_0 = \epsilon_0 \frac{A}{h}$$

BaTiO₃

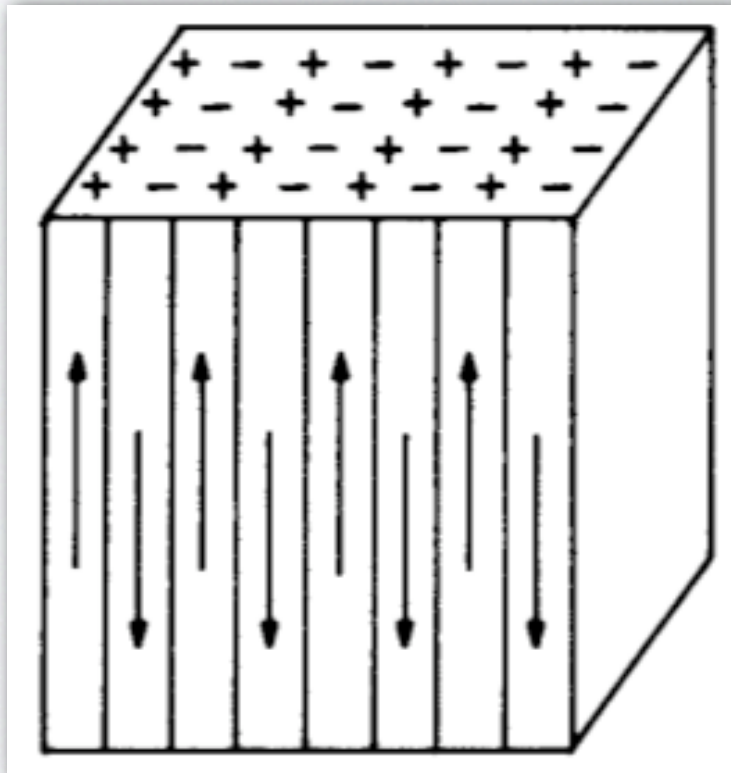


BaTiO₃ transitions

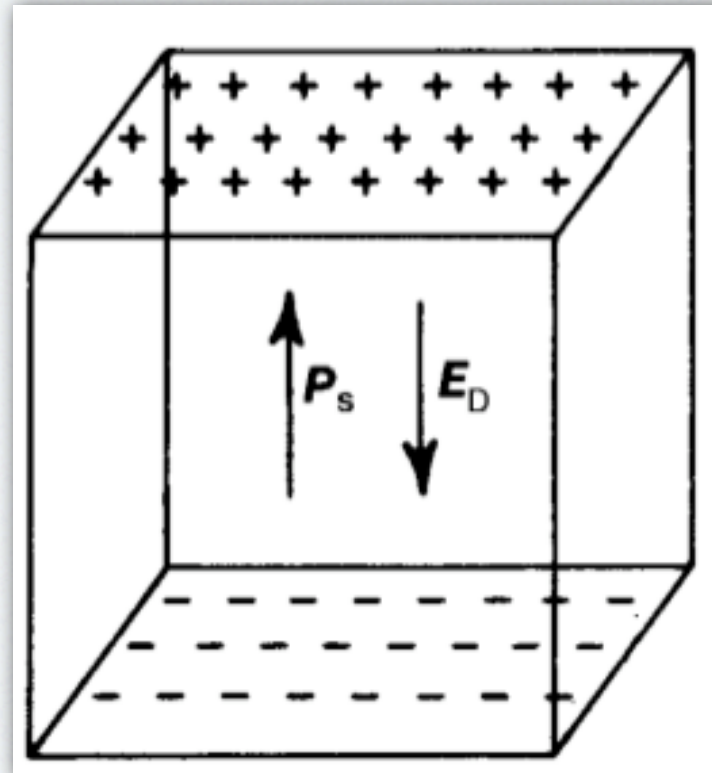


BaTiO₃ single crystal

Cool down from T_c

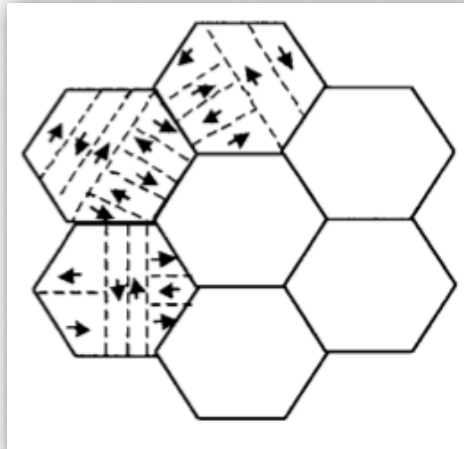


Polarized (spontaneous)

