EEE105 Tutorial Questions & Review Topics W11

Fundamental Constants
Boltzman Constant, $k = 1.381\text{x}10^{-23}$ JK^{-1} = 8.62×10^{-5} eVK^{-1}
Charge on Electron, $q = 1.602\text{x}10^{-19}$ C
Mass of the Electron, $m_e = 9.11\text{x}10^{-31}$ kg
Planck's Constant, $h = 6.626\text{x}10^{-34}$ Js
Speed of Light in a Vacuum, $c = 3\text{x}10^{8}$ ms^{-1}
Mass of a Proton, $m_p = 1.673\text{x}10^{-27}$ kg
Permittivity of Free Space, $\varepsilon_0=8.85\text{x}10^{-12}$ Fm^{-1}
Avogadro's Number, $A=6.0221415 \times 10^{23}$

1. A certain n-p-n bipolar transistor has the following properties:

emitter resistivity	3×10^{-4} Ωm
base resistivity	6×10^{-3} Ωm
cross-sectional area	10^{-8} m^2
electron mobility	0.13 $m^2V^{-1}s^{-1}$
hole mobility	0.05 $m^2V^{-1}s^{-1}$
intrinsic carrier density	1.5×10^{16} m^{-3}

The transistor is operated at 20°C with a base-emitter applied voltage of 0.65 V and a collector voltage of 10 V.

Determine:

(a) the majority and minority carrier concentrations in base and emitter
($n_n = 1.6\times10^{23}$ m^{-3}, $p_n = 1.4\times10^{9}$ m^{-3}, $p_p = 2.1\times10^{22}$ m^{-3}, $n_p=1.1\times10^{10}$ m^{-3})

(b) the built-in potential at the base-emitter junction
(0.77 V)

(c) the base-emitter junction current, assuming a saturation current density of 1 μAm^{-2}
(1.52 mA)

(d) the approximate ratio of electron to hole currents flowing across the base-emitter junction
(20:1)

(e) the collector current, neglecting recombination in the base and leakage current
(1.45 mA)

n.b. In order to make the sheet more similar to the exam – a full list of constants is provided so as to not give any "clues"….

Revision Topics, Bipolar Junction Transistor….

Solutions

1.(a) For the majority carrier concentrations, use the standard equation for resistivity:

$$\rho = \frac{1}{nq\mu}$$

and apply to the emitter and the base. The resistivities and mobilities are given so you should find

$p=2.08x10^{22}$ m^{-3}

$n=1.6x10^{23}$ m^{-3}

Looking at these numbers, they are reasonable for majority carrier densities. To get the minority carrier concentrations use $pn=n_i^2$. The intrinsic carrier concentration is given so:

$n_p=1.08x10^{10}$ m^{-3}

$p_n=1.4x10^9$ m^{-3}

As expected, these are much smaller than the majority carrier concentrations.

(b) For this, you need to remember that the built in potential across a junction is given by

$$V_0 = \frac{kT}{q}\ln\left(\frac{n_n}{n_p}\right)$$

Putting in the values calculated in (a) gives **$V_0 = 0.77$ V**

Try using the equation for the holes and prove that it gives the same result.

(c) To calculate the base emitter current, first calculate the current density. Remember that

$$J = J_0\left(e^{\frac{qV}{kT}} - 1\right)$$

You're told the applied voltage is 0.65 V and the saturation current density is 1 μAm^{-2}. You should get an answer around **$1.52x10^{-3}$ A**

(d) The ratio of electron and hole currents across a junction can be considered to be controlled by the ratios of conductivity. **So the electron current is 20 times the hole current**. Of course this is what we want in a bipolar transistor since we want most of the emitter current to be due to carriers injected from the emitter into the base.

(e) Note that if we neglect any recombination in the base, then all the electrons injected at the emitter will reach the collector. Written another way $I_C=I_e$

We know the emitter current (from part c) and the proportion of that due to electrons(from part d)

$$I_E = I_e + I_h = I_e\left(1 + \frac{1}{20}\right) = \frac{21}{20}I_e$$

$$\therefore I_C = \frac{20}{21}I_E = 1.45mA$$