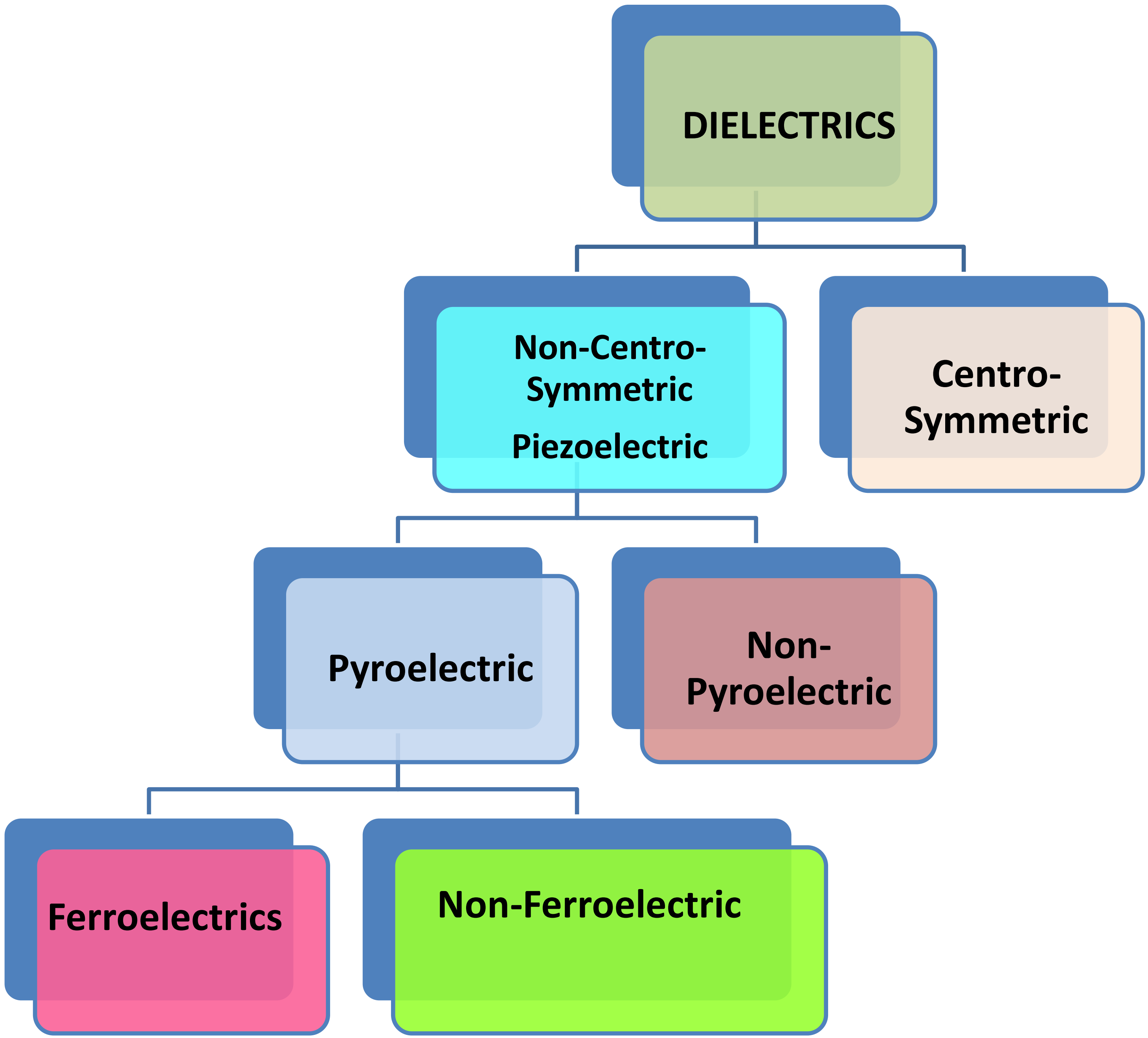
Classification of Dielectrics
&
Applications


DIELECTRICS
Non-Centro-
Symmetric
Piezoelectric
Centro-
Symmetric
Pyroelectric
Non-
Pyroelectric
Ferroelectrics
Non-Ferroelectric

Piezoelectric Effect

- When an electric field is applied, a dielectric material gets polarized, i.e.; shifting of charge occurs or dipoles are oriented.

