

Section 20

PN Diode I-V Characteristics

Gerhard Klimeck

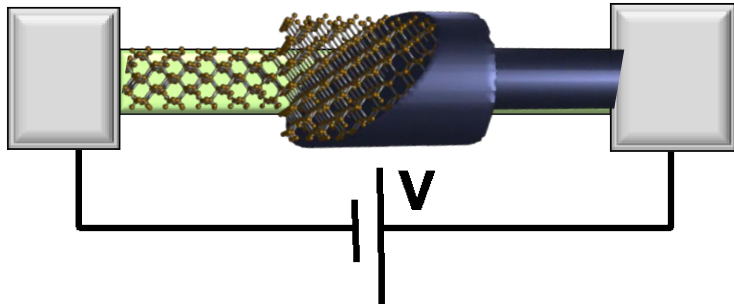
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School of Electrical and
Computer Engineering

Section 20

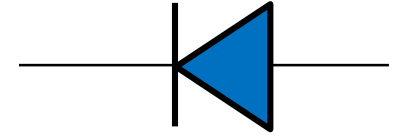
PN Diode I-V Characteristics




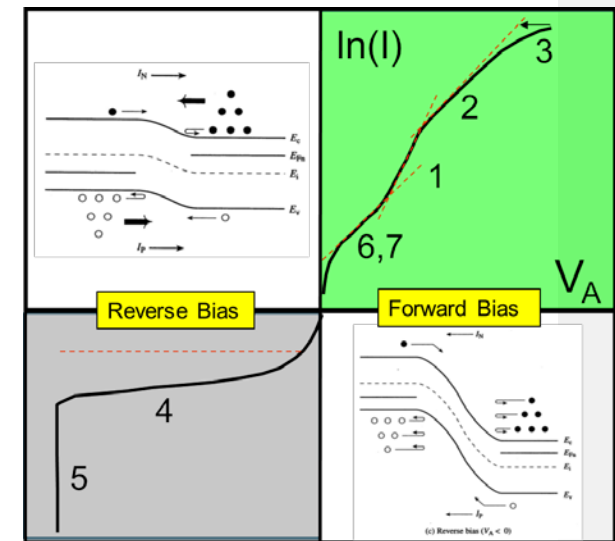
$$I = G \times V$$

$$= q \times n \times v \times A$$

↑ charge density ↑ ↑ velocity area

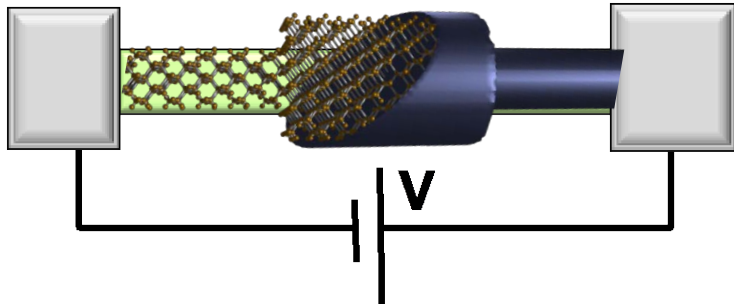


	Equilibrium	DC	Small signal	Large Signal	Circuits
PN Diode			<div style="background-color: yellow; border: 1px solid black; padding: 5px; display: inline-block;">Diode in DC Bias</div>		
Schottky Diode					
BJT/ HBT					
MOS					



