Ch. 14: ~~1~~, ~~2~~, ~~3~~, ~~4~~, ~~5~~, ~~6~~, ~~7~~, ~~19~~, ~~20~~, ~~21~~, ~~27~~

#1: Determine λ_{max} of a source that can generate e-h pairs in

In all cases, the maximum wavelength that can generate e-h pairs is determined by the bandgap energy.

$$\lambda_{max} = \frac{hc}{E_g} = \frac{1.24}{E_g} \; [\mu m] \qquad [hc] = [eV \cdot \mu m]$$

a) Si: $\lambda_{max} = \frac{1.24 \, eV \cdot \mu m}{1.12 \, eV} = 1.107 \, \mu m$

b) Ge: $\lambda_{max} = \frac{1.24 \, eV \cdot \mu m}{.66 \, eV} = 1.88 \, \mu m$

c) GaAs: $\lambda_{max} = \frac{1.24 \, eV \cdot \mu m}{1.42 \, eV} = .873 \, \mu m$

d) InP: $\lambda_{max} = \frac{1.24 \, eV \cdot \mu m}{1.35 \, \mu m} = .9185 \, \mu m$

#2:

a) $\lambda = 480 \, nm$: $E = \frac{1.24}{.48 \mu m} = 2.583 \, eV$

$\lambda = 725 \, nm$: $E = \frac{1.24}{.725 \mu m} = 1.71 \, eV$

b) $E = 0.87 \, eV$; $\lambda = \frac{1.24}{0.87} = 1.425 \, \mu m$

$E = 1.32 \, eV$; $\lambda = \frac{1.24}{1.32} = .940 \, \mu m$

$E = 1.90 \, eV$: $\lambda = \frac{1.24}{1.90} = .653 \, \mu m$

#3:

a) GaAs $1.2 \mu m$ thick illuminated with light of energy $h\nu = 1.65 \, eV$. Determine

(i) absorption coeff.

from fig. 14.4 $\alpha \approx 10^4 \, cm^{-1}$

(ii) fraction of energy absorbed in sample.

using Beer's law: $I(x) = I_0 e^{-\alpha x}$, we have

$$\frac{I(d)}{I_0} = e^{-\alpha d} = e^{-(10^4 cm^{-1})(1.2 \times 10^{-4} cm)} = 0.3$$

Which is the fraction transmitted, so the fraction absorbed is

$$1 - .3 = .7 \rightarrow 70\%.$$

b) repeat with $.8 \mu m$ thick sample illuminated with light of energy $h\nu = 1.9 \, eV$

(i) $\alpha \simeq 3 \times 10^4 \, cm^{-1}$

(ii) $1 - \frac{I(d)}{I_0} = 1 - e^{-(3 \times 10^4 cm^{-1})(.8 \times 10^{-4} cm)} = .91 \rightarrow 91\%.$

#4: light source of energy $h\nu = 1.3 \, eV$ at $I = 10^{-2} \, W/cm^2$ incident on a thin slab of Si. Excess minority carrier lifetime is 10^{-6} s. Determine e-h generation rate and steady-state excess carrier concentration.

from fig. 14.4, $\alpha \approx 5\times10^2\ cm^{-1}$ and the e-h generation rate is

$$g' = \frac{\alpha I(x)}{h\nu} = \frac{(5\times10^2 cm^{-1})(10^{-2}\ W/cm^2)}{(1.3\,eV)(1.602\times10^{-19}\frac{J}{eV})}$$

$$\Rightarrow g' = 2.4\times10^{19}\ \frac{\text{e-h pairs}}{cm^3\cdot s}.$$

The excess carrier concentration is then

$$\delta n = g'\tau = 2.4\times10^{13}\ cm^{-3}$$

#5: n-type GaAs with $\tau_p = 2\times10^{-7}\,s$, incident light of energy $h\nu = 1.65\,eV$ generates $\delta P = 5\times10^{15}\ cm^{-3}$ at the surface.

a) Determine the required incident power. ← Should say intensity in the book.

