ELECTRONICS DEVICES AND MATERIALS

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FERROELECTRIC DEVICES

1.Capacitor ~high permittivity devices~

2.Piezoelectric Devices

3.Pyroelectric Devices

4.Ferroelectric Memory Devices

5.Electrooptic Devices

VARIOUS EFFECTS IN MATERIALS

Input ⇨ Material Device ⇨ Output

Input \ Output	Charge Current	Magnetization	Strain	Temperature	Light
Electric Field	Permittivity Conductivity	Elect.-Mag. efficient	Converse piezo-effect	Elec. Caloric effect	Elec.-optic effect
Magnetic Field	Mgg.-elect. effect	Permeability	Magneto-striction	Mag.caloric effect	Mag.optic effect
Stress	Piezoelectric effect	Piezomag. effect	Elastic constant		Photoelastic effect
Heat	Pyroelectric effect		Thermal expansion	Specific heat	
Light	Photovoltaic effect		Photostriction		Refractive index

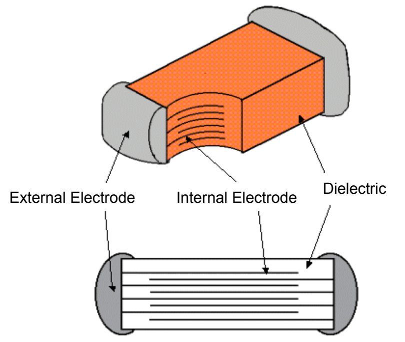
Sensor (Charge Current column) — Actuator (Strain column)

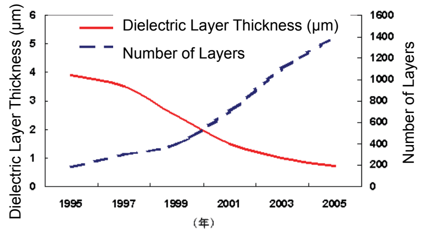
CERAMIC CAPACITORS ~HIGH PERMITTIVITY DIELECTRICS~

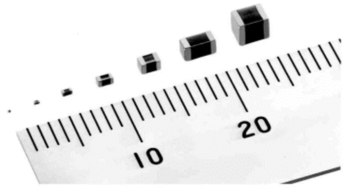
The basic Specifications required for capacitors:

- **Small size, large capacitance**
  Materials with a large dielectric constant are desired.
- **High frequency characteristics**
  Ferroelectrics with a high dielectric constant are sometimes associated with dielectric dispersion, which must be taken into account for practical applications.
- **Temperature characteristics**
  We need to design materials to stabilize the temperature characteristics.

MULTILAYER CERAMIC CAPACITOR (MLCC)





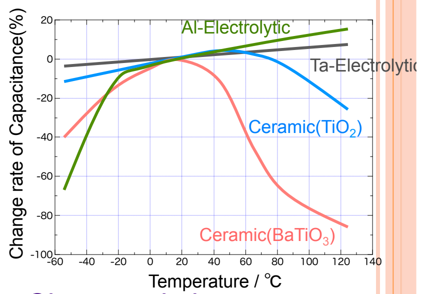


$$C=\varepsilon_0\varepsilon_r\frac{A}{d} \quad =n\varepsilon_0\varepsilon_r\frac{S}{L/n}$$

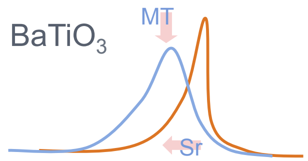
TEMPERATURE CHARACTERISTICS

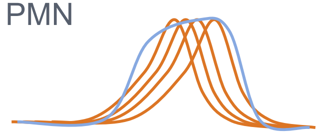
Categories of dielectrics

- thermal compensation type (TiO_2)
  high frequency, filtering, amplifier cir.
- high permittivity type ($BaTiO_3$)
  coupling or decoupling circuite



Some approach to improve Temp. Characteristics

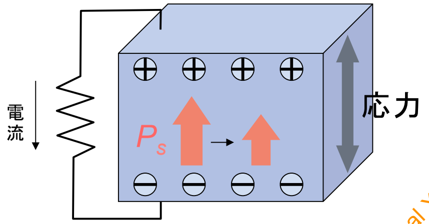




Shifter additive (decreasor: Sr, elevator: Pb)
Depressor additive ($MgTiO_3$, $CaTiO_3$)

Combination of ferroelectrics with deferent composition (deferent Curie Temp.)

