Lecture
PN Junction: Minority Carrier Distributions

Vincent Chang
Outline

- Zero Bias
  - Thermal equilibrium

- Forward Bias
  - Physical meaning
  - Distribution

- Reverse Bias
  - Distribution
  - Saturation current
Minority Carrier Distribution—Zero Bias
Minority Carrier Distribution—Zero Bias

Depletion
Minority Carrier Distribution—Zero Bias

Concentration

Depletion

\( \text{Concentration} \)

\( \text{Depletion} \)

\( x_p \)

\( x_n \)
Minority Carrier Distribution—Zero Bias

Concentration

\( n_{po} \)

\( x_p \)

\( x_n \)

Depletion

Dr. Vincent Chang (張文清)
Minority Carrier Distribution—Zero Bias
Outline

Zero Bias
- Thermal equilibrium

Forward Bias
- Physical meaning
- Distribution

Reverse Bias
- Distribution
- Saturation current
Minority Carrier Distribution—Forward
Independence Hall, Philadelphia
Zero Bias

\[ +qV(x) \]

\[ qV_{bi} \]

Zero bias
Forward Bias

\[
qV_F \quad \text{Zero bias} \quad qV_{bi}
\]

\[
+qV(x) \quad \text{Forward bias}
\]
Minority Carrier Injection
Minority Carrier Diffusion

$V_F$
Minority Carrier Diffusion

$V_F$

Concentration

$0 \quad x_p \quad x_n \quad x$

High concentration

Low concentration

Dr. Vincent Chang (張文清)
Carrier Generation

Covalent bond

Valence electron
Carrier Generation

Conduction electron

Hole
Carrier Recombination

Conduction electron

Hole
Carrier Recombination

Conduction electron

Hole
Carrier Recombination
Carrier Recombination

Valence electron
Minority Carrier Diffusion

Concentration

\[ V_F \]

Depletion

High concentration

Low concentration

\[ x_p \]

\[ x_n \]
Minority Carrier Distribution

Concentration

\[ V_F \]

Depletion

High concentration

Low concentration

\[ p_n(x) \]
Minority Carrier

\[ n_p(x) \]

\[ n_p(-x_p) \]

\[ n_{p0} \]

\[ L_n \]

\[ x_p \]

\[ x_n \]

\[ p_n(x_n) \]

\[ p_n(x) \]

\[ p_{no} \]

\[ V_F \]

Concentration

Depletion
Minority-Carrier Storage Effect

\[ n_p(-x_p) \]

Area = \( Q_n \)

\[ n_p(x) \]

Area = \( Q_p \)

\[ p_n(x) \]

\[ p_n(x_n) \]

\[ p_{no} \]

\[ L_p \]

\[ x_n \]

\[ x_p \]

\[ V_F \]

Concentration
Outline

Zero Bias
- Thermal equilibrium

Forward Bias
- Physical meaning
- Distribution

Reverse Bias
- Distribution
- Saturation current
Minority Carrier (Fig.3-16b, P144)
Minority Carrier (Fig.3-16b, P144)
Physical Concept (Take Note)

High concentration

Low concentration

Concentration

\( n_{po} \)

\( n_p(x) \)

\( p_{no} \)

\( p_n(x) \)
Physical Concept

- **Hole diffusion**
  - **High concentration**
  - **Low concentration**

The diagram illustrates the concept of hole diffusion in a semiconductor material. The graph shows the concentration of holes, denoted as $n_p(x)$, against the concentration of electrons, denoted as $n_{po}$, along the $x$-axis. The region $-x_p$ to $x_n$ represents the diffusion of holes. The concentration $n_p(x)$ decreases with distance, while the concentration $n_{po}$ remains constant. The diagram also indicates the movement of holes from high concentration to low concentration regions.
Physical Concept

Hole diffusion

High concentration

Low concentration

$V_R$

$n_{po}$

$p_n(x)$
Physical Concept

- **Electron diffusion**
- **High concentration**
- **Low concentration**
- **Hole diffusion**

\[ n_{po} \]

\[ n_p(x) \]

\[ p_n(x) \]
Minority Carrier Diffusion Current

Electron diffusion

Hole diffusion

Concentration

$n_{po}$

$E_{p}(x)$

$p_{n}(x)$

$-x_{p}$

$x_{n}$

$V_{R}$
Reverse Saturation Current

Electron diffusion

Hole diffusion

Concentration

Dr. Vincent Chang (張文清)
pn Junction Diode
Circuit Symbol

anode($p$)

cathode($n$)
Circuit Symbol

anode\((p)\)

cathode\((n)\)
Diode Current and Voltage
Current-Voltage Characteristic

\[ I = I_s \left( e^{V/V_T} - 1 \right) \]

Diagram:
- Anode \((p)\)
- Cathode \((n)\)
- Symbol for current \((I)\)
- Symbol for voltage \((V)\)
Device Parameters

\[ I = I_S \left( e^{\frac{V}{V_T}} - 1 \right) \]

- Saturation current
- Thermal voltage

Diagram:
- Anode (p)
- Cathode (n)
Forward Bias

\[ I = I_S \left( e^{V/V_T} - 1 \right) \]

Diagram showing a diode with anode (p) and cathode (n) with an applied voltage \( V \) and current \( I \).
Forward Bias

\[ I = I_S \left( e^{V/V_T} - 1 \right) \]

Diagram:
- Anode \((p)\)
- Cathode \((n)\)
- Forward bias: \(V > 0\), \(I > 0\)
Reverse Bias

\[ I = I_S \left( e^{\frac{V}{V_T}} - 1 \right) \]

- **anode**\((p)\)
- **cathode**\((n)\)
Reverse Bias

\[ I = I_S \left( e^{\frac{V}{V_T}} - 1 \right) \]
I-V Characteristic

\[ I = I_S \left( e^{V/V_T} - 1 \right) \]

- Anode (p)
- Cathode (n)
Saturation Current

\[ I_S = A q n_i^2 \left[ \frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A} \right] \]

\[ I = I_S \left( e^{V/V_T} - 1 \right) \]
Saturation Current

\[ I_S = A g n_i^2 \left[ \frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A} \right] \]

\[ I = I_S (e^{V/V_T} - 1) \]
The course contents are protected under the copyright laws of the United States, Taiwan and other countries. All intellectual property rights of the course contents are reserved by Knowledge Master, Inc. Any distributing, copying or public performance of such course contents, including PowerPoint slides and audio sound-track, is strictly prohibited and may subject the offender to severe criminal penalties. (Title 17, United State Code, Section 501 & 506)

(本课程内容智慧财产权属Knowledge Master, Inc. 所有，并受到美国，台湾等国家著作权法律保护，禁止任何复制与公开播放。)