EE 203. Final Sp. 2001

For $k_B T$ at 300K, use 26 meV.

1. Assuming a dispersion relation

$$E = E_C + \frac{\hbar^2}{ma^2}\left[1 - \cos(ka)\right]$$

where a = 0.3 nm and *m* is the bare electron mass.

(a) Calculate the velocity of the electron at $k = \pi/2a$ (a number in cm/s).

(b) Calculate the effctive mass at $k=\pi/4a$ in terms of *m*.

(c) At $t = 0$, an electron is at $x=0$ and $k=0$ in an electric field of $E = 10^4$V/cm. What is the value of k (1/cm) at t =1 ps?

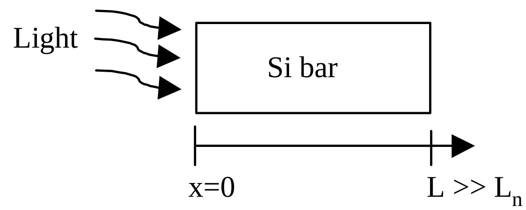
(d) What is the period of the electron oscillation assuming no scattering?

2. Calculate the quantity E_c - E_f for intrinsic Si at T=300K where E_c is the conduction band edge and E_f is the Fermi level.

3. Calculate the electron and hole densities for Si doped with both B and P such that N_D = $10^{17}/cm^3$ and N_A = $5x10^{16}/cm^3$ assuming complete ionization.

4. Derive the Einstein relation for degenerate statistics relating D_n to μ_n.

5. A Si bar has the following properties: $N_A = 10^{15}/cm^3$, $\mu_n = 1350\ cm^2/Vs$, $\mu_p = 500\ cm^2/Vs$, $\tau_n = \tau_p = 10^{-6}s$. The left end of the bar is illuminated so as to create $10^{10}/cm^3$ excess electron hole pairs at x=0. Assuming none of the light penetrates into the interior of the bar (x>0),



(a) Determine the excess minority carrier profile.

(b) Is there current flowing? Explain.

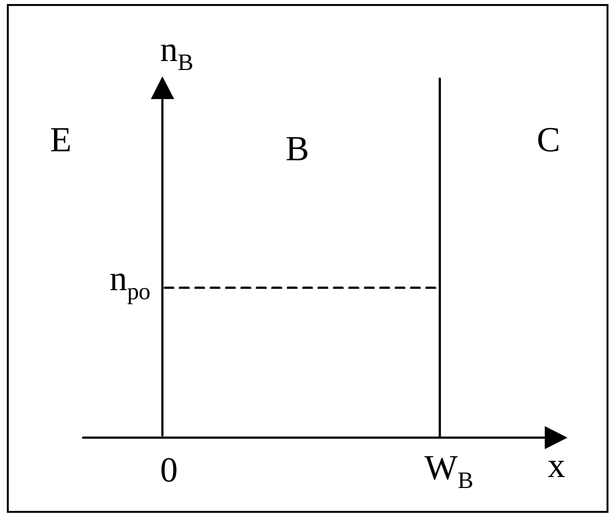
6. For a short base (100) Si n^+p diode: $N_D = 2e18/cm^3$, $N_A = 2e16/cm^3$, $W_B = 0.1\ \mu m$ where W_B is the length of the neutral region of the p-side, μ_n (on p-side) = $1200\ cm^2/Vs$, $V_A = 0.75$ V;
(a) Calculate the diffusion current from the minority carrier diffusion equations.

(b) For $\tau_n = 0$, the electrons are in equilibrium with the holes on the p-side which means that, on the p-side, $F_n = F_p$. For these conditions, use thermionic emission theory to determine the maximum current that can flow.

7. The reverse bias leakage current, I_{CB0}, of an npn BJT is measured with the emitter open.
(a) Use the Ebers-Moll equations to determine V_{BE}. $\beta_F = 100$, T=300K, and $V_{BC} = -10V$. You will need to use the relation $\alpha_F I_{F0} = \alpha_R I_{R0}$.

(b) On the figure at right, sketch the minority carrier electron distribution in the base.

(c) For a base doping of $1x10^{18}/cm^3$, what is the minority electron distribution n_B, at x = 0 and $x=W_B$?



8. For an npn BJT at T=300K with a base width of 0.05 μm and a minority electron mobility in the base of 800 cm^2/Vs, what is the maximum value for the transition frequency, f_T?

9. For an NMOS FET with μ_n in the channel equal to 800 cm^2/Vs, a gate length of 0.18 μm, and $(V_{GS} - V_t) = 1V$ what is the maximum value for the transition frequency, f_T, assuming the "square law" relation for I_D.

10. Consider an NMOS FET with a polysilicon (poly) gate (instead of metal). The poly is heavily doped poly-crystalline Si. For p-type poly, assume that in the poly, $E_f = E_v$, and for n-type poly, assume that $E_f = E_c$. For the electrostatic calculations, you can treat the poly as a metal, i.e. there is no voltage drop in the poly. The thickness of the SiO_2 is 10 nm and it is grown on a 10 Ω cm p-type Si wafer. At the Si / SiO_2 interface there is a surface state charge of 10^{11} charges / cm^2.

(a) Calculate the threshold voltage for an n-type poly gate.

(b) Calculate the threshold voltage for a p-type poly gate.

11. For an NMOS FET we write that the electron charge per unit area under the gate is $Q_n(y) = Cox[V_{GS} - V(y) - V_t]$. Using the same approach that we used to derive the "square law" for I_D, derive an expression for the potential V(y) and the electric field component $E_y(y)$ in saturation.