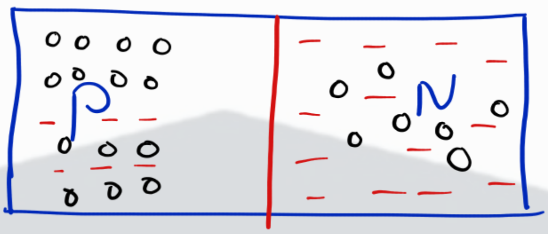
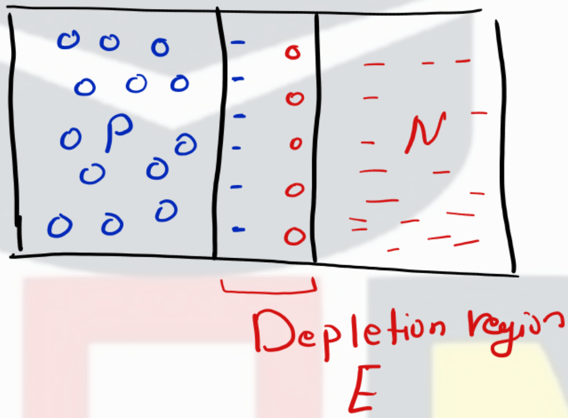
Fundamental of Electronics
Lecture 3-semiconductor
Part 1

EE1224 Fundamentals of Electronic Devices

P-N Junction



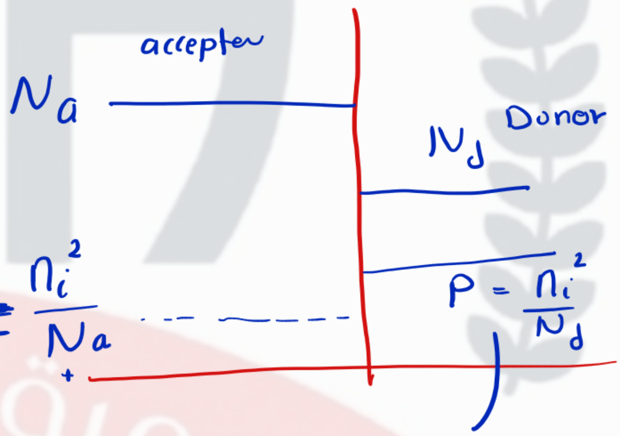


$n = p = n_i$

$n * p = n_i^2$

$n_i = \sqrt{n p}$

Doping



$n_i^2 = N_a * n_p \Leftarrow n_p = \frac{n_i^2}{N_a}$

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

$n_i^2 = N_d * p$

n-Type

elec عدد $n = N_D$

hole عدد $p = \frac{n_i^2}{N_D}$

pType

عدد الhole $p = N_A$

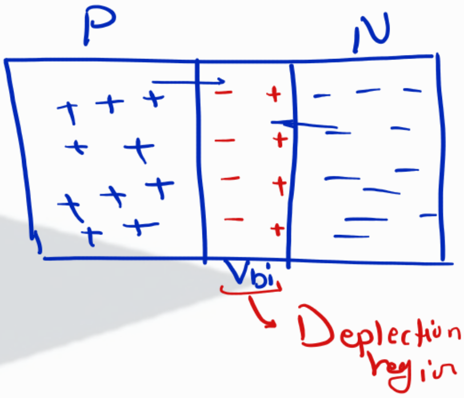
عدد الelec $n = \frac{n_i^2}{N_A}$

التيار الناتج من الشحنات بتتحرك من التركيز الأعلى للتركيز الأقل

Diffusion Current

Diffusion hole ⇒ From P region – N region

Diffusion electron ⇒ From N " – P "