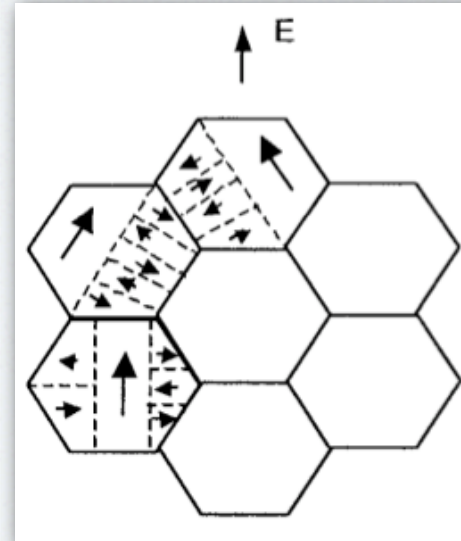


BaTiO₃ poly-crystal

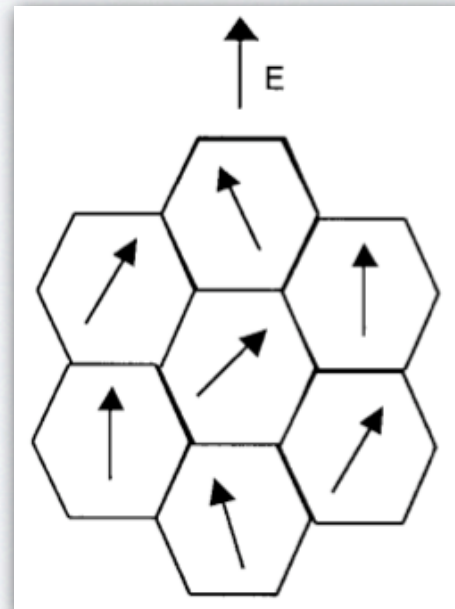
No electric field



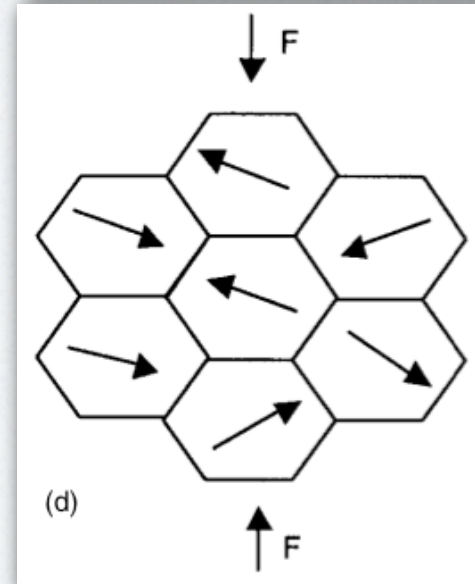
Small electric field



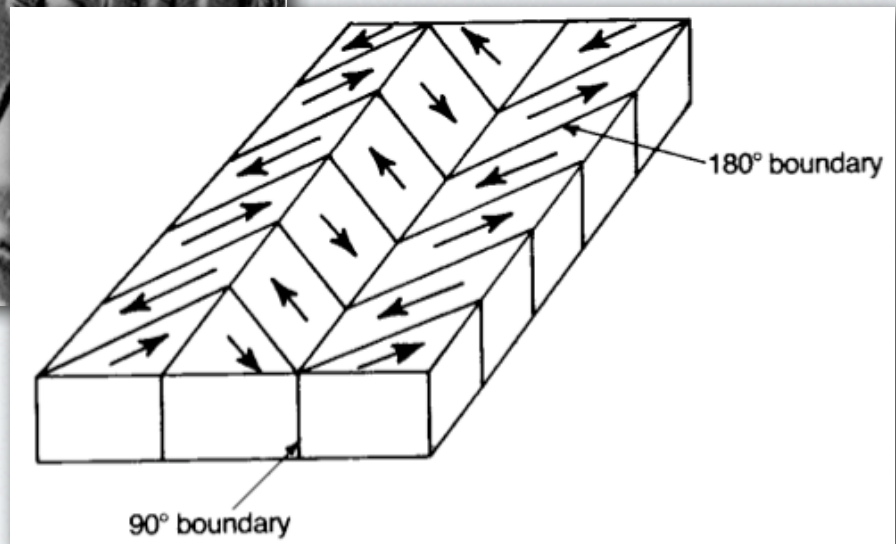
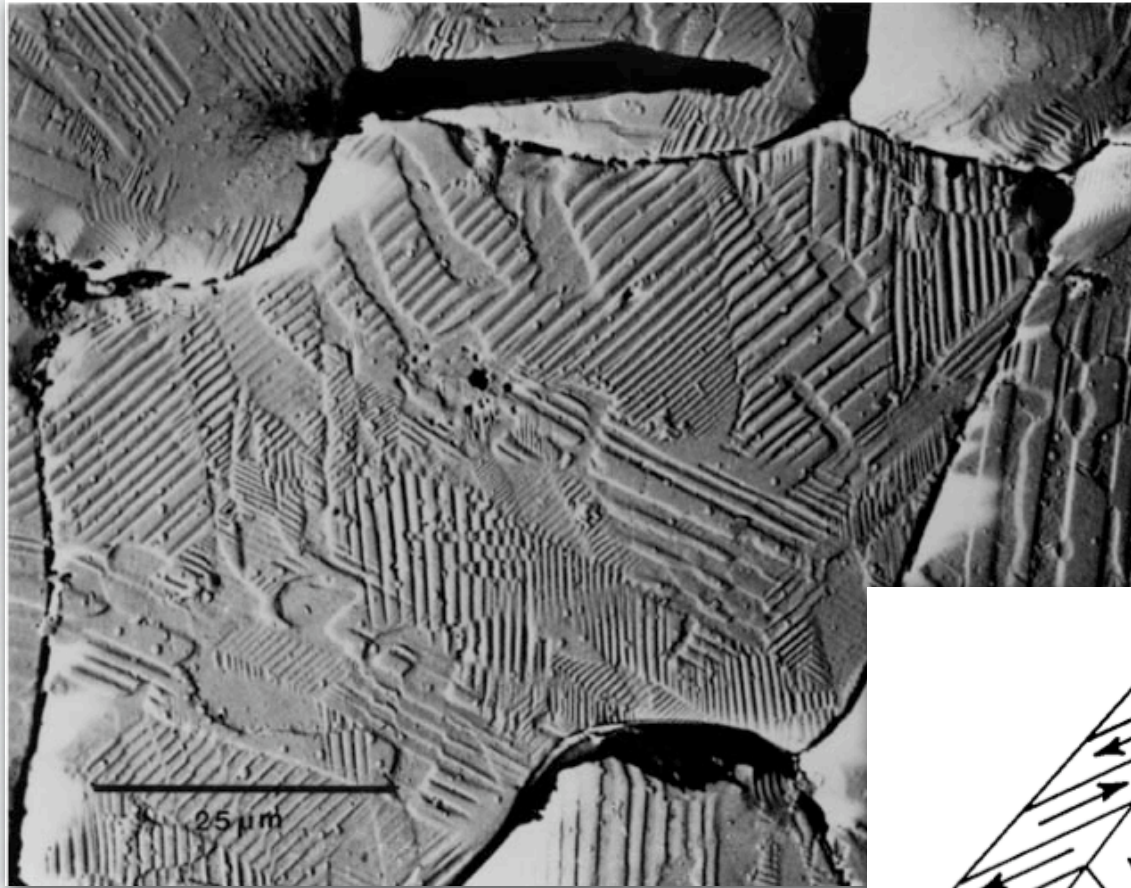
High electric field