  So, the dimension of the material changes slightly or, when EF is applied, a strain is produced in the dielectric, which is called **<u>electrostriction effect.</u>**

- In dielectrics, having no centre of symmetry (no inversion centre), strain produced is proportional to the EF applied. When EF is reversed, strain also changes sign—i.e., expansion becomes contraction or vice versa)

- On the other hand, when mechanical stress is applied to these dielectrics, they get polarised and the polarisation is proportional to the stress applied

- Such materials are called **piezoelectric materials**

- These can be used to convert electrical energy to mechanical energy and vice versa (transducers)

Ex;-Quartz , $BaTiO_3$, $PbTiO_3$, $Pb_{1-x}Zr_xTiO_3$ (PZT), Lithium Niobate

- **Direct Piezoelectric Effect:**

On application of a mechanical stress on the material, charge appears across the faces of the material, material gets polarised (material can sense a strain)

- If 'P' is the polarisation , 'σ' is the applied stress then, → **$P = d\sigma$**

  'd' = piezoelectric strain co-efficient

- Used to convert mechanical energy to electrical energy--Strain or pressure sensor, microphone, gas lighter, ultrasonic detector

- **Indirect (Inverse) Piezoelectric Effect:**

On application of an electric field on the material, a strain appears across it. Material changes shape by applying an electric field.

- If 'S' is the strain produced due to applied EF 'E' then → **$S = dE$**
- Used to convert electrical energy to mechanical energy
- Crystal oscillators, crystal speakers, ultrasonic generator, actuators, record player pick-ups

Pyroelectric Materials

<u>Pyroelectric Effect: (</u>Pyro-fire**)**

- Pyroelectric materials are spontaneously polarized, but require very high electric field to orient the dipoles.
- The electric field required is so high that the material breaks down before orientation of dipoles can take place.
- In Pyroelectric materials, polarisation of different parts in the crystal is developed which are at different temperature (high).
- When temperature changes, polarisation also change.
- **Ex;-** $LiNbO_3$, $BaTiO_3$, Rochelle Salt(Sodium Potassium Tartrate Tetrahydrate), Triglycerine Sulphate, PZT

Applications: IR detector, IR imaging

Ferroelectric materials

- In some Polar dielectrics, the permanent dipoles are oriented in certain directions, even in the absence of ext. applied electric field So they show **spontaneous polarisation** . These are called **ferroelectric materials .**
- Their special characters are**: [1] Hysteresis behavior (P~E curve)**

[2] spontaneous polarisation [3] reversibility of polarisation

[4] ferroelectric transition temperature

❖ **Ferroelectric domains**

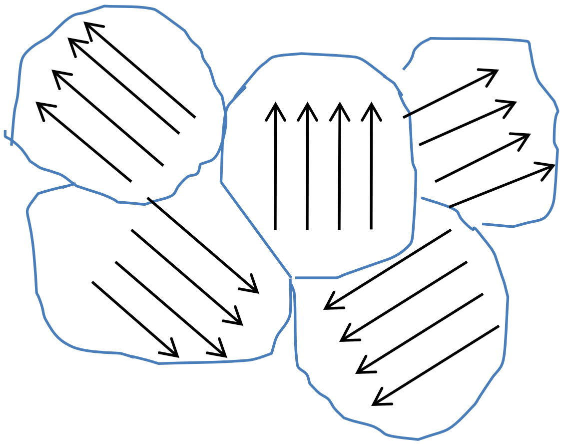
- In such materials , where permanent dipoles are present with electric dipole moments, a large internal field, (E_{int}) act, which create alignment of dipoles even when no external electric field is applied. In Ferroelectric material, dipoles are aligned spontaneously in **different grains** of a polycrystalline material at **zero applied electric field**. These grains are called Ferroelectric domains.