I_D : Diffusion Current

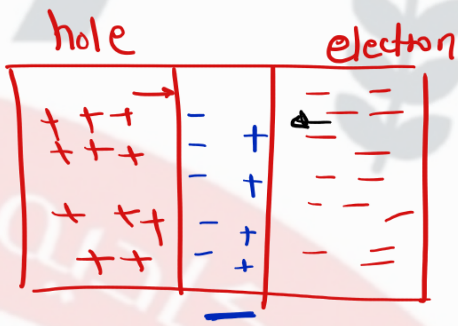
$V_{bi} \uparrow \longrightarrow$ Diffussion $\downarrow$ – $I_D \downarrow$

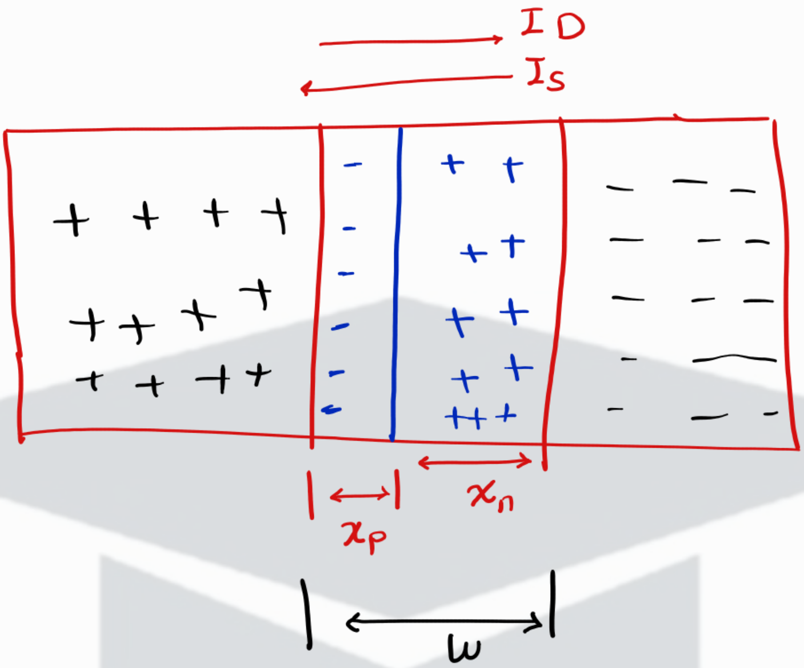
$$V_{bi} = \frac{kT}{q} \ln\left(\frac{N_a N_d}{n_i^2}\right) = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

Drift Current

نتيجة جهد كهربى

Drift Current I_s : Caused by electrical Field





For $\underline{N_a} > N_d$

ε_s : electric primitivey

ε_s For silicon $= 11.7\,\varepsilon_0$

$= 11.7 * 8.85*10^{-14}$

$$W = x_n + x_p$$

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)V_{bi}}$$

$$x_n = W\,\frac{N_a}{N_a+N_d}$$

$$x_p = W\,\frac{N_d}{N_a+N_d}$$

$$Q = A\,q\,W\left(\frac{N_a N_d}{N_a+N_d}\right)$$

$$Q = A\sqrt{2\varepsilon_s q\left(\frac{N_a N_d}{N_a+N_d}\right)V_{bi}}$$

Semiconductor Materials and Properties

The pn Junction

- Ready to consider our first practical semiconductor structure.

لما اجمع p مع n دا كونه p-n junc

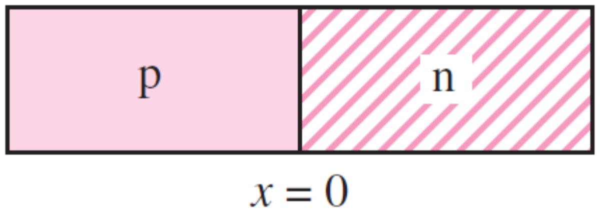
- The real power of semiconductor electronics occurs when p- and n-regions are directly adjacent to each other, forming a pn junction.
- The pn junction implements the diode and plays the dominant role in the structure and operation of the bipolar junction transistor (BJT).
- Understanding pn junctions is very important to the study of the MOSFET operation.

