Welcome

To

ENEE236 0
Analog Electronics

T1 Outline & Semiconductors

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Main Reference1 (~ text book) : Electronic Devices and Circuit Theory , 10th Edition by R. Boylestad & L. Nashelsky

Main Reference 2: Electronic Devices, 8th edition, by Floyd

1

ENEE2304 1190111 Nasser Ismail

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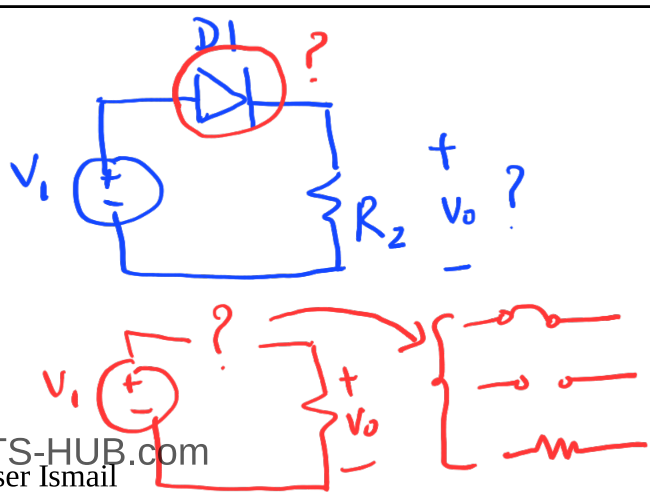
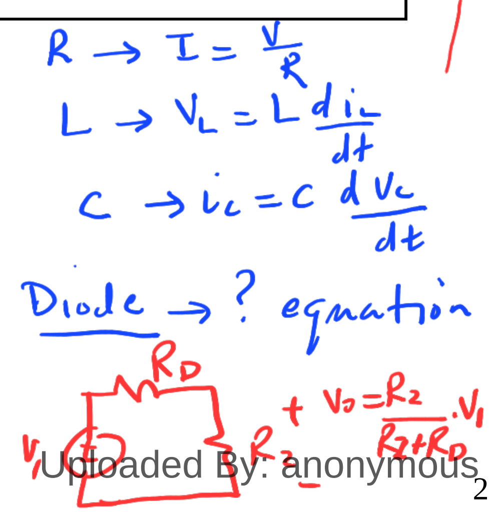
Course Objectives

- Study diode construction, basic operating principles and modeling.
- To analyze and design diode based circuits used in different application such as ac-dc rectifiers, limiting and clamping, voltage multiplication.
- To Study zener diode operation and usage as voltage regulator.
- To Study construction, operation, biasing of Bipolar Junction Transistors and Field Effect Transistors.
- To design and analyze BJT and FET based amplifier circuits using small signal analysis techniques including their high and low frequency response
- To study operational amplifiers and how to use them in various applications such as amplification, summation, comparison, integration, differentiation
- To study different discrete and integrated circuit Voltage Regulators and be able to design them for different applications

2





ENEE 2304 →
1) ohm's law $I = V/R$
2) KVL + voltage Divider
3) KCL + current Divider
4) Superposition
5) Thevenin

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Course Contents

T1-T5

1. **Introduction to Semiconductors and Semiconductor diodes**
   - **Atomic Structure; Semiconductors , Conductors And Insulators; Covalent Bonds;**
   - **Conduction in Semiconductors; N-Type and P-Type Semiconductors**
   - **The diode; biasing a Diode; V-I Characteristics of a Diode; Diode Models**

Diodes

2. **Diode Applications**
   - **Load Line Analysis, Half-Wave and Full-Wave Rectifiers; Power supply Filters and Regulators; Diode Limiting and Clamping Circuits; Voltage Multipliers; The diode Data Sheet, Zener Diodes and their Applications**

T6

3. **Bipolar Junction Transistors (BJT)**
   - **Transistor construction and operation, Transistor Characteristics and Parameters; The Transistor as an Amplifier; The Transistor as a Switch.**

BJT

T7

4. **DC Biasing of BJTs**
   The DC Operating Point (Quiescent Operating Point); Voltage-Divider Bias; Other Bias Methods.

3

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Course Contents

T8

5. BJT AC Analysis

Amplifiers and small signal analysis, Transistor AC Equivalent Circuits- Hybrid Parameters, Common-Emitter Amplifier; Common-Collector Amplifier; Common-Base Amplifier; Multistage Amplifiers.