PIEZOELECTRIC DEVICES



Relationship of polarization and piezoelectric strain

$$P=\varepsilon_0\varepsilon(X)\,E$$

Fundamental Piezoelectric equations:

$$x=c(E)X+dE$$

$$P=dX+\varepsilon_0\varepsilon(X)E$$

If external X=0

external E=0
P=dX

$$E=\frac{P}{\varepsilon_0\varepsilon(X)}=\frac{dX}{\varepsilon_0\varepsilon(X)}$$

Therfore $g=\frac{d}{\varepsilon_0\varepsilon_r}$

Piezoelectric Figures of Merit

Piezoelectric Strain Constant: d

$$x=dE$$

External electric field: E,
magnitude of he induced strain : x

An important figure of merit for actuator applications

Piezoelectric voltage constant: g

$$E=gX$$

External stress: X,
induced electric field: E

An important figure of merit for sensor applications

OTHER IMPORTANT FIGURE OF MERIT FOR PIEZOELECTRIC APPLICATIONS

Electromechanical Coupling Factor: k

$$k^2=\frac{\text{Stored mechanical energy}}{\text{Input electrical energy}}$$

Conversion rate between electrical energy and mechanical energy

Mechanical Quality : Q_m

$$Q_m=\frac{\omega_0}{2\Delta\omega}$$

ω_0:resonance frequency

The inverse of mechanical loss

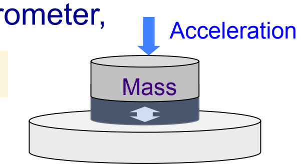
Acoustic Impedance : Z

Evaluating the acoustic energy transfer between two materials

APPLICATIONS OF PIEZOELECTRICS

Gas igniter Pressure sensor, Accelerometer,

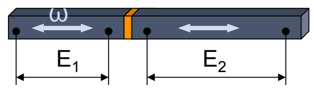
Stress → Internal electrical field



Basic structure of an accelerometer

Piezoelectric transformer

External electrical field
→Stress
→ Internal electrical field

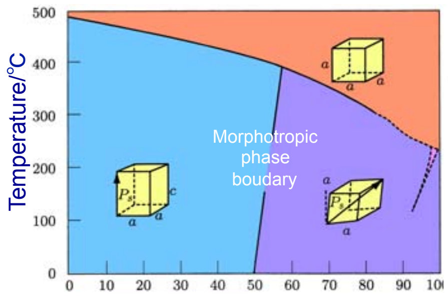


Basic structure of a piezoelectric transformer

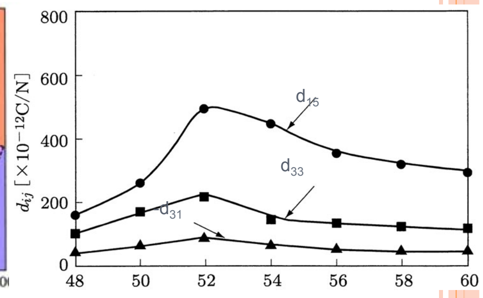
Piezo-actuator･Ultorasonic Motor

External electrical field →Stress

PZT'S COMPOSITION AS PIEZOELECTRIC DEVICES



$PbTiO_3$ $PbZrO_3$ [mol%] $PbZrO_3$

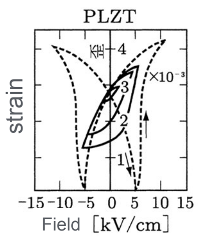


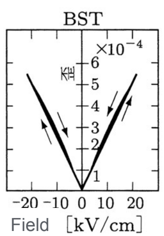
$PbZrO_3$ [mol%]

Dependence of several d constants on composition near morphotropic phase boundary in the PZT system