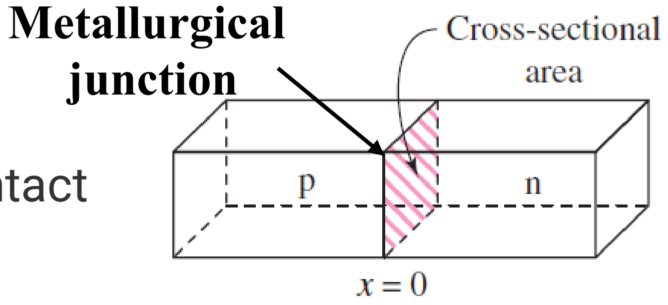
A. S. Sedra and K. C. Smi, *Microelectronic Circuit*, 7th ed. 2016.
D. Neamen, Microelectronics Circuit Analysis and Design, 4th ed. 2010.

Semiconductor Materials and Properties

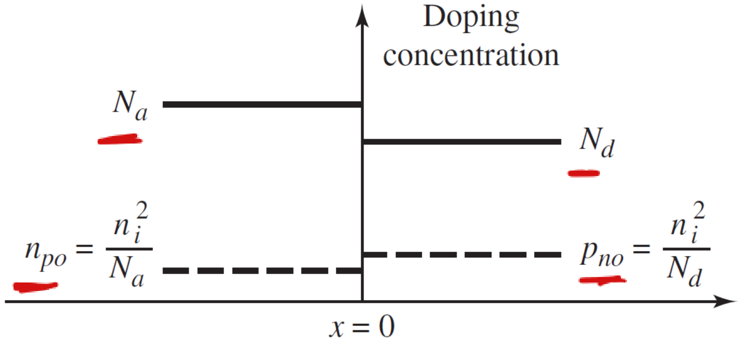
The pn Junction

- Simplified block diagram of a pn junction





- Consisting of a p-type semiconductor **(e.g., silicon**) brought into close contact with an n-type semiconductor material (**also silicon**).
- In actual practice, both the p and n regions are part of the same silicon crystal.
- The pn junction is formed within a single silicon crystal by creating regions of different dopings (p and n regions).
- Showing the respective p-type and n-type doping concentrations



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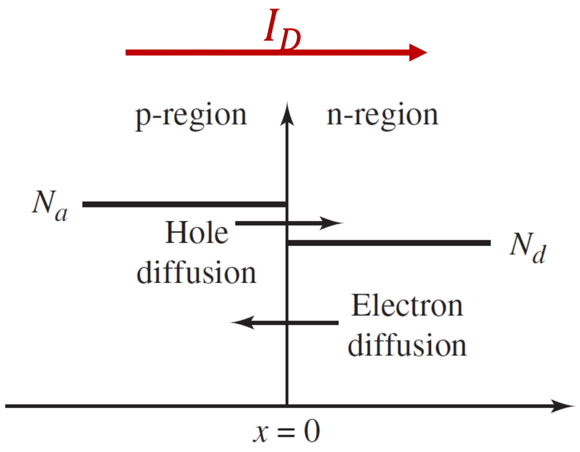
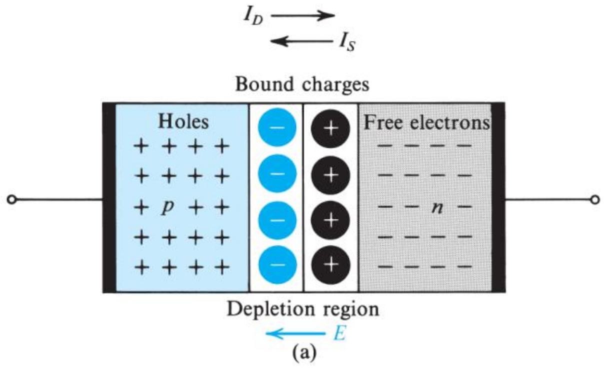
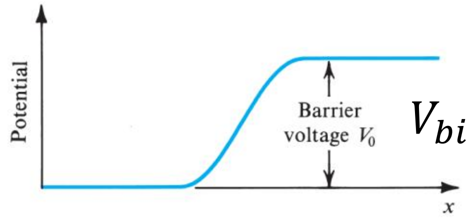
Semiconductor Materials and Properties