BJT

T9

6. Field-Effect Transistors (FETs)

The JFET; JFET Characteristics and Parameters; JFET Biasing; The MOSFET Characteristics and Parameters; MOSFET Biasing

FET

T10

7. FET Amplifiers.

FET Amplification; Common-Source Amplifiers; Common- Drain Amplifiers and Common-Gate Amplifiers;

T11

8. Operational Amplifiers and Applications

Introduction to Operational Amplifiers; Op-Amp Input Modes and Parameters Negative Feedback; Op-Amps with Negative Feedback ; Comparators; Summing Amplifiers; Integrators and Differentiators.

Instrumentation Amplifier; Converters and Other Op-Amp Circuits.

OpAmp

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Course Contents

T12

9. Amplifier Frequency Response
Basic Concepts; The Decibel; Low-Frequency Amplifier Response.
High- Frequency Amplifier Response; Total Amplifier Frequency Response.

T13

10. Voltage Regulators
Voltage Regulation; Basic Series Regulator; Basic shunt Regulator; Integrated Circuit Voltage Regulators.

5

Grading Policy

Quizzes	On Mondays	~ 15%
Design and simulation home-works		10%
Oral on Camera Test		10%
Midterm and discussion (essay+ multiple choice, fill solution into space)		30%
Final Exam		35%

Exact % are subject to minor modifications

Value of I_D = — A

Value of V_o = — V

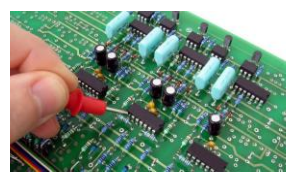
6

Introduction to Semiconductors and 1) Semiconductor Diodes

Electronics Circuits

- We encounter electronics in our daily life in form of telephones, radios, television, audio equipment, home appliances, computer and equipment for industrial control and automation .





- The field of electronics deals with the design and application of electronic design .

Electronics Devices

a)

- Diodes
  - a) Rectifier diode
  - b) Zener diode
  - c) Light Emitting Diode (LED)

b)

c)

- Transistors
  - a) Bipolar Junction Transistor (BJT)
  - b) Field Effect Transistor (FET)

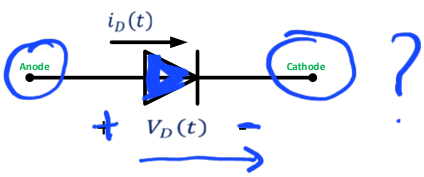
- Integrated Circuits (IC)

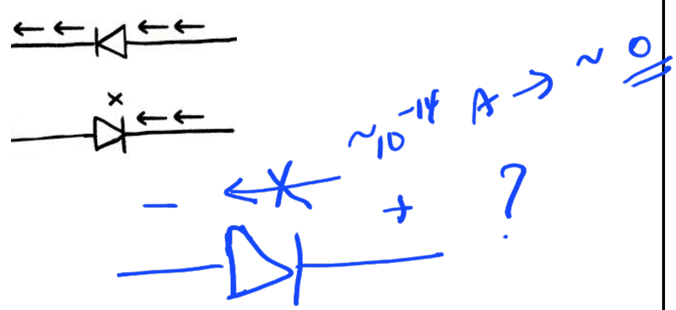
OpAmps
Voltage Regulators

Diode

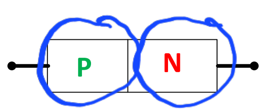
- It is an electronic device with a single p-n junction and it has the ability to conduct current in one direction while blocking current in the other direction.

- Circuit Symbol :

