VE320 – Summer 2024

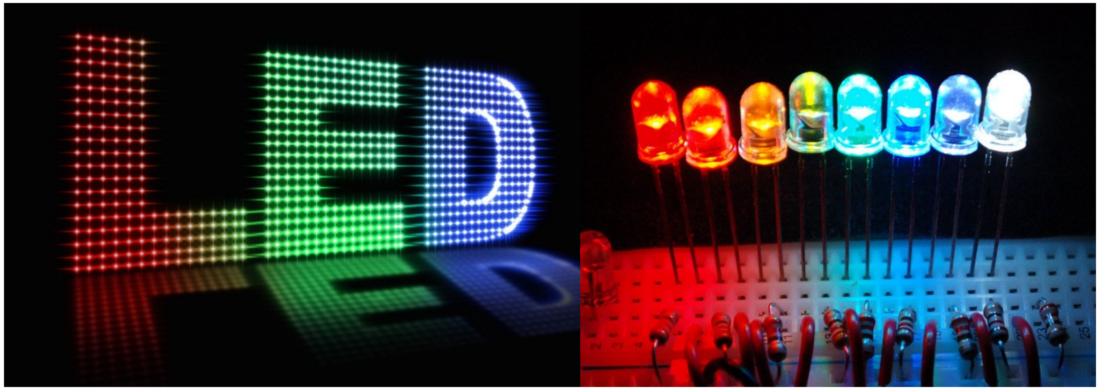
Introduction to Semiconductor Devices

Instructor: Yaping Dan （但亚平）
yaping.dan@sjtu.edu.cn

Chapter 7 The pn Junction

Outline

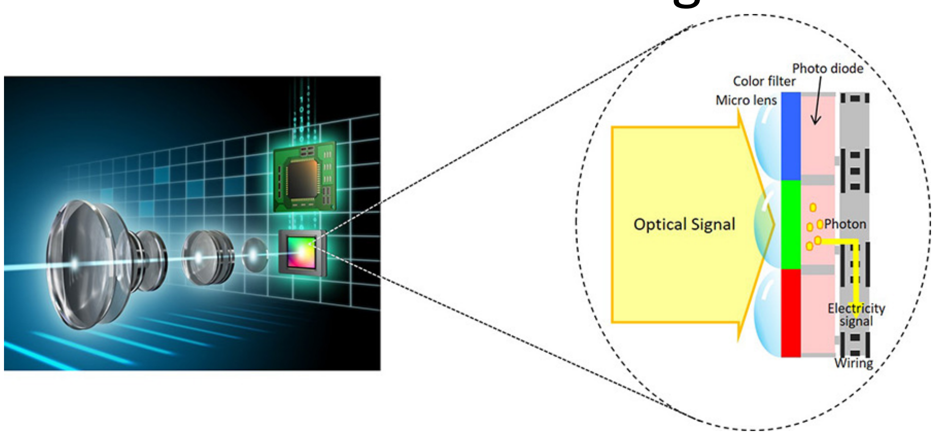
7.0 Introduction to semiconductor devices