- **Inside a particular domain all the dipoles are in the same direction**

- **A ferroelectric material consists of a large no. of such domains, each having a specific polarisation direction.**

- **Usually, domains are randomly oriented, s.t. net polarisation of the dielectric is zero.**

- **When an EF is applied, domains are oriented in the field direction or domains in a favorable direction grow at the expense of other domains.**



Ferro-electric Domains

Ferroelectric Hysteresis

- Let the material is completely depolarized in the absence of an EF and the curve starts from origin
- As ‘E’ increases , ‘P’ increases
- When all domains are oriented,

Saturation polarisation is reached (P_s)

- When ‘E’ decreases, ‘P’ decreases,

But slower than ‘E’ (lags behind)

- When ’E’= 0 , P≠0 but **$P= P_r$,** called

Remanent polarisation

- ‘E’ applied in the other direction,

‘P’ becomes zero for E =- E_c, called

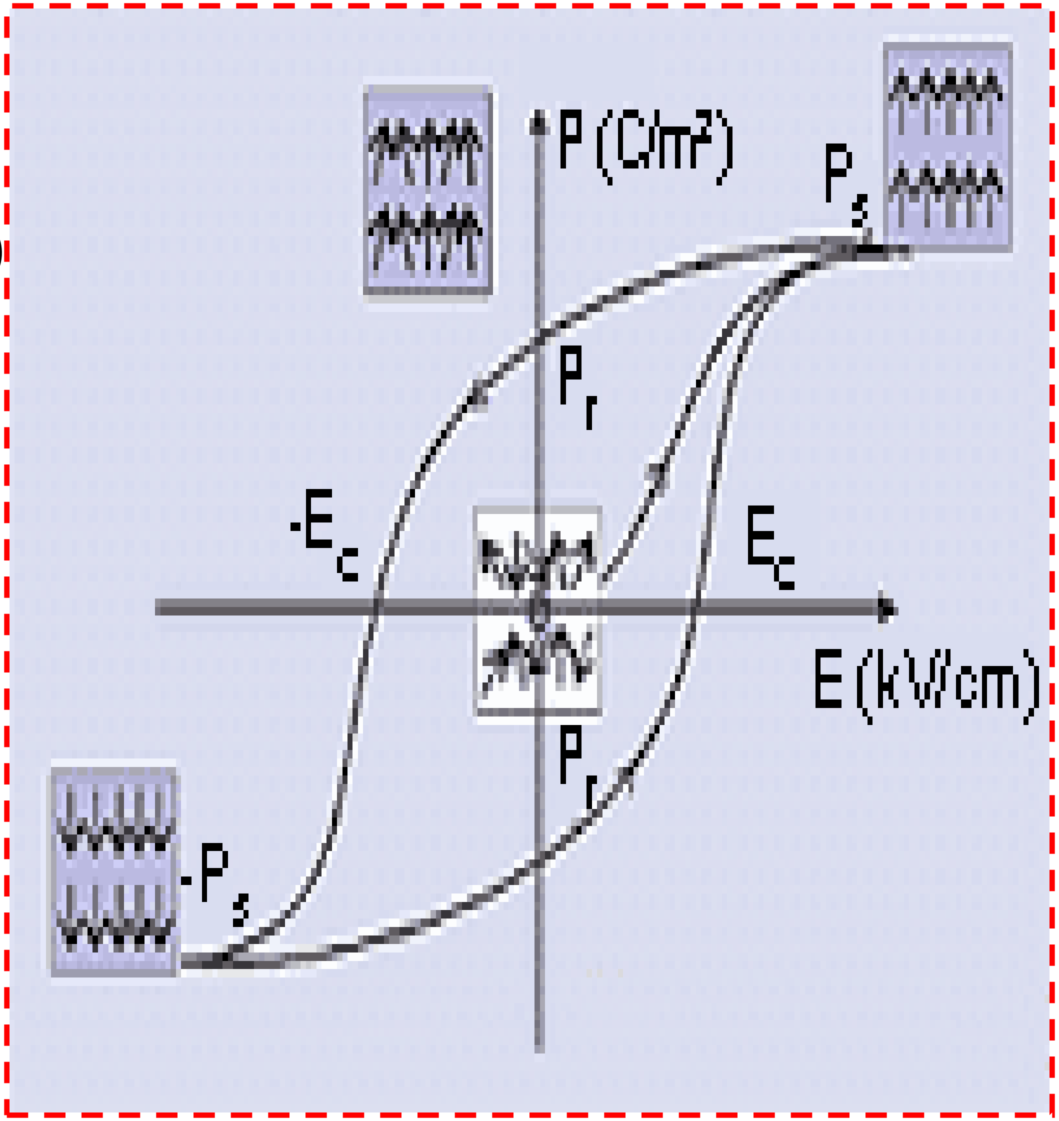
The **coercive field.**

- **‘E’** increases in opposite direction

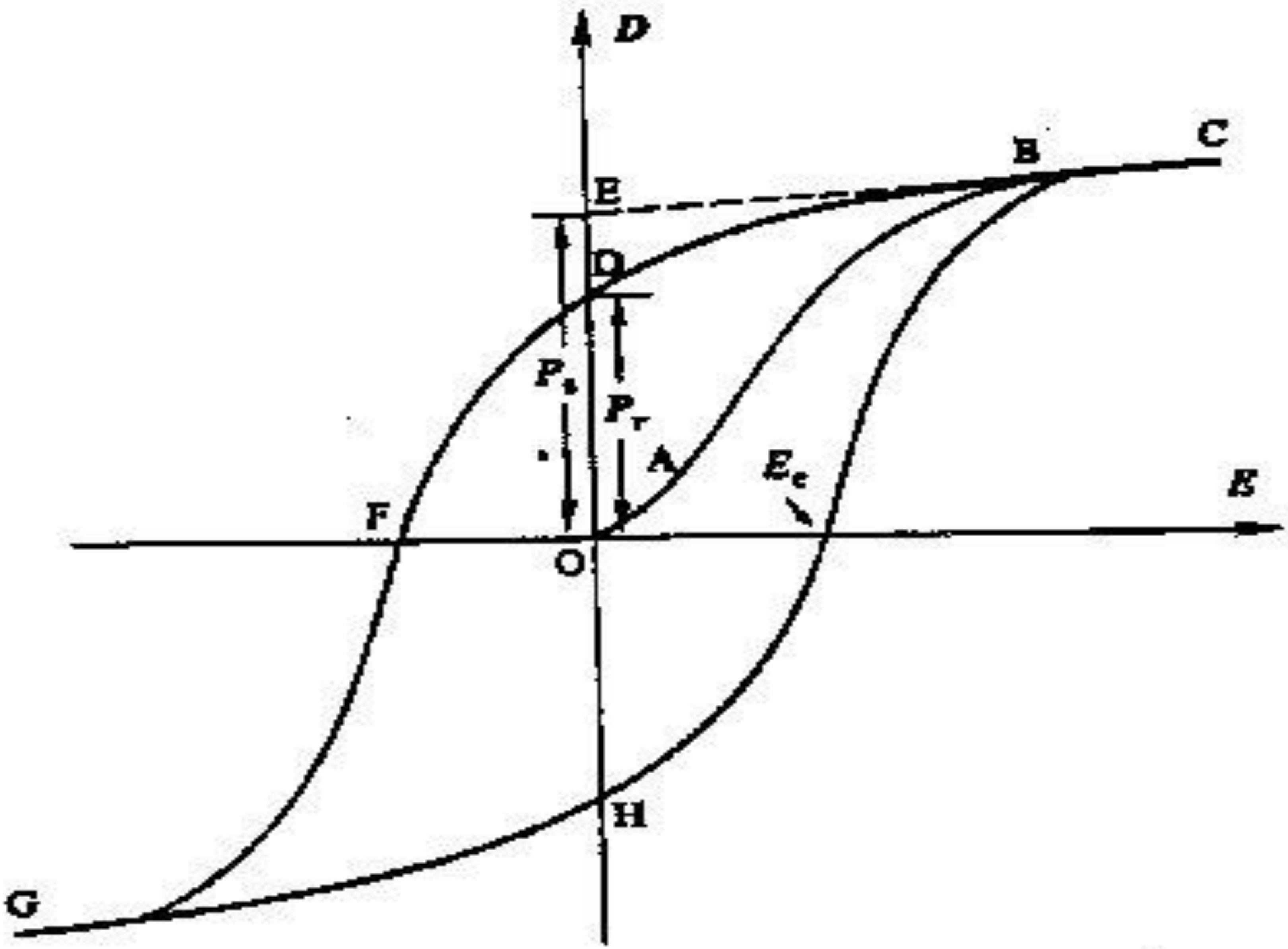
Saturation polarisation, remanent

Polarisation,and coercive fields are

(- Ps, - P_r **&** E_c**)**



- hysteresis loop is obtained, whose area gives the work done or energy loss
- reversibility of polarisation is observed in ferroelectric materials