Section 20

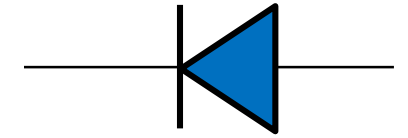
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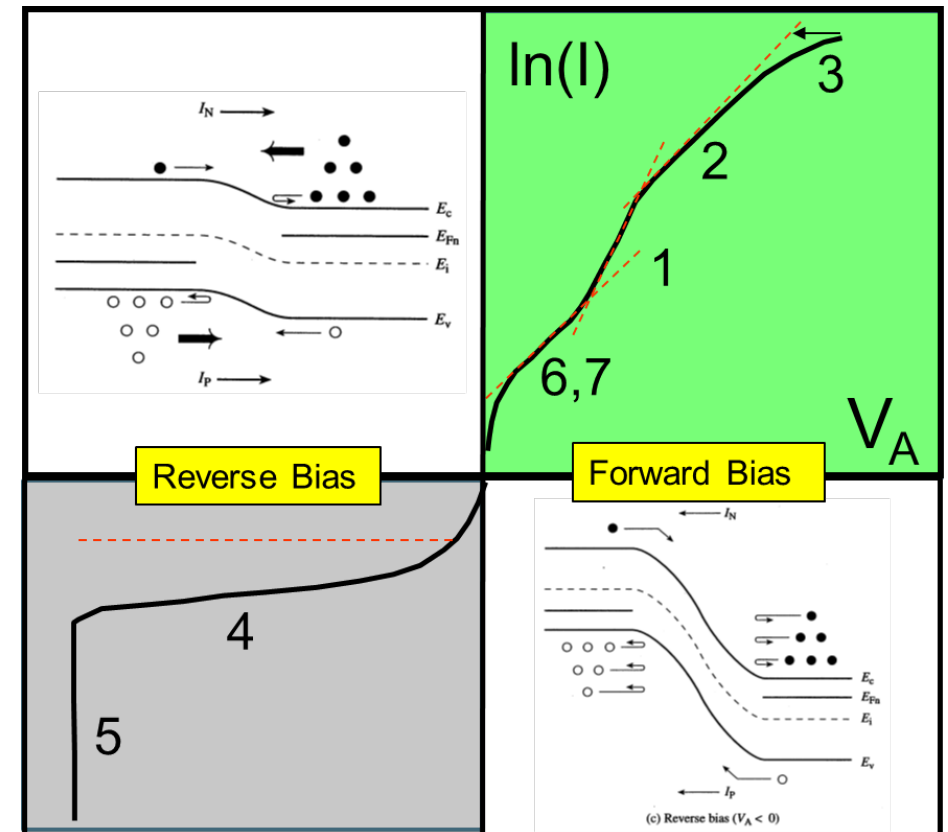
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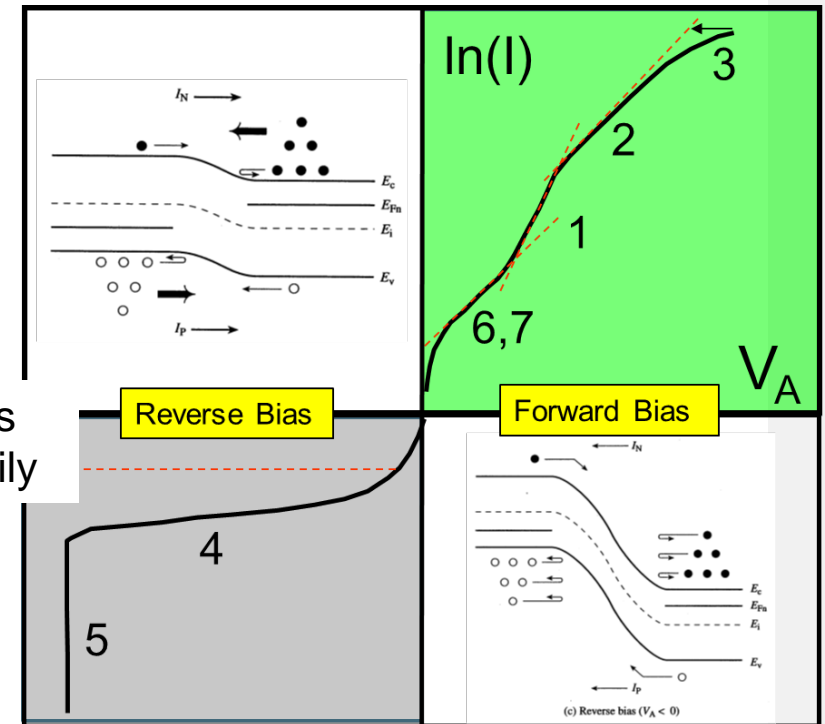
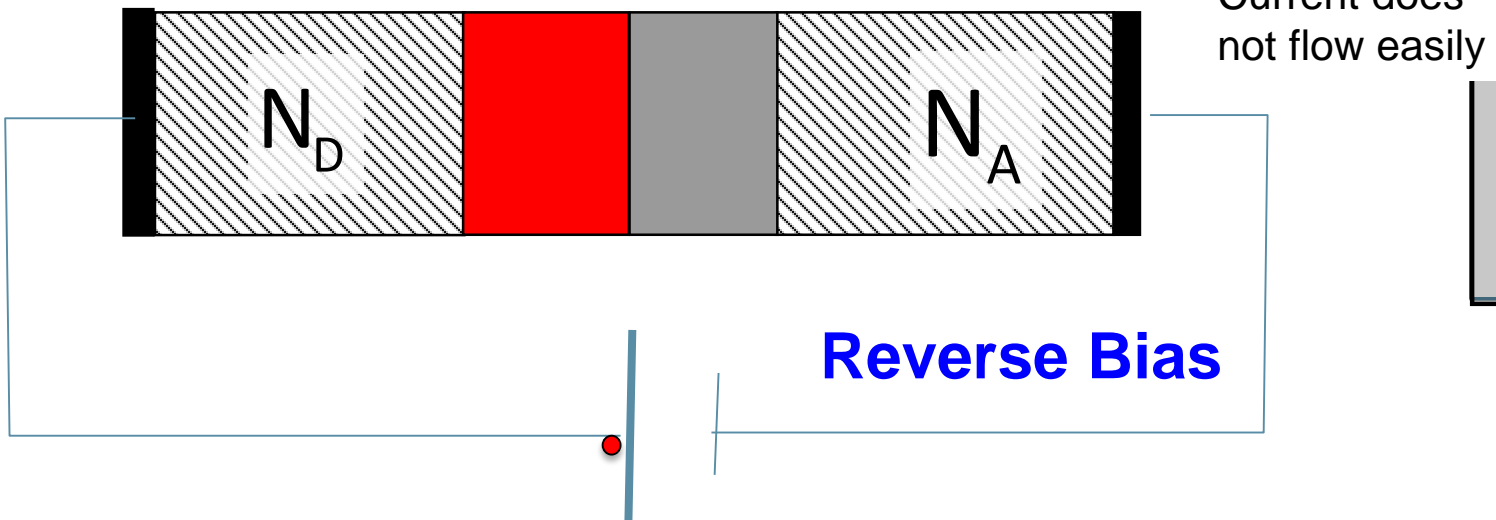
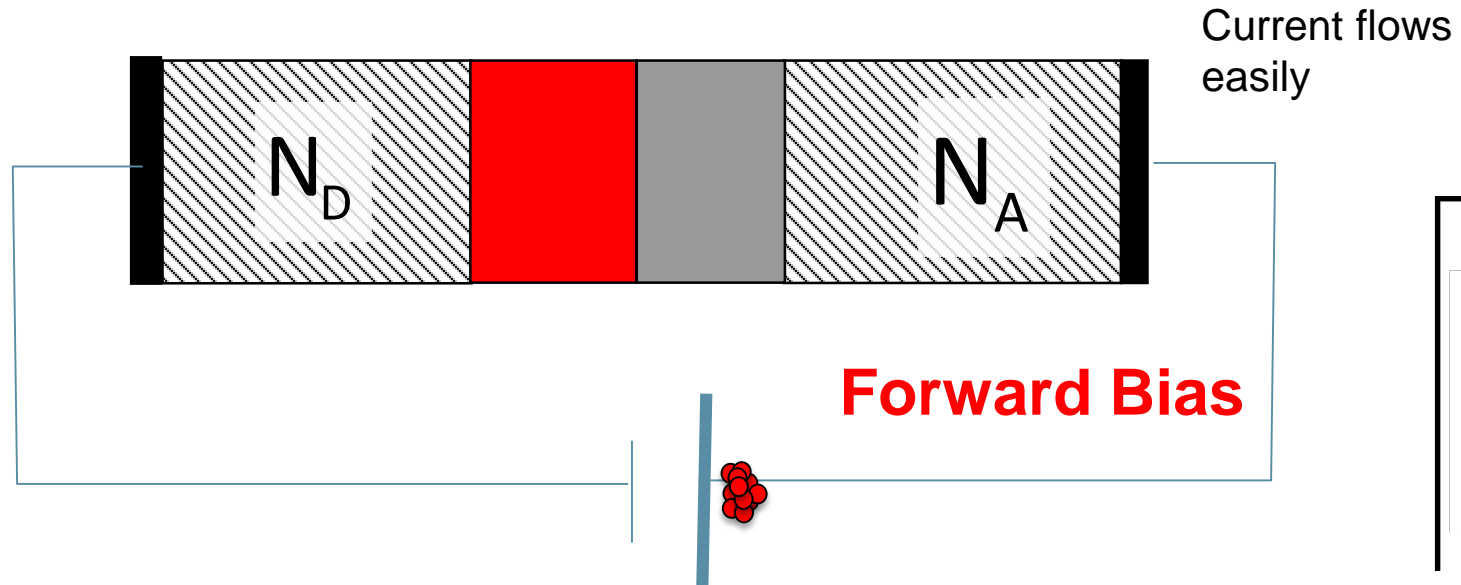
↑ charge density ↑ velocity ↑ area



- > • 20.1 Band diagram with applied bias
- > • 20.2 Derivation of the forward bias formula
- > • 20.3 Forward Bias - Non-linear Regime
- > • 20.4 Non-ideal effects:

