EEE105
“Electronic Devices”

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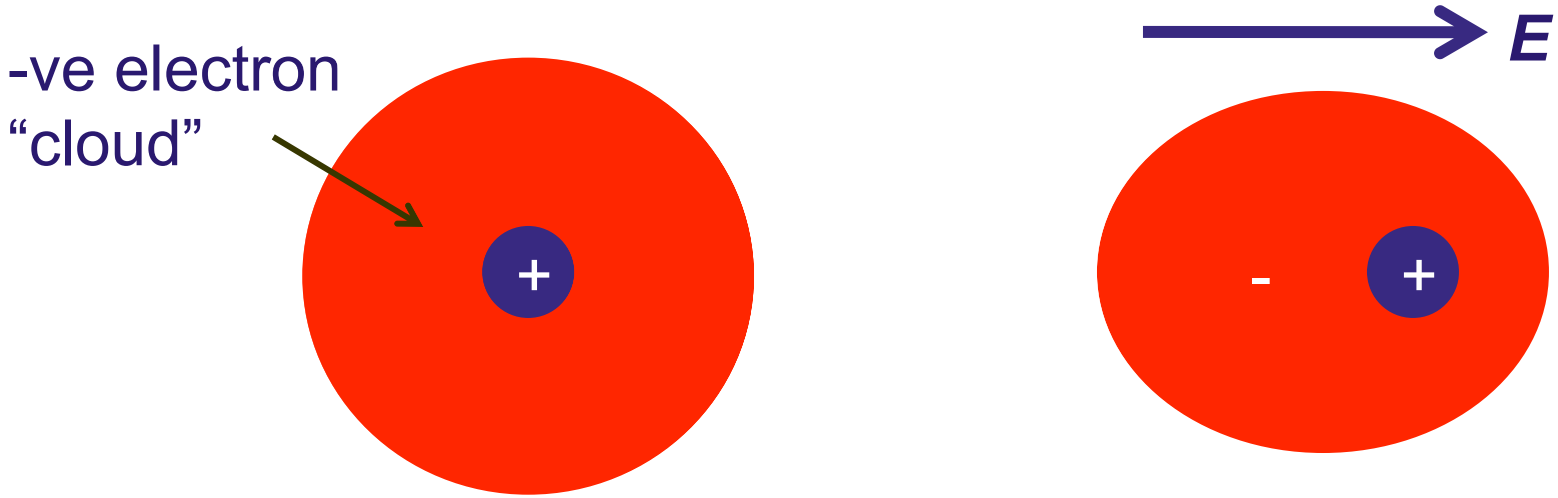
Lecture 3

- Insulator Review
- Polarization
- Capacitors
- RC time constant

Insulators

- Insulators –electrons in bands for which a large amount of energy is required to promote them to the conduction band – essentially the charge remains in the chemical bonds
- e.g. NaCl, C (diamond)
- Used as “Jam in the sandwich” in capacitors – termed a dielectric - insulation between conductors which modifies capacitor performance

Electronic Polarization -Dielectric



- When a system is subject to an electric field, ***E***, there is a tendency of the +ve and –ve charge to displace relative to one another so the system has an electric dipole moment. The dipole moment per unit volume is the polarization ***P***. See EEE101.

Permittivity

- **Permittivity, ε ,** is a physical property of a solid (dielectric medium). Measure of the ability of the material to polarize in response to the field, and thereby reduce the total electric field inside the material. It is a measure of how easily the material "permits" the electric field to propagate.
- We usually compare the permittivity of a material to free space (i.e. vacuum) ε_0 (= 8.8× 10^{-12} F/m) through the relative permittivity ε_r
- The permittivity of air ~ permittivity of free space so ε_r = 1 for air

$\varepsilon = \varepsilon_0 \varepsilon_r$ Often we forget to mention ε_0 but it is important!

