PN Junction  Lect. 3

Recall p-type and n-type material.

Consider the following two material types:

1. \( N_A = 10^{17} \) holes/cm\(^3\)  \( N_D = 10^3 \) electrons/cm\(^3\)
2. \( N_A = 10^4 \) holes/cm\(^3\)  \( N_D = 10^{16} \) electrons/cm\(^3\)

Classify them...
1. \( \rightarrow p\)-type
2. \( \rightarrow n\)-type

If we take these two pieces of material and put them together, what happens?

We know that the high concentration of holes on the \( p\)-side will cause a diffusion current into the \( n\)-side.

\[
\begin{array}{c}
\text{p-type} \\
N_A = 10^{17} \\
N_D = 10^3
\end{array}
\quad
\quad
\begin{array}{c}
\text{n-type} \\
N_A = 10^4 \\
N_D = 10^{16}
\end{array}
\]

Anode \quad \text{metallurgical junction} \quad \text{Cathode}
We have already stated that a p-n junction creates what we more commonly refer to as a diode.

[Diagram of a diode]

**Question.** In a diode with nothing connected to the terminals, how much net current is flowing? \( A = 0 \)

But we just said that there was a diffusion current. So there must be a competing process on the n-side to balance this. Do electrons counterbalance this?

**Electrons are going to diffuse from the n-side (high concentration) to the p-side (low). Does this counterbalance?** No! 

[Graph showing concentrations]
Blow up the transition region.

\[ j_p = -q D_p \frac{df}{dx} \]

\[ j_n = q D_n \frac{dn}{dx} \]

The competing process is a Drift current, but more is needed to understand its origin.

Placing these two types of material together will cause a depletion region to form (in your book called a space charge region).
From equ. we know that a region of space charge $\rho$ will be accompanied by an $E$-field measured in $\text{V/m}$, they are related by Gauss' law:

$$\nabla \cdot E = \frac{\rho}{\varepsilon_s}$$

$\varepsilon_s$ - permittivity of a semiconductor

rearranged as 1D:

$$E(x) = \frac{1}{\varepsilon_s} \int \rho(x) \, dx$$

we also know that a diode must be charge neutral which implies

$$q N_{A\text{XP}} = q N_{A\text{XM}}$$

This results in:

```
You end up with:
```

```
you create an E-field which causes drift current
```

```
reg. p-type
```

```
Electrons drift
```

```
reg. n-type
```

```
Holes drift
```

```
Ionized atoms
```

\[ \Phi_j = -\int \varepsilon(x) \, dx \]

\( \Phi_j \rightarrow \text{built in potential or junction potential} \)
Width of depletion region

$\omega_d = (x_p + x_n) = \sqrt{\frac{2e\phi_f}{q} \left( \frac{N_i}{N_+} + \frac{1}{N_-} \right) \phi_f}$

Internally

$J^* = q\frac{\partial \phi}{\partial x} E + qD_n \frac{\partial n}{\partial x} = 0$

$J^0 = q\frac{\partial \phi}{\partial x} E - qD_p \frac{\partial p}{\partial x} = 0$
I-V Characteristics of

\[ V_D < \Phi \]

\[ \Phi(x) \]

\[ V_D < \Phi \]

\[ V_D = \Phi \]

\[ V_D > \Phi \]

\[ (\Phi_D - V_D) \]

Very rapid

ropped on voltage
$J_s = \text{Reverse Saturation Current}$

Band Diagram Again

$E_c$ \hspace{1cm} $E_v$

$p$-side \hspace{1cm} Depletion Region \hspace{1cm} $n$-side

$\Phi_b$
If $V_D < 0$

$E_c$

$E_v$

Drift

$\phi_s - V_0$

If $V_D > 0$

$E_c$

$E_v$

Diffusion

$\phi_j - V_0$

\[ I_D = I_S \left(e^{\frac{V_D}{nkt}} - 1\right) = I_S \left(e^{\frac{V_D}{n\mu n^+}} - 1\right) \]

$n \rightarrow$ non ideality factor