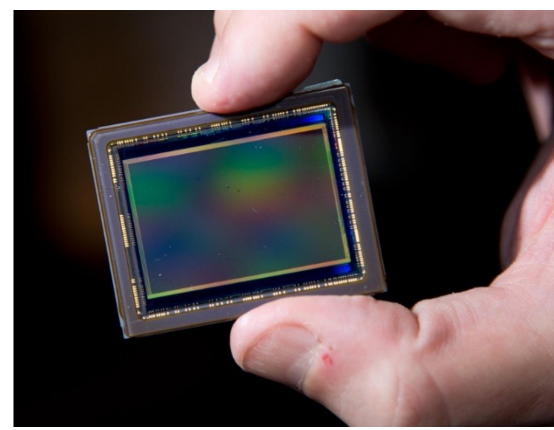


Light emitting diodes

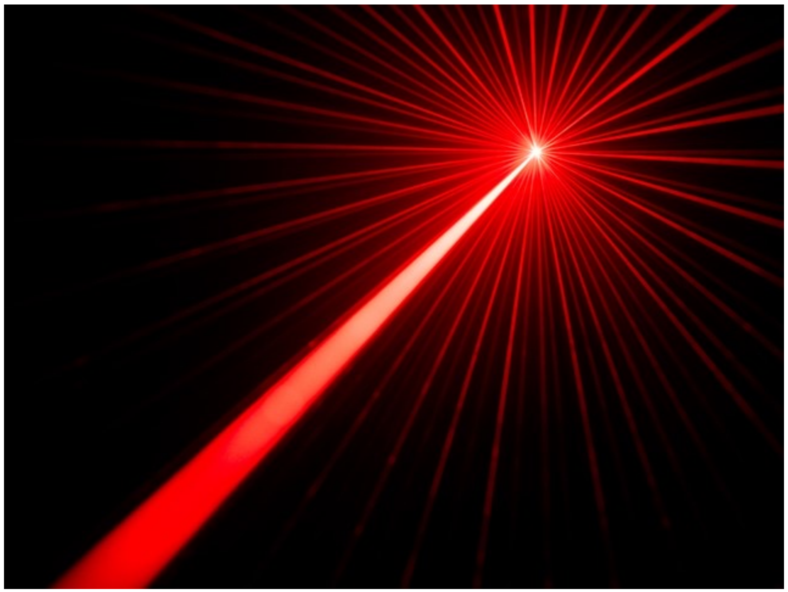
Cold light source

Photodetector: CMOS image sensor





7.0 Introduction to semiconductor devices



Semiconductor lasers

Solar cells

Outline

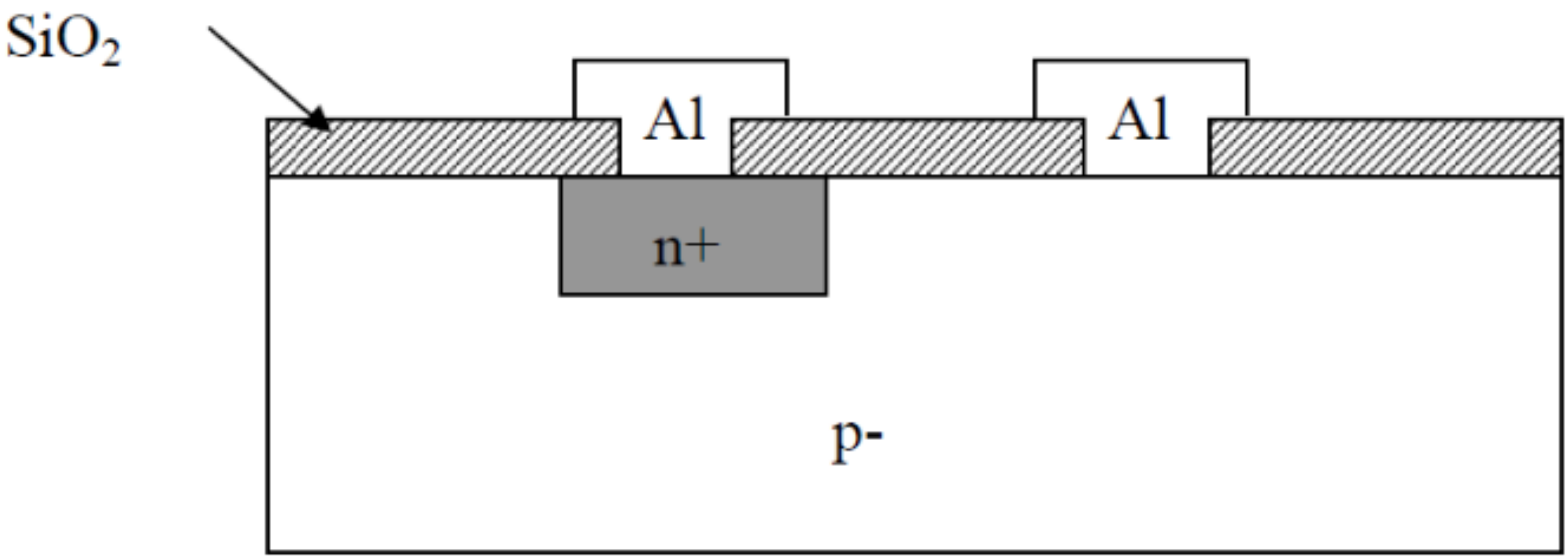
7.0 Introduction to semiconductor devices

7.1 Basic structure of the pn junction

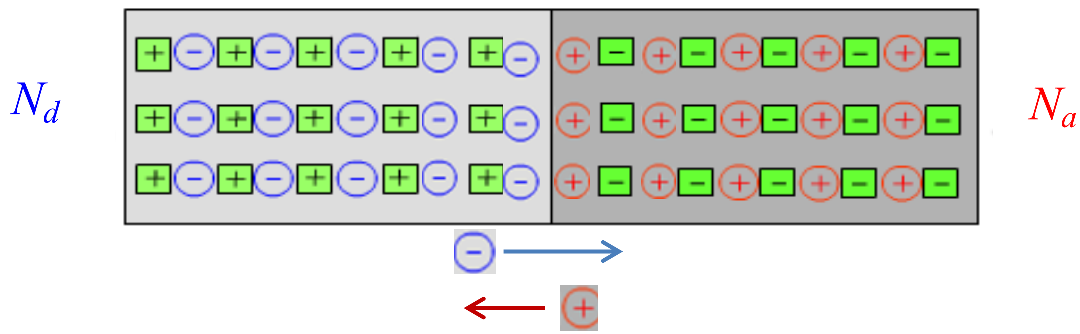
7.2 Zero applied bias

7.3 Reverse applied bias

7.1 Basic structure of pn junction



7.1 Basic structure of pn junction



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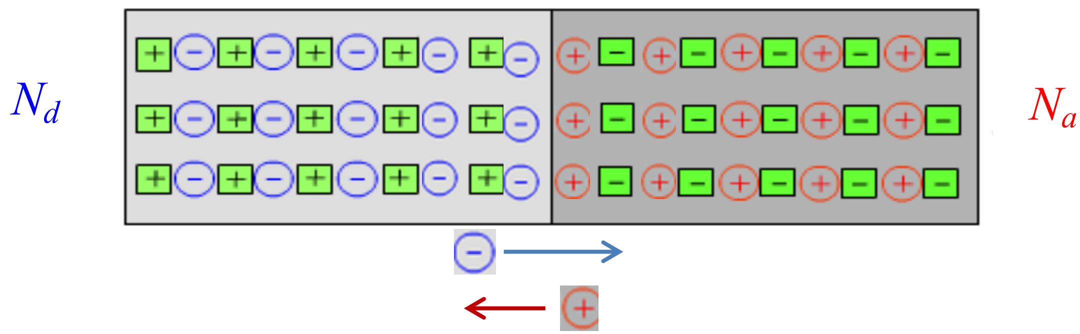
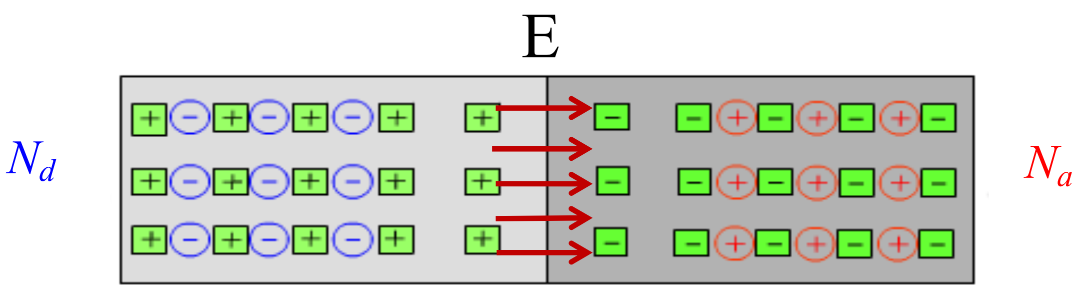