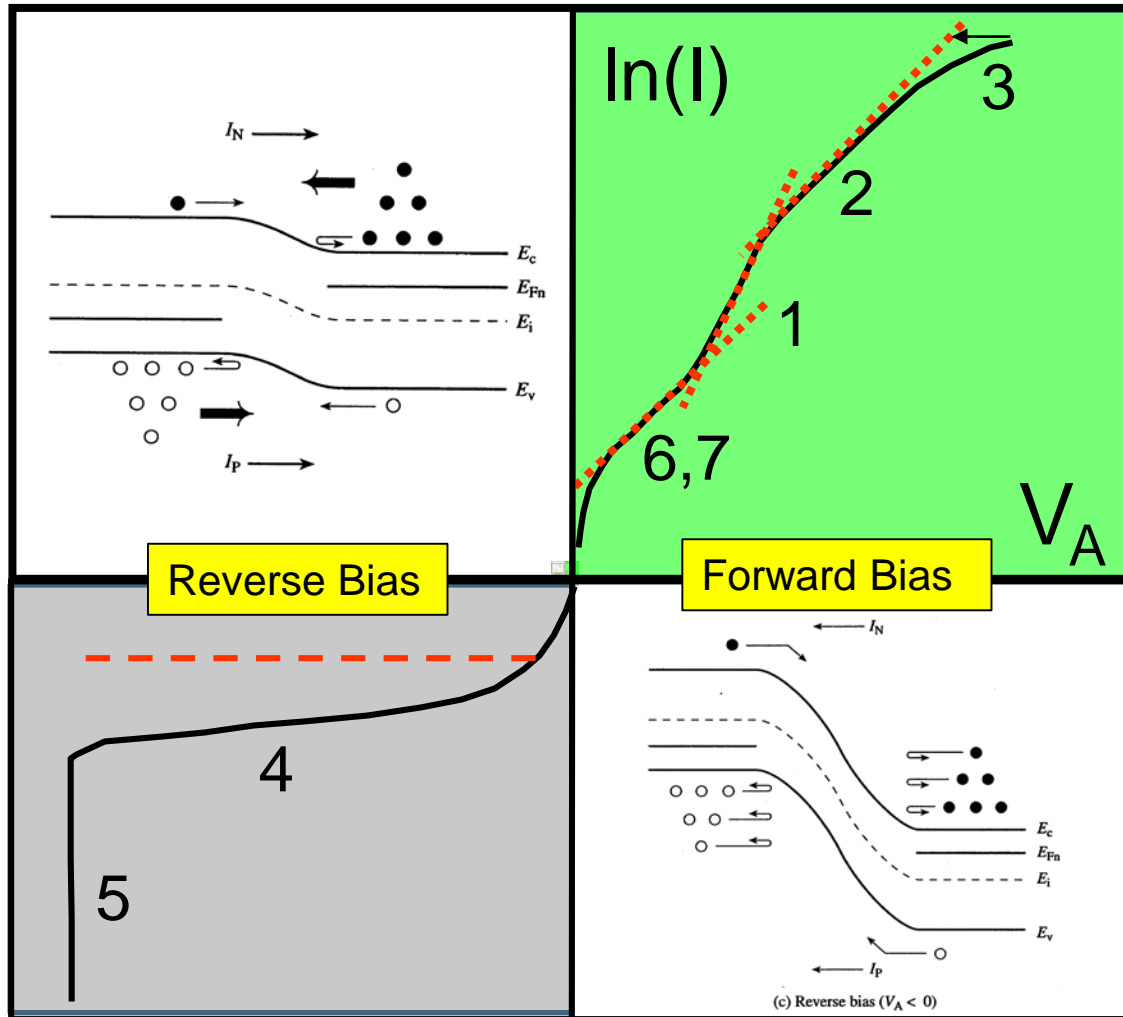


Forward and Reverse Bias



Applying Bias to p-n Junction

IV characteristics of a Diode



To be discussed in detail

1. Diffusion limited
2. Ambipolar transport
3. High injection
4. R-G in depletion
5. Breakdown
6. Trap-assisted R-G
7. Esaki Tunneling

Band Diagram with Applied Bias...

$$\nabla \cdot \mathbf{D} = q(p - n + N_D^+ - N_A^-)$$

$$\frac{\partial n}{\partial t} = \frac{1}{q} \nabla \cdot \mathbf{J}_N - r_N + g_N$$

$$\mathbf{J}_N = qn\mu_N \mathbf{E} + qD_N \nabla n$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q} \nabla \cdot \mathbf{J}_P - r_P + g_P$$

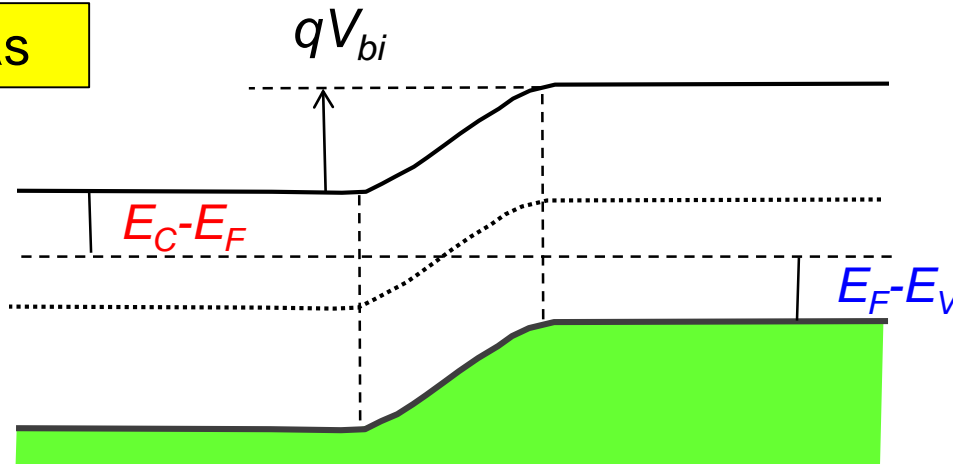
$$\mathbf{J}_P = qp\mu_P \mathbf{E} - qD_P \nabla p$$

Band diagram (this segment)

Next segment / lecture ...