Polarization Mechanisms

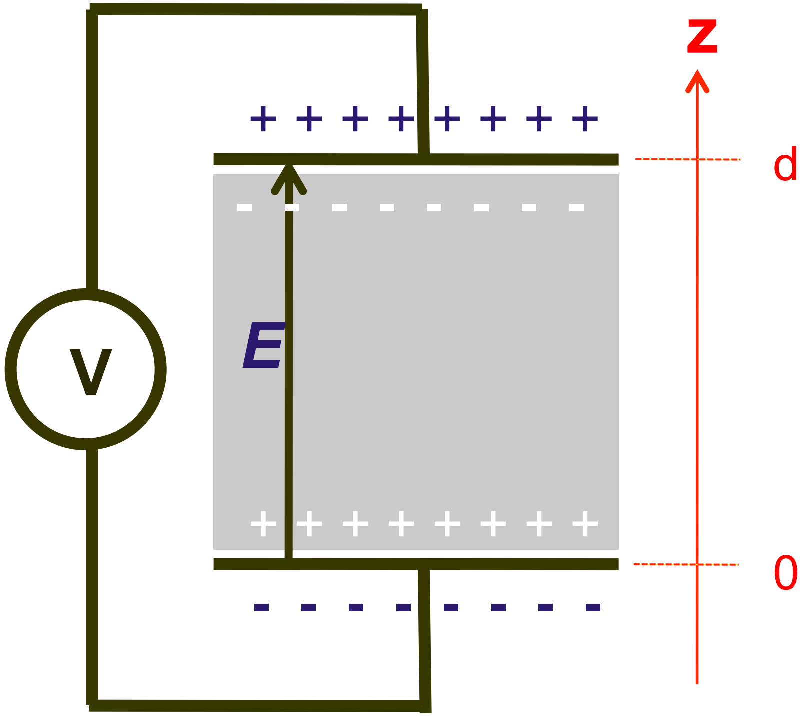
- **Electronic or Induced Polarization**. All dielectric materials – fast frequency response ~10^{15} s^{-1}

- **Ionic Polarization** – In ionic crystals e.g. NaCl E field can shift sub lattice of Na+ and Cl- ions. Moderate frequency response ~10^{9} s^{-1}

- **Orientational Polarization** – can have a dipole within a molecule (polar molecule). E field aligns randomly oriented dipoles causing net polarization. Important for liquids & gases. Slow frequency response ~10^{4} s^{-1}

- Moving charge and molecules takes energy – loss appears as resistive component to impedance – energy is lost – "leaky"

Dielectric Capacitor



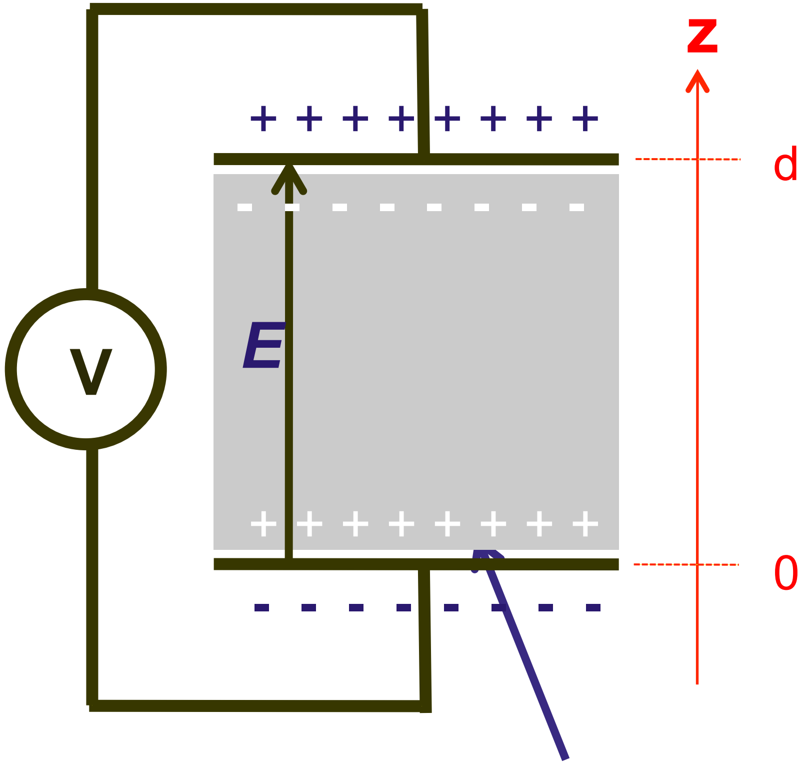
- In response to an ***E***-field a dielectric produces a polarization