Outline

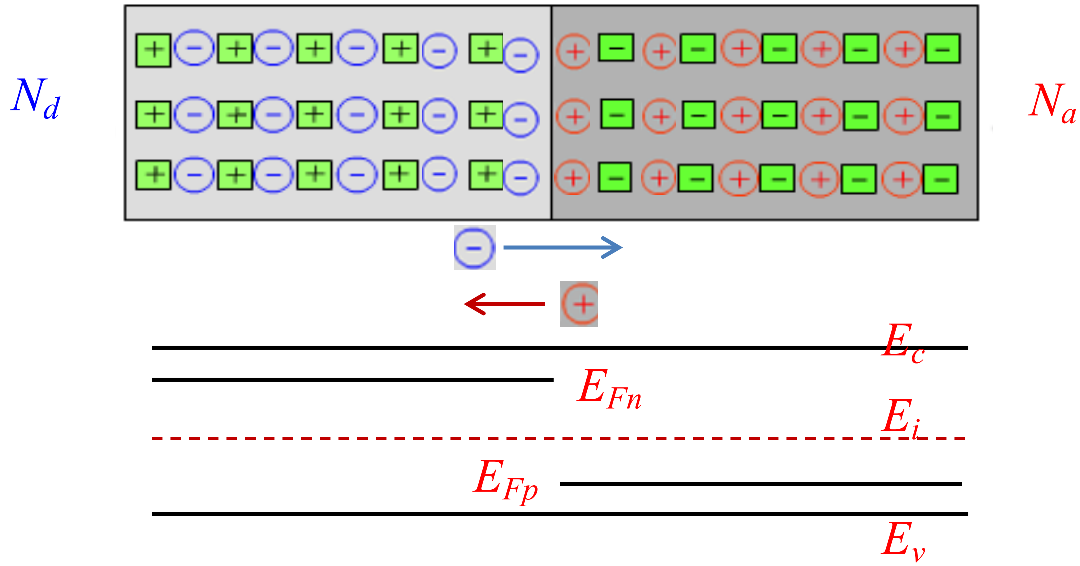
7.1 Basic structure of the pn junction

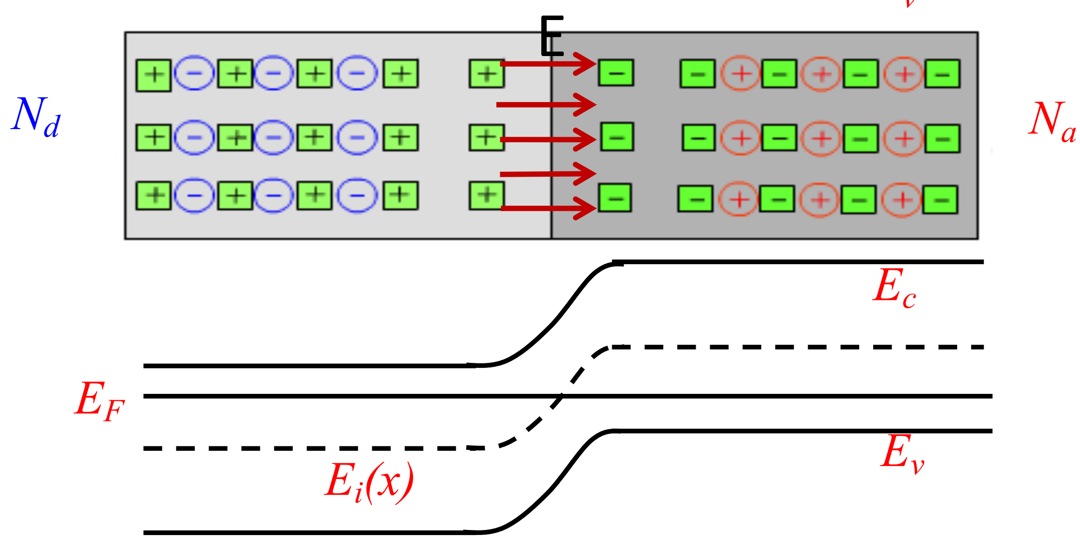
7.2 Zero applied bias

7.3 Reverse applied bias

7.2 Zero applied bias

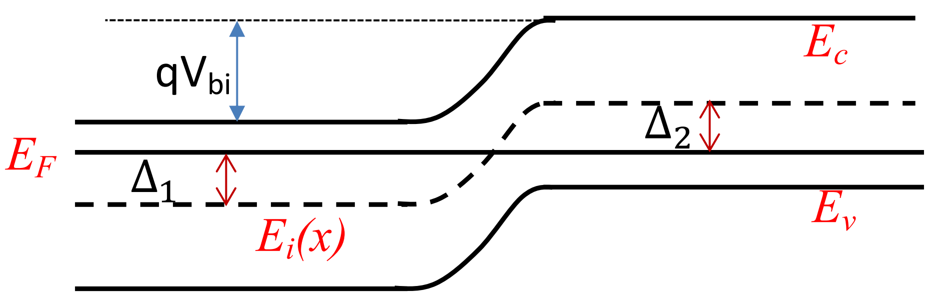
Built-in potential barrier





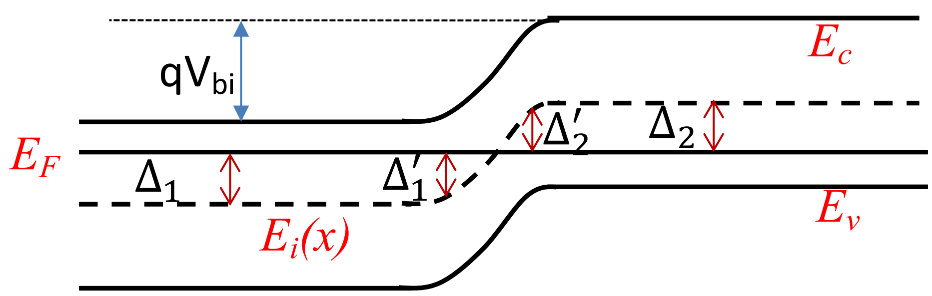
7.2 Zero applied bias

<u>Built-in potential barrier</u>



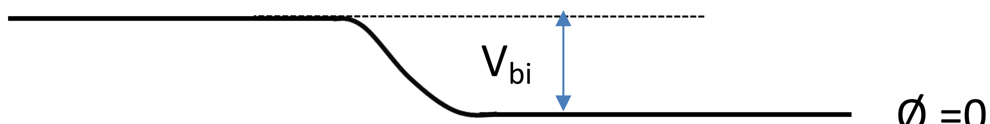
7.2 Zero applied bias

Charge carrier distribution

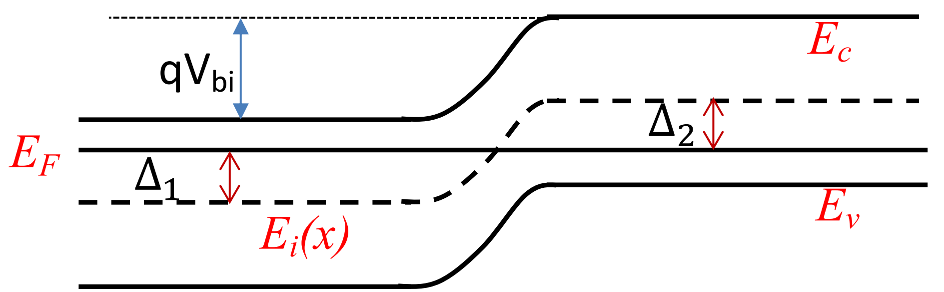


7.2 Zero applied bias

Potential profile



Potential profile

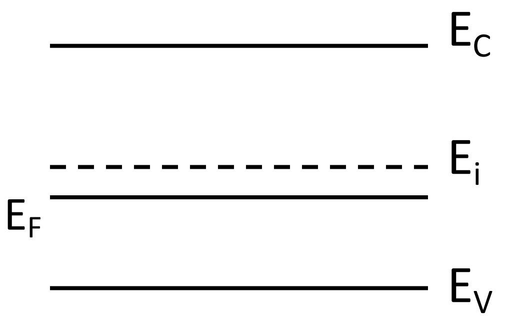


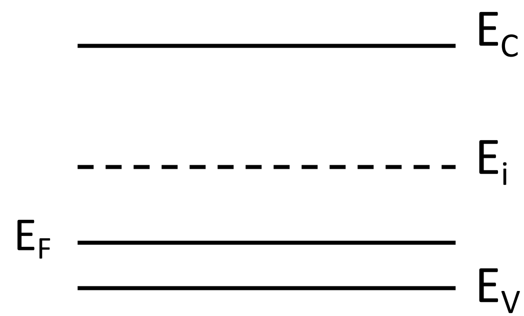
