Diffusion currents

ECE 2204
Diffusion

• When there are changes in the concentration of electrons and/or holes along a piece of semiconductor
  ▫ The Coulombic repulsion of the carriers force the carriers to flow towards the region with a lower concentration.
The plus sign means that the impurity concentration is very high. The minus sign means that it is low.
Note that current is defined as the flow of positive charges.

Thus, the current caused by the electrons in the n⁺-n⁻ structure is flowing in the opposite direction of the current caused by the flow of holes in the p⁺-p⁻ structure. However, the direction of the carrier movement is from the heavily doped layer to the lightly doped layer.

But, these two diagrams do not show all of the carriers that are moving.
There is also a difference in the minority carrier concentrations.

There are more holes in the $n^-$ layer than in the $n^+$ layer. This causes a flow of holes from the $n^-$ layer to the $n^+$ layer.

There are more electrons in the $p^-$ layer than in the $p^+$ layer. This causes a flow of electrons from the $p^-$ layer to the $p^+$ layer.

The total diffusion current is the sum of the electron and hole diffusion currents.
Diffusion Currents

\[ \frac{I_{n}^{\text{diff}}}{A} = J_{n}^{\text{diff}} = qD_{n} \nabla n = qD_{n} \frac{dn}{dx} \]

\[ \frac{I_{p}^{\text{diff}}}{A} = J_{p}^{\text{diff}} = -qD_{p} \nabla p = -qD_{p} \frac{dp}{dx} \]

\[ \frac{I^{\text{diff}}}{A} = J_{n}^{\text{diff}} + J_{p}^{\text{diff}} = q \left( D_{n} \nabla n - D_{p} \nabla p \right) \]

The gradient of the carrier concentration (\( \nabla n \) or \( \nabla p \)) is the first derivative with respect to \( x \) (distance) in the example shown in the previous slides.
Diffusivity and Mobility

\[ D_n = \frac{kT}{\mu_n} \]
\[ D_p = \frac{kT}{\mu_p} \]
Carrier Mobility in Si

- Carrier mobility has a strong dependence on temperature.
- It has a strong dependence on doping concentration when the electron or hole concentration is greater than \( \sim 5 \times 10^{16} \text{ cm}^{-3} \) and
  - Assume that:
    \[
    \mu_n = 1350 \text{ cm}^2\text{-V}^{-1}\text{-s}^{-1} \\
    \mu_p = 500 \text{ cm}^2\text{-V}^{-1}\text{-s}^{-1}
    \]
Total Current Flow

- is the sum of the drift and diffusion currents

\[
\frac{I^T_n}{A} = J^T_n = q(\mu_n nE + D_n \nabla n)
\]

\[
\frac{I^T_p}{A} = J^T_p = q(\mu_p pE - D_p \nabla p)
\]

\[
I^T = I^T_n + I^T_n
\]

J is the current density or current I divided by the cross-sectional area A through which the carriers move.