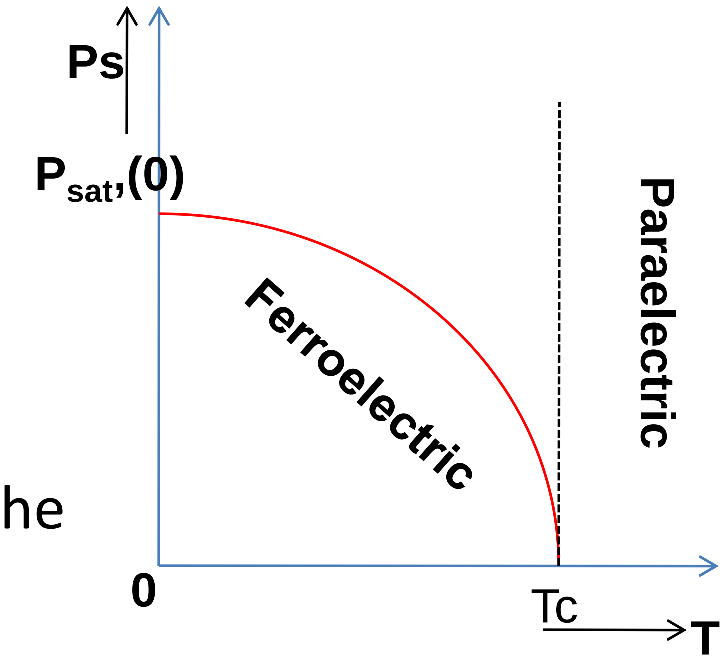
D
E
B
C
D
P_s
P_r
A
E_c
E
F
O
H
G

- P~E curve is non-linear for ferroelectric materials

- **'ε_r** 'is not a constant

It is measured only at low value of EF where linearity of the curve is observed

- It is of very high order of 10^4- 10^5



Spontaneous polarisation

When polarisation is observed even in the absence of applied field (ext.), it is called Spontaneous polarisation, which decreases with temperature. When all the dipoles are aligned the polarisation is called saturation polarisation P_s

P_s becomes zero at Curie temperature, Tc, and material shows paraelectric behavior for T > Tc.

As an internal field is responsible for spontaneous polarisation in ferroelectrics, where, **$E_{int} = E + \gamma P/ \varepsilon_0$**

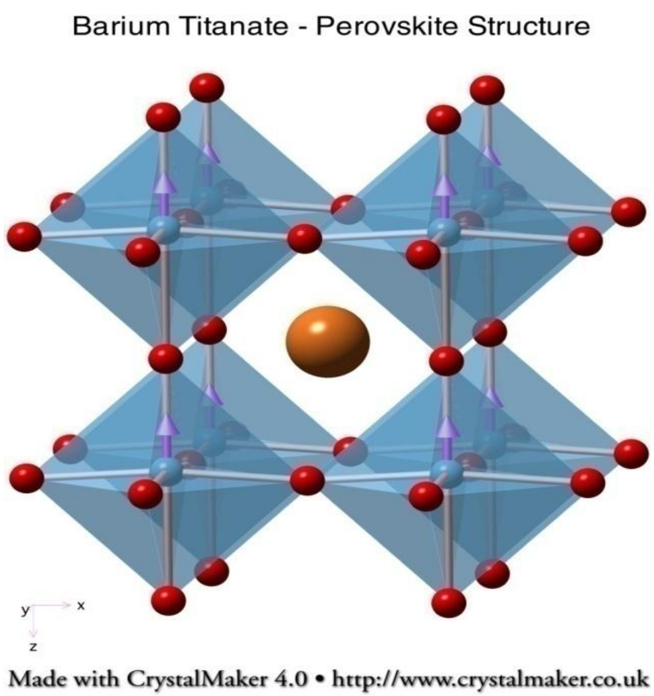
polarisation $P = N \mu L(a) = N \mu \{\mu E_{int}/ 3k_\beta T\}$

or, $$P = \frac{N\mu^2}{3k_\beta T}\left(E + \frac{\gamma P}{\varepsilon_0}\right)$$