Applying a Bias: Poisson Equation

No bias



$$n(x) = n_i e^{(E_F - E_i(x))\beta}$$

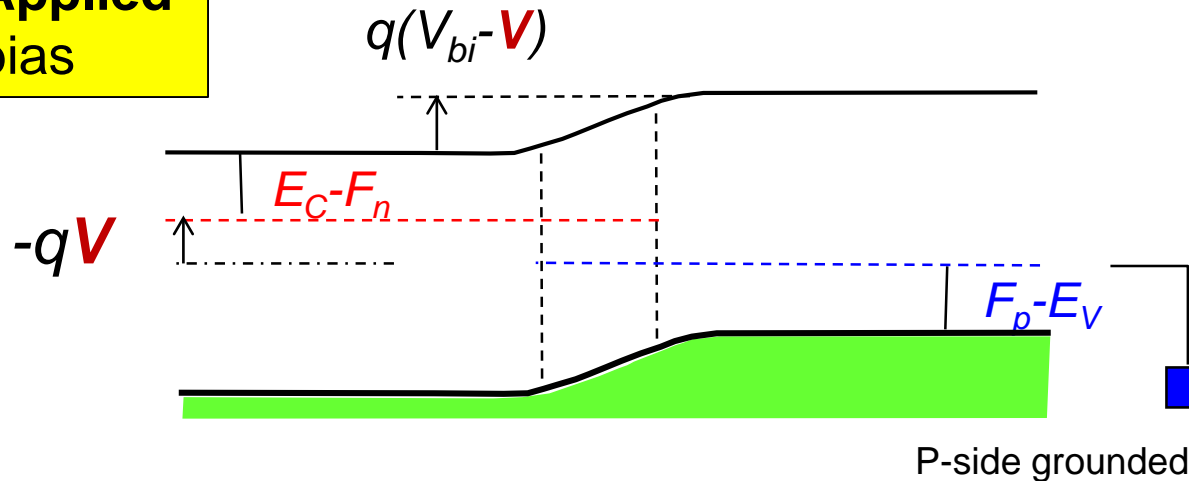
$$p(x) = n_i e^{-(E_F - E_i(x))\beta}$$

$$n \times p = n_i^2$$

Question: Max value of V_{bi} ?

Answer: for degenerate s.c.,
if $E_C - E_F = 0$, $E_F - E_V = 0 \rightarrow E_g$

Applied bias



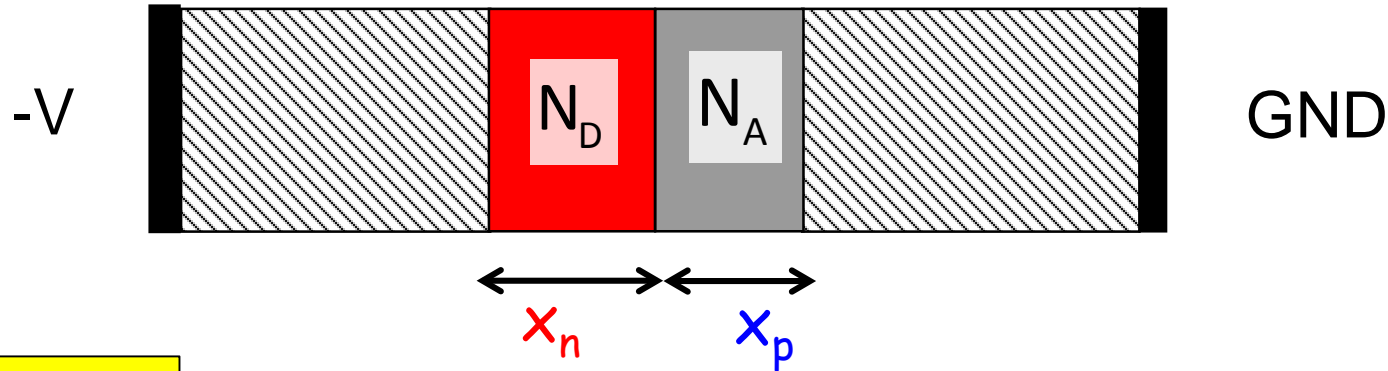
$$n(x) = n_i e^{(F_n - E_i(x))\beta}$$

$$p(x) = n_i e^{-(F_p - E_i(x))\beta}$$

$$n \times p = n_i^2 e^{(F_n - F_p)\beta}$$

$$n \times p = n_i^2 e^{qV_{AB}}$$

Depletion Widths



From previous lecture
(homo-junction)

$$N_D x_n = N_A x_p$$

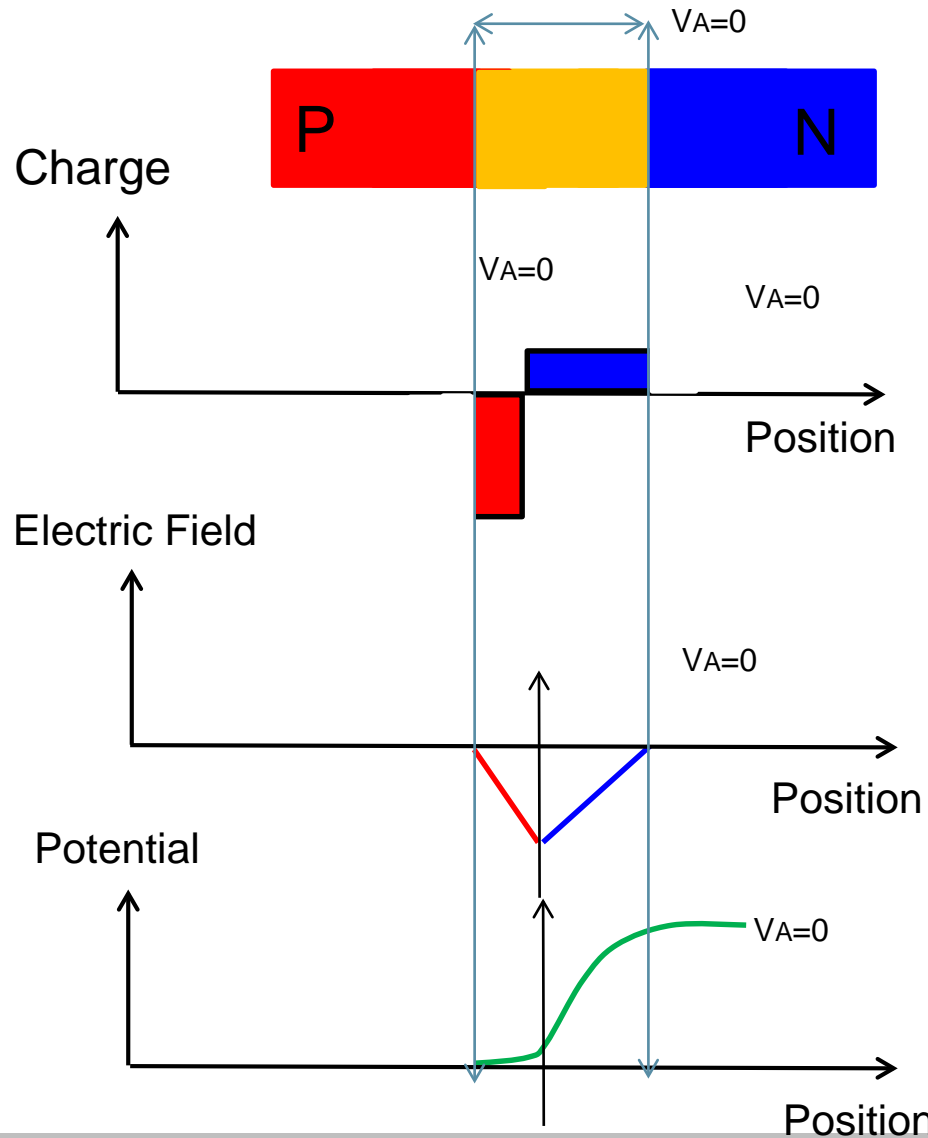
$$q(V_{bi} - V) = \frac{qN_D x_n^2}{2k_s \epsilon_0} + \frac{qN_A x_p^2}{2k_s \epsilon_0}$$