→ Dipoles below surface cancel out – only consider surface charge

→ Displaced surface charge opposite the capacitor plates

- Charge on plates to maintain ***E***-field
- Capacitance, C=Q/V where Q = charge and V = voltage

Dielectric Capacitor



Charge per unit area =Q/A= ρ

$$V = \int_0^d E\,dz = \int_0^d \frac{\rho}{\varepsilon}\,dz$$

$$= \frac{\rho d}{\varepsilon} = \frac{Qd}{\varepsilon A}$$

$$\text{inserting } C = \frac{Q}{V}$$

$$C = \frac{\varepsilon A}{d}$$

$$\text{where } \varepsilon = \varepsilon_0 \varepsilon_r$$

$\varepsilon_r =$ relative permittivity

Dielectric Breakdown

- Sudden increase in current above a critical electric field
- Limitation to dielectric – capacitor or insulator become a ~short circuit
- Can be reversible or non-reversible (i.e. catastrophic)

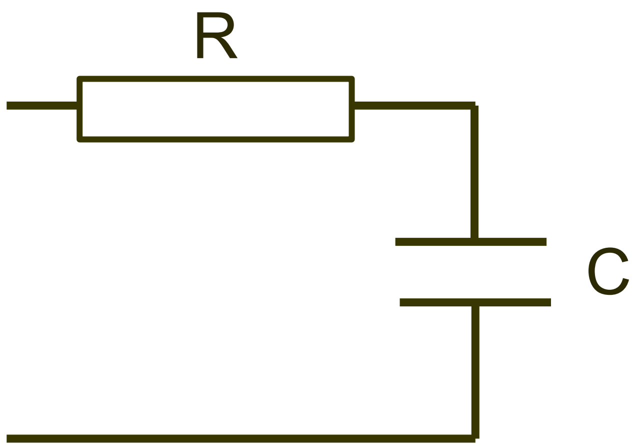
- Breakdown E-field can be ~ 10^9 Vm^{-1}
- Ideally as high as possible

Ideal Capacitor Dielectric

- High ε_r
- Breakdown only at very high fields
- Low cost
- Manufacturability of thin films
- Reliability

RC Time Constant

- Vital importance to many areas of operation of devices
- Often a fundamental limit to high frequency operation



$$f_c = \frac{1}{2\pi RC}$$

For high frequency response – small R and C

$$C = \frac{\varepsilon A}{d}$$

Summary

- In an insulator charge is not free to move around the crystal
- In some materials their positions around the nuclei can be distorted if an E-field is applied - Polarization
  - This distortion leads to a surface charge which opposes the applied field – there is an increase in capacitance as ε increases
- Different polarization mechanisms have different frequency responses and different breakdown/failure mechanisms
- Breakdown and Ideal dielectric discussed
- RC time constant discussed as a vital factor which impacts device dimensions and dielectric choice

Capacitor Example

Q- For the same capacitor the new dielctric between the plates has a breakdown field of 50 MVm^{-1}

What is the maximum voltage which can be applied across the capacitor?

A- The maximum voltage will be that which gives breakdown field

E=V/d so

$V_{max} = E_{Breakdown} \times d_2 = 50 \times 10^6\ Vm^{-1} \times 10^{-3} m = 50kV$

Capacitor Example

Q- A parallel plate capacitor has a spacing 100 µm with air between them. If a dielectric plate of relative permitivity $\varepsilon_r = 10$ is placed between the plates what should the new spacing be to leave the capacitance unchanged?

A- Capacitance needs to be constant in state "1" (before) and state "2" (after).

$$C = \frac{\varepsilon_0 \varepsilon_{r1} A}{d_1} = \frac{\varepsilon_0 \varepsilon_{r2} A}{d_2}$$

giving –

$$d_2 = \frac{\varepsilon_{r2}}{\varepsilon_{r1}} d_1 = \frac{10}{1}.1x10^{-4}$$

$$d_2 = 1\text{mm}$$

