Solid States Electronics a.k.a. fresh new history, part 2

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Introduction
Doping the semiconductor structure

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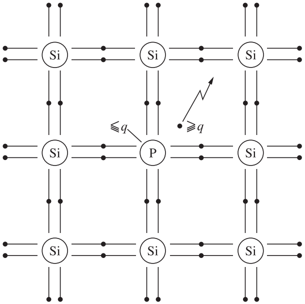
- 

Impurities in Silicon: Donor

- Donor for Si are from group V, it means 5 valence band electrons
- The most common elements used are: Phosphorus, arsenic and antimony
- While a donor is immersed within the Si lattice, 4 e^- fill the covalent bond structure
- It requires very little thermal energy to free the extra electron for conduction
- Each donor that is ionized by giving an e^-, will produce a net charge of $+q$

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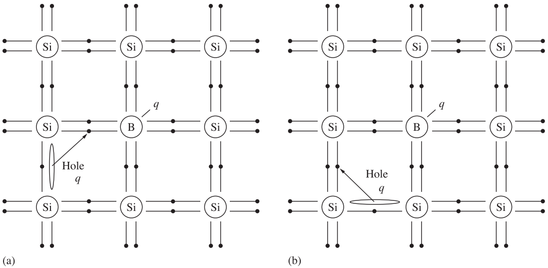
- 

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- Charge neutrality requires:

$$q(N_d + p - N_A - n) = 0$$

n-type material ($N_D > N_A$)

By considering that pn=n_i^2, we have

$$n^2 - (N_D - N_A)n - n_i^2 = 0$$

Solving for n

$$n = \frac{(N_D - N_A) + \sqrt{(N_D - N_A)^2 + 4n_i^2}}{2}$$

also,

$$p = \frac{n_i^2}{n}$$

Nevertheless, in reality we require to be practical so,
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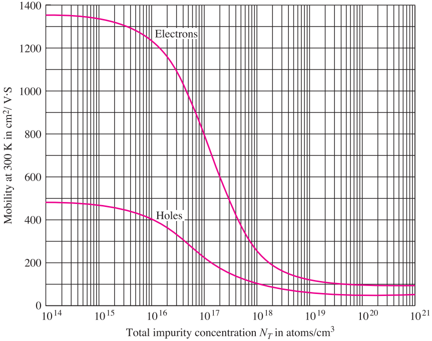
- 

Mobility approximations

$$\mu_n = 92 + \frac{1270}{1 + \left(\frac{N_T}{1.3 \times 10^{17}}\right)^{0.91}}$$

$$\mu_p = 48 + \frac{447}{1 + \left(\frac{N_T}{6.3 \times 10^{16}}\right)^{0.76}}$$

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- $\sigma \approx q\mu_n n \approx (N_D\text{-}N_A)$ for n-type
- $\sigma \approx q\mu_p n \approx (N_A\text{-}N_D)$for p-type
- Resistivity is defined as
- $$\rho = \frac{1}{\sigma}$$

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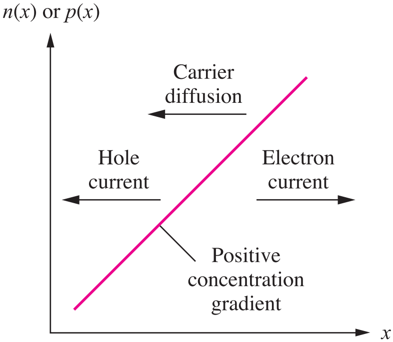
- Diffusion current densities are proportional to the negative of the carrienr gradient
- $$j_p^{diff} = +qD_p(-\frac{\partial p}{\partial x}) = -qD_p\frac{\partial p}{\partial x}$$
- $$j_n^{diff} = -qD_n(-\frac{\partial p}{\partial x}) = +qD_n\frac{\partial n}{\partial x}$$

Diffusion Currents



Proportionality constants D_p & D_n are e^- and h^+ diffusivities (cm^2/s). Both diffusivity and mobility are related by Einstein's relationship

$$\frac{D_n}{\mu_n} = \frac{kT}{q} = \frac{D_p}{\mu_p}$$

Total Currents

Currents within a semiconductor have drift and diffusion components. e^- and h^+ densities j_n^T and j_p^T can be found if a few parameter are included such as

$$j_n^T = q\mu_n nE + qD_n \frac{\partial n}{\partial x}$$

$$j_p^T = q\mu_p pE + qD_p \frac{\partial p}{\partial x}$$

By using the Einstein's relationships

$$j_n^T = q\mu_n n(E + V_T \frac{1}{n} \frac{\partial n}{\partial x})$$

$$j_p^T = q\mu_p p(E + V_T \frac{1}{p} \frac{\partial p}{\partial x})$$

Energy Band Model

While Si is doped by either acceptor or donor, the band energy changes. The donors introduce a localized energy level within the band gap know as donor energy level E_D. For phosphorus $\approx$ 0.045 eV, it takes a bit of thermal energy to access to the conduction band.

As for doped with acceptors N_A, it is created an acceptor energy level E_A close to the valence band. For boron it is 0.044 eV. It requires a bit amount of energy to move electrons from the valence in to the acceptor energy band.

It contains both kind of impurities. In here, there are more donors. e^- search for the lowest state available filling all acceptors. Free e^- population is $n = N_D - N_A$

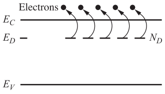


Figure 2.13 Donor level with activation energy $(E_C - E_D)$. This f gure corresponds to the bond model of Fig. 2.6.

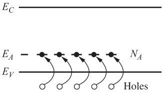


Figure 2.14 Acceptor level with activation energy $(E_A - E_V)$. This f gure corresponds to the bond model of Fig. 2.7(b).

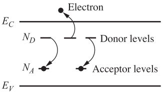
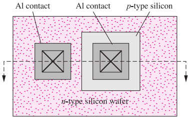
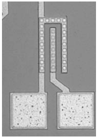


Figure 2.15 Compensated semiconductor containing both donor and acceptor atoms with $N_D > N_A$.

Fabrication of Simple Structures

- 

(a)


(b)

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