The pn Junction – Diffusion

- A diffusion of holes from the p-region into the n-region, and a diffusion of electrons from the n-region into the p-region.
- Two current components add together to form the diffusion current I_D, whose direction is from the p side to the n side
- The flow of holes from the p-region uncovers negatively charged acceptor ions, and the flow of electrons from the n-region uncovers positively charged donor ions.
- A potential difference results across the depletion region, with the n side at a positive voltage relative to the p side.
- This action creates a charge separation which sets up an electric field oriented in the direction from the positive charge to the negative charge.







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Semiconductor Materials and Properties

The pn Junction – Diffusion

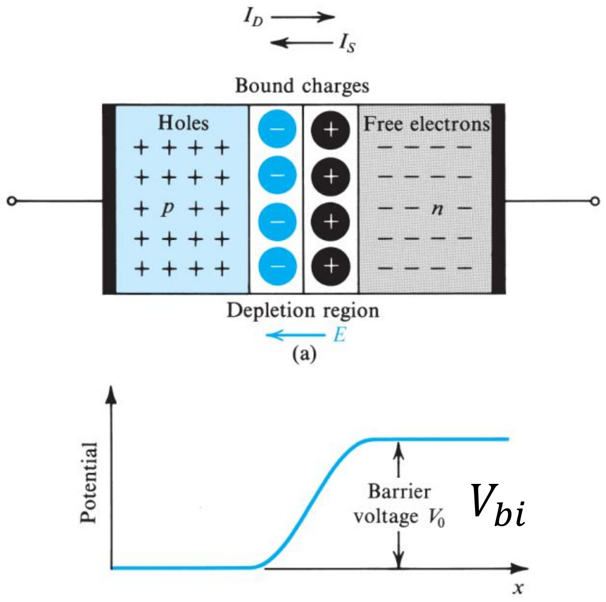
- The voltage drop across the depletion region acts as a barrier that has to be overcome for holes to diffuse into the n region and electrons to diffuse into the p region.

- The larger the barrier voltage (Built-in Voltage), the smaller the number of carriers that will be able to overcome the barrier, and hence the lower the magnitude of diffusion current:

$$V_{bi} \uparrow \rightarrow Diffusion \downarrow \rightarrow I_D \downarrow$$

- I_D depends strongly on the voltage drop V_{bi} across the depletion region.

$$V_{bi} = \frac{kT}{q} ln\left(\frac{N_a N_d}{n_i^2}\right) = V_T ln\left(\frac{N_a N_d}{n_i^2}\right)$$



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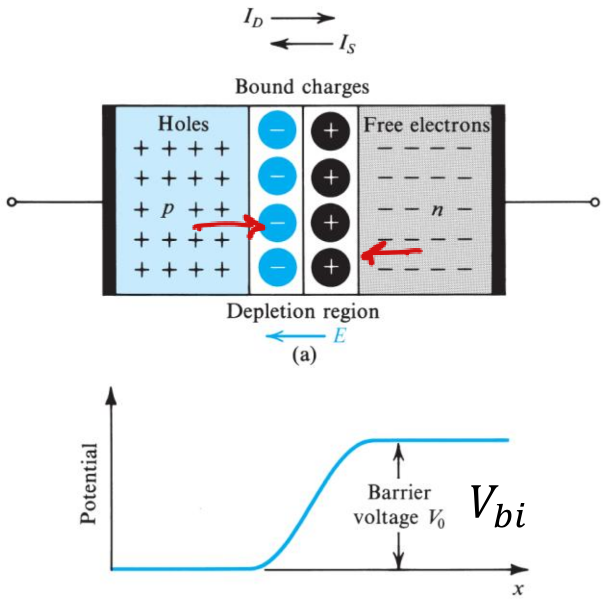
Semiconductor Materials and Properties

