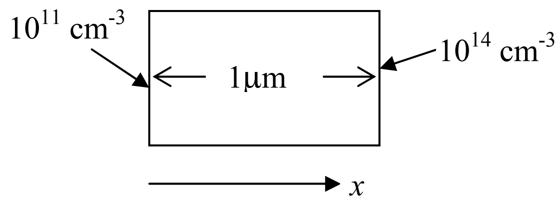
ECSE-2210 Microelectronics Technology
Class Activity 7 – Solution

1) A silicon piece of 1 µm thick is shown below. By some magic, we maintain an electron concentration linearly varying from 10^{11} cm^{-3} to 10^{14} cm^{-3} inside the sample. Calculate the electron diffusion current density $J_{n|\,diff}$ in A/cm^2 and its direction. Repeat if carriers were holes. Assume $D_n = 25$ cm^2/s and $D_p = 10$ cm^2/s.



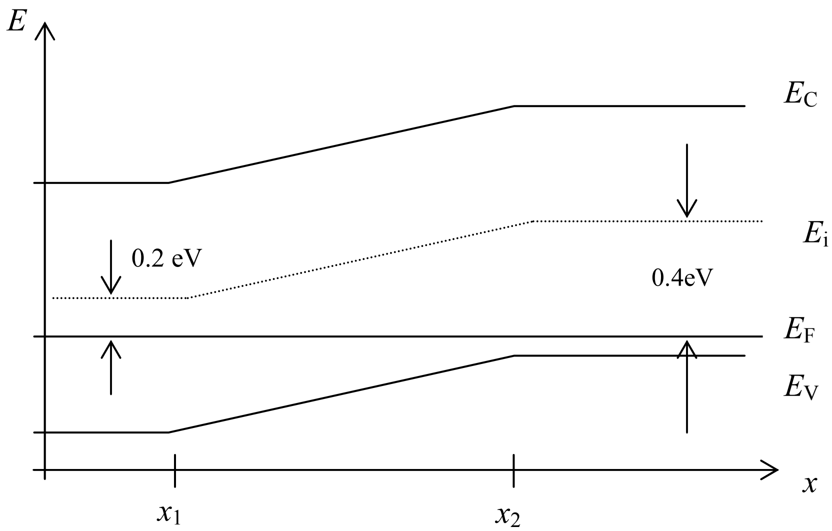
$$J_{n|\,diff} = q\, D_n \frac{dn}{dx}$$
$$= 1.6 \times 10^{-19}\ \text{C} \times 25\ \text{cm}^2/\text{s} \times (10^{14} - 10^{10})\ \text{cm}^{-3}/(10^{-4}\ \text{cm})$$
$$= 4\ \text{A/cm}^2$$

As the electrons diffuse from right to left (higher concentration to lower concentration), the $J_{n\,diff}$ is from left to right.

$$J_{p\,diff} = q\, D_n \frac{dp}{dx}$$
$$= 1.6 \times 10^{-19}\ \text{C} \times 10\ \text{cm}^2/\text{s} \times (10^{14} – 10^{10})\ \text{cm}^{-3}/(10^{-4}\ \text{cm})$$
$$= 1.6\ \text{A/cm}^2$$

$J_{p\,diff}$ is in the direction of hole diffusion. Hence $\mathbf{J}_{p\,diff}$ is from right to left.

2) A silicon sample maintained at 300 K is characterized by the energy band diagram in the figure. Answer the questions below. Also write down (on the side) the general equations that you used to get the answer.

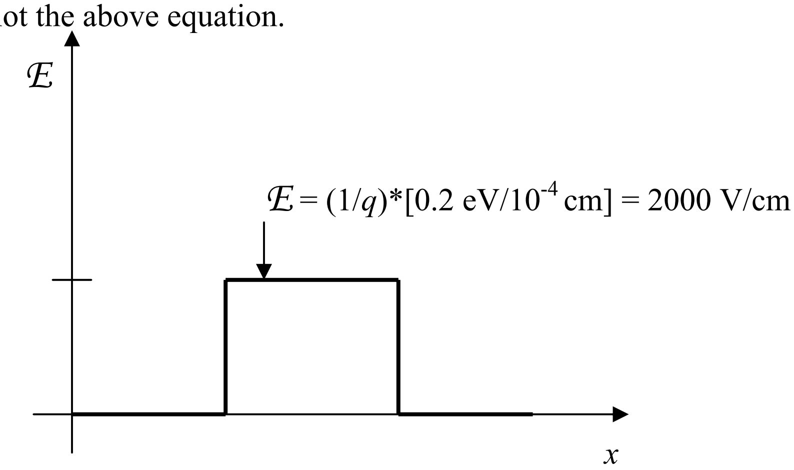


x_2 - x_1 = 1µm

(a) Sketch the electric field $\mathcal{E}$ inside the semiconductor as a function of x. Find the numerical value for the $\mathcal{E}$-field in units of V/cm.

$\mathcal{E} = (1/q)\, dE_i/dx$

So, plot the above equation.

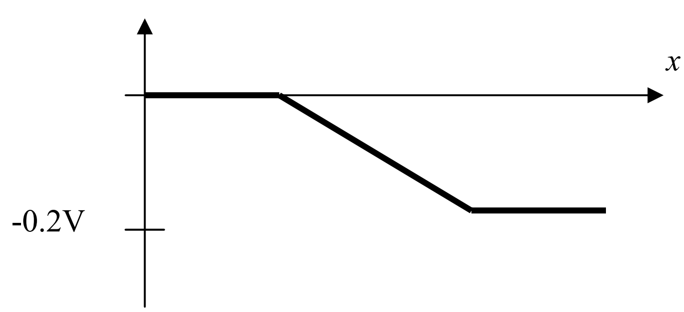


For $x<x_1$, $\mathcal{E} = 0$ and for $x > x_2$, $\mathcal{E} = 0$ since the slope of the band is zero.

