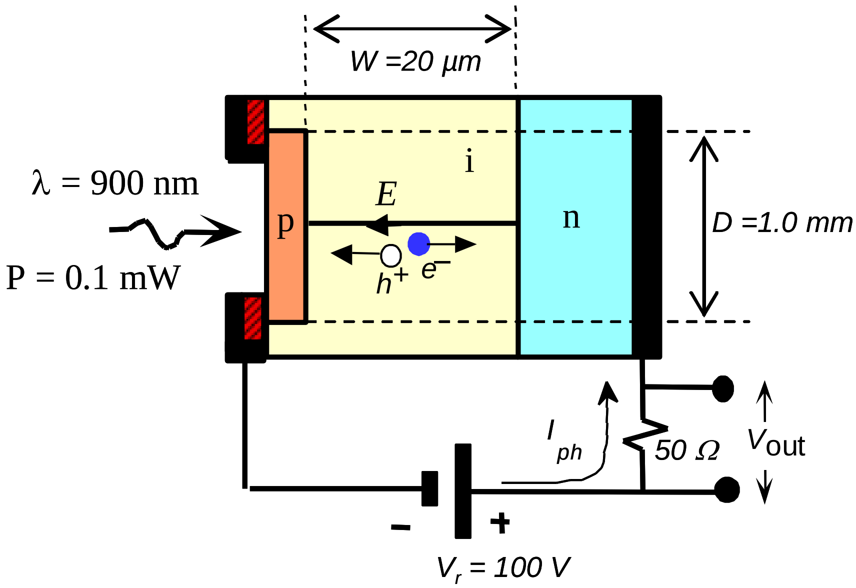
OPTI 500 D, HOMEWORK #2

Solutions



1. The p-i-n photodiode shown above is fabricated from n-type, p-type and i-type (undoped) silicon. The front surface has been anti-reflection coated so that all incident light enters the semiconductor. The absorption coefficient for silicon is approximately 300 cm^{-1} for light with a wavelength of 900 nm. The n-type layer is 0.1 microns thick – sufficiently thin so that light absorption is negligible for this layer. Calculate the quantum efficiency for the photodiode at 900 nm, assuming the any light that passes through the i–layer into the p-layer is lost and does not contribute to photocurrent.

The fraction of light that is absorbed in the i-layer is $1-e^{-300 \times .002} = 0.45$, all other light is lost. The quantum efficiency is $\boxed{\eta=0.45}$.

2. Find the responsivity for the photodiode at 900 nm in units of Amps/Watt. (Planck's constant is $h = 6.6261 \times 10^{-34}$ J s).

$R = \eta e/h\upsilon = \eta e\lambda/hc = 0.45(1.6\text{x}10^{-19})(.9\text{x}10^{6}) /(6.6261\text{x}10^{-34})(3.0\text{x}10^{8}) = \boxed{0.33 \text{ Amps/Watt}}$

3. Find the voltage across the external 50-ohm load if the optical power on the photodiode is 0.1 mW at a wavelength of 900 nm.

The current in the circuit is RP = 0.33 x 0.1 mW = .033 mAmp. The voltage is .033 mA x 50 ohm = 1.65 mV.

4. The photodiode has a reverse bias of 100 volts that appears entirely across the undoped i-layer of width 20 microns. Find the transit time for an electron, and for a hole, across the entire 20-micron length of the i-layer, using the drift velocity curves below.

The electric field in the i-layer is $E = V/d = 100/20\times10^{-6} = 5\times10^{6}$ V/m. The corresponding drift velocities are 10^{5} m/s for electrons and 7×10^{4} m/s for holes. The corresponding transit times are $20\times10^{-6}/10^{5}$ = 0.20 nanoseconds for electrons and $20\times10^{-6}/7\times10^{4}$ = 0.29 nanoseconds for holes.

5. The photodiode has a diameter of 1.0-mm.

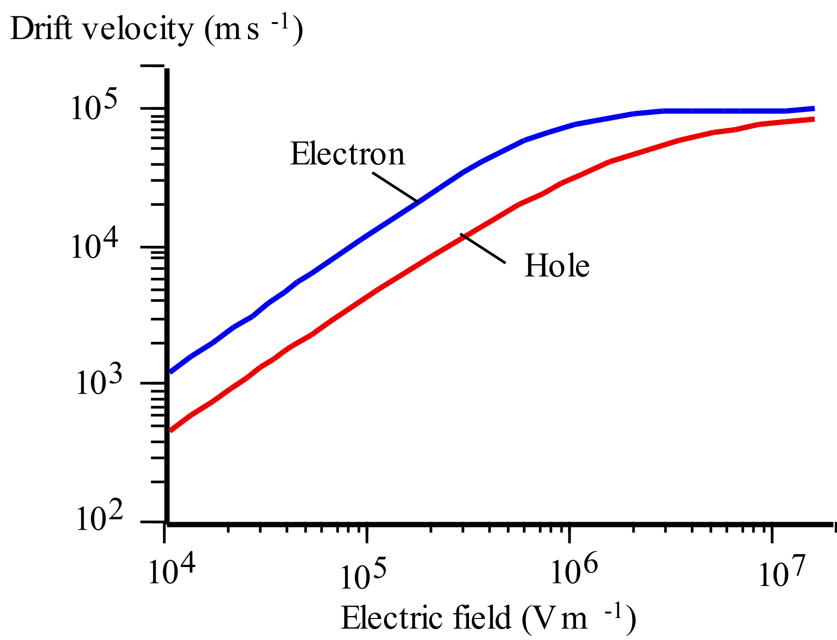
   a. Find its capacitance.

   $C = Ak\varepsilon_0/w = \pi(.05)^2(11.9)(8.8542\times10^{-14})/20\times10^{-4}$ = 4.14 picofarad

   For this calculation, use a simple model for the photodiode. Treat the p-i-n structure as if it were equivalent to a parallel metal plate capacitor, with the plates separated by 20 microns and the gap between the plates filled with silicon, a material that has a dielectric constant of 11.9. Parallel plates have a capacitance $Ak\varepsilon_0/w$, where A is area of the plates, k is the dielectric constant of the material between the plates, $\varepsilon_0 = 8.8542 \times 10^{-14}$ F/cm is the permittivity of free space, and w is the plate separation.

   b. Neglecting any "parasitic" resistance or capacitance, find the RC time constant for the photodiode circuit.

   $RC = 50 \times 4.14\times10^{-12}$ = 0.21 nanoseconds.



Drift velocity vs. electric field for holes and electrons in Si.