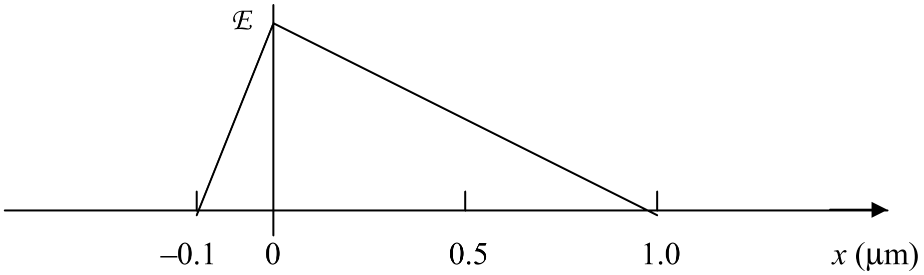
ECSE-2210 Microelectronics Technology
Class Activity 12 – Solution

1. Shown below is the electric field profile in the depletion region of a semiconductor p-n junction in thermal equilibrium. Answer the following questions with explanations.



(a) Which side is p-type and which side is n-type? Write down Poisson's equation and obtain the answers from this equation.

$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{K_s\varepsilon_o} = \text{positive on left} - \text{side}$$

Left side is n-type and right side is p-type:

Since $\rho = qN_D$ (ionized donor atoms are positively charged!) the left side is n-type. On the right side i.e the p-type side, $\frac{dE}{dx}$ is negative $\rho = -qN_A$ (ionized acceptor atoms are negatively charged)

(b) Is the n-type region uniformly doped within the depletion layer? Is the p-type region uniformly doped? Explain.
Yes. The slope of $\mathcal{E}$-field versus x is constant.

$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{K_s\varepsilon_o} \qquad \text{where} \qquad \rho = -q\,N_A + q\,N_D$$

Hence both the n-type region and the p-type region are uniformly doped.

(c) Which side is more heavily doped?

Left side is more heavily doped since the depletion layer width is smaller. It requires smaller width to uncover the same amount of charges as the right side.\

$$N_A x_p = N_D x_n$$

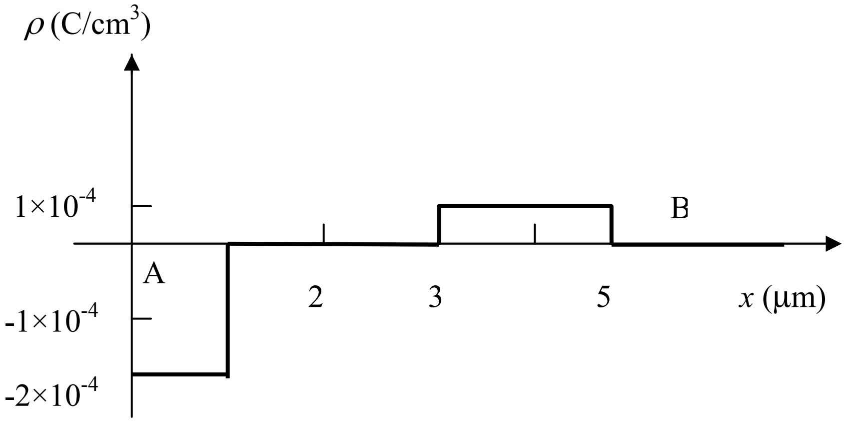
(d) If the p-type region has a net doping concentration of 10^{15} cm^{-3}, what will be the doping concentration in the n-type region?

$$N_A x_p = N_D x_n$$

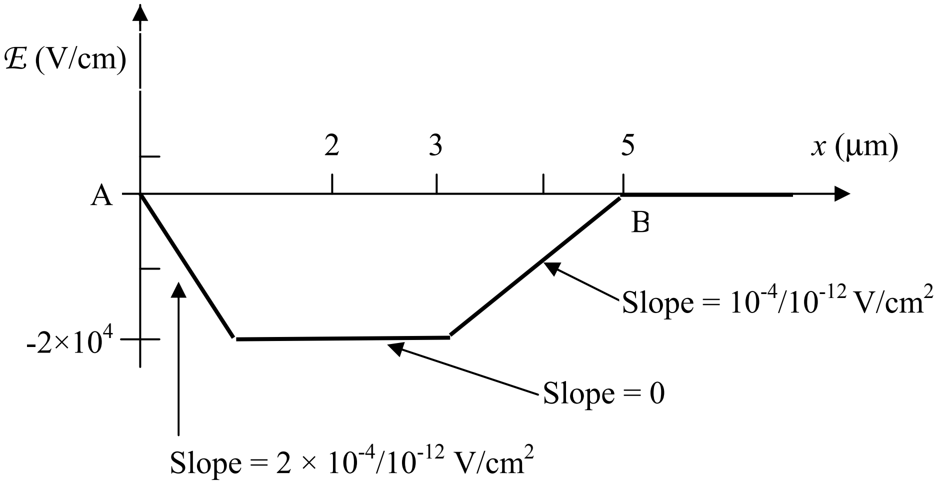
$$N_D = \frac{N_A x_p}{x_n} = 10^{15} \times 1 \times 10^{-4} / (0.1 \times 10^{-4}) = 10^{16}\ \text{cm}^{-3}$$

The n-type region doping should be 10 times that value, i.e. 10^{16} cm^{-3}.

2. The figure below shows the space charge density in Si as a function of x under applied bias. Assume $\varepsilon_{Si} = 10^{-12}$ F/cm in your calculations.



(a) Calculate and plot the electric field as a function of distance assuming $\mathcal{E} = 0$ at $x = 0$.



$\frac{d\mathcal{E}}{dx} = \frac{\rho}{K_s \varepsilon_0}$. Hence when ρ is negative $\frac{d\mathcal{E}}{dx}$ is sloping downward, when ρ is zero the slope $\frac{d\mathcal{E}}{dx}$ is zero and while ρ is positive $\frac{d\mathcal{E}}{dx}$ is sloping upward.

(b) What is the electrostatic potential difference between A and B, i.e., what is $V(\mathrm{B}) - V(\mathrm{A})$?

Potential difference = – (area under the $\mathcal{E}$-field curve)
$= (0.5 \text{ x } 2\text{x } 10^4 \times 1 + 2 \times 2 \times 10^4 + 0.5 \times 2 \times 2 \times 10^4) \times 10^{-4}$
$= 7$ V.

(c) Determine the doping concentration at $x = 0.5$ µm, $x = 2$ µm and at $x = 4$ µm.

Doping concentration = ρ / q

So, doping is $N_A = 1.25 \times 10^{15}$ cm^{-3} at $x = 1$µm,

Intrinsic at $x = 2$ µm,

$N_D = 6 \times 10^{14}$ cm^{-3} at $x = 4$ µm.