The pn Junction – Drift



- The drift current I_S: caused by the electrical field
- Some of the thermally generated holes in the n material move toward the junction and reach the edge of the depletion region → they experience the electric field in the depletion region → sweeps them across that region into the p side.
- The minority thermally generated electrons in the p material move to the edge of the depletion region and get swept by the electric field in the depletion region across that region into the n side.
- These two current components—electrons moved by drift from p to n and holes moved by drift from n to p—add together to form the drift current I_S.
- Since the current I_S is carried by thermally generated minority carriers, its value is strongly dependent on **temperature.**
- Any minority carriers that manage to get to the edge of the depletion region will be swept across by E regardless of the value of E or, correspondingly, of V_{bi}.

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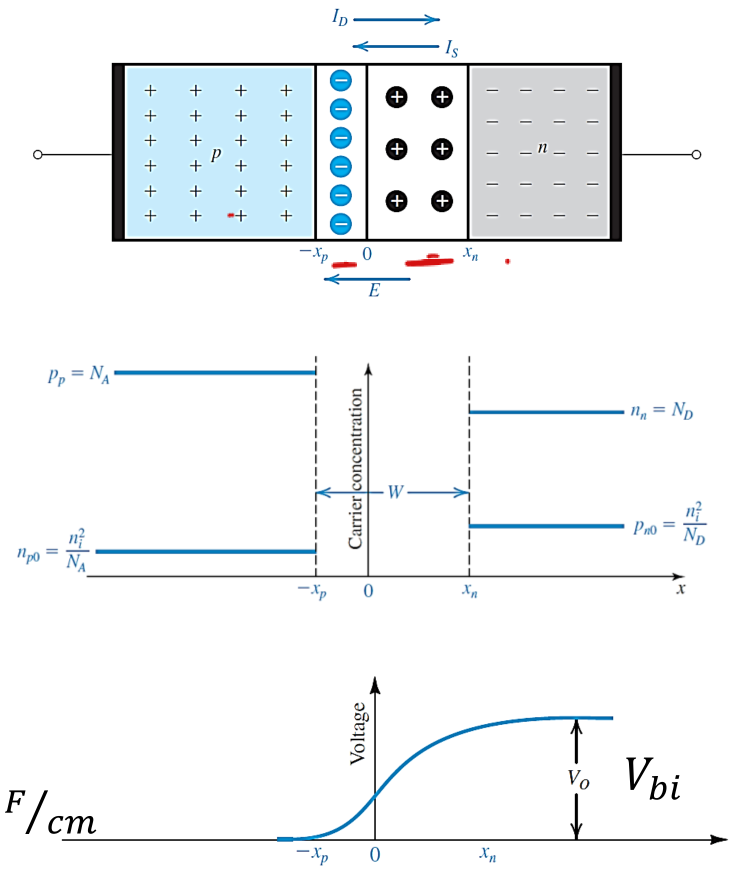
Semiconductor Materials and Properties

The pn Junction



- A junction in which $N_a > N_d$
- The width of the depletion layer will not be the same on the two sides.
- The depletion layer will extend deeper into the more lightly doped material.
- The width of the depletion region in the p side by x_p and in the n side by x_n.
- The width W of the depletion layer:

$$W = x_p + x_n = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right) V_{bi}}$$

- where ε_s is the electrical permittivity of silicon $=11.7\varepsilon_o = 11.7 \times 8.85 \times 10^{-14}\ {}^{F}/_{cm}$ $= 1.04 \times 10^{-12}\ {}^{F}/_{cm}$.
- Typically, W is in the range 0.1 μm to 1 μm