Energy band diagram

Check your understanding

Problem Example #1

Two pieces of p-type silicon are in contact. The doping concentrations are 10^{16} cm^{-3} and 10^{18} cm^{-3}. Calculate the built-in potential between these two pieces of silicon and plot the energy band bending diagram.



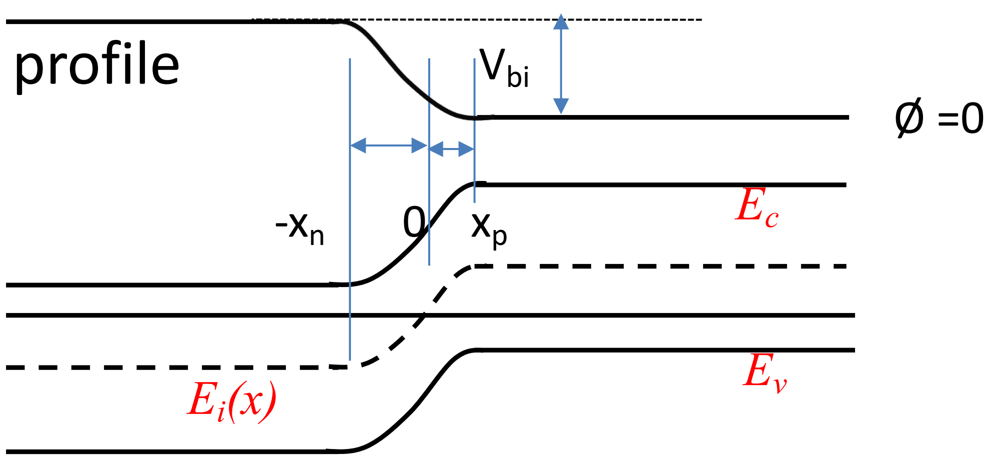


7.2 Zero applied bias

Poisson's equation

$$\frac{d^2V(x)}{dx^2} = -\frac{\rho(x)}{\varepsilon}$$

Potential profile



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Poisson's equation

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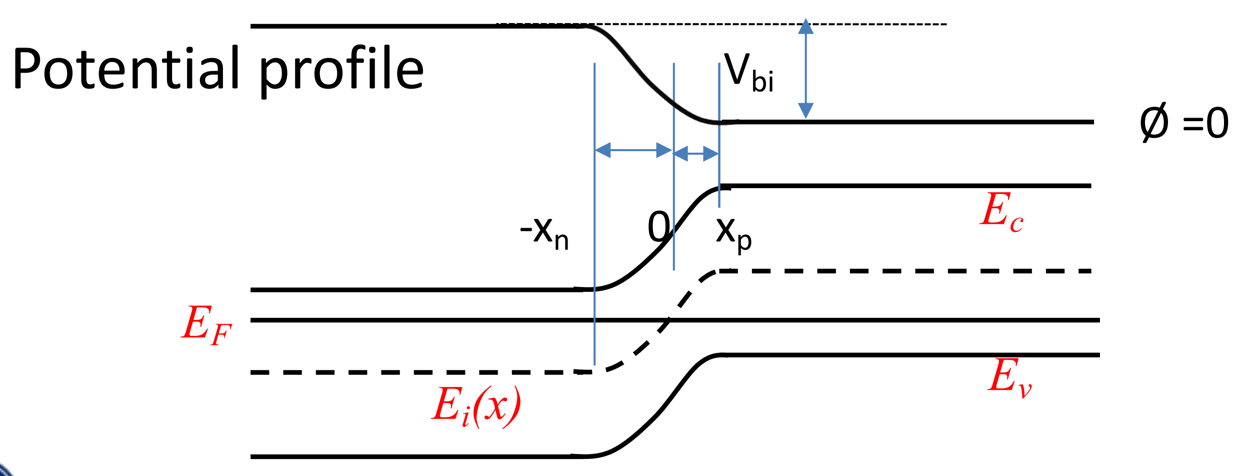