Compression applied

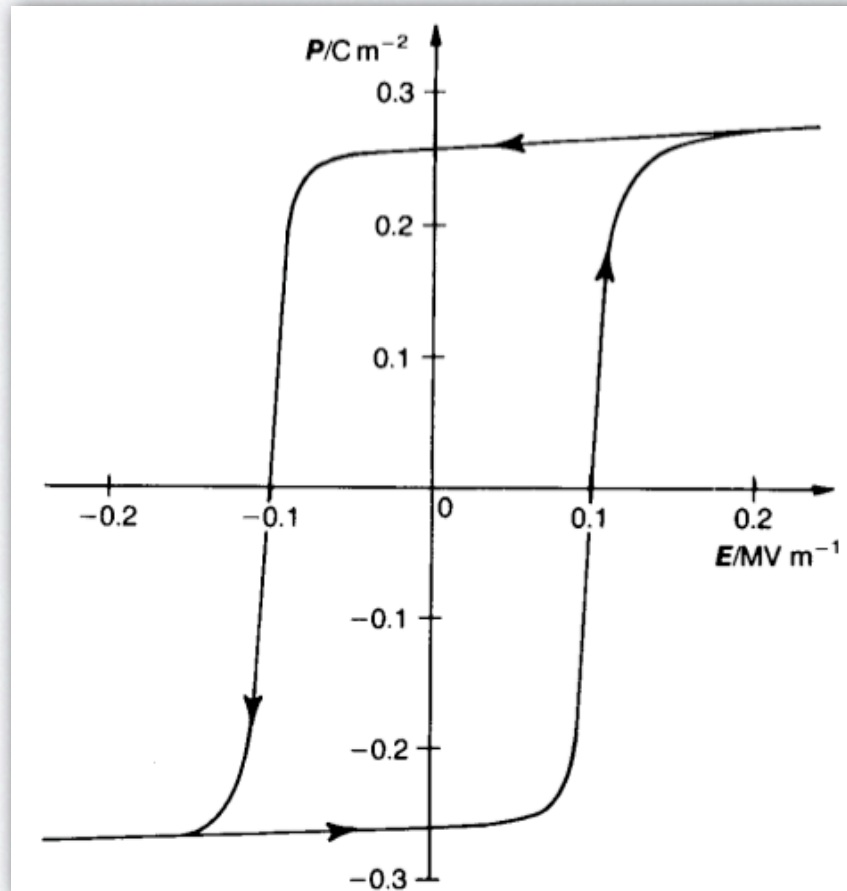


BaTiO₃ poly-crystal



Polarization curves

Single crystal



Poly-crystal