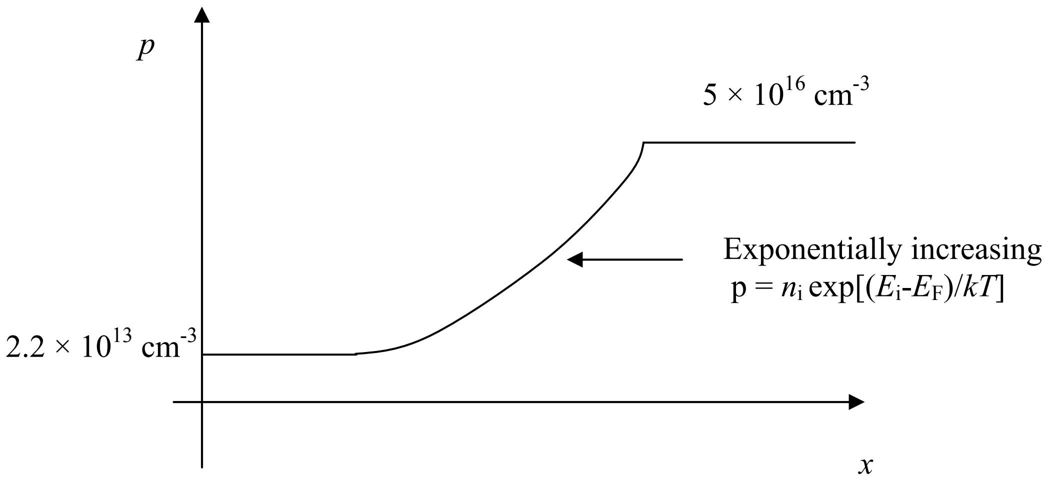
For $x1<x<x2$ $\mathcal{E} = (1/q)\, dE_i/dx = 2000\text{V/cm}$ = constant (due to the constant slope of E_i).

(b) Sketch the potential inside as a function of x. What is the potential difference between the two ends?

The potential $V = -\int \mathcal{E}\, dx$, or negative of area under $\mathcal{E}$-vs-x curve. It turns out to be an "upside-down curve" of the band diagram. The potential difference is - 0.2 V. Note that this is the same as the amount of band bending. Therefore the slope indicates the strength of $\mathcal{E}$-field, and the amount of band bending indicates the potential difference.



(c) Roughly sketch p versus x. Find p at the two ends and plot qualitatively in between.



$p = n_i \exp[(E_i\text{-}E_F)/kT]$

At x1, E_i-E_F = 0.2 eV

$p=10^{10}\ \exp(0.2/0.0259)$

$= 2.2 * 10^{13}\ cm^{-3}$

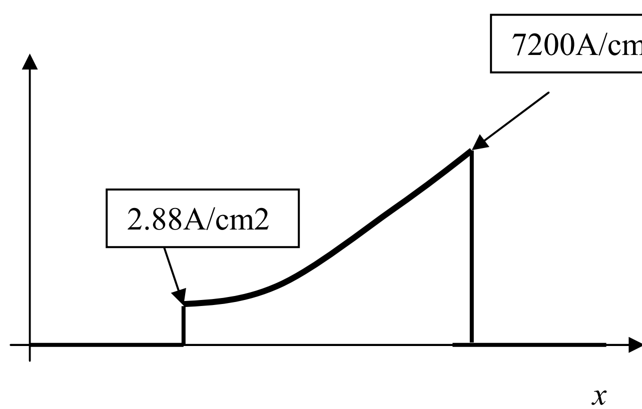
At x2, , E_i-E_F = 0.4 eV

$p=10^{10}\ \exp(0.4/0.0259)$

$=5.1 *10^{16}\ cm^{-3}$

Between x1 and x2 the hole concentration increases exponentially. Below x1 and above x2 it is constant.

(d) Make a rough sketch (qualitatively) of the hole drift-current density ($J_{p|\ drift}$) as a function of x. [Assume μ_p = 400 $cm^2/(Vs)$ if you want to calculate a numerical answer].



Since you have the graph for p and $\mathcal{E}$, just multiply both of them

At x1,

$J_{p\ |drift} = q\mu_p p\ \mathcal{E}$

$= 1.6 \text{ x } 10^{-19} \text{ x } 400 \text{ x } 2.2 \text{ x } 10^{13} \text{ x } 2000 = 2.8\ A/cm^2$

At x2,

$J_{p|drift} = q\mu_p p \mathcal{E}$

$= 1.6 \times 10^{-19} \times 400 \times 5 \times 10^{16} \times 2000 = 6400\ A/cm^2$

(e) What will be the hole diffusion current density ($J_{p|diff}$) based on the result of problem 2 (d)?
Since $J_{pdrift} + J_{pdiff} = 0$ under equilibrium condition.
$J_{p|diff}$ is opposite of $J_{p|drift}$ .The graph will be exactly negative of the curve in e. Or you can calculate $J_{p|diff}$ from the equation, i.e., $-q D_p dp/dx$. So, the answer will be the negative of the slope of the curve in problem (d) multiplied by qD_p.