Applied bias

$$x_n = \sqrt{\frac{2k_s \epsilon_0}{q} \frac{N_A}{N_D(N_A + N_D)} (V_{bi} - V)}$$

$$x_p = \sqrt{\frac{2k_s \epsilon_0}{q} \frac{N_D}{N_A(N_A + N_D)} (V_{bi} - V)}$$

Fields and Depletion at Forward/Reverse Biases

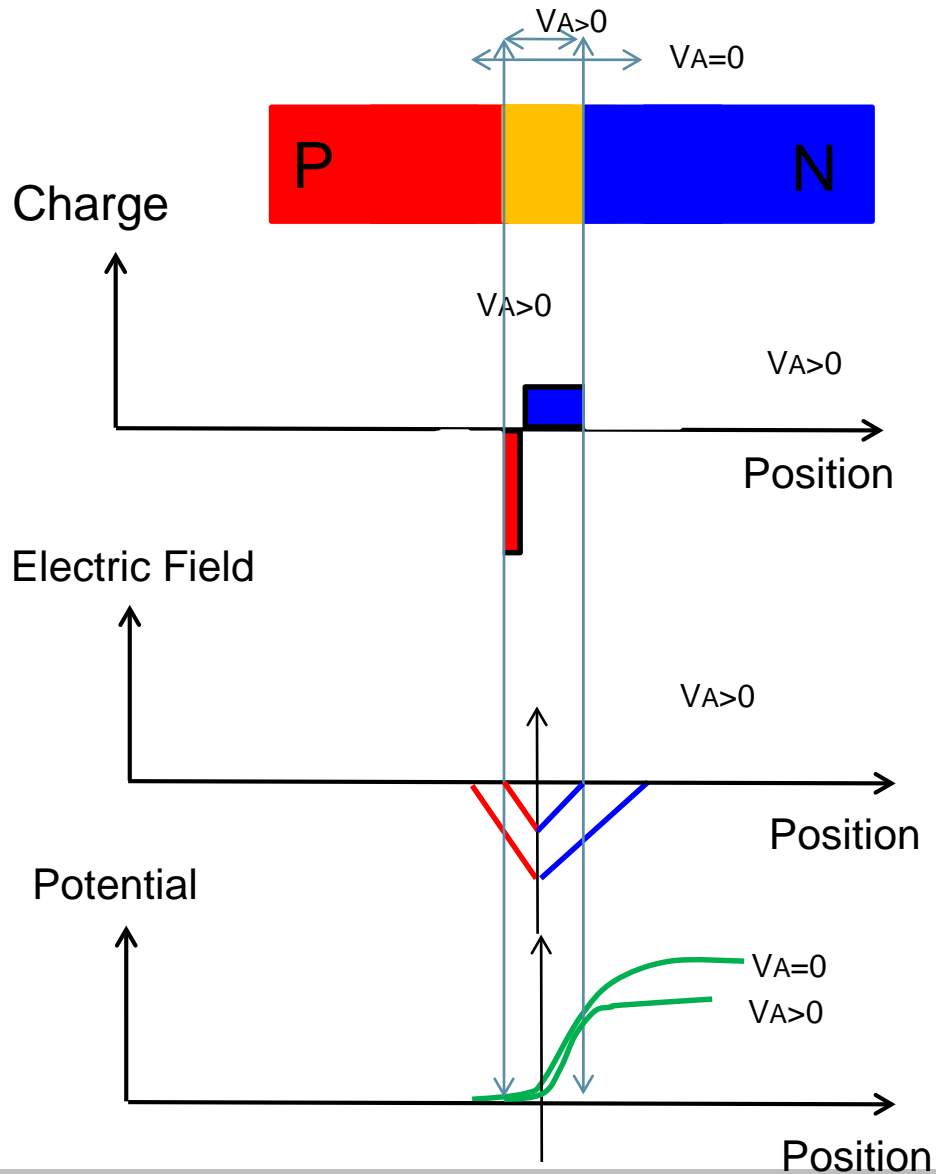