CERAMIC ACTUATOR MATERIALS

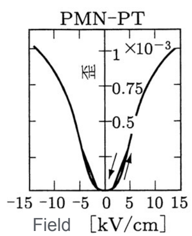
~PIEZOELECTRIC, ELECTROSTRICTIVE AND PHASE CHANGE MATERIAL ~





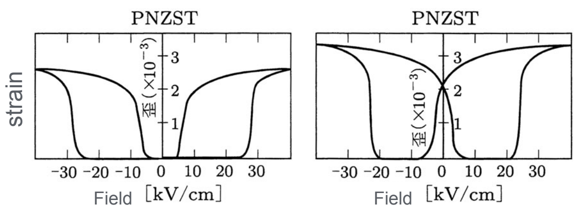
Electrostriction
$\Delta y \propto E_y^2$

Piezoelectric
$\Delta x \propto E_x$



Piezoelectric material, $(Pb, La)(Zr, Ti)O_3$, $Ba(Sn, Ti)O_3$

Electrostrictive material, $Pb(Mg_{1/3}Nb_{2/3}, Ti)O_3$



Phase change material, $Pb(Zr, Sn, Ti)O_3$

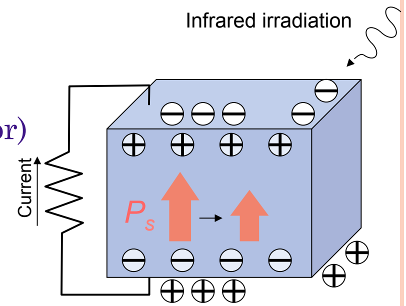
PYROELECTRIC DEVICES

Types of Infrared-sensors

- semiconductor type
  →Imaging and its processing
- pyroelectric type (Pyrosensor)
  →Infrared light sensors, Temperature sensors

The merits of pyrosensors

- wide range of response frequency
- use at room temperature
- quick response in comparison with other temperature sensors
- low costs



Principle of pyroelectric sensor

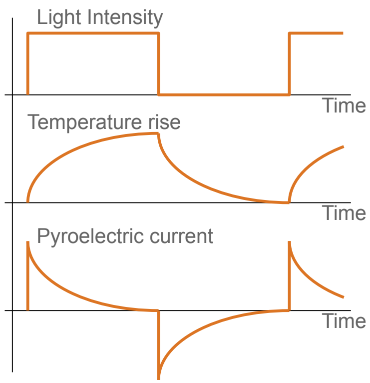
A temperature increase due to the infrared irradiations (such as human body)
⇒ Spontaneous polarization decrease
⇒ Variation in electric charge (or current)

PYROELECTRIC RESPONSE

Current responsivity : r_i

$$r_i = \frac{\eta p}{\rho C_p h}$$

η: transmittance of incident radiation
p : pyroelectric coefficient
ρ: density of pyro-material
C_p :specific heat of detector
h :thickness of detector



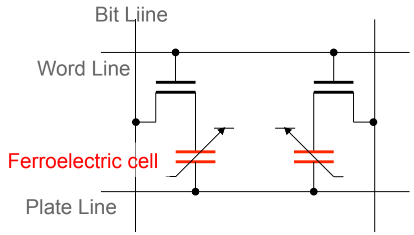
Pyroelectric response to chopped IR irradiation

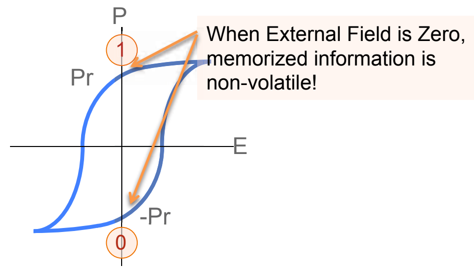
Example of pyro-material for IR detector:

$(Ba, Sr)TiO_3$

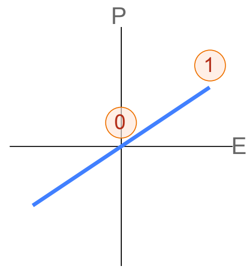
FERROELECTRIC MEMORY DEVICES

FeRAM (FRAM)
Non-volatile memory device
(cf. MRAM, PRAM)