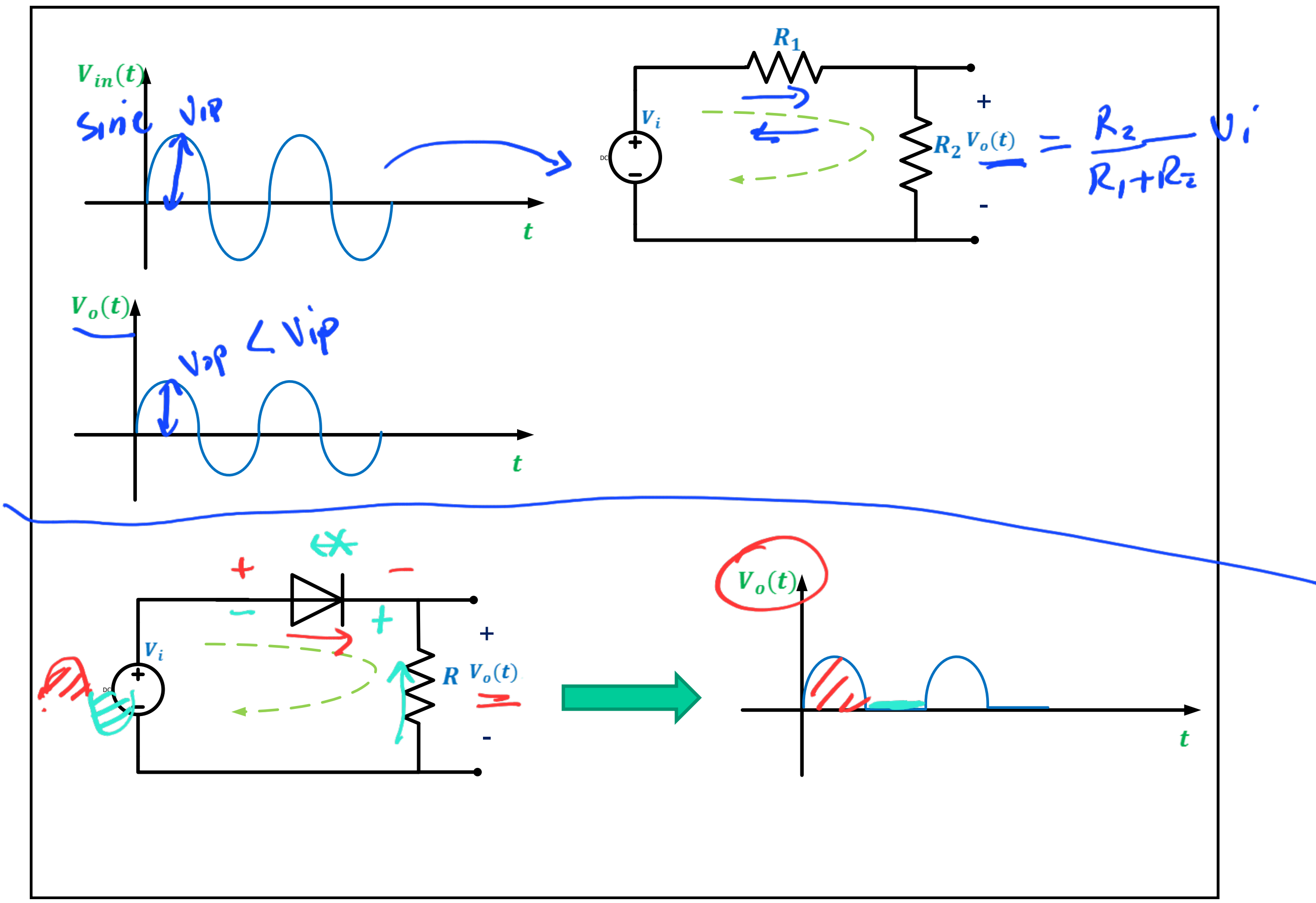




- Physical constriction



pn junction ≡ Diode


$V_{in}(t)$
sinc
Vip
t
R_1
V_i
+
R_2
$V_o(t)$
-
$= \frac{R_2}{R_1+R_2} V_i$
$V_o(t)$
Vop < Vip
t
+
-
V_i
+
R
$V_o(t)$
-
$V_o(t)$
t