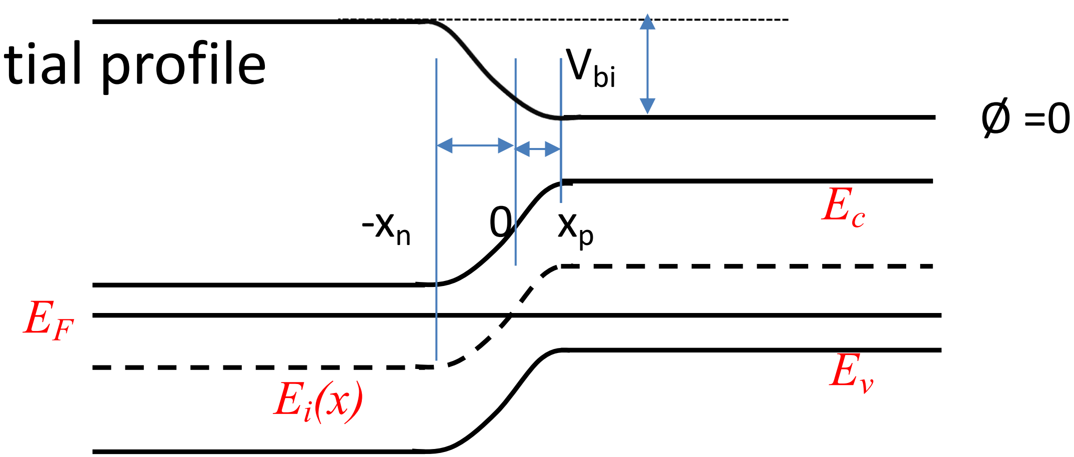
7.2 Zero applied bias

Third time approximation

Poisson's equation

$$\frac{d^2V(x)}{dx^2} = -\frac{\rho(x)}{\varepsilon}$$

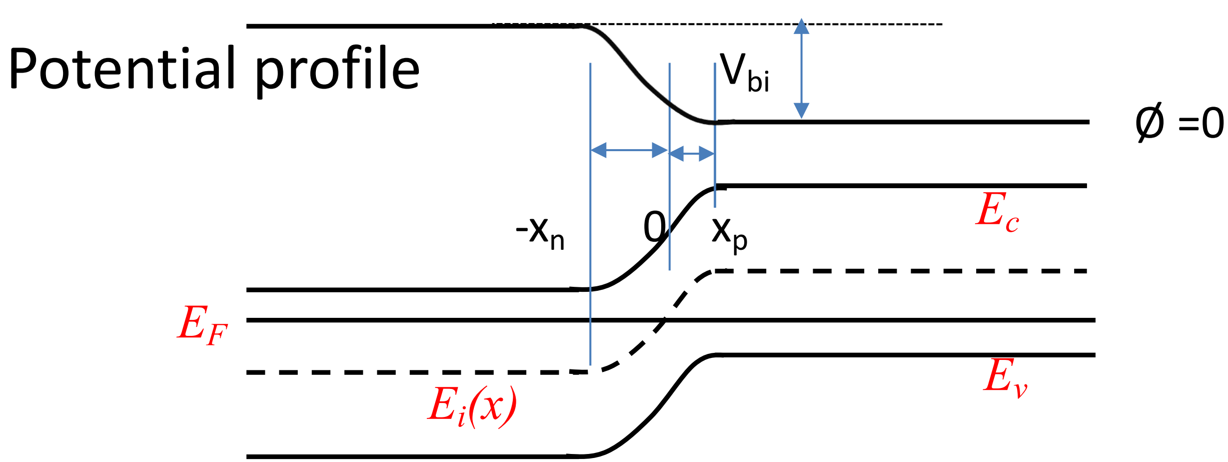
Potential profile



7.2 Zero applied bias

Poisson's equation

$$\frac{d^2V(x)}{dx^2} = -\frac{\rho(x)}{\varepsilon}$$



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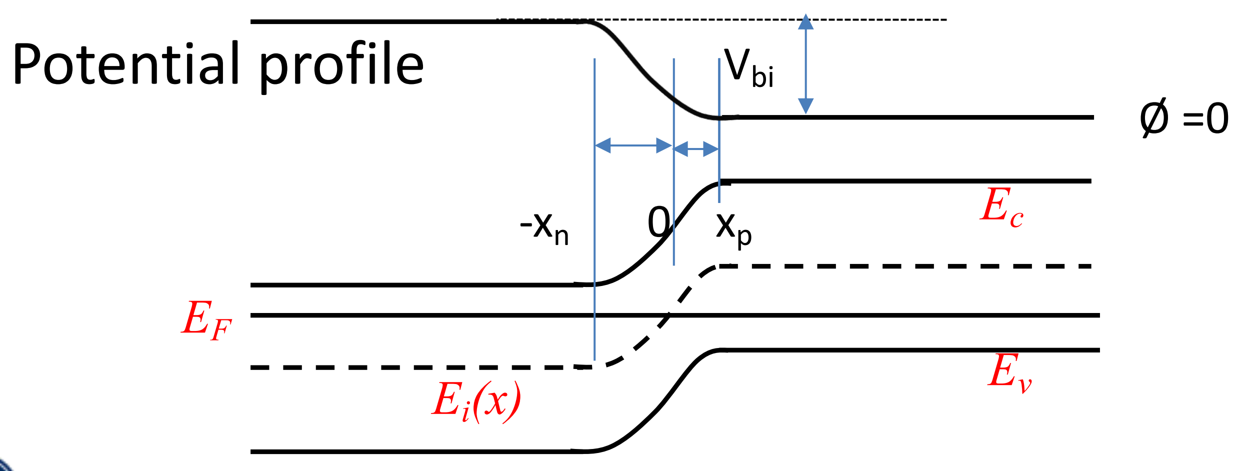