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Zero Bias

Fields and Depletion at Forward/Reverse Biases

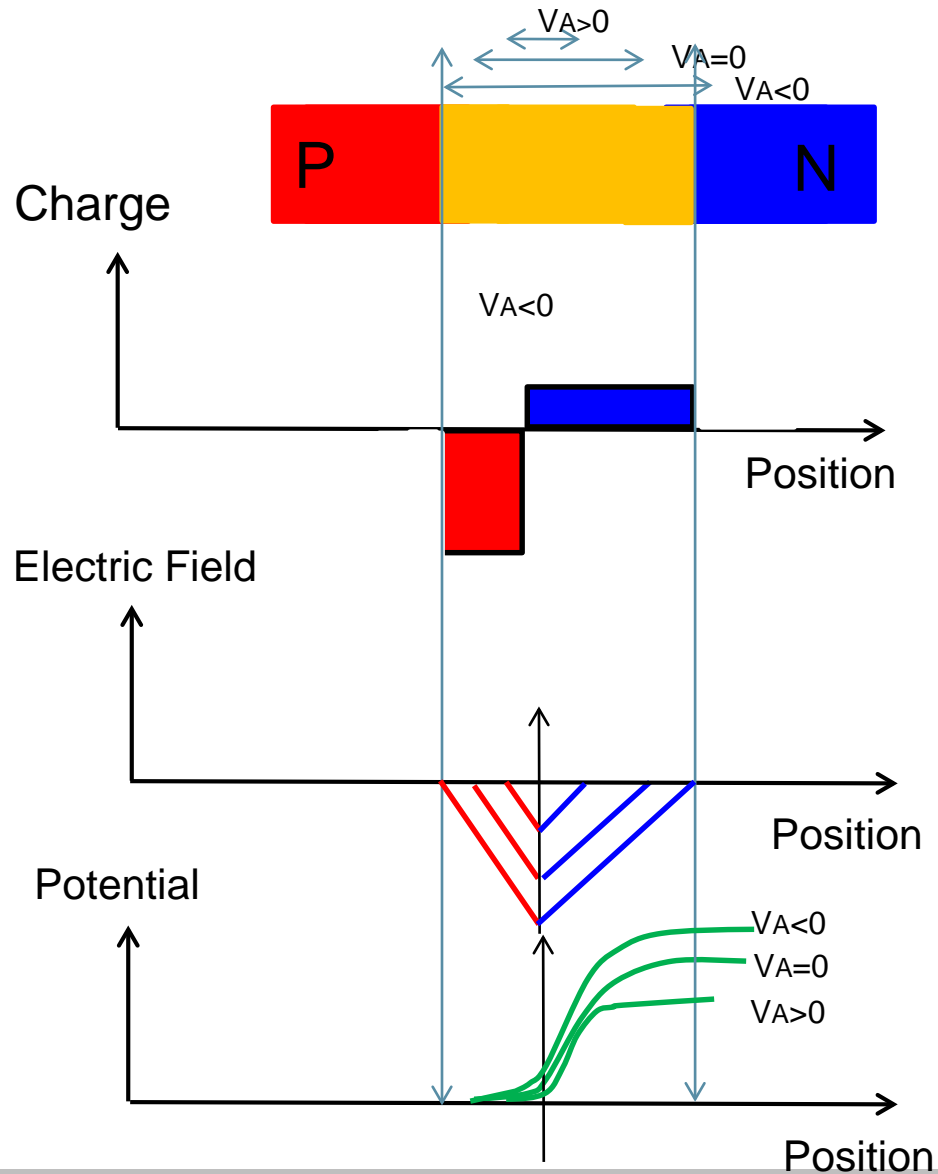


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Forward Bias

Fields and Depletion at Forward/Reverse Biases

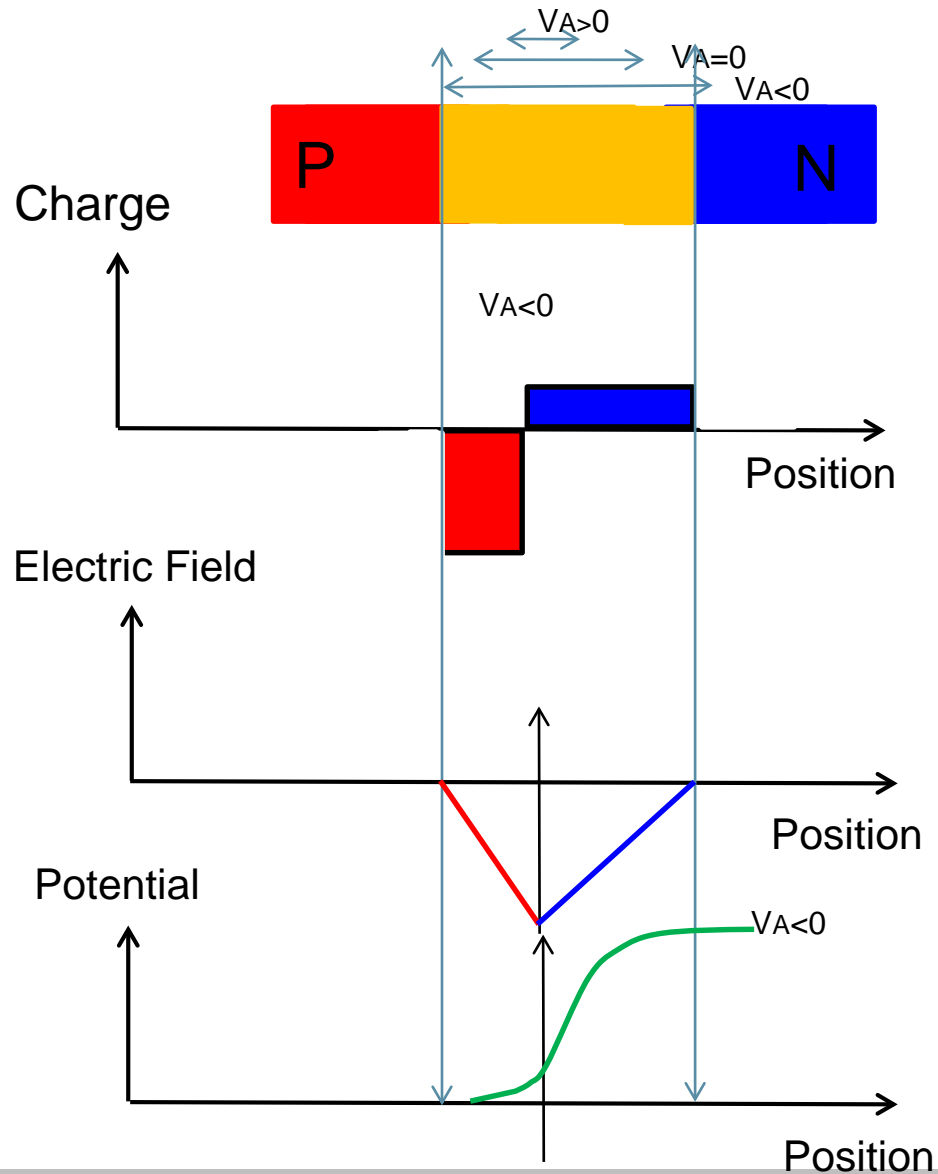


