ECE 4211 HW5 BJT Design, Heterojunctions, and LEDs 02162017 Due 02212017 F. Jain

HW4-Q.4. Draw a hybrid  model for a BJT or HBT that you have studied in a prerequisite course. **Calculate any two component** values (in the model) using transistor parameters from the device of Q.2 HW4.

Q.4. Solution The ac circuit model of BJT is



Various circuit components are defined and computed.

(i) is assumed to be 1.25.

Substituting the value of IE from Q.2, 

,

 We can now get 

(ii)  is made of junction capacitance of the emitter-base junction and the diffusion capacitance CD due to excess charge stored in the base under forward biasing.

Junction width WjEB for the base-emitter junction under forward bias is . We need to find Vbi

. As

Substituting various parameters, we get , or 

Diffusion capacitance CD=

Also it is expressed as 



(iii) **Collector junction capacitance CjC**



We used the built-in voltage 



(iv) **Base resistance rb:**



The resistivity B of base region is computed from ‘resistivity-doping concentration plot on page 113, Fig. 29. For p-base doping ND = 5x1018 cm-3, the resistivity on n-Si is 1x10-2 Ohm-cm. Here, WBase = 0.25 x 10-4 cm is the base width and AEB (=100 m2) is the cross-sectional area.

(v) **Collector resistance rC:** Width of the collector is WC (=100 microns), resistivity C (computed from doping NDC =5x1016 cm-3) is 10.0 Ohm-cm, and area ABC is 300 m2.



**HW4**-Q.5. Energy band diagram of an N-AlGaAs/pGaAs/P-AlGaAs double heterojunction diode is shown below in Fig. 5a (Page 170 Notes). A p-n heterojunction is shown in Fig. 5b (Fig. 36 p 163).

## Modify Fig. 5a energy band diagram to include N-AlGaAs collector in place of p-AlGaAs layer on the right side of the GaAs layer.

|  |  |
| --- | --- |
| Fig. 5a A double heterojunction. | Fig. 5b. A single heterojunction. |

 Equilibrium energy band diagram



Doping of NAlGaAs emitter ND,E = 1016 cm-3.Doping of the pGaAs base = NA,B= 3x1018 cm-3.

**Energy band diagram under E-B forward and B-C reverse biased.**

##

**Optional**

Q5(b) Calculate the emitter IE (=IEN + IEP), where IEP is calculated on page 167 (Examples 1 and 2). IEN will be different now as the boundary condition in the p-region has changed. HINT: Use IEN expression as on page 167 with appropriate np0,B value in p-GaAs. The neutral base width W is 0.1 microns. The diffusion coefficients and carrier lifetimes are same as used on page 164. Dp,E= 10 cm2/s, tp =2x10-9s, Dn,B=100 cm2/s and tn =1x10-8s.

USE AlGaAs and GaAs information from pages 164-167. Use Al composition to be to be 30%.

## For a forward biased VBE=1.0V and reverse biased base-collector junction VCB = 2.0V or VBC = -2V.

Q. 5 (b) Emitter current computation



,

We are using

and . , W=0.1x10-4cm
= 3.1mA.









**HW5-Q.1 Design specifications***:* Design an n-p-n transistor with a common emitter gain, o = 500. The device cross-section and a typical layout are given in Figure 13. The design is presented in Class Notes (part I) pages 245-254.

Given for guideline purposes are the following device parameters:

Emitter: Base:

Dp,E =20 cm2/sec. Dn,B =40 cm2/sec (diffusion coefficient for electrons)

Hole lifetime p =10 sec Electron lifetime n =2 sec

Emitter area AEB = 2 m x 2 m Base-collector area ABC = 6 m x 6 m

Emitter-collector voltage VCE = 5 Volts



Figure 13. Cross-section and Top view of a n-p-n transistor

Q.1(a) Summarize value of emitter, base and collector doping levels and base thickness tht give a  = 500 per BJT specification.

**Solution:** Given o=500 o = o/(1-o) or αo = βo/(1+βo)

n-Si (Collector) Epi = 10 Ω- cm. From resistivity –doping concentrtoan plots,

1. ND]collector= nn0]collector = 4\*1014 cm-3.
2. αo = βo/(1+βo)=500/501 = 0.998
3. αo = αT\*γ 0.998 = αT\*γ

 Let us pick γ= 0.9995, then αT = 0.998/0.9995 = 0.998499

1. Neutral base width W is related as



Using, W2 = (1-T)\* and substituting for =159.8472\*10-6

as



W 2= (1-0.998499) \* 159.8472\*10 -6, and W=4.898\*10-4 cm ~ 4.9 m.

Using injection efficiency γ= 0.9995, we can get the ratio of ND,E/NA,B = 34.62. the steps are shown below:





and we substitute for diffusion coefficients.

=0.9995, = 34.62

If we select emitter doping NA,E =1020 cm-3, we get base doping to be Na,B =2.88\*1018 cm-3.

Q1(b) Name factors that are important in determining the values of the cut-off frequencies f& f.

Time constant τe = re CTEB = 25.9 × 7.88 × 10-14 = 2.04\*10-12 s

τc = rsc CTEB = 2.7 × 103 × 0.935 × 10-15 = 2.52 × 10-12 s

τβ = W2 / (2Dn,B) = (4.9 × 10-4)2 / (2 × 40) = 1.2 × 10-8 s;

or τβ = 3 × 10-9 , if W = 0.1m

τCD = 1.56m/ 107 (base collector junction width at zero bias),

At 4.3V reverse bias, the base-collector junction width is 3.904m. Thus the transit time is

τCD = 3.904m/107 = 3.904 × 10-11s. Here, 107 cm/s is the saturation velocity in Si.

