
EE566 Solid State Devices

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Dept of Electrical Engineering
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Assignment 7

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Heterojunction currents, and graded base HBTs

Problem 1: *Effect of energy spikes on current flow through n-n heterojunctions*

A simple first-order theory of reverse current of Schottky barriers and n-n heterojunctions leads to an expression of the current density of the form

$$J = J_0 \cdot \exp(-q\Phi_B / kT) \cdot [1 - \exp(-qV_a / kT)],$$

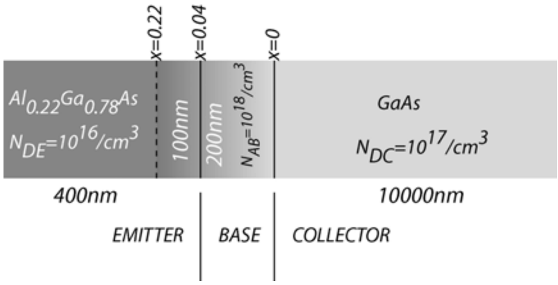
where J_0 is a constant current density (typically 10^9A/cm^2 at 300K), and $q\Phi_B$ is the barrier height measured from the metal side of a Schottky barrier or the accumulation side of the n-n heterojunction (*sketch* the two cases). The bias voltage V_a is counted positive for reverse bias (convince yourself of this). Denote all parameters on the narrow-gap side with the subscript '1' and the wide-gap side by the subscript '2'.

a) Calculate and plot the *linear* (NOT logarithmic!) I-V characteristics (i.e., J/J_0) of three GaAs/AlGaAs heterojunctions for applied bias voltages 0 *volt*$<V_a<10$ *volt* with the following parameters -

$N_{D1}=10^{16}, 10^{17}, 10^{18}/\text{cm}^3$
$N_{D2}=10^{16}/\text{cm}^3$ (all three cases)
$\Delta E_c=0.3$eV

Use all material properties needed for GaAs from data sheets. To do the calculation, you have to first draw the band diagram at any applied bias, find a relation between the total band bending ψ_1 and ψ_2 (pg 23 in handouts) on both sides of the heterojunction and the discontinuity of electric field across the two sides of the heterojunction, and relate the effective barrier height $q\Phi_B$ with the applied bias V_a. Define an asymmetry parameter $\alpha=\varepsilon_{s1}N_{D1}/\varepsilon_{s2}N_{D2}$ to simplify the math. You will need an iterative numerical procedure where you specify V_a and then determine $q\Phi_B$ by iteration. If you write a program to do the iterations, attach the program with sufficient comments. Otherwise, give a detailed description of your iteration algorithm.

Problem 2: *Graded base HBT*



Consider the n-p-n HBT in the figure on the left, where the base is linearly graded from $Al_{0.04}Ga_{0.96}As$ at the emitter end to *GaAs* at the collector end. The emitter material is $Al_{0.22}Ga_{0.78}As$ linearly graded to $Al_{0.04}Ga_{0.96}As$ at the base end. Take note of the fact that all lengths in the diagram below are the TOTAL layer thicknesses. For most calculations, you will need to subtract the depletion thicknesses. Refer to Kroemer's paper (pg 76-78, handouts) for this problem. Use constants for GaAs at 300K.

a) Sketch the detailed band diagram of the HBT in equilibrium. What is the quasi-electric field F_B in the base? Calculate, and then verify both with 1D Poisson.

b) Solve the drift-diffusion equation in the base to obtain an expression for the minority carrier concentration in the base $n_B(x)$ in terms of F_B, collector current J_C, and *effective* base width W_B^{eff}.

c) Obtain an analytical expression, and calculate the numerical value for the base transit time τ_{tr} in the graded base. Compare it with the value for an ungraded base. What is the ratio? Make reasonable approximations.

d) Find the emitter injection efficiency γ_E and the base transport factor α_T. What is the ideal gain β_F at V_{BE}=0.8 volt? What is the improvement due to base grading?

e) What drawbacks would a homojunction bipolar transistor with the *same doping densities* have? Comment on why one would prefer a HBT for better performance.

Debdeep Jena (03/20/04) *Please attach this sheet to the top of your solutions.*