

## Semiconductor Devices and Models II

### Homework # 4

#### Reading Assignment: 5/1, 5/2, 5.3, 5.4, 5.5

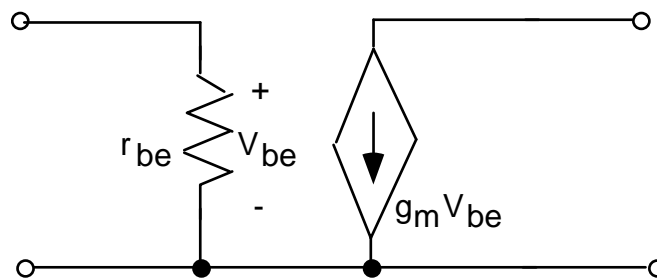
Instructor: [Michael Shur](mailto:shurm@rpi.edu) E-mail: [shurm@rpi.edu](mailto:shurm@rpi.edu) Home page: <http://www.ecse.rpi.edu/shur/>

#1. Derive the following expression for the ac emitter current,  $i_e$

$$i_e = v_{b'e} (1 + j \omega C_e r_e) / r_e = i_{e0} (1 + j \omega C_e r_e),$$

where  $C_e$  and  $r_e$  are parameters of the T-equivalent circuit.

#2. A Si bipolar junction transistor operates at room temperature (300 K). The collector current is 10 mA. The short circuit common emitter current gain  $\beta = 100$ . Estimate parameters of the simplified transistor small signal equivalent circuit shown in the figure and  $h$ -parameters,  $h_{ie}$  and  $h_{fe}$ .



#3. Using the AIM-Spice model HBTA (with default parameters), calculate the output HBT  $I$ - $V$  characteristics for the common emitter configuration for values of the base current from 1  $\mu$ A to 11  $\mu$ A with 2  $\mu$ A steps.

#4. Calculate the dependence of the collector current density,  $j_c$ , in the center of a silicon bipolar junction transistor on the base spreading resistance  $r_{bb'}$ . Neglect the recombination currents.

**Hint:** assume that  $j_c = j_n \exp[(V_{eb} - I_b r_{bb'}) / V_{th}]$  where  $I_b$  is the base current,  $j_n = q D_n n_{b0} / W$ . Also assume that  $x_e \ll L_{pe}$ .

Use the following parameters (you might not need all of them):

Auger recombination coefficient  $G_p = G_n = 2 \times 10^{-31} \text{ cm}^6/\text{s}$

Emitter region width  $x_e = 1 \text{ } \mu\text{m}$

Base region width  $W = 0.5 \text{ } \mu\text{m}$

Device area  $S = 1 \times 10^{-8} \text{ m}^2$

Emitter doping  $N_{de} = 5 \times 10^{18} \text{ cm}^{-3}$

Base doping  $N_{ab} = 2 \times 10^{17} \text{ cm}^{-3}$

Collector doping  $N_{dc} = 5 \times 10^{15} \text{ cm}^{-3}$

Energy gap  $E_g = 1.12 \text{ eV}$

Effective density of states in the conduction band  $N_c = 3.22 \times 10^{19} \text{ cm}^{-3}$

Effective density of states in the valence band  $N_v = 1.83 \times 10^{19} \text{ cm}^{-3}$

Temperature  $T = 300 \text{ K}$

Dielectric permittivity  $\epsilon = 1.05 \times 10^{-10} \text{ F/m}$

Effective recombination time in the emitter-base depletion region  $t_{rec} = 1 \times 10^{-7} \text{ s}$

Diffusion length of electrons in the base  $L_{nb} = 40 \text{ } \mu\text{m}$ .

Diffusion length of holes in the emitter  $L_{pe} = 25 \text{ } \mu\text{m}$ .

Electron mobility in the base region  $\mu_n = 0.1 \text{ m}^2/\text{Vs}$

Hole mobility in the emitter region  $\mu_p = 0.04 \text{ m}^2/\text{Vs}$

Width of the device,  $t_e = 10 \text{ } \mu\text{m}$

Emitter-base voltage,  $V_{be} = 0.65 \text{ V}$ .

5. In heterojunction bipolar junction transistors the emitter is made from a semiconductor with a larger energy gap. This increases the common-emitter current gain by a factor equal to  $\exp(\Delta E_v/k_B T)$  where  $\Delta E_v$  is the valence band discontinuity,  $k_B$  is the Boltzmann constant, and  $T$  is temperature. On the other hand, the recombination current in the base region may increase because of the decrease in the effective lifetime,  $\tau_{eff}$ , which may be crudely estimated as

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau} + R_t v_{th} N_{st}$$

where  $\tau_{eff}$  is the effective lifetime,  $\tau$  is the lifetime,  $v_{th}$  is the thermal velocity,  $R_t$  is the effective radius of a surface state,  $v_{th} = (3k_B T/m_n)^{1/2}$  is the electron thermal velocity,  $m_n$  is the electron effective mass,  $N_{st}$  is the density of the surface states. Calculate the common emitter current gain,  $\beta$ , as a function of  $N_{st}$  for an  $n-p-n$  AlGaAs/GaAs bipolar junction transistor assuming that  $\beta$  is limited by the recombination current in the base and by the hole injection current. Hole and electron diffusion coefficients are  $D_p$  and  $D_n$ , emitter and base doping levels are  $N_{de}$  and  $N_{db}$ , thicknesses of the emitter and base regions are  $x_e$  and  $W$ .

<b>Problem</b>	<b>Maximum score</b>
#1	10
#.2	20
#3	20
#4	20
#5	30