**NE 205: Semiconductor Devices and IC Technology**
**Indian Institute of Science, Bangalore.**
**Autumn Semester 2019, Digbijoy N. Nath**
**Homework III Total points: 40**

*In all the questions below, assume depletion approximation (i.e. neglect Gummel correction), which means, do not try to estimate electron concentration n(x) as a function of depth in the so-called depletion regions!*

## 1. Ballistic Collector transistor

Fig. 1(a) shows the schematic of a special type of Gallium Arsenide (GaAs) BJT, also called *Ballistic Collector Transistor*. It consists of an n-doped emitter, a heavily p-doped base (as usual), an intrinsic collector and a heavily n-doped sub-collector. The difference with a conventional BJT is that there is a sheet of p-type dopants ($\sigma_A$) *intentionally* inserted at the collector/sub-collector (or i-GaAs/n-GaAs) junction as shown. The equilibrium band diagram (excluding the emitter part) is also shown for the ease of understanding. The sheet acceptor density ($\sigma_A$) is such that there is a 0.3 eV drop across the i-GaAs layer. The doping concentration are: base doping (p) = $4 \times 10^{19}$ cm$^{-3}$, sub-collector doping (n) = $2 \times 10^{18}$ cm$^{-3}$.

(a) Assume that the sheet of acceptors is a very high p-doping layer of $N_{sh} = 2 \times 10^{19}$ cm$^{-3}$, spread over a very small distance 't', that is, $\sigma_A = N_{sh} \times t$. What is the value of 't' ?
*Note that there is a depletion region in the sub-collector n-GaAs layer.* 6

(b) Now, a base-collector reverse bias, $V_{CB}$ = 2 V is applied. If I still want to maintain a drop of 0.3 eV across the i-GaAs (collector) region, what should be the value of 't'? 3

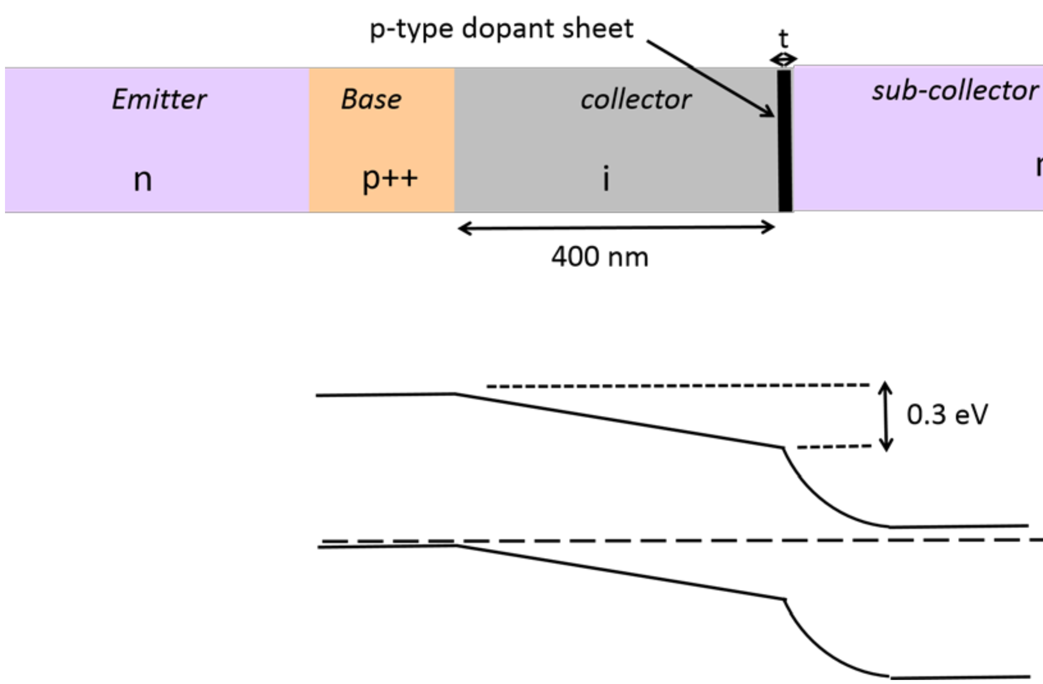


**Figure 1 (a)**

The reason why the device needs to have 0.3 eV drop across the i-GaAs (collector) region for desired operation can be understood from Figure 1(b) which shows the velocity-field relation for GaAs (expressed as velocity vs. voltage drop in collector). The sudden drop in the velocity is due to the intervalley transfer of electrons in GaAs from Γ → L valley.