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Semiconductor Materials and Properties

The pn Junction

$$W = x_p + x_n = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)V_{bi}}$$

- x_p and x_n can be obtained:

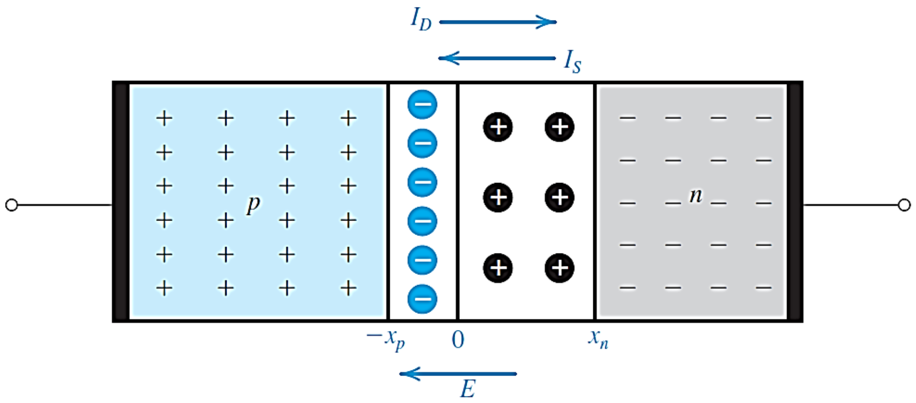
$$x_n = W\frac{N_a}{N_a + N_d}$$

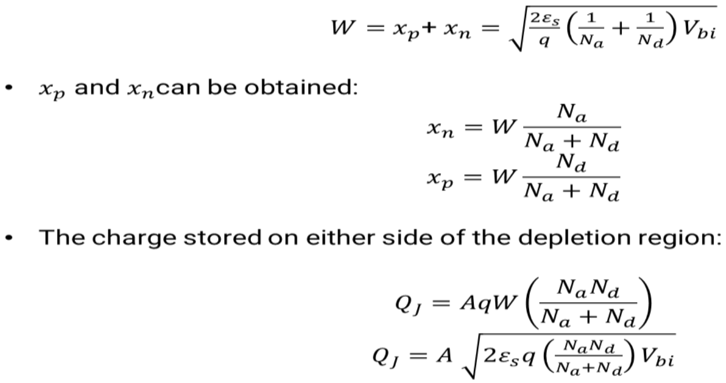
$$x_p = W\frac{N_d}{N_a + N_d}$$

- The charge stored on either side of the depletion region:

$$Q_J = AqW\left(\frac{N_aN_d}{N_a + N_d}\right)$$

$$Q_J = A\sqrt{2\varepsilon_s q\left(\frac{N_aN_d}{N_a+N_d}\right)V_{bi}}$$





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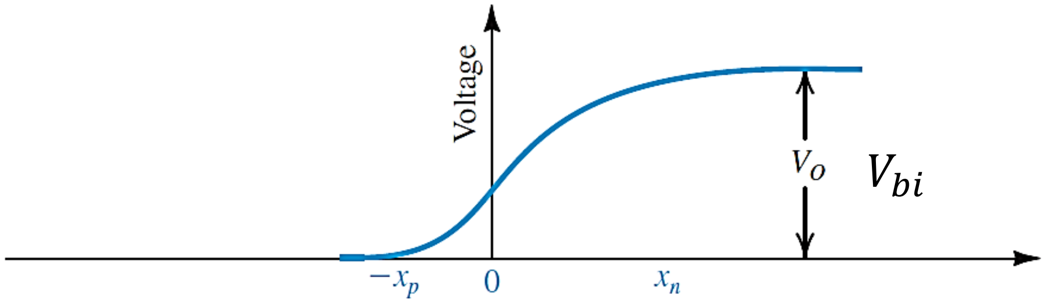

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