$P/E = \chi = C/ T\text{-}T_c$ ...Curie-Weiss law

Above Curie temperature Tc, the material shows a paraelectric behavior. Below Curie temperature, P is high and it shows a Ferroelectric behavior & there is a ferroelectric to paraelectric transition at Tc.

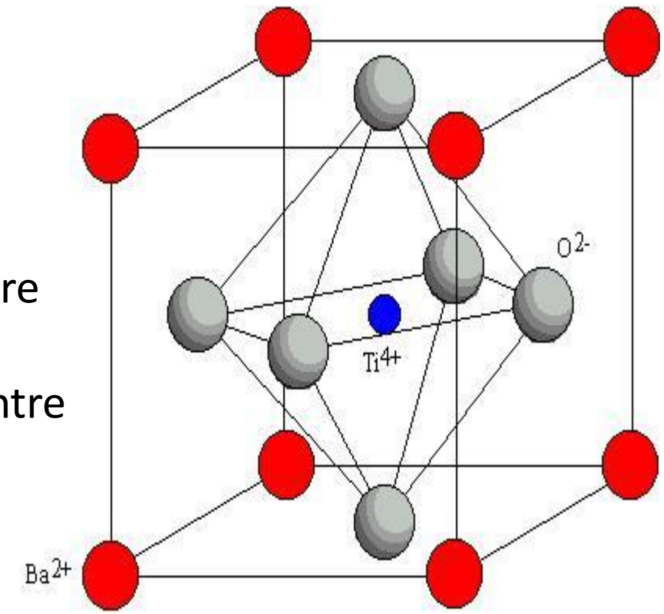
Ferroelectric Barium titanate (BaTiO3)



Ba^{2+} Ions – Corners

O^{2-} Ions – Face centre

Ti^{4+} Ions – Body centre



Below 393K (120°C), Ti4+ ions move up and O2- ions move down in the (110) plane. This converts the cubical structure to tetragonal and loss of its centre of symmetry. A dipole moment appears due to displacement of +ve and –ve ions w.r.t each other. So BaTiO3 is ferroelectric below 120^0C and paraelectric above. One molecule contains one Ba^{2+} Ion, 3 O^{2-} Ion and 1 Ti^{4+} Ions in the unit cell Dipole moment per unit cell $\mu = 6ed$ & polarisation $P = 6ed / V$

