H3-2022: Extra Practice Question Set 3

1. A light source is directed onto an n-type Si sample, producing a uniform generation rate of 2.5×10^{19} $\text{cm}^{-3}\text{s}^{-1}$. The minority carrier lifetime is 10 μs and the hole diffusion coefficient is 20 cm^2/s.

   (a) What is the steady state excess hole concentration in the sample?

   (b) Determine the excess hole concentration 50 μs after the light source is switched off at time $t = 0$.

   (c) Sketch the decay profile of the hole concentration as a function of time t. Indicate, on your sketch, the time at which the excess hole concentration decays to $1/e$ times the steady state value at $t = 0$.

   [Ans: (a) 2.5×10^{14} cm^{-3}, (b) 1.685×10^{12} cm^{-3}]

2. Minority carriers are electrically injected into one end of a p-type Si sample ($x = 0$) such that the electron diffusion current density in the sample is

$$J_{n,diff}(x) = -20.5\ \exp\left(\frac{-x}{50\ \mu\text{m}}\right)\quad \text{mA/cm}^2$$

   Assume $T = 300$ K, $\tau_n = 0.6$ μs and $\tau_p = 2.2$ μs.

   (a) What is the value of the minority carrier diffusion length?

   (b) Explain the meaning of the minority carrier diffusion length.

   (c) Determine the excess electron concentration at $x = 10$ μm.

   [Ans: (a) 50 μm, (c) 1.258×10^{13} cm^{-3}]

3. A bias voltage of V_s is applied across an n-type Si sample with a length of 0.6 cm and a cross-sectional area of 2×10^{-4} cm^2. The acceptor and donor impurity concentrations in the sample are $N_a = 3\times10^{16}$ cm^{-3} and $N_d = 6\times10^{16}$ cm^{-3}, respectively. The sample is uniformly illuminated with light at time $t < 0$ to produce a steady-state excess carrier concentration of $\Delta p = 3\times10^{14}$ cm^{-3}. The excitation light is removed at time $t = 0$. The current in the sample at time $t = 0.1$ μs is 1 mA. Assume that $T = 300$ K, $L_p = 80$ μm, $\mu_n = 200$ cm^2/V-s, $\mu_p = 2110$ cm^2/V-s and $n_i = 5\times10^{10}$ cm^{-3}.

   (a) Calculate the majority carrier concentration in the compensated semiconductor.

   (b) Determine the lifetime of the minority carrier and the optical generation rate at time $t < 0$.

   (c) Derive an expression for the conductivity of the Si sample as a function of time t after the excitation light is removed. Hence find the value of V_s.

   [Ans: (a) 3×10^{16} cm^{-3}, (b) 1.174 μs, 2.56×10^{20} cm^{-3}/s,
   (c) $\sigma(t) = 0.111\exp(-t/1.174\ \mu\text{s}) + 0.9612$, 2.822 V]

4. The donor and acceptor impurity concentrations in a compensated semiconductor sample at T = 300 K are $N_d = 8\times10^{15}$ cm^{-3} and $N_a = 3\times10^{15}$ cm^{-3}, respectively. The sample is uniformly illuminated with light at time t = 0, producing an optical generation rate of 4×10^{19} cm^{-3} s^{-1}. The electron and hole minority carrier parameters in the semiconductor material are given in Table A. Assume that $n_i = 2\times10^9$ cm^{-3} and $E_g = 1.2$ eV.

Table A

	electron	hole
Minority carrier diffusion length (μm)	200	35
Minority carrier diffusion coefficient (cm^2/s)	40	15

(a) Calculate the position of the thermal equilibrium Fermi level E_F relative to the intrinsic Fermi level E_i, i.e. before the semiconductor sample is illuminated with light.

(b) Show that, for low injection condition, the excess electron and hole concentrations in the semiconductor sample at time t is given by

$$\Delta n(t) = \Delta p(t) = 3.27\times10^{13}\left[1-\exp\left(-\frac{t}{\tau_0}\right)\right] \text{ cm}^{-3}$$

where τ_0 is the minority carrier lifetime. State the value of τ_0 and any assumptions made.

(c) Calculate the time it takes for the excess carrier concentration to increase to half the steady state value.

(d) Determine the position of the steady state electron and hole quasi Fermi energy levels, E_{Fnq} and E_{Fpq}, with respect to the thermal equilibrium Fermi level, E_F. Hence sketch the energy band diagram of the semiconductor sample and indicate clearly the positions of E_F, E_i, E_{Fnq} and E_{Fpq}.

[Ans: (a) 0.381 eV, (c) 0.566 μs, (d) E_{Fnq}-E_F = 0.0002 eV, E_{Fpq}-E_F = -0.631 eV]