Solutions

HW #9

ECE 606

Q1 The maximum electric field strength in a p-n junction is given as

$$F_M = \frac{-q N_{aB} x_p}{\varepsilon_s}$$

Substituting for x_p, the extent of depletion region within the base yields

$$x_p = \left[\frac{2\varepsilon_s}{q} \frac{N_{dC}}{N_{aB}(N_{aB}+N_{dC})}(V_{bi}+V_j)\right]^{1/2}$$

where V_j is assumed negative and is the voltage applied on the junction.

Neglecting the built-in-voltage, the electric field can be written as

$$F_m = -\frac{qN_{aB}}{\varepsilon_s} \sqrt{\frac{2\varepsilon_s}{q} \frac{V_j N_{dC}}{(N_{aB}+N_{dC})}}$$

Solving for V_j yields $V_j = \dfrac{F_m^2 \varepsilon_s (N_{aB}+N_{dC})}{2qN_{aB}N_{dC}}$

If the collector doping is heavy, with respect to base $N_{dC} \gg N_{aB}$ V_j can be written as $V_j = \dfrac{F_m^2 \varepsilon_s}{2qN_{aB}}$ —①

The junction voltage at the breakdown field is just the avalanche breakdown voltage in the common-base configuration. $\Rightarrow \underline{\underline{BV_{CB0} = V_j}}$

Evaluating eq ① yields $\underline{\underline{BV_{CB0} = 29.6\ V}}$

Punch-through voltage can be determined as follows.

$$V_{pt} = \frac{q W_B^2 N_{aB} (N_{aB} + N_{dc})}{2 \varepsilon_s N_{dc}}$$

Using the fact $N_{dc} >> N_{aB}$, V_{pt} becomes

$$V_{pt} = \frac{q W_B^2 N_{aB}}{2 \varepsilon_s} = 7.6 V$$

$\therefore$ Punch through occurs before avalanche break-down sets in

$\underline{\underline{(\because V_{pt} < BV_{CB0})}}$

11.17

(a) $\boxed{\text{Transistor A}}$. Referring to Eq. (11.41),

$$\gamma = \frac{1}{1 + \frac{D_E}{D_B}\frac{N_B}{N_E}\frac{W}{L_E}}$$

In Transistor A, $N_E >> N_B$ and $\gamma \rightarrow 1$. In Transistor B, $N_E < N_B$ and γ is expected to be considerably less than unity.

One might alternatively argue that $I_{Ep} >> I_{En}$ in Transistor A, while $I_{En} > I_{Ep}$ in Transistor B. Since $\gamma = I_{Ep}/(I_{Ep}+I_{En})$ in a *pnp* transistor, Transistor A clearly has the greater emitter injection efficiency.

(b) Under active mode biasing $V_{EB} > 0$ and $V_{CB} < 0$. Considering the more important reverse-bias collector-base junction, there is very little incursion of the depletion region into the base in Transistor A. For Transistor B, however, most of the depletion region lies in the base because $N_C >> N_B$. Thus $\boxed{\text{Transistor B}}$ will be more sensitive to base width modulation.

(c) $\boxed{\text{Transistor A}}$. V_{CB0} is approximately equal to V_{BR} of the C-B junction if the BJT is limited by avalanche breakdown. V_{BR} in turn is roughly inversely proportional to the doping on the lightly-doped side of the *pn* junction. In Transistor A, the collector is the lower doped with $N_C = 10^{14}/\text{cm}^3$; in Transistor B, the base has the lighter doping, $N_B = 10^{15}/\text{cm}^3$. Since N_C of Transistor A is less than N_B of Transistor B, Transistor A will exhibit the larger V_{CB0}.

Q3

ECE-606 ~~Homework No. 9 Assigned: Mar. 30 Due: Apr. 8~~

1a) compute the DC common emitter current gain.
Use the equation and parameters for SiGe given in the question,

$$\beta_{DC} \approx \frac{D_n W_E n_{i,B}^2 N_E}{D_p W_B n_{i,E}^2 N_B} \approx 2520$$

Where Dn and Dp are obtained from Einstein relation.

1b) compute the DC common base current gain for SiGe.

$$\alpha_{DC} \approx \frac{\beta_{DC}}{1+\beta_{DC}} \approx 0.9996$$

1c) repeat the above again for Si parameters, we get.

$\beta_{DC} \approx 70$ and $\alpha_{DC} \approx 0.9859$

As expected the performance for SiGe is more superior.

1d) you are asked to compute electrical base width.
Consider Si base first.
Compute the built in potential for base/emitter junction using

$$V_{BI,EB} = kT \times \log\left(\frac{N_E N_B}{n_{i,Si}^2}\right) \approx 0.9786V$$

And the depletion length into the base due to emitter using

$$x_{EB} = \sqrt{\frac{2\kappa_{Si}\varepsilon_0 N_E V_{BI,EB}}{q\left(N_E + N_B\right) N_B}} \approx 3.43\times10^{-6}\,cm$$

Now we repeat the above but for base/collector junction

$V_{BI,BC} \approx 0.8636V$ and $x_{BC} \approx 1.02\times10^{-6}\,cm$

So the electrical base width is

$$W_B - x_{BC} - x_{EB} \approx 4.55\times10^{-5}\,cm$$

Note that the electron affinity of SiGe is approximately 4eV,
Since both Si and Ge are also about 4eV.
You would also need to know that the bandgap of Ge is 0.66eV.