$$g' = \frac{\delta P}{\tau} = 2.5\times10^{22}\ \frac{\#}{cm^3 s}$$

$$\Rightarrow I(0) = \frac{h\nu g'}{\alpha} = \frac{(1.602\times10^{-19}\frac{J}{eV})(1.65\,eV)(2.5\times10^{22}\frac{\#}{cm^3\cdot s})}{10^4\ cm^{-1}}$$

$$\Rightarrow \boxed{I(0) = .661\ \frac{W}{cm^2}}$$

b) At what distance does g' drop to 10% of that at the surface?

$$g_0' = \frac{\alpha I(0)}{h\nu}, \quad .1 g_0' = \frac{\alpha I(x)}{h\nu}$$

$$\Rightarrow \frac{.1 g_0'}{g_0'} = \frac{I(x)}{I(0)} = e^{-\alpha x} \Rightarrow -\alpha x = \ln(.1)$$

$$\Rightarrow x = \frac{-\ln(.1)}{\alpha} = 2.3\times10^{-4}\ cm = 2.3\ \mu m$$

#6: Si illuminated with light of energy $h\nu = 1.4\,eV$

a) Determine thickness such that 90% of the energy is absorbed.
$\alpha \approx 5\times10^2\ cm^{-1}$

$$1 - \frac{I(x)}{I(0)} = 1 - .9 = 0.1 \Rightarrow 0.1 = e^{-\alpha x}$$

$$\Rightarrow x = \frac{-\ln(.1)}{\alpha} = 4.61\times10^{-3}\ cm = 46.1\ \mu m$$

b) Determine thickness s.t. 30% is transmitted.

$$.3 = e^{-\alpha x} \Rightarrow x = \frac{-\ln(.3)}{\alpha} = 2.41\times10^{-3}\ cm = 24.1\ \mu m$$

#7: Determine incident light energy on $1\,\mu m$ thick GaAs sample such that 50% of the light is absorbed.

$$\frac{I(d)}{I_0} = e^{-\alpha d} = .5 \Rightarrow \alpha = \frac{-\ln(.5)}{d} = 6931.5\ cm^{-1}$$

$$\text{or } \alpha \approx 7\times10^3\ cm^{-1} \Rightarrow \boxed{h\nu \simeq 1.5\,eV \rightarrow \lambda \simeq 830\,nm}$$

#19: n-type Si photoconductor at $T = 300\,K$ doped with $N_d = 5\times10^{15}\ cm^{-3}$.
$A = 5\times10^{-4}\ cm^2$, $L = 120\,\mu m$, $\mu_n = 1200\ cm^2/V\cdot s$, $\mu_p = 400\ cm^2/V\cdot s$, $\tau_{n0} = 5\times10^{-7}\,s$,

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$\tau_{po} = 10^{-7}\,s$. Photoconductor is uniformly illuminated s.t. $G_L = 10^{21}\ cm^{-3}\cdot s^{-1}$.
For 3 volts applied, determine

a) thermal equil. current

$$J = \sigma E \Rightarrow J\cdot A = I = \sigma\left(\frac{V}{L}\right)A = (e\mu_n N_d)\left(\frac{V}{L}\right)A = .120\ A = \boxed{120\ mA = I}$$

b) Steady-state excess carrier concentration

$$\delta P = G_L \tau_{po} = 1\times10^{14}\ cm^{-3}$$

c) photoconductivity

$$\Delta\sigma = e\,\delta P(\mu_n + \mu_p) = .0256\ (\Omega\,cm)^{-1}$$

d) steady-state photocurrent. First determine t_n using $E = \frac{V}{L}$

$$t_n = \frac{L}{\mu_n E} = \frac{L^2}{\mu_n V} = 4\times10^{-8}\,s = 40\,ns$$

$$\Rightarrow I_L = e G_L\left(\frac{\tau_p}{t_n}\right)\left(1 + \frac{\mu_p}{\mu_n}\right)AL = 3.204\times10^{-3}\ A = 3.204\ mA$$

e) photocurrent gain

$$\Gamma_{ph} = \frac{\tau_p}{t_n}\left(1 + \frac{\mu_p}{\mu_n}\right) = \frac{10}{3} = 3.\bar{3}$$

