HW #23

5.1 a) $E_g = \frac{hc}{\lambda} = \frac{1240 \text{ eV nm}}{600 \text{nm}} = 2.07 \text{eV}$

b) $A = 5\times10^{-2} \text{cm}^2$

$I = 2 \text{mW/cm}^2 = 2\times10^{-3} \text{W/cm}^2$

$\lambda = 600 \text{ nm}$

$$I = \frac{\text{Power}}{\text{Area}} = \frac{\text{Energy/time}}{\text{Area}} = \frac{N_{photons} E_{photon}}{A \cdot t} = \frac{N_{photons}}{tA} \cdot \frac{hc}{\lambda}$$

$$\rightarrow \frac{N_{photons}}{t} = \frac{IA\lambda}{hc} = \frac{2\times10^{-3} \text{W/cm}^2 \cdot 5\times10^{-2} \text{cm}^2 \cdot 600 \text{nm}}{1240 \text{ eV}\cdot\text{nm} \times 1.602\times10^{-19} \text{J/eV}} = 3.02\times10^{14} \text{photons/s}$$

the number of electron-hole pairs equals the number of electrons per second, then

$$\frac{N_{pairs}}{t} = 3.02\times10^{14} \text{ pairs/s}$$

c) $E_g = 1.42 \text{eV}$, $\lambda = \frac{hc}{E_g} = \frac{1240 \text{ eV nm}}{1.42 \text{ eV}} = 873.2 \text{nm}$

d) No, it is in the infrared region.

e) From table 5.1, $E_g^{Si} = 1.10 \text{ eV}$, so a GaAs laser ($E_\gamma = E_g^{GaAs} = 1.42 \text{eV}$) would be energetic enough to promote electrons from the valence band to the conduction band.

5.5 $\rho = 1\ \Omega\cdot\text{cm}$ For p-type the conductivity (& resistivity) depends only on the acceptor concentration, Na, and the hole mobility:

$$\rho = \frac{1}{\sigma} = \frac{1}{eN_a\mu_n}$$

$$N_a = \frac{1}{e\mu_n\cdot\rho}$$

from table 5.1, for silicon $\mu_n = 450\ \text{cm}^2/\text{Vs}$

$$N_a = \frac{1}{(1.6\times10^{-19}\text{C})(450\,\text{cm}^2/\text{Vs})(1\,\Omega\text{cm})} = 1.38\times10^{16}/\text{cm}^3$$

* The drift mobility actually depends on concentration, from Fig. 5.19, $\mu_n \sim 350\,\text{cm}^2/\text{Vs}$ for $N_a \sim 10^{16}/\text{cm}^3$, then

$$N_a = \frac{1}{e\mu_n\rho} = 1.78\times10^{16}/\text{cm}^3$$

* Note: we didnt cover this in class.

5.6 a) Doping does not always increase the conductivity. If the hole drift mobility is smaller than the electron drift mobility and we slighty doze a material p-type, then the conductivity would decrease. Further p-doping would increase the conductivity ones enough holes were contributing to conduction.

b) $\sigma = en\mu_e + ep\mu_h$ and $np = n_i^2$

$n = \frac{n_i^2}{p}$, then $\sigma = \frac{en_i^2\mu_e}{p} + ep\mu_h$

to find the minimum, $\frac{d\sigma}{dp} = 0$,

$$\frac{d\sigma}{dp} = -\frac{en_i^2\mu_e}{p_{min}^2} + e\mu_h = 0 \rightarrow p_{min} = n_i\sqrt{\frac{\mu_e}{\mu_h}}$$

and the minimum conductivity:

$$\sigma_{min} = \frac{en_i^2\mu_e}{n_i\sqrt{\mu_e/\mu_h}} + e\mu_h n_i\sqrt{\frac{\mu_e}{\mu_h}} = en_i\sqrt{\mu_e\mu_h} + en_i\sqrt{\mu_e\mu_h} = 2en_i\sqrt{\mu_e\mu_h}$$

c) from table 5.1, for silicon $\mu_e = 1350\,\mathrm{cm}^2/\mathrm{V\cdot s}$, $\mu_h = 450\,\mathrm{cm}^2/\mathrm{Vs}$, $n_i = 1.0\times10^{10}/\mathrm{cm}^3$.

$$p_m = n_i\sqrt{\frac{\mu_e}{\mu_h}} = (1.0\times10^{10}/\mathrm{cm}^3)\sqrt{\frac{1350\,\mathrm{cm}^2/\mathrm{Vs}}{450\,\mathrm{cm}^2/\mathrm{Vs}}} = 1.73\times10^{10}/\mathrm{cm}^3$$

$$\sigma_{min} = 2en_i\sqrt{\mu_e\mu_h} = 2(1.6\times10^{-19}\mathrm{C})(1.0\times10^{10}/\mathrm{cm}^3)\sqrt{1350\times450\,(\mathrm{cm}^2/\mathrm{Vs})^2} =$$

$$= 2.5\times10^{-6}/\Omega\mathrm{cm}$$

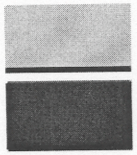
$$\rho_{max} = \frac{1}{\sigma_{min}} = 4\times10^{5}\,\Omega\mathrm{cm}$$

comparing to intrinsic values:

$$\frac{p_m}{n_i} = \frac{1.73\times10^{10}/\mathrm{cm}^3}{1.0\times10^{10}/\mathrm{cm}^3} = 1.73, \quad \frac{\sigma_{min}}{\sigma_{int}} = \frac{2.5\times10^{-6}/\Omega\mathrm{cm}}{en_i(\mu_e+\mu_h)} = \frac{2.5\times10^{-6}/\Omega\mathrm{cm}}{2.88\times10^{-6}/\Omega\mathrm{cm}} = 0.87$$

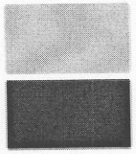
2. a) Which of the following pictures or descriptions represent n-type semiconductors and which represent p-type semiconductors?

A



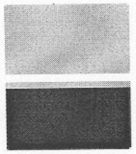
n-type

B



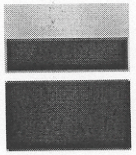
intrinsic

C



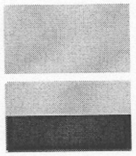
p-type

D



n-type

E



p-type