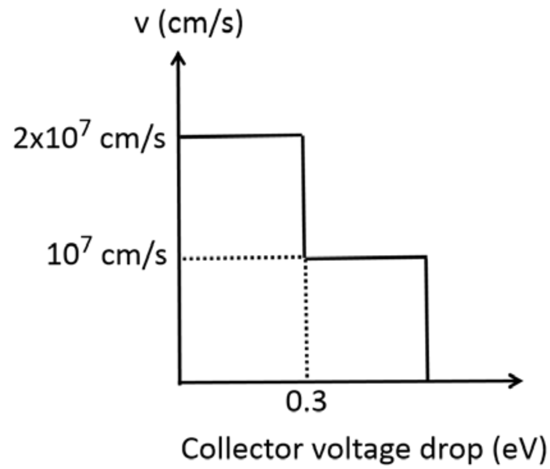


**Figure 1(b)**

(c) With the information provided, explain why this transistor is called a *Ballistic Collector transistor*, and justify its uniqueness over a conventional BJT. 2

(d) Revisit part (a) of this question. Estimate the <u>transit delays</u> of this device under equilibrium and under a base-collector reverse bias = 1 V. 4

2. **Delay in a special type of BJT**

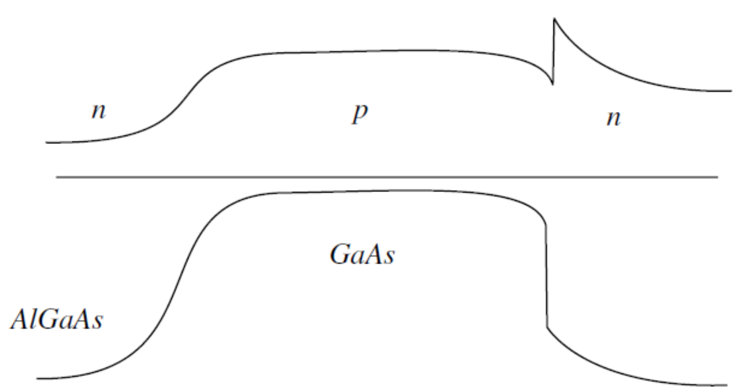


**Figure 2**

Consider a bipolar transistor as shown in Figure 2, where a wide band gap collector is used such that $\Delta E_C$ = 0.3 eV (i.e. the notch in conduction band on base-collector junction). Calculate the additional delay introduced by this notch-like barrier, for a current density of 12 kA/cm$^2$.
Assume that

i) Electrons travel thermionically over the notch (i.e. neglect tunneling)
ii) The notch is a quantum well of width 8 nm with infinite barriers.

Hint: You'll have to invoke 2D density of states to estimate the Fermi level position!

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3. Here is a real-life problem in dealing with junctions, especially if you are a great device engineer at the hands of a not-so-great crystal grower. Suppose you requested the grower to grow you a GaAs p-i-n junction. After growing the p-layer, he stopped the growth and went outside to have some tea. Then he came back and resumed the growth by growing the i–layer (thickness $W_i$), followed by the n-layer.

   After he gave the sample to you, you performed a C-V measurement and found that the depletion capacitance is the same as the normal p-n junction, i.e. as if there was NO i-layer at all! The reason is that while the grower stopped the growth, oxygen, a donor, incorporated in the crystal and formed a sheet of density $q\sigma$/cm$^2$ at the *p-i* interface as shown in Fig. 3.

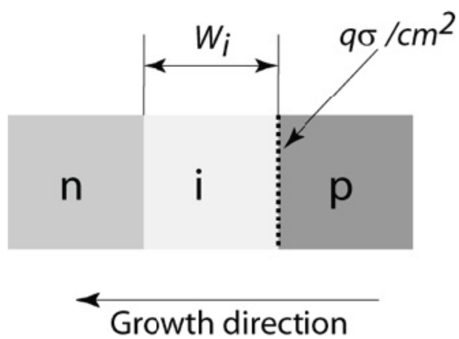


**Figure 3**

(a) Derive an algebraic relation between the doping densities $N_D$, $N_A$, $q\sigma$ and $W_i$, which will explain the capacitance. To do this, you *have* to sketch the charge, field and band diagram. Assume $N_A = N_D$ for simplicity.

(b) Calculate a numerical value for $W_i$. Assume $N_A = N_D = 10^{17}$ cm$^{-3}$, and $q\sigma = 5\text{x}10^{11}$ cm$^{-2}$

12 + 3