UNIT-4(DIELECTRIC MATERIALS)

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DIELECTRICS

40. DIELECTRICS

What are Dielectrics?

- Dielectrics are **insulating materials** that **do not conduct electricity** but can support an **electrostatic field**.
- When placed in an electric field, they **polarize**, meaning their positive and negative charges slightly separate, creating dipoles.

Important Points about Dielectrics:

- They increase the **capacitance** when used as an insulating material between capacitor plates.
- Dielectrics reduce the electric field inside them by **aligning their dipoles opposite to the external field**.
- Examples: Glass, rubber, plastic, mica.

41. TYPES OF POLARIZATION

Polarization in dielectrics means the **alignment or displacement of charges** under an electric field. There are mainly **four types** of polarization:

1. Electronic Polarization

- Caused by the **displacement of electron clouds** relative to the nucleus in atoms.
- Happens instantly when the electric field is applied.

2. Ionic Polarization

- Occurs in **ionic crystals** where positive and negative ions shift slightly in opposite directions under the electric field.
- Usually slower than electronic polarization.

3. Orientation (Dipolar) Polarization

- Happens in materials with **permanent dipole moments** (like water molecules).
- The dipoles **rotate to align** with the external field.
- Depends on temperature and frequency.

4. Space Charge (Interfacial) Polarization

- Caused by **accumulation of charges at interfaces or defects** inside the material.
- Occurs in heterogeneous materials or composites.
- Happens at low frequencies.

42. TYPES OF POLARIZATION IN DIELECTRICS

1. Electronic Polarization

- Happens when an external electric field **displaces the**

negatively charged electron cloud slightly away from the positively charged nucleus in an atom.

- Creates a tiny **induced dipole** in the atom.
- This polarization **occurs instantly** when the field is applied and disappears when removed.
- Present in **all dielectric materials**.

2. Ionic Polarization

- Occurs in **ionic crystals** (like NaCl), where **positive and negative ions shift in opposite directions** under an electric field.
- The shift creates dipoles at the atomic scale.
- It is **slower than electronic polarization** because ions are heavier and move less quickly.

3. Orientation (Dipolar) Polarization

- Happens in dielectrics with **permanent dipole moments** (e.g., water molecules).
- The dipoles **rotate and try to align** with the applied electric field.
- Requires thermal energy to overcome random molecular motion.
- Strongly depends on **temperature** and **frequency** of the applied field.

4. Space Charge (Interfacial) Polarization

- Caused by **accumulation of charges at interfaces, grain boundaries, or defects** inside the material.
- Happens mainly in **heterogeneous materials** or at **low frequencies**.
- Charges get trapped and cause localized polarization.
- Takes longer time to build up compared to other types.

43. EXPRESSIONS FOR IONIC AND ELECTRONIC POLARIZABILITY

1. Electronic Polarizability

- Electronic polarizability is due to the **displacement of the electron cloud** relative to the nucleus in an atom under an electric field.
- When an electric field EE is applied, the electron cloud shifts by a small distance xx, creating an induced dipole moment pp:

$$p = q \cdot x$$

where:

- p = induced dipole moment (C·m)
- q = charge of the electron cloud displaced (magnitude of charge)
- x = displacement of electron cloud relative to nucleus

Frequency and Temperature Dependence of Dielectric

Polarization

2. Ionic Polarizability α_{ion}

- **Definition:**
  Ionic polarizability occurs in **ionic crystals** when an applied electric field causes **positive and negative ions** to be displaced **in opposite directions**, creating an induced dipole.
- The displacement of ions leads to an induced dipole moment p.

Frequency Dependence

Dielectric polarization depends strongly on the **frequency of the applied electric field** because different types of polarization respond differently to changing fields:

1. **Electronic and Ionic Polarization**:
   - These polarizations involve the displacement of electrons and ions, which are very fast processes.
   - They can follow high-frequency fields, including visible light frequencies (around 101410^{14} Hz).
   - So, electronic and ionic polarizations **remain effective even at very high frequencies**.
2. **Orientation (Dipolar) Polarization**:
   - Dipolar molecules rotate to align with the field, which is slower.
   - At **low frequencies** (up to around 10610^{6} Hz), dipoles can follow the field and contribute to

polarization.

  - At **high frequencies**, dipoles cannot reorient fast enough and their contribution **decreases**, causing a drop in the dielectric constant.

3. **Space Charge Polarization**:
   - Involves migration and accumulation of charges, which is very slow.
   - Effective only at **very low frequencies** (below 10310 ^{3} Hz).
   - At higher frequencies, charges cannot move fast enough, so this polarization disappears.

Temperature Dependence

Temperature affects the **ability of dipoles to orient** and thus influences polarization:

1. **Electronic and Ionic Polarization**:
   - These are **less affected by temperature** because displacement of electrons and ions depends mostly on the bond strength, which is not significantly changed by normal temperature variations.
2. **Orientation (Dipolar) Polarization**:
   - Strongly temperature-dependent.
   - As temperature **increases**, thermal agitation

disrupts the alignment of permanent dipoles, reducing polarization.
    - At low temperatures, dipoles align better, increasing polarization.

3. **Space Charge Polarization**:
    - Also temperature-dependent because higher temperatures help charges move more easily, enhancing space charge polarization.
    - However, at very high temperatures, increased thermal vibrations can reduce effective polarization by causing more random motion.

Practical Impact:

- Dielectric constant usually **decreases with frequency**, especially due to loss of dipolar and space charge contributions at high frequencies.
- Dielectric constant generally **decreases with temperature** for materials where orientation polarization dominates.

44. FERROELECTRICITY

What is Ferroelectricity?

- Ferroelectricity is a property of certain materials that have a **spontaneous electric polarization** (permanent electric dipole moment) which can be **reversed by applying an external electric field**.

- These materials behave like tiny electric dipoles aligned in domains, similar to how ferromagnets have magnetic domains.
- The direction of polarization can be switched by an electric field, making them useful in memory devices.

45. BARIUM TITANATE ($BaTiO_3$)

What is Barium Titanate?

- Barium Titanate is a well-known **ferroelectric ceramic material**.
- It has a **perovskite crystal structure** and shows strong ferroelectric properties below its **Curie temperature (~ 120°C)**.
- Above the Curie temperature, it behaves like a normal dielectric (paraelectric).
- Barium Titanate exhibits **high dielectric constant** and good piezoelectric and pyroelectric properties.

Key Properties:

- Spontaneous polarization that can be switched by an external electric field.
- High dielectric constant makes it suitable for capacitors.

- Exhibits **phase transition** from cubic (non-ferroelectric) to tetragonal (ferroelectric) structure.

46. APPLICATIONS OF FERROELECTRICS

1. Non-volatile Memory Devices

- Used in **Ferroelectric RAM (FeRAM)**, which stores data by switching polarization states.

2. Capacitors

- High dielectric constant materials like $BaTiO_3$ are used to make **high-performance capacitors**.

3. Piezoelectric Devices

- Ferroelectrics convert mechanical stress to electrical signals and vice versa, used in **sensors, actuators, and transducers**.

4. Electro-optic Devices

- Used in **modulators and switches** for controlling light in optical communication.

5. Pyroelectric Sensors

- Detect changes in temperature by generating electric charge.