Collaborative Learning Exercise
Non-Steady State Diffusion SOLUTIONS

Doping of semiconductors through diffusion

One of the ways to make a semiconductor conductive is to dope it. That is, to replace some of the semiconductor atoms (say silicon) with other atoms that have extra electrons (such as phosphorous which has on more valence electron than silicon) or atoms that have missing electrons (such as B which has one less valence electron with silicon).

A typical processing step in the making of computer chips is to make a junction between Si doped with P (or another atom from column V) and Si doped with B (or another atom from column III). One way to do this is to start with Si doped with B evenly throughout and then introduce P at the top surface. If enough P is introduced, the surface will have more P atoms than B atoms. The phosphorous can be introduced into the silicon by annealing (baking) the silicon wafer (solid) in the presence of P gas. The depth where the P and B concentrations are equal is known as the junction depth.

- The concentration of P at the surface of the Si that is in equilibrium with the P gas at 1000°C is 1×10^{21} atoms/cm^3.
- The background concentration of B is 10^{16} atoms/cm^3.
- The initial concentration of P in the material is 0 atoms/cm^3.
- For P, D_o= 3.9 cm^2/s and E_A=3.66eV.

Question: What is the anneal time at 1000°C to have a junction depth (concentration of P= background concentration of B) of 1 μm.

$$D = D_o \exp\left[\frac{-E_A}{kT}\right] = 3.9\frac{\text{cm}^2}{\text{s}}\exp\left[\frac{-3.66\text{eV}}{8.62\times10^{-5}\frac{\text{eV}}{\text{K}}(1000+273)\text{K}}\right] = 1.28\times10^{-14}\frac{\text{cm}^2}{\text{s}}$$

$$\frac{C_x - C_o}{C_s - C_o} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\text{erf}\left(\frac{x}{2\sqrt{Dt}}\right) = 1 - \frac{C_x - C_o}{C_s - C_o} = 1 - \frac{10^{16}\frac{\text{atoms}}{\text{cm}^3} - 0\frac{\text{atoms}}{\text{cm}^3}}{10^{21}\frac{\text{atoms}}{\text{cm}^3} - 0\frac{\text{atoms}}{\text{cm}^3}} = 0.99999$$

$$\left(\frac{x}{2\sqrt{Dt}}\right) = 2.8\,(\text{from Table 5.1})$$

$$t = \frac{x^2}{2.8^2\cdot4\cdot D} = \frac{\left(1\times10^{-4}\,\text{cm}\right)^2}{2.8^2\cdot4\cdot1.28\times10^{-14}\frac{\text{cm}^2}{\text{s}}} = 24912\text{s} = 6.9\text{hrs}$$