The collector and emitter are n doped.
Next, we need to compute the Fermi energy in the collector and emitter wrt Ec.
We can find that,

$\left|E_{F,C} - E_c\right| \approx 0.1444eV$ and $\left|E_{F,E} - E_c\right| \approx 0.0293eV$

For the collector and emitter side respectively.
Since the base is heavily p-doped, we assume it is ~ at Ev.

Therefore we obtain,

$$V_{BI,BC} \approx 0.66 - 0.1444 \approx 0.5156eV$$

$$V_{BI,BE} \approx 0.6307eV$$

To compute the depletion width, we need the following formula from class · ~~Lundstrom~~'s notes, first do it for emitter-base

$$x_{EB} = \sqrt{\frac{2\varepsilon_{sige}}{qN_B}\frac{\varepsilon_{si}N_E}{\varepsilon_{si}N_E + \varepsilon_{sige}N_B}V_{BI,EB}} \approx 3.05\times10^{-6}\,cm$$

Similarly for collector base,

$$x_{CB} \approx 7.96\times10^{-7}\,cm$$

So the electrical base width is

$$W_B - x_{BC} - x_{EB} \approx 4.61\times10^{-5}\,cm$$

So the early voltage is slightly better for SiGe based on the consideration of their electrical width.

Q4 The doping concentration is 10^{17} cm^{-3}.

∴ Minority carrier concentration at thermal equilibrium is $\underset{n_{p0}}{\underset{\parallel}{2.25 \times 10^{3}}}$ cm^{-3} (Mass-action law).

When $V_{BE} = 0.6$ V

$n_{pE} = n_{p0} \exp\left(V_{BE}/V_T\right) = 2.37 \times 10^{13}$ cm^{-3} $\quad V_T = kT/q = 0.026$ eV.

while when $V_{BE} = -5$ V, $n_{pE} = 0$ (appx).

Thus to change V_{BE} from 0 to 0.6 V, n_{pE} and therefore Q_{nB} have to change by ten orders of magnitude $\left(\frac{n_{pE}}{n_{p0}}\right)$

while when V_{BE} changes from 0 to -5V, n_{pE} changes by only three orders of magnitude. This explains why the change in $\underset{\parallel}{V_{BE}}$ is a much slower process.

under

forward-biasing

Q5 $\Delta E_g = 1.247\beta$.

$\beta = 0.25 \Rightarrow \Delta E_g = 0.31\ eV$.

Conduction-band edge discontinuity ΔE_c is 62% of ΔE_g

$\therefore \Delta E_c = 0.19\ eV$.

Improvement in gain can be estimated by taking the ratio of β_{max} for each case

$$\frac{\beta_{max}(graded)}{\beta_{max}(abrupt)} = \frac{e^{\Delta E_g/KT}}{e^{\Delta E_v/KT}}$$

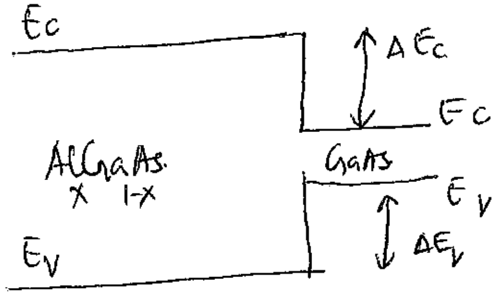
Since AlGaAs-GaAs forms a type-I heterostructure

ΔE_v is found simply as 0.12 eV

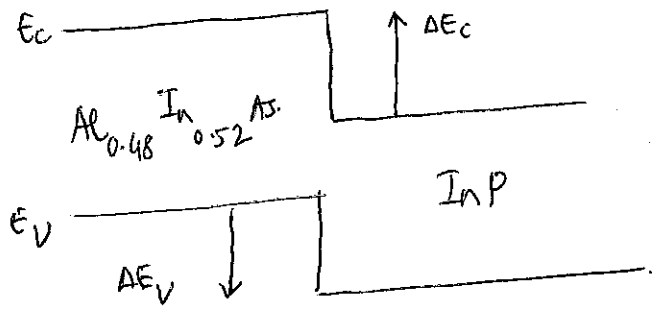
$\therefore$ Desired ratio is found by inserting values in ①

$$\boxed{= 103}$$

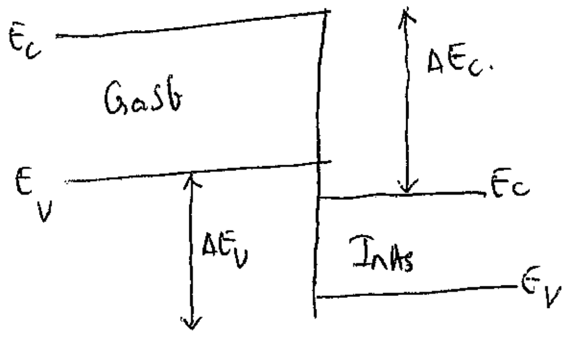
Q6 Three types of heterostructures



Type. 1



Type II



Type III