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Reverse Bias

Fields and Depletion at Forward/Reverse Biases

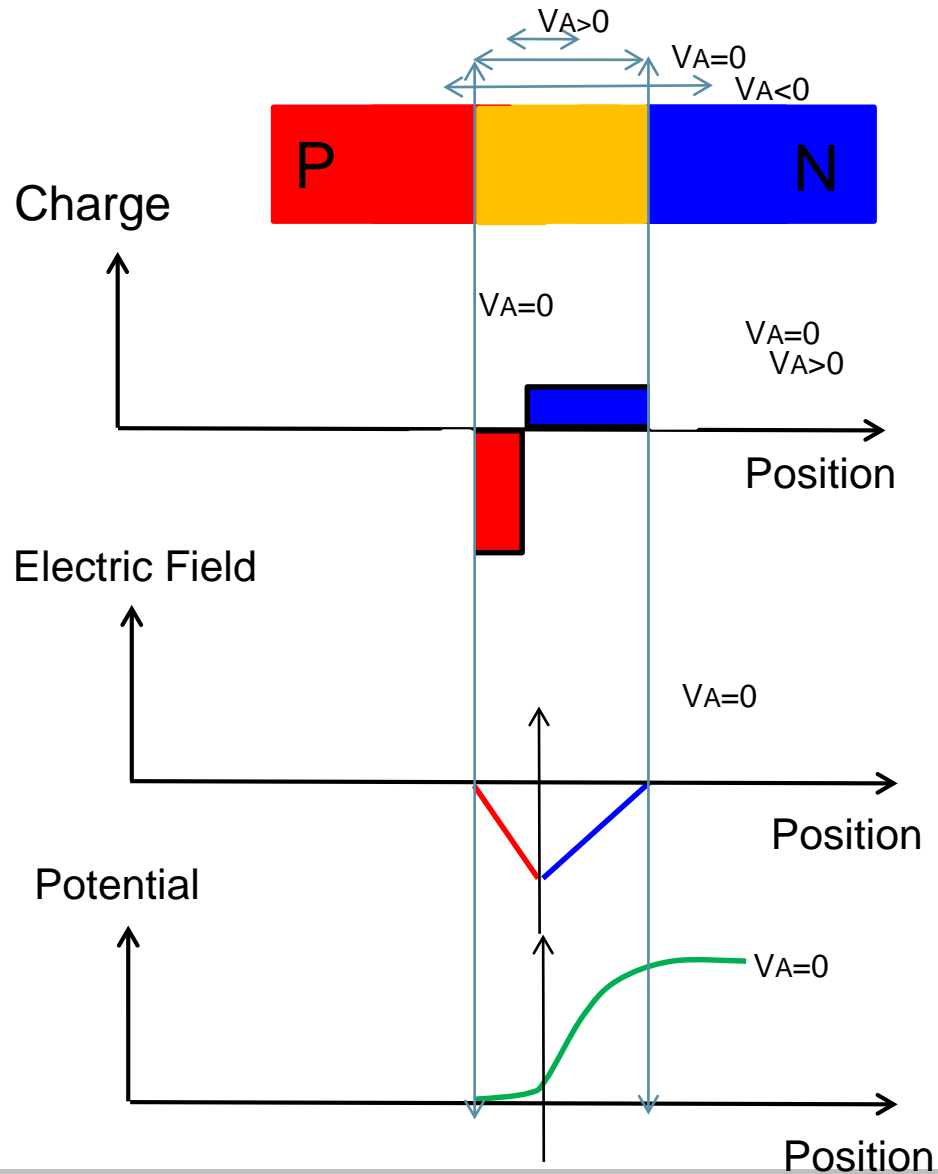


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Reverse Bias

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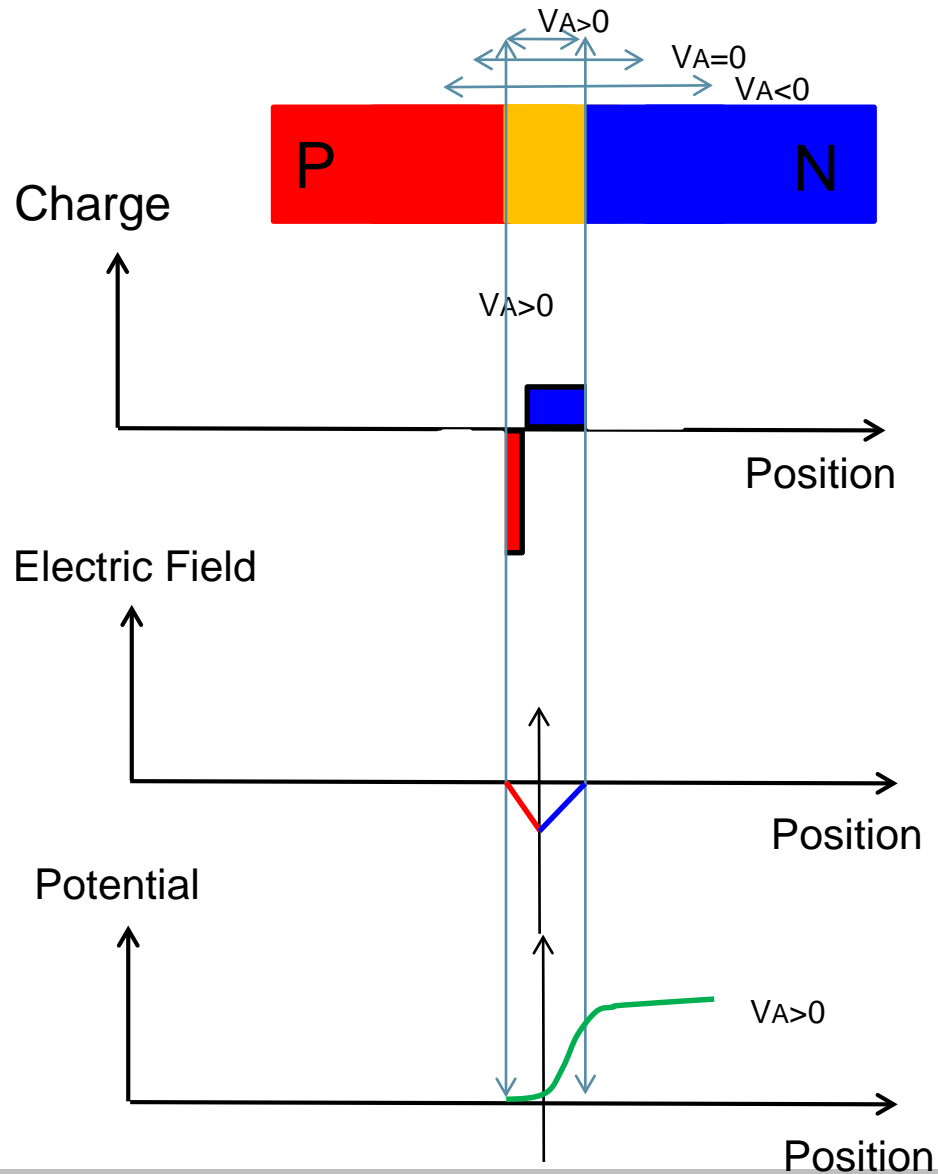


