ECSE-2210 Microelectronics Technology
Class Activity 9 – Solution

1. A Si slab of thickness 100 μm is illuminated from one side with light of energy 1.2 eV. Calculate the wavelength of the light. Calculate the fraction of light intensity that is transmitted through the slab (ignore reflections). Assume an absorption coefficient of $\alpha = 20\ \text{cm}^{-1}$ at 1.2 eV (see figure 3.20).

   The relationship between the wavelength of light and the energy is: $E = h\,c\,/\,\lambda$.
   Here, $E = 1.2\ \text{eV} = 1.2 \times 1.6 \times 10^{-19}$ J; $c = 3 \times 10^{8}$ m/s; $h = 6.63 \times 10^{-34}$ Js

   So, $\lambda = h\,c\,/\,E$

   $$= (6.63 \times 10^{-34}\ \text{J s} \times 3 \times 10^{8}\ \text{m/s}) / (1.2\ \text{eV} \times 1.6 \times 10^{-19}\ \text{J/eV})$$

   $$= 1.036\ \mu\text{m} = 1036\ \text{nm} = 10360\ \text{Å (in the infrared region).}$$

   $I_t = I_0 \exp(-\alpha x)$ where x is the thickness, here $x = 100\ \mu\text{m} = 0.01$ cm.
   So, transmitted light intensity, $I_t = 0.818\ I_0$. That is, approximately 19 % of the 1 μm wavelength light is absorbed by a silicon slab of thickness 100 μm.

2. If the light energy is 3 eV in the above case, what will be the fraction of light intensity that is transmitted? What fraction will be absorbed? Assume the absorption coefficient at 3 eV is 10^{5}cm^{-1}. Will Si be transparent or opaque to 3eV radiation?

   $I_t = I_0 \exp(-\alpha x)$.

   You will find that I_t is almost zero, indicating almost 100 % of light is absorbed. This is because the photon energy ($h\nu$) is greater than (3eV) than the band gap energy (1.12 eV) for Silicon. Hence almost 100 % of the light is absorbed and electron hole pairs are created as the light passes through the semiconductor.

3. Suppose we have to make a photo-conductive detector to detect radiation of energy 1 eV. Of the three (Ge, Si and GaAs) which one will you use? Explain. (Hint: To detect, the radiation has to be absorbed by the semiconductor!).

   We should use Ge since Ge will absorb the radiation creating electron-hole pairs. So, the conductivity of Ge will change which can be detected using simple electronic circuits. The bandgap of Si and GaAs are higher than 1 eV, so Si and GaAs are transparent to 1 eV radiation. No light absorption will take place.

4. Consider three semiconductors: Si, ZnSe and SiC. Which one will look transparent to visible light, and why? (The bandgap are: Si = 1.1 eV, ZnSe = 2.7 eV, and SiC = 3.26 eV).
   Only SiC will look transparent. The visible-light energy range is from about 2 eV to 3 eV (or about 4000 Å to 7000 Å).

5. Explain what is meant by “low-level injection”.

Low level injection implies

$\Delta p << n_0,\ n \approx n_0$, in an n-type material

$\Delta n << p_0, p \approx p_0$, in a p-type material

The majority carrier concentration generally remains undisturbed while the minority carrier concentration changes by several orders of magnitude.

6. Explain what is meant by "life-times of minority carriers".

   It is the average time an excess minority charge carrier will "survive" (i.e. not annihilate with one of the surrounding majority charge carriers) inside the semiconductor.

7. Why are we concerned with the lifetimes of ONLY the minority carriers? (i.e., when we generate excess holes, we generate excess electrons as well. But we don't care about the excess electrons we generate in n-type, for example).

   In our case of low level injection, the majority carrier concentration does not change at all. Only the minority carrier concentration may change appreciably. Hence we are interested in the minority carrier lifetimes only.

8. A p-type Si sample with $N_A = 10^{15}$ cm^{-3} is steadily illuminated such that excess carrier concentrations $\Delta n = \Delta p = 10^{12}$ cm^{-3}. Assume that $\tau_n = \tau_p = 1$ μs in this sample. Assume $\mu_n = 1350$ cm^2/(V s); $\mu_p = 480$ cm^2/(V s).

   (a) Is this low-level injection? Explain.
   Yes. $\Delta n = \Delta p = 10^{12}$ cm^3 $<< N_A$.

   (b) What is the conductivity of the sample before and after the excitation?
   Conductivity $\sigma = 1/\rho = q\,\mu_n n_0 + q\,\mu_p p_0$

   $q = 1.6 \times 10^{-19}$ C, μ_n and μ_p are given above, and $p_0 = 10^{15}$ cm^{-3} (N_A), and $n_0 = n_i^2 / N_A = 10^5$ cm^{-3}.

   p_0 and n_0 refer to equilibrium values (i.e. without illumination).
   $\sigma = 0.0768$ ohm^{-1}cm^{-1}

   After illumination, $p = 10^{15}$ cm^{-3}, and $n = 10^{12}$ cm^{-3}. Therefore the conductivity increases slightly.
   $\sigma = 0.07702$ ohm^{-1} cm^{-1}

   (c) Suddenly, the optical excitation is removed (say, at time $t = 0$ s). Plot the carrier concentration as a function of time, and calculate the carrier concentrations (n and p) at the time $t = 1$ μs. What will be n and p at $t \rightarrow \infty$?

The excess carrier concentration will reduce exponentially with time:

$\Delta n(t) = 10^{12}\ \text{cm}^{-3} \times \exp(-\,t/\tau_n)$.

Evaluate this for time $t = 1\ \mu\text{s}$, and for $t \to \infty$.

At $t = 1\ \mu\text{s}$, $\Delta n(t) = 3.678 \times 10^{11}\ \text{cm}^{-3}$

For $t \to \infty$, $\Delta n(t\to\infty) = \Delta p(t\to\infty) = 0$.

Therefore n and p assume their equilibrium values:

$p(t\to\infty) = 10^{15}\ \text{cm}^{-3}$

$n(t\to\infty) = 10^{5}\ \text{cm}^{-3}$