Semiconductor Device Theory:
Operation of a PN Diode – Advanced Theoretical Exercise

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1. Sketch qualitative distributions of the electric field, electrostatic potential, and carrier concentration in thermal equilibrium for a *p*-*i*-*n* diode.

2. Consider a p^+n diode with $N_A = 10^{17}\,cm^{-3}$ and $N_D = 10^{15}\,cm^{-3}$. The recombination and generation lifetimes are $\tau_{rec} = \tau_{gen} = 10^{-8}\,s$. The device area is $A = 10^{-4}\,m^2$. The electron and hole mobilities are $\mu_n = 0.1\,m^2/Vs$ and $\mu_p = 0.04\,m^2/Vs$. The energy gap equals to $E_g = 1.12\,eV$. At T=300 K, the effective density of states of the conduction and valence bands are $N_C = 3.22\times 10^{19}\,cm^{-3}$ and $N_V = 1.83\times 10^{19}\,cm^{-3}$, respectively. The dielectric permitivity of silicon equals to $k_s\varepsilon_0 = 1.05\times 10^{-10}\,F/m$.

   (a) Calculate and plot the forward and reverse bias characteristics of the diode at T=300 K, taking into account the recombination current in the depletion region, in addition to the diffusion current. For the forward bias recombination current calculation use

   $$J_{rec} = J_{recs} e^{V/2V_T},$$

   where

   $$J_{recs} = q\left(\frac{\pi}{2}\right)^{1/2} \frac{n_i V_T}{\tau_{rec} E_{np}}$$

   and the electric field E_{np} is given by

   $$E_{np} = \left[\frac{qN_D(2V_{bin} - V)}{k_s\varepsilon_0}\right]^{1/2}$$

   where V_{bin} is the built-in voltage drop in the depletion region of the *n*-section of the diode.

(b) Calculate the temperature dependence of the forward and reverse bias characteristics assuming that the carrier mobilities and diffusion constants remain the same as those at T=300 K. Use temperature range from 280 to 450 K. For the forward bias use V=0.5 V, and for the reverse bias use V= - 3 V.

3. The current waveform through a p^+n-junction is shown in the figure below. The effective hole lifetime τ_p in the n-region is 1 ns. Temperature T=300 K. The diode saturation current is I_S=0.1 nA. I_1=1 mA, I_2=2 mA. Diffusion ciefficient D_p=12 cm^2/s. The length of the n-section is much longer than the hole diffusion length.
   (a) Find the voltage across the diode and the charge of minority carriers in the n-section before and after the transient.
   (b) Sketch the qualitative time dependence of the voltage across the diode.
   (c) Sketch the qualitative dependence of minority carriers distribution in the n-section vs. distance for t=0 and for t→∞.