Ferroelectric for memory-cell (FeRAM)

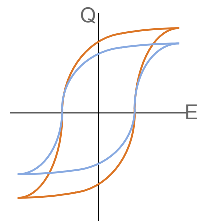


Paraelectrics for memory-cell (DRAM)

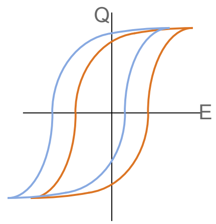
EQUIVALENT CIRCUITS AND SCHEMATIC STRUCTURES OF TYPICAL MEMORY DEVICES

		DRAM	Flash EEPROM	FeRAM	MRAM	PRAM
Equivalent Circuit		Plate Line, Word Line, Bit Line	Source, Word Line, Floating Gate, Drain	Plate Line, Word Line, Bit Line	Bit Line, Word Line	Bit Line, Word Line
Memory State	1	+ + + + / - - - -	- - - -	+ + + + / - - - -		Amorphous
	0	Electrode / Insulator / Electrode	Control Gate / Floating Gate / Si substrate	Electrode / - - - - / + + + + / Electrode / Ferroelectric Film	Insulator / Ferromagnetic Films	Crystalline

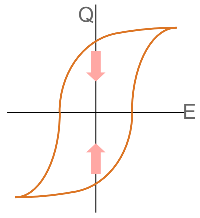
PROBLEMS OF FERROELECTRICS FOR FERAM APPLICATIONS



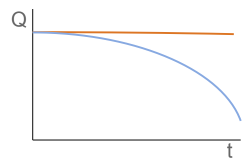
Fatigue



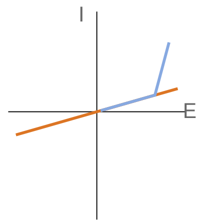
Imprint



Retention



Leak-current



Dielectric breakdown

FERROELECTRIC MATERIALS FOR FERAM

PZT ($Pb(Zr,Ti)O_3$)	Material	SBT ($SrBi_2Ta_2O_9$)
Large Pr Relatively easy fabrication	Merits	Low Ec（low operation Voltage） Good tolerance for Fatigue
Relatively large Ec Large Fatigue Preparation conditions（Pb-composition）	Demerits	Low Pr Difficult preparation conditions（High Temp., Bi-composion）
La addition → leakage & Ec Ca, Sr additions → Imprint and Retention Oxide Electrode, Buffer → Fatigue Properties Film Orientation → Pr, Fatigue、reduction of thickness Ramtron, Fujitsu, …	Improvement Approach	Nb addition → Increment of Pr SBT-BT composite → dielectric properties Symetrix, Panasonic, NEC, …

ELECTROOPTIC DEVICES

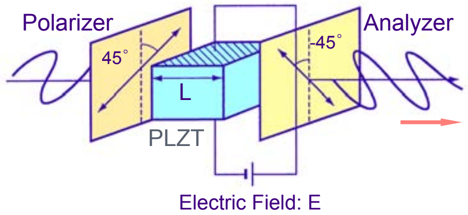
Birefringence

Second-order electrooptic effect (Kerr effect)

Birefringence: Δn

$$\Delta n = -\frac{1}{2} R n^3 E^2$$

R: quadratic electrooptic coefficient
n: original refractive index (E=0)
E: electric field



Fundamental Construction of an electrooptic light shutter

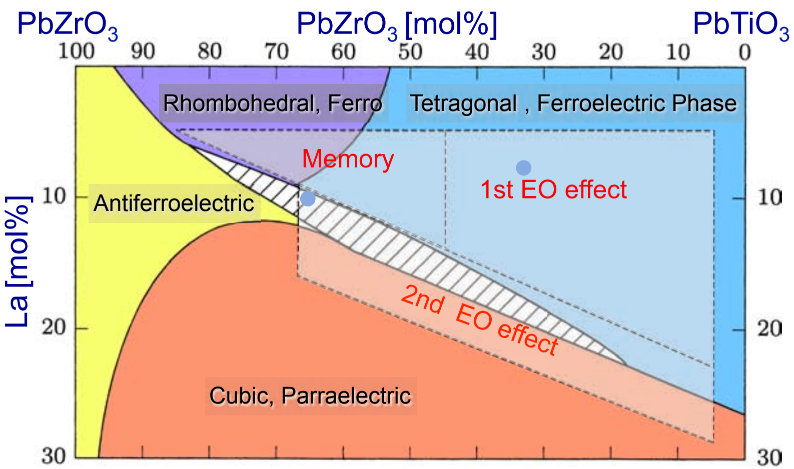
⇔ First-order electrooptic effect (Pockels effect)