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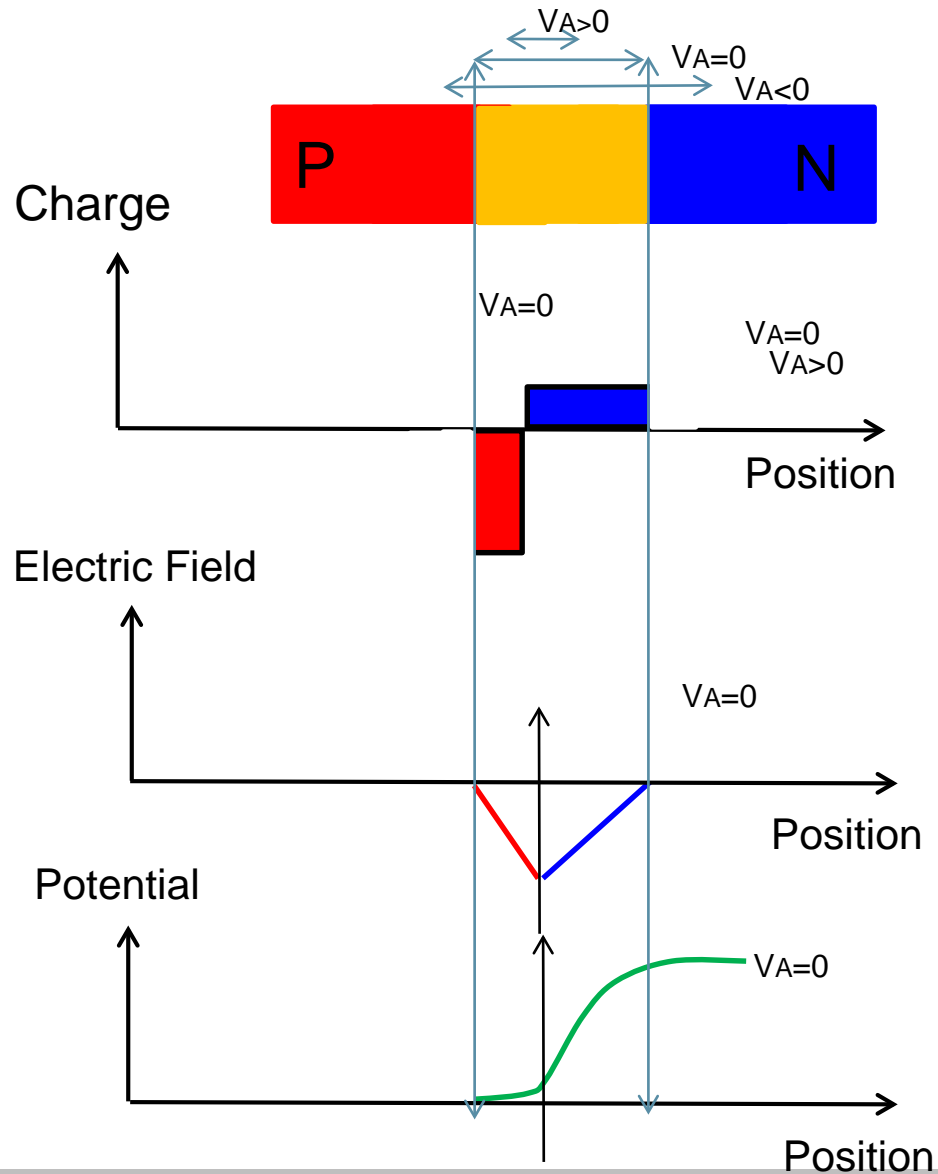


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Forward Bias

Fields and Depletion at Forward/Reverse Biases



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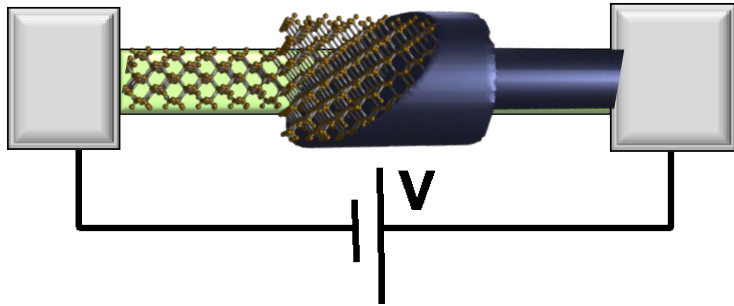
$$x_p = \sqrt{\frac{2k_s \epsilon_0}{q} \frac{N_D}{N_A(N_A + N_D)} (V_{bi} - V)}$$

Barrier height is **reduced** at **forward** biases

Significant **increase** of peak field at **reverse** bias

Zero Bias

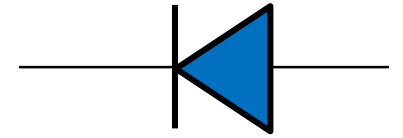
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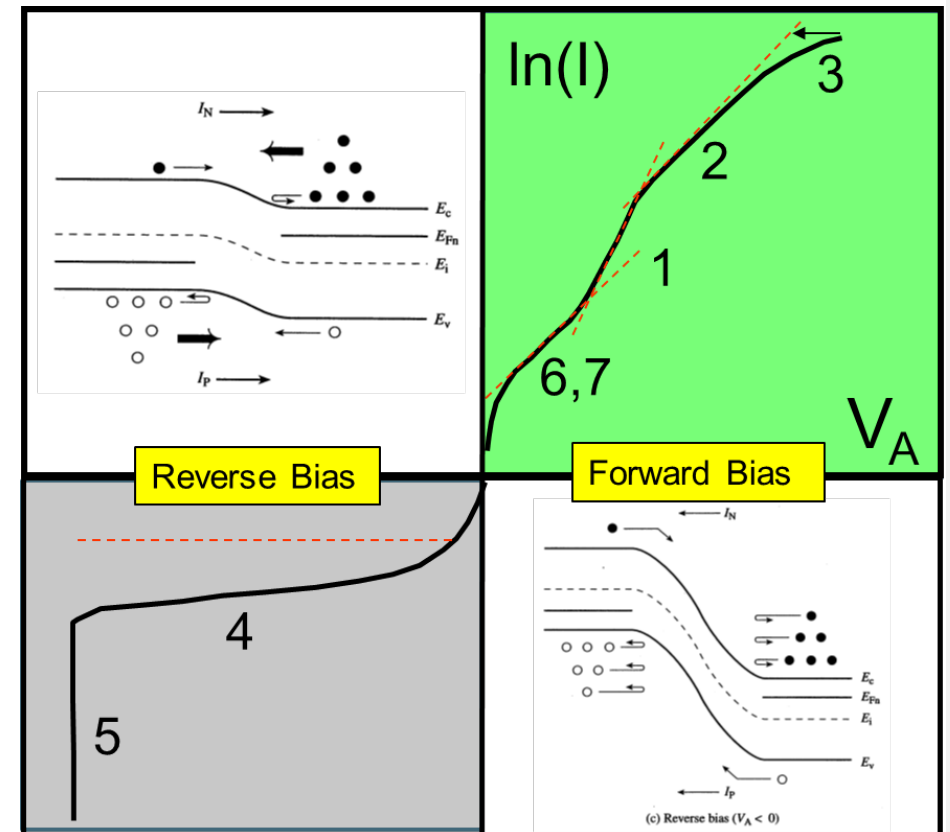


> • 20.1 Band diagram with applied bias

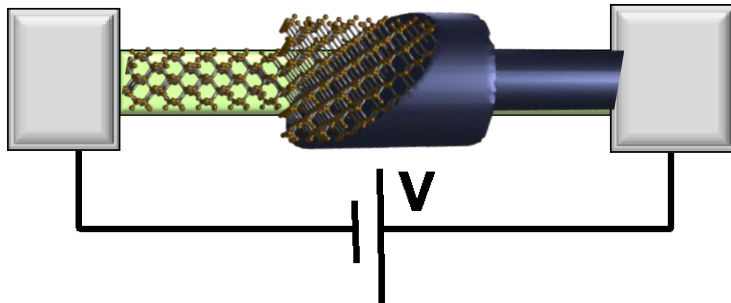
> • 20.2

> • 20.3

> • 20.4



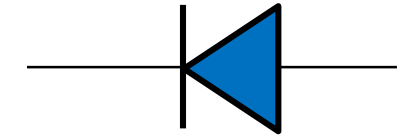
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