or, $\mathbf{P = 6ed / a^2c}$

$\mathbf{d = Pa^2c / 6e}$

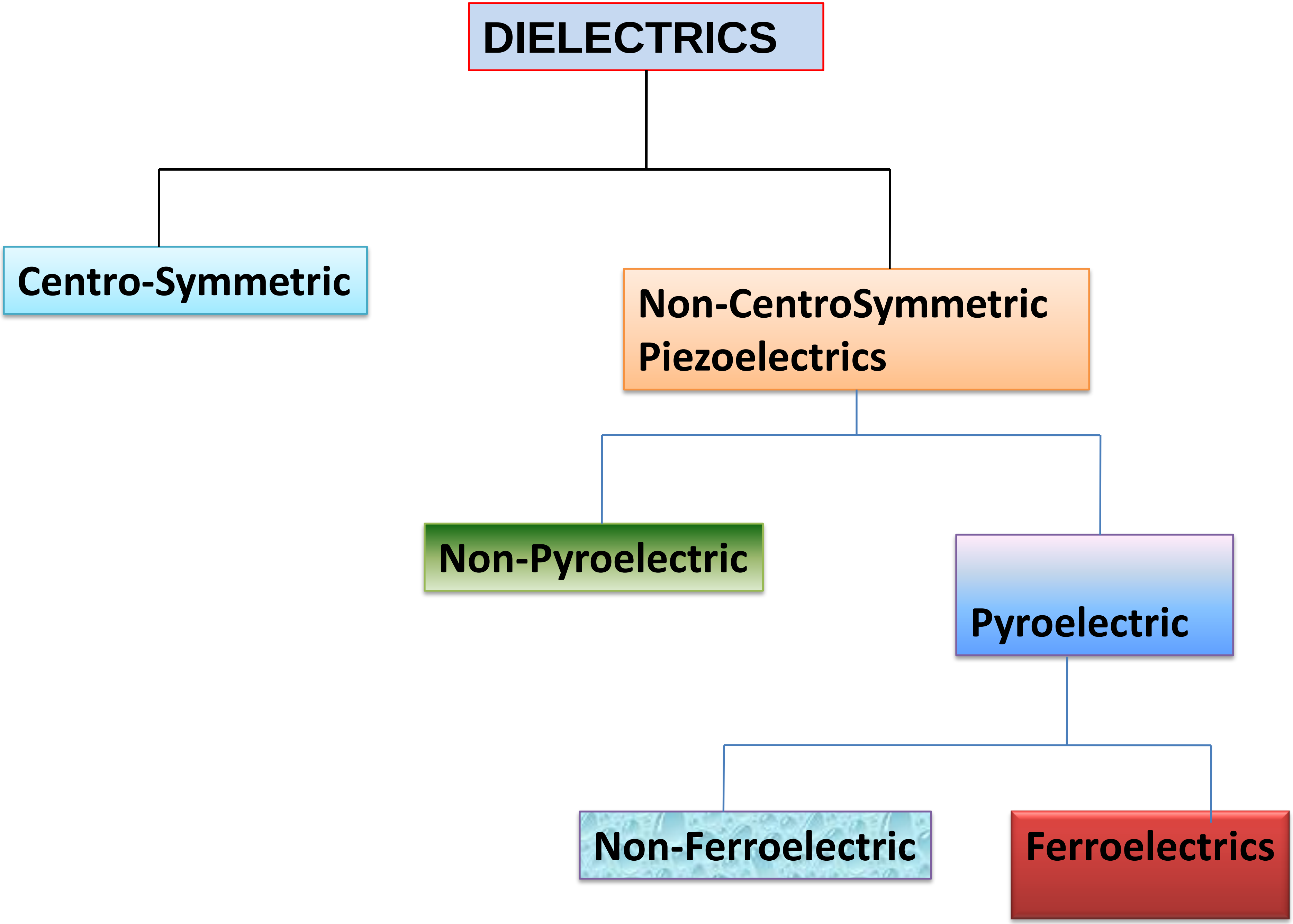
Applications of ferroelectrics:

- They are used in capacitors where capacitance is large– because the value of ‘ε_r‘ is large
- Their piezoelectric constants are large , for which they are used in sonar detector, strain sensor, actuators
- Their Pyroelectric property is used for IR imaging and IR detector
- They have large non-linear polarisation, for which they are used in optical memory display, optical wave guides
- Since the switching speed is slow and large EF is required for polarisation , presently these are not preferred for memory devices as compared to ferromagnetic materials..

- While using a dielectrics as insulators for practical applications, its (i)breakdown voltage and (ii) working temperature (AC field- as dielectric loss will be more)are noted, otherwise it may be damaged.
- Proper dielectrics should be choosen for specific applications, as some of them are frequency dependent.

Applications of Dielectric Materials

- **As Electrical Insulation (ε_r should be less than 12)**
- Room temperature – Paper, cotton, polythene, porcelain
- Medium temperature – Glass fibre, asbestos, teflon, polyamide
- High temperature – alumina, BeO, AlN
- **As Capacitor (ε_r should be large)**
- Ceramic capacitor – monolithic BaTiO3
- Multilayer capacitor – thin layers of BaTiO3
- Barrier layer capacitor – Semiconducting BaTiO3
- **As Sensors and Actuator**
- Sonars, hydrophones, Ultrasonic probes – Quartz, PZT
- Micropositioning table – PZT
- RF oscillator – PZT
- Phone ringer – PZT disc
- Clocks - quartz
- **As Infrared Sensor**
- LiNbO3 pyroelectric detector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