ELEC-3140 Semiconductor physics Nov 23, 2021

011Exercise 7: Electrical properties, recombination, continuity equation

1. a) Calculate the hole diffusion current in n-type silicon (N_d = 10^{17} cm^{-3}) when hole density decreases linearly from 10^{14} cm^{-3} to 10^{13} cm^{-3} in 1 μm length. The mobility of the holes is μ_h = 317 cm^2/Vs.
   b) A piece of silicon ($n_0 = 10^{17}\,\text{cm}^{-3}$) is illuminated and electron-hole pairs are generated $G_L = \dfrac{\delta p}{\tau_p} = 3.5\cdot 10^{20}\,\text{cm}^{-3}$ (pairs/s). The known parameters for the sample are $\mu_p = 480\,\text{cm}^2/\text{Vs}$, $\mu_n = 1350\,\text{cm}^2/\text{Vs}$ and $\tau_n = \tau_p = 1\,\mu\text{s}$. Calculate the hole density in silicon and the change in conductivity caused by illumination.

2. TSC method (TSC = thermally stimulated current) can be used to measure the energy level of an electron trap. The sample is cooled down and the trap states are filled by shining intense light onto the sample. Then, the sample is heated up in dark and the conductivity of the sample is measured at the same time. The conductivity reaches its maximum value σ_m at the temperature of T_m. At that temperature, the Fermi level is at the same level as the trap state. What is the trap level in a GaAs sample when the maximum conductivity is achieved at T_m = –33°C? The sample is 0.5 mm long and the cross-sectional area is 1 mm^2. The current of 280 μA flows through the sample when the bias is 10 V. The electron mobility of the sample at the same temperature is 7 000 cm^2 V^{-1} s^{-1}.

3. A piece of semiconductor is illuminated continuously so that generation G_L is constant throughout the piece (quite difficult to arrange in practice). If there is surface recombination rate of S at one end of the piece, what is the hole concentration as a function of position (away from that surface) at the steady state?

4. a) Calculate the theoretical emission curve $r(E)$ as a function of energy E when it is known that $r(E) \propto J_{vc}(E)\, f_n(E_2)\left[1 - f_p(E_1)\right]$, where

   $J_{vc}(E) \propto \sqrt{E - E_g}$ is 3D joint density of states,

   $f_n = e^{-\frac{E_2 - E_{Fn}}{kT}}$ is the probability of electron occupation on energy E_2 and

   $1 - f_p = e^{\frac{E_1 - E_{Fp}}{kT}}$ is the probability of hole occupation on energy E_1.

   b) At which energy the emission curve $r(E)$ has its maximum?
   c) What is the full width at half maximum (FWHM) of the emission curve?