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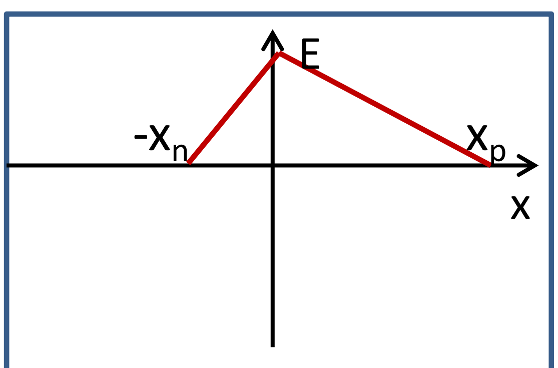

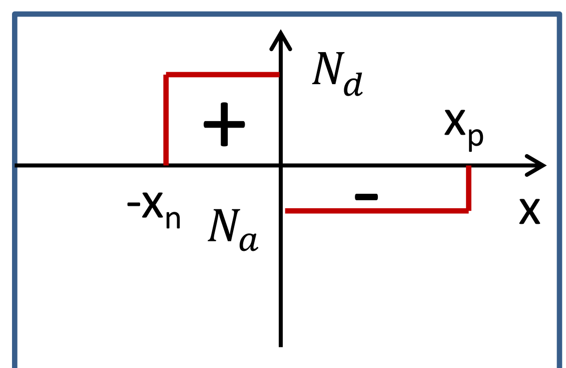

7.2 Zero applied bias

Space charge width

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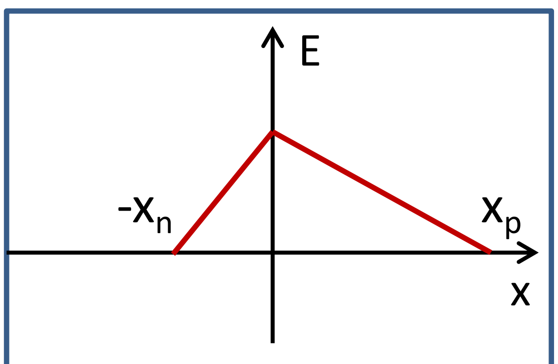
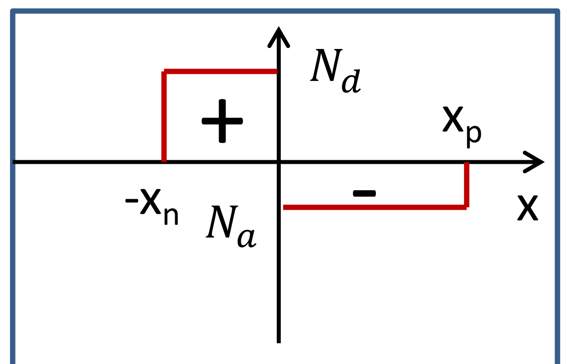
<u>Space charge width</u>





Check your understanding

Problem Example #2

A silicon pn junction at T=300K with zero applied bias has doping concentration of $N_d = 5 \times 10^{16}$ cm^{-3} and $N_a = 5 \times 10^{15}$ cm^{-3}. Determine x_n, x_p, W and $|E_{max}|$.

Outline

7.1 Basic structure of the pn junction

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7.3 Reverse applied bias

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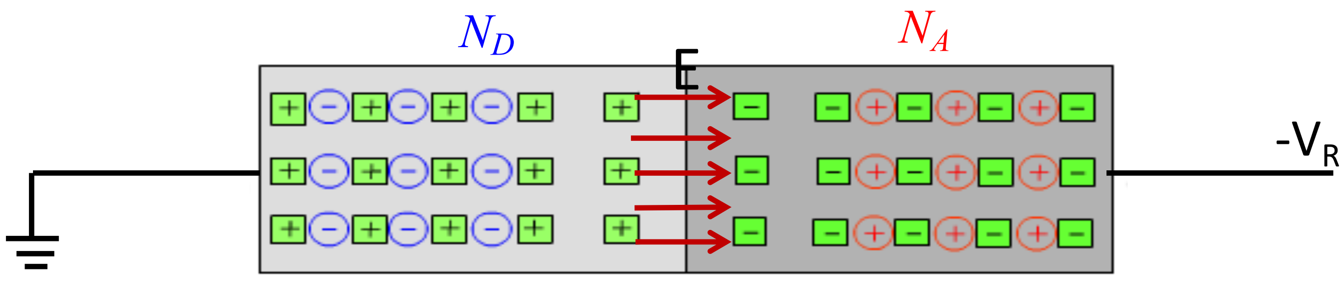
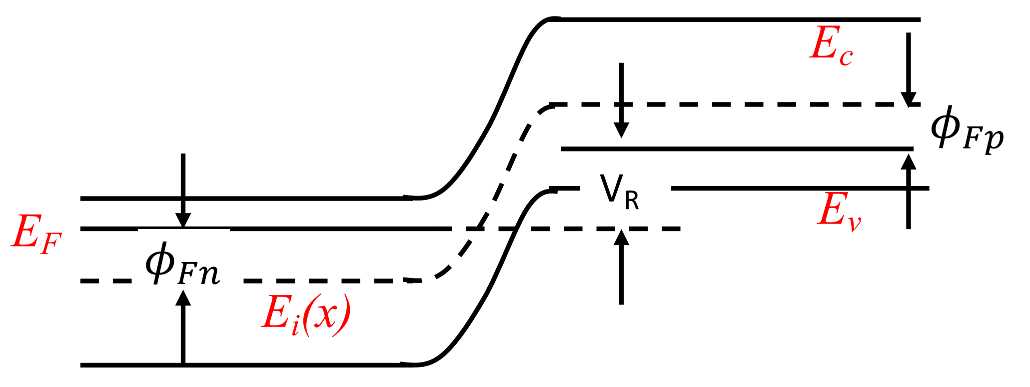
Space charge width and electric field