Semiconductors

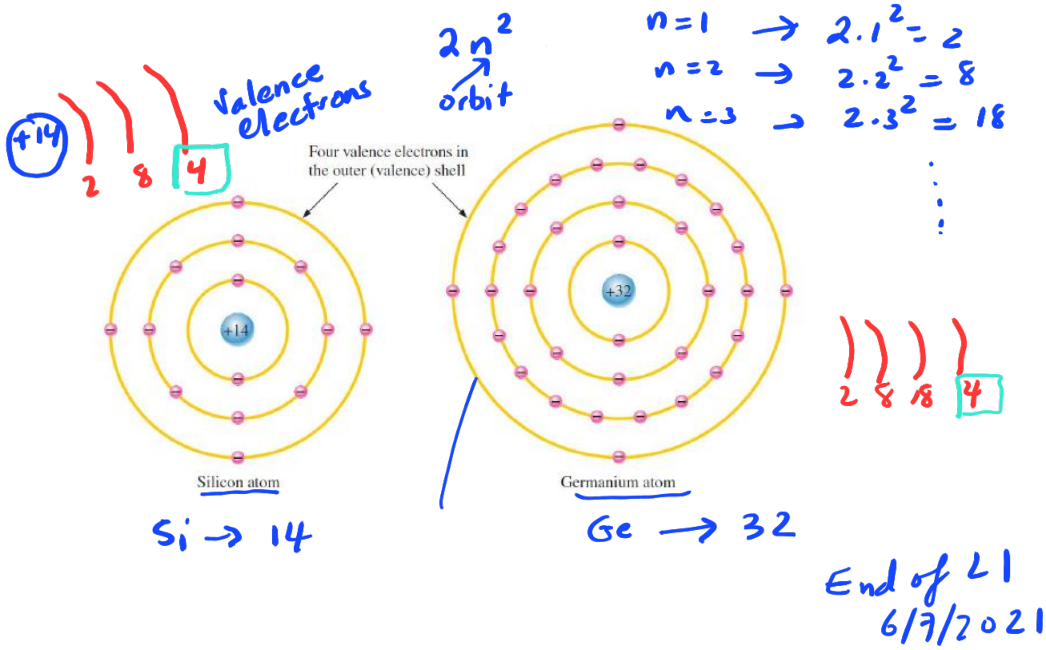
- Electronic devices as diodes, transistors and integrated circuits are made of semiconductor material .

- 3) Semiconductors : materials whose resistance lies between low resistance of 1) conductor and the high resistance of insulator . 2)

↘ R << (conductor)

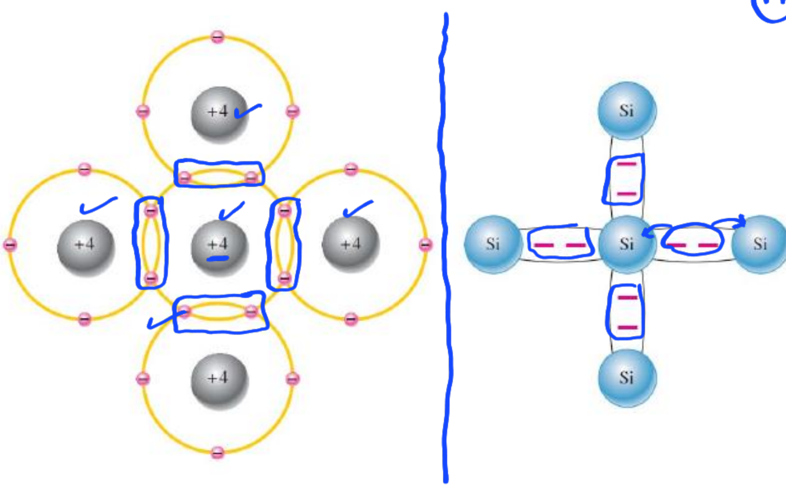
↘ R >> (insulator)

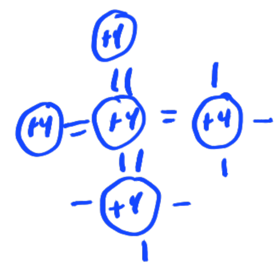
Atomic Structure



start of L2 7/7/2021

Covalent bond

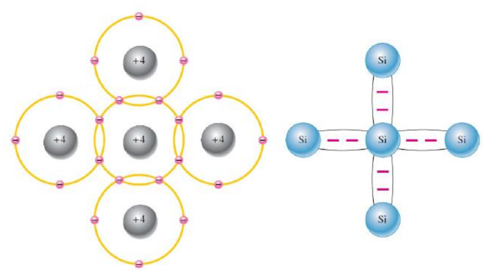




Covalent bond

- A silicon (Si) atom with its four valence electrons shares an electron with each of its four neighbors
- This effectively creates eight shared valence electrons for each atom and produces a state of chemical stability .

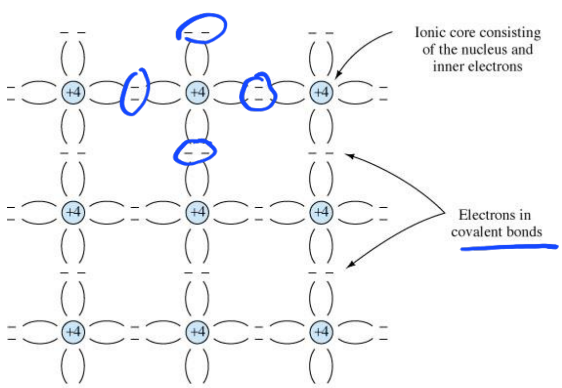
- Also, this sharing of valence electrons produce the covalent bonds that hold the atom together; each valence electron is attracted equally by the two adjacent atoms which share it .