Q1(c) Name the single most important parameter used in design pass#2 to enhance f to 5.62GHz from 5.26\*107 Hz (almost by a factor of 100).

Base transit time B

Q1(d) what is the advantage of using p-SiGe base as opposed to pSi base and having a nSi- pSiGe-nSi heterojunction bipolar transistor. The main consideration is cut off frequency.

**Solution:** SiGe has a lower energy gap than Si (as Ge band gap is 0.67eV and Si band gap of 1.1eV). This results in ni(SiGe) >> ni(Si). Higher ni(SiGe) in SiGe base region gives higher value of minority electron concentration npo,B in p-SiGe base of a nSi-pSiGe-nSi heterojunction bipolar transistor (HBT).

Having SiGe base permits higher doping NA,B than the emitter region. This reduces the emitter-base junction capacitance and tE on one hand and the base width W [reduction due to higher doping than emitter or collector]. Reduction in base width W results in reduced tB.

These factors result in higher cutoff frequencies.

**Q.2 (a).** What is the distance from junction edge (xp) in which electron concentration decays by 1/e? **Circle one**

Ln 2Ln Lp 2Lp

1. What is the advantage of having a heterojunction such as shown in Fig. 1(a) ? **Circle one**

 Higher injection efficiency improved injection efficiency even if emitter doping is lower than p-side

(c) What happens in an N-AlGaAs/p-GaAs/P-AlGaAs double heterojunction diode of Fig. 1(b) in terms of the recombination of the injected electrons. Can we make p-GaAs thinner than a diffusion length Ln.

YES NO

(d) For a given electron current IEN, which of the two diodes of Fig. 1 will give higher photon density? Assume the junction area A to be same. Thickness of pGaAs in Fig. 1b is smaller than the diffusion length Ln.

 Fig. 1(a) Fig. 1(b)

|  |
| --- |
| Fig. 1(a). A forward biased N-AlGaAs-p GaAs diode. Fig. 1(b) band diagram of a double heterojunction.  |
|  |

 Fig. 2 shows the energy of injected electrons at a point x on the p-side.

Q.3. (a) If the quantum efficiency q for GaAs is 0.95 and for Si 0.05 how many photons are produced per second for an electron current of 1mA in n-p diodes on the p-side.

**Answer:** photons produced per second=[10-3/1.6\*10-19]\* 0.95 = 5.9\*1015

Q3(b) Write the mechanism of electrons and holes recombination for Si diode (Fig. 2a) and GaAs diode (Fig. 2b).

Si is an indirect gap semiconductor. Photon emission is associated with phonon emission

 hν(photon) = Ec,elec – Ev,hole – hνq (phonon emission) (D)

or hν(photon) = Ec,elec – Ev,hole + hνq (phonon absorption) (E)

**The conservation of momentum can be seen from the vectors in Fig. 2(left).**

(h/2π) kc,elec + (h/2π) kv, hole + (h/2π) kphoton + (h/2π) kphonon = 0 (F)

Neglecting photon momentum, we get

 (h/2π) kc,elec + (h/2π) kv, hole + (h/2π) kphonon = 0 (G)

The sign of phonon momentum depends if a phonon is generated or absorbed.

GaAs: *Direct gap semiconductors*: In a direct energy semiconductor, the transitions from conduction band to the valence band results in the emission of a photon with energy hν as expressed by:

Photon energy hν = Ec,elec – Ev,hole = Energy gap Eg. (A)

The momentum conservation requires:

 (h/2π) kc,elec + (h/2π) kv, hole + (h/2π) kphoton = 0 (B)

 h/2π 

Q.4(a). Find the energy of emission for points A and B using Figure 22 (on page 303) and Fig. 3a (below).

|  |  |
| --- | --- |
| Fig. 22 page 303.Hint: Point A is the intersection of vertical line through InP. Horizontal line through A on Eg axis gives the energy. Fig. 22 has no scales so it is hard to use it.  | D:\_students\xiao\Dr.Jain\bandgap.jpg |

See page 303

Point A: Project GaAs-A-InAs curve on the horizontal O-C-2 line.

Find the fraction OC/O2 = 0.528 C2/O2 = 0.472.

Therefore, at point A the composition is Ga0.472In0.528As.

Point B: Find the fraction between Ga0.472In0.528As (point A) and InP. Assume B is half way up from point A along InP line.

That is, indium composition for point B is = 0.528 + (AB/A-InP) \* 0.472 = 0.764

The Ga composition is 1-In composition fraction =Ga0.236

The P composition using the fraction = (AB/A-InP) =0.5

The As composition is 1-P frication = 0.5

So point B is In0.764Ga0.236As0.5P0.5

Q4(b) What is the wavelength of emission for points A and B?

Point A = 0.7eV, Point B = 0.7 + (1.3-0.7)/2 =1.0eV. InP energy gap is ~1.3eV.

Wavelength at 0.7 is 1.24/0.7= 1.77 micron,

Wavelength at 1.0eV is 1.24/1.0= 1.24 micron.

|  |  |
| --- | --- |
| D:\_students\xiao\Dr.Jain\bandgap.jpg | Fig. 3a (left)Fig. 3b Lattice constant versus energy gap. |