Typical Application of Electrooptic Devices

Light Shutter, Light Switch, Waveguide Modulator

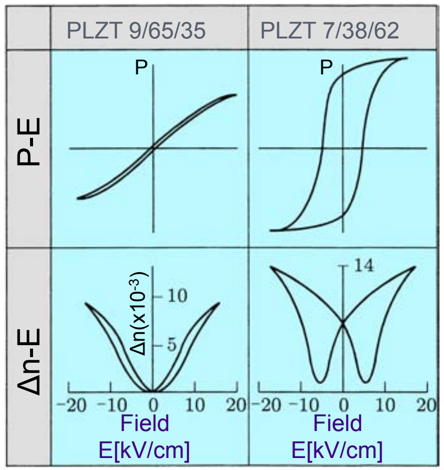
○ high speed, high contrast, gradation
× high cost, high operation voltage

RELATION BETWEEN PLZT COMPOSITION AND STRUCTURE AND ELECTROOPTIC APPLICATION



$PLZT:(Pb_{1-x}La_x)(Zr_{1-y}Ti_y)_{1-x/4}O_3$

POLARIZATION AND BIREFRINGENCE AS A FUNCTION OF ELECTRIC FIELD FOR PLZT



2nd order EO effect　1st order EO effect

Polarization P and Birefringence Δn as a Function of Electric Field E for some PLZT ceramics

DIELECTRIC MATERIALS OF ELECTROOPIC DEVICES

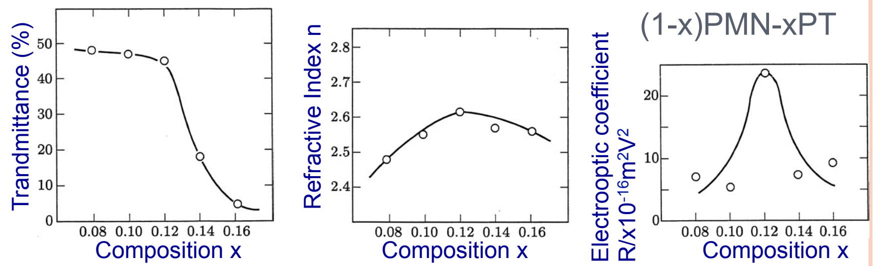
Pockels (1st) and Kerr (2nd) electrooptic coefficients for various materials

	Material	r (×10^{-10} [m/V])
Primary electrooptic coefficient	$LiNbO_3$	0.17
	$Ba_2(K_{0.9}Na_{0.1})Nb_5O_{15}$	0.52
	KH_2PO_4	0.52
	$(Sr_{0.5}Ba_{0.5})Nb_2O_6$	2.10
	PLZT (8/65/35) (GS = 10 [μm])	5.23
	PLZT (8/65/35) (GS = 3 [μm])	6.12
		R (×10^{-16} [m^2/V^2])
Secondary electrooptic coefficient	$KTa_{0.65}Nb_{0.35}O_3$	5.30
	PLZT (9/65/35) (GS = 2 [μm])	9.12
	PLZT (10/65/35) (GS = 2 [μm])	1.07

REQUIRED PROPERTIES FOR ELECTROOPTOIC DEVICES

Required Properties for electrooptoic devices

- high electrooptic coefficient
- good mechanical properties（especially high toughness）
- high transmittance
- Δn close to zero, when external electric field is zero
- low porosity, high sintered density



$(1-x)Pb(Mg_{1/3}Nb_{2/3})O_3-xPbTiO_3$