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## EE566 Solid State Devices

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Dept of Electrical Engineering

University of Notre Dame

Instructor: Debdeep Jena ([djena@nd.edu](mailto:djena@nd.edu), x8835)

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### 2<sup>nd</sup> Mid-Term Exam

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#### **Problem (20 Points): Ultrafast Heterostructure Bipolar Transistors**

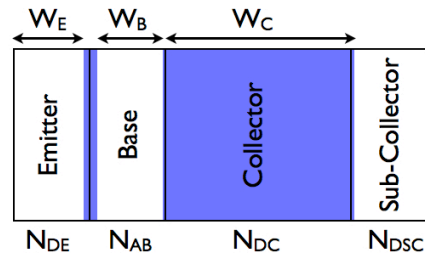


Figure 1 above shows the layer structure of an AlGaAs/GaAs HBT. Assume that the doping densities in the AlGaAs emitter, GaAs (*thin*) base, and GaAs sub-collector regions are such that the neutral regions are just degenerate ( $N_{DE} \sim N_C$ ,  $N_{AB} \sim N_V$ ,  $N_{DSC} \sim N_C$ ) in the respective layers. The GaAs collector region is doped much lighter ( $N_{DC} \ll N_C$ ). The bandgap of GaAs is  $E_g = 1.4$  eV and that of the AlGaAs emitter is  $E_{gE} = 1.7$  eV. The dielectric constant of all layers is  $\epsilon_s$ , and the diffusion constants are  $D_{nB}$  and  $D_{pE}$ . First, answer the following ‘basic’ questions (answer algebraically before giving numerical answers if asked, make any necessary approximations):

- We are going to assume that the emitter-base heterojunction is graded linearly such that the entire difference in bandgap is absorbed within the depletion region thickness at that junction. Explain why this is desirable. Find an algebraic expression for the maximum thickness over which this grading must be performed. (2 Points)
- The reasons for doping the collector lightly are to minimize the Early effect and obtain a high base-collector breakdown. Find an expression for the doping  $N_{DC}$  in the collector such that it is just fully depleted at  $V_{CB} = 0$  Volt in terms of other given quantities. Assume that this is the collector doping for the rest of the problem. (2 Points)
- Find an expression for the Early voltage. (2 Points)
- Sketch the band diagram of the HBT under equilibrium (no bias at either junction) accurately. (2 Points)
- Give expressions for: the emitter injection efficiency  $\gamma_E$ , the base transport factor  $\alpha_T$ , and the current gain  $\beta_F$ . Also, find an expression for the Kirk current threshold  $J_{Kirk}$  at a B/C reverse bias of  $V_{CB}$  Volts. (3 Points)
- Sketch the band diagram (with Quasi-Fermi levels) when the HBT is biased in the forward-active mode ( $V_{BE} = +1$  Volt,  $V_{CB} = -5$  Volt) as accurately as possible. (2 Points)

Now answer this:

- When the collector is lightly doped, the mobility of electrons is very high, and they can move *ballistically* from the base-edge through the collector region, into the sub-collector (meaning, electrons injected from the base into the collector will not lose energy till they reach the sub-collector contact). However, GaAs has a *low-mobility* satellite L-valley at an energy  $E_{\Gamma-L} \sim 0.3$  eV above the  $\Gamma$ -valley minimum. Argue with band diagrams why this will result in a slowing down of the HBT as designed in the figure above. (3 Points)
- Find a way to modify the doping profiles of the above HBT base-collector-subcollector regions layer structure to prevent this effect. Sketch charge/field/band diagrams to support your design. Discuss any possible penalties paid for your modified design. (4 Points)