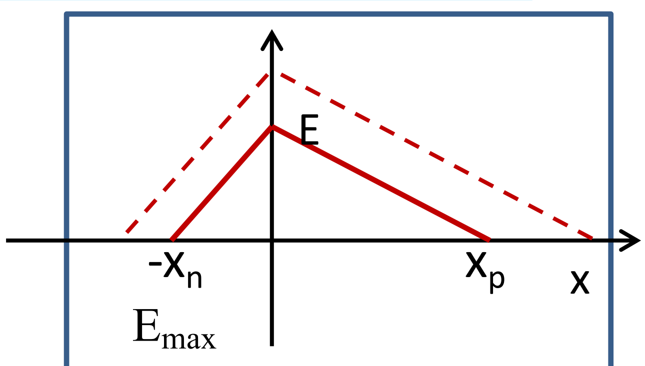
$$V_{\text{total}} = |\phi_{Fn}| + |\phi_{Fp}| + V_R$$

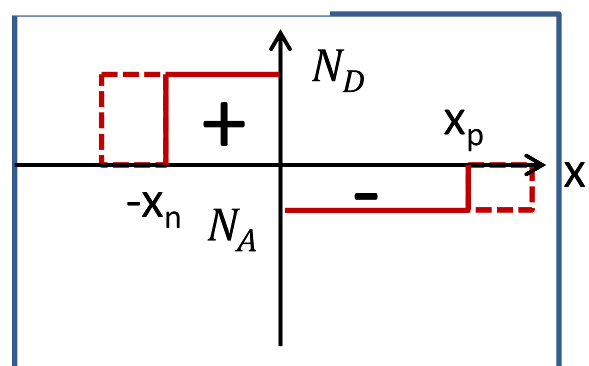




7.3 Reverse applied bias

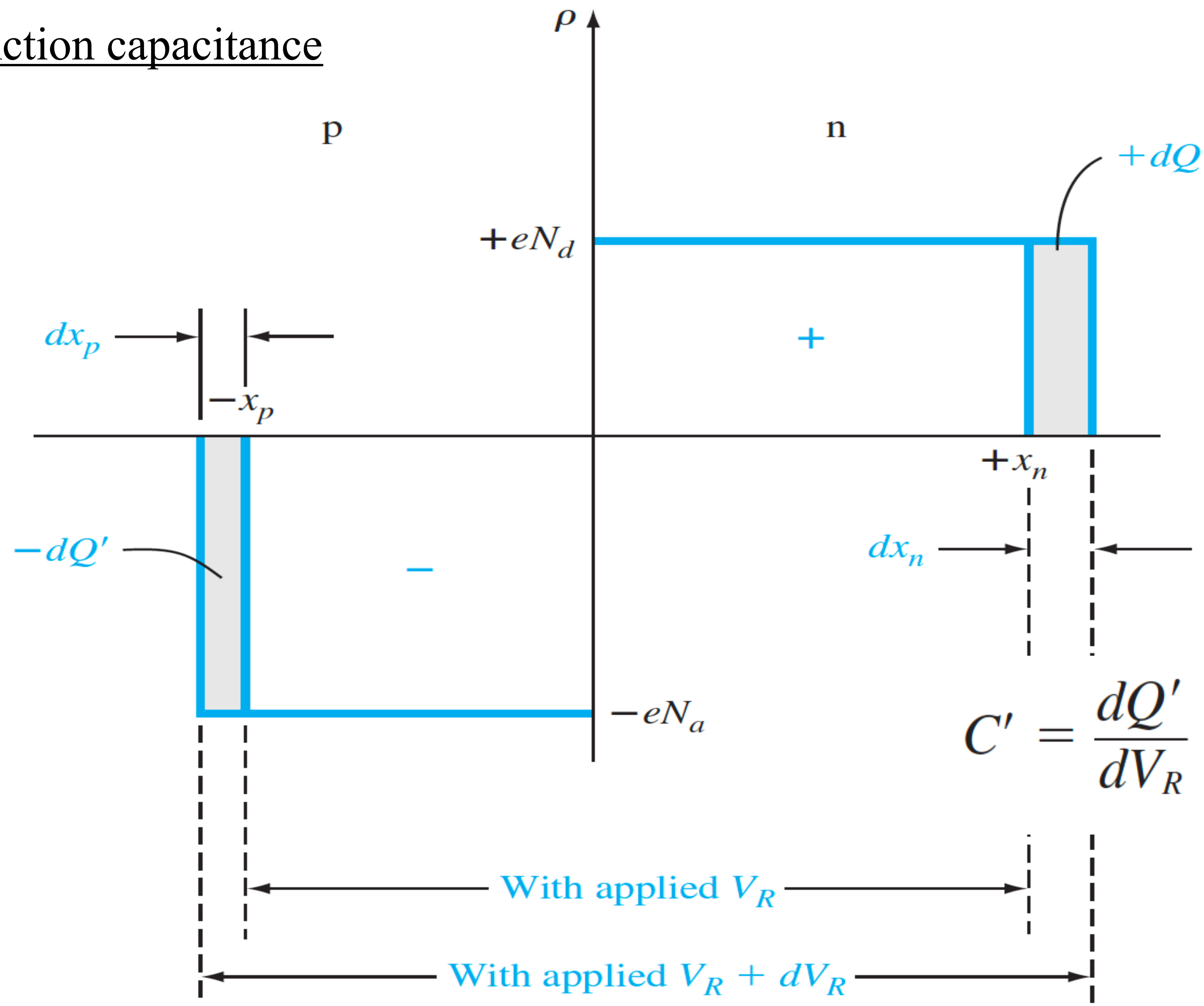
Space charge width and electric field





7.3 Reverse applied bias

Junction capacitance



7.3 Reverse applied bias

Junction capacitance

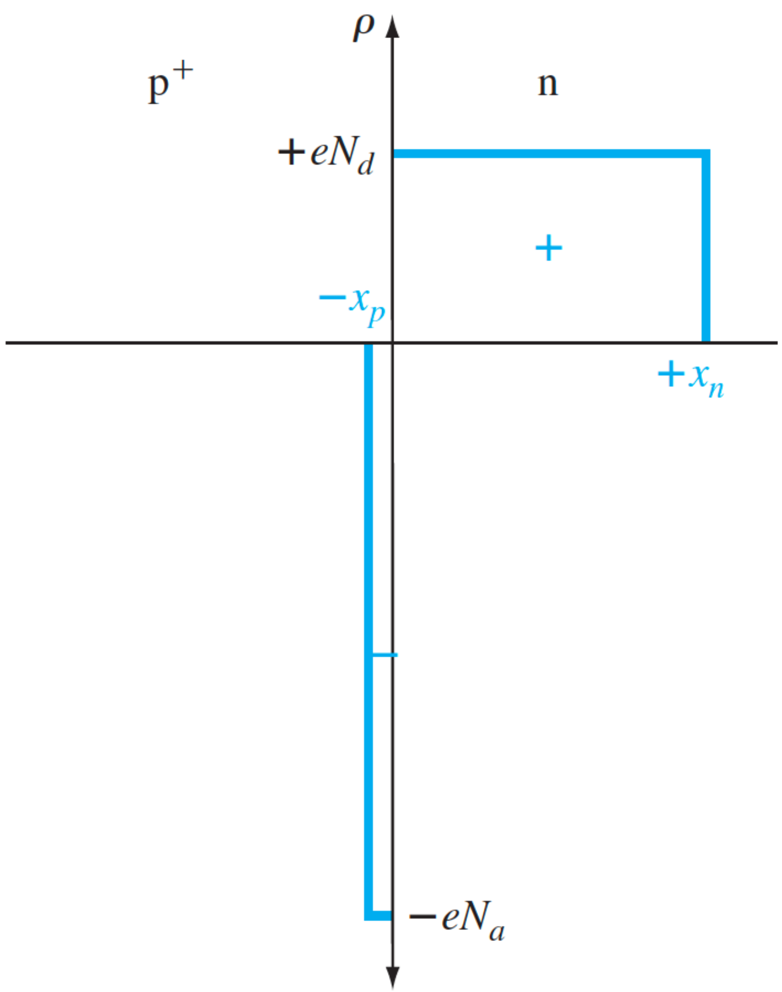
Check your understanding

Problem Example #3

Consider a GaAs pn junction at $T = 300K$ doped to $N_a = 5 \times 10^{15}\ cm^{-3}$ and $N_d = 2 \times 10^{16}\ cm^{-3}$. (a) Calculate V_{bi}. (b) Determine the junction capacitance C' for $V_R = 4V$.

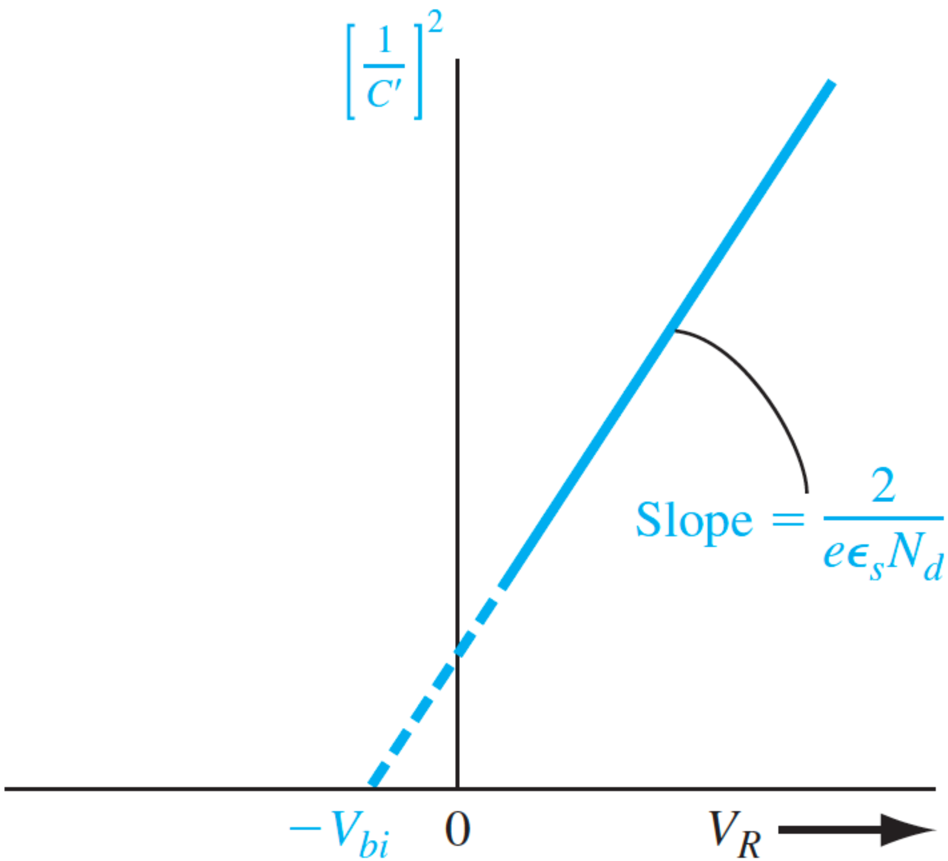
7.3 Reverse applied bias

<u>One-sided junction</u>



7.3 Reverse applied bias

<u>One-sided junction</u>



Check your understanding

Problem Example #4

nature COMMUNICATIONS

Control sample: Au is in contact with a uniform doped n-type Si substrate forming a device similar to a pn junction.
SAMM-doped sample: Au is in contact with Si that is doped with SAMM
Take Au as p^{++} doping in this case.

ARTICLE

DOI: 10.1038/s41467-017-02564-3 OPEN

Deep level transient spectroscopic investigation of phosphorus-doped silicon by self-assembled molecular monolayers

Xuejiao Gao[1], Bin Guan[1], Abdelmadjid Mesli[2], Kaixiang Chen[1] & Yaping Dan[1]