#20: Excess carriers uniformly generated in GaAs photoconductor at a rate of
$G_L = 10^{21}\ cm^{-3}\,s^{-1}$. $A = 10^{-4}\ cm^2$, $L = 100\,\mu m$

$$N_d = 5\times10^{16}\ cm^{-3} \qquad N_a = 0$$
$$\mu_n = 8000\ cm^2/V\cdot s \qquad \mu_p = 250\ cm^2/V\cdot s$$
$$\tau_{no} = 10^{-7}\,s \qquad \tau_{po} = 10^{-8}\,s$$

5 volts applied; calculate
a) steady-state excess carrier concentration

$$\delta P = G_L \tau_{po} = 1\times10^{13}\ cm^{-3}$$

b) Photoconductivity

$$\Delta\sigma = e\,\delta P(\mu_n + \mu_p) = .0132\,(\Omega\,cm)^{-1}$$

c) steady-state photocurrent

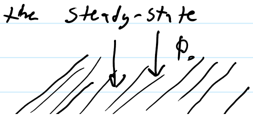
$$t_n = \frac{L^2}{\mu_n V} = 2.5\times10^{-9}\,s = 2.5\,ns$$

$$\Rightarrow I_L = e G_L\left(\frac{\tau_p}{t_n}\right)\left(1 + \frac{\mu_p}{\mu_n}\right)AL = 6.6\times10^{-4}\ A = .66\ mA$$

d) Photoconductor gain

$$\Gamma_{ph} = \frac{\tau_p}{t_n}\left(1 + \frac{\mu_p}{\mu_n}\right) = \frac{33}{8} = 4.125$$

#21: n-type Si photoconductor that is $1\,\mu m$ thick and $50\,\mu m$ wide and has an applied longitudinal electric field of $50\ V/cm$. If the incident photon flux is $\phi_o = 10^{16}\ cm^{-2}\,s^{-1}$ and the absorption coeff. is $\alpha = 5\times10^4\ cm^{-1}$, calculate the steady-state photocurrent if $\mu_n = 1200\ cm^2/V\cdot s$, $\mu_p = 450\ cm^2/V\cdot s$, and $\tau_{po} = 2\times10^{-7}\,s$.



First we determine the excess carrier concentration using

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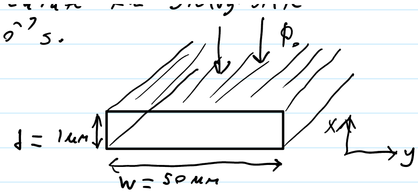

First, we determine the excess carrier concentration using

$$\delta P = g' \tau_p$$

where $g' = \alpha \phi(x) = \alpha \phi_0 e^{-\alpha x}$

$$\Rightarrow \quad \delta P = \alpha \phi_0 \tau_p e^{-\alpha x}.$$

Then the photoconductivity is

$$\Delta\sigma = e\,\delta P(\mu_n + \mu_p)$$

$$\Rightarrow \quad I_L = \iint \Delta\sigma E\, dA = \int_0^W dy \int_0^d \Delta\sigma E\, dx = W E \alpha \phi_0 \tau_p e(\mu_n + \mu_p) \int_0^d e^{-\alpha x}\, dx$$

$$= W E \phi_0 \tau_p e(\mu_n + \mu_p)\left[1 - e^{-\alpha d}\right] = (1.322 \times 10^{-7} A)[.9933] = 1.313 \times 10^{-7} A$$

$$\Rightarrow \quad \boxed{I_L = .1313\ \mu A}$$

#27: Consider Si PIN photodiode exposed to sunlight. Calculate intrinsic region width s.t. $\geq 90\%$ of all photons with $\lambda \leq 1\mu m$ are absorbed in I-region.

We want

$$\frac{I(x)}{I_0} = e^{-\alpha x} = .1$$

$$\Rightarrow \quad x = \frac{-\ln(.1)}{\alpha} \qquad \text{where } \alpha \simeq 10^2\ cm^{-1} \text{ at } \lambda = 1\mu m$$

$$\Rightarrow \quad x = .023\ cm = 230\ \mu m$$