# EE566 Solid State Devices

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## Assignment 6

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*R-G Currents and Bipolar Transistors*

**Problem 1:** *Recombination-Generation currents*

Consider a symmetrically doped Silicon *p-i-n* junction with $N_d = N_a = 10^{17}/cm^3$. The intrinsic region layer thickness is $t = 1\mu m$. The minority carrier lifetime is dominated by a deep level trap located exactly at the intrinsic Fermi energy, $E_t = E_i$, with a concentration such that the Shockley-Read-Hall (SRH) lifetimes are $\tau_n = \tau_p = 5\mu s$. Both n- and p-layer thicknesses are long compared to minority carrier diffusion lengths. Assume the temperature to be $T = 300K$ and the intrinsic carrier density $n_i^2 = 4.46\text{x}10^{19}/cm^6$. Include the Gummel correction in your calculations.

a) Plot the electric field at zero-bias condition. *Make suitable approximations*. Verify with 1D Poisson. What is the "average" electric field at a forward bias $V_f$?
b) Calculate the *recombination current density* $J_{rec}$ in the depletion region for forward bias voltages $0.1V \leq V_f \leq 0.7V$. Give a derivation how the recombination current is calculated.
c) Calculate the normal forward-bias *diffusion current density* $J_{diff}$ for the same forward bias range.
d) Plot both current densities in a common semi-log plot ($log_{10}(J_{...})$ vs $V_f$). Comment on the slopes, and find the voltage at which the two components cross. Which component dominates at sufficiently high forward bias?

**Problem 2**: *Bipolar Transistor, Heavy doping effects*

Consider the Si *n-p-n* bipolar transistor show in the figure below. Assume T=300K, and excess minority carrier density at an ohmic contact to be zero. Use the following for your calculations: $\mu_n = 1500 cm^2/V.s$ | $\mu_p = 450 cm^2/V.s$ | $\tau_n = \tau_p = 0.5\mu s$ | $n_i^2 = 4.46\text{x}10^{19}/cm^6$. Note for this problem that due to heavy doping in the base, there is a *bandgap narrowing* of $\Delta E_g = 22.5(N_D/10^{18} cm^3)^{1/2} meV$, appreciable only in the emitter.

a) Draw the band-diagram for the BJT with the E-B junction forward biased at 0.5V, and the B-C reverse biased at 5V. Include quasi-Fermi levels for electrons and holes throughout the structure. Give an expression for the electron quasi-Fermi level in the base.
b) Find the base Gummel number ($GN_B$). Is it a "short" or "long" emitter? What is the emitter $GN_E$?
c) Find the emitter injection efficiency $\gamma_E$, base transport factor $\alpha_T$, and the corresponding current gain $\beta_F$ first neglecting emitted bandgap narrowing, and then by including it. Comment.
d) Find the collector current density and the base current density. Verify that $J_C/J_B = \beta_F$. What fraction of base current goes into reverse injection and what fraction into base recombination?