# EEE105 Tutorial Questions & Review Topics – Sheet 2

**Fundamental Constants and Materials Data**

**Constants**
Permitivity of free space = $8.8 \times 10^{-12}$ F/m
Electron charge = $1.6 \times 10^{-19}$ C
Electron mass = $9.1 \times 10^{-31}$ Kg

**Materials – Room Temperature**
For silicon (Si);
Mobility =$0.12\ m^2V^{-1}s^{-1}$
Electron effective mass = 0.97

For germanium (Ge);
Mobility = $0.39\ m^2V^{-1}s^{-1}$
Electron effective mass = 0.22

**Question 1**

A parallel plate capacitor has a spacing 10 μm with air between them. The area of the capacitor is $1 \times 10^{-5} m^2$.

**(a).** 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?

**(b).** Calculate the capacitance?

**(c).** The dielectric in the capacitor in question 1 has a breakdown field of $50MVm^{-1}$. Calculate the maximum voltage which may be applied to the capacitor.

(d) The capacitor is connected in series with a 50Ω resistor. Calculate the cut-off frequency for this filter.

**Question 2**

**(a).** Calculate the average scattering time of electrons at room temperature in Si and Ge based upon their mobilities and effective masses.

**(b).** If these crystals are ultra-pure, what is the origin of these scattering events?

**Review Topics – Keywords**

Dielectric. Polarization. Capaciatnce. RC time constant.

Derivation of drift velocity and mobility of a conductor. Impurities, Defects & Phonons.

**Solutions**

1(a). Call the situation with air "state 1", and with dielectric "state 2". i.e in state 1 we have a relative permittivity $\varepsilon_{r1,}$ and plate separation $d_1$. (A is constant in both cases). As we aim to keep capacitance constant, we can equate capacitance in state 1 and state 2.

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

giving –

$$d_2 = \frac{\varepsilon_{r2}}{\varepsilon_{r1}} d_1 = \frac{10}{1} \text{ x } 1\text{x}10^{-5}$$

$$d_2 = 100\ \mu\text{m}$$

So the plate separation with dielectric needs to be 100 μm.

(b)

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

So –

$$C = \frac{8.8\text{x}10^{-12} \text{ x } 10.1\text{x}10^{-5}}{1\text{x}10^{-4}}$$

$$C = 8.8\text{x}10^{-12}\,\text{F} = 8.8\text{pF}$$

(c) E=V/d so $V_{max} = E_{Breakdown} \text{ x } d_2$

$= 50\text{x}10^{6}\ \text{Vm}^{-1} \text{ x } 10^{-4}\text{m} = 5\text{kV}$

(d) The cut-off frequency is given by the RC time-constant;

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

so

$$f_c = \frac{1}{2\pi \text{ x } 50 \text{ x } 8.8\text{x}10^{-12}} = 3.6\text{x}10^{8}\,\text{Hz} = 360\text{MHz}$$

2. The mobility and scattering time are related by;

$$\mu = \frac{q\tau}{m^*}$$

*so*

$$\tau = \frac{\mu m^*}{q}$$

Remembering that m* is the electron mass multiplied by the effective mass….

So for Si

$$\tau = \frac{\mu m^*}{q} = \frac{0.12 \text{ x } 0.97 \text{ x } 9.1\text{x}10^{-31}}{1.6\text{x}10^{-19}} = 6.6\text{x}10^{-13}\text{s} = 660\text{fs}$$

And for Ge

$$\tau = \frac{\mu m^*}{q} = \frac{0.39 \text{ x } 0.22 \text{ x } 9.1\text{x}10^{-31}}{1.6\text{x}10^{-19}} = 4.9\text{x}10^{-13}\text{s} = 490\text{fs}$$

(b) The origin of the electron scattering events are disruptions to the perfection of the crystal lattice. This can be through crystal defects such as; ionised impurities, interstitial defects, vacancy defects, and through the disruption of the lattice by lattice vibrations (heat/sound) – these are quantized and are known as “phonons”.

If the crystals are ultra-pure (i.e. defects and unintentional impurities are essentially zero) then the only major source of electron scattering is with phonons.