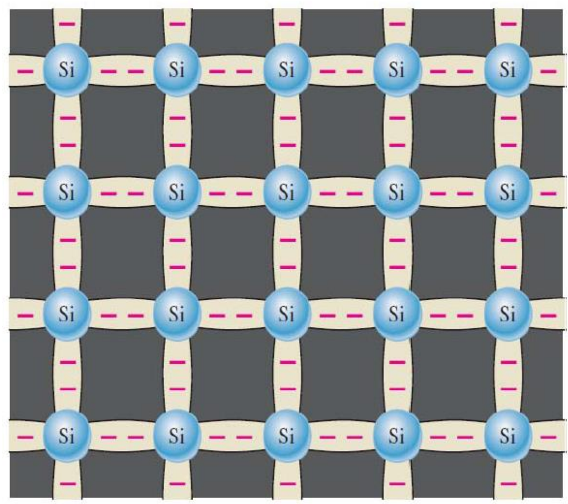


Covalent bond in (intrinsic)silicon crystals

نقي

- At absolute zero degree all valence electrons are tightly bonded to their atoms and there is no free electrons, so the silicon behave as an insulator .





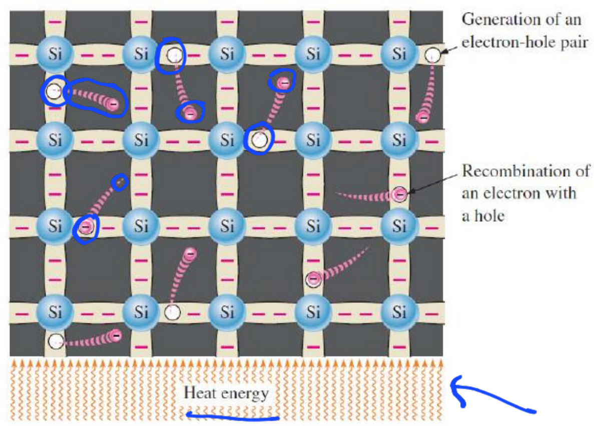
@ zero degrees

Rupture of the a covalent bond

تكسر

(intrinsic) pure silicon

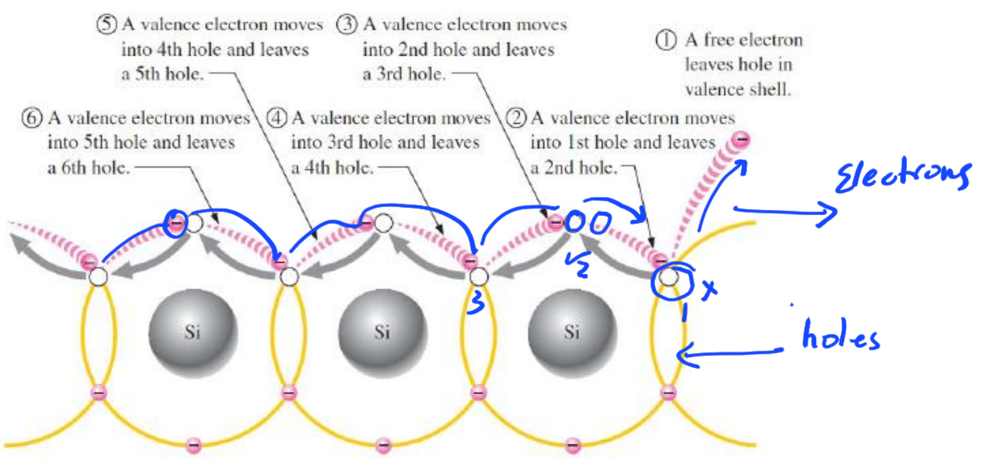
- When an electron becomes free that is unattached to any atom, a vacancy is left in the valence band within the crystal . This vacancy is called hole .
- For every free electron, there is one hole .
- One broken covalent bond → one free electron + one hole
  - At room temperature there is one broken covalent bond for every 3x10^{12} pure Si atoms .



- At room temperature there are few available charge carriers (free electrons + holes)

Hole motion

- When a valence electron moves left to right to fill a hole while leaving another hole behind, the hole has effectively moved from right to left.



→ passive sign convention
→ conventional current / Electron current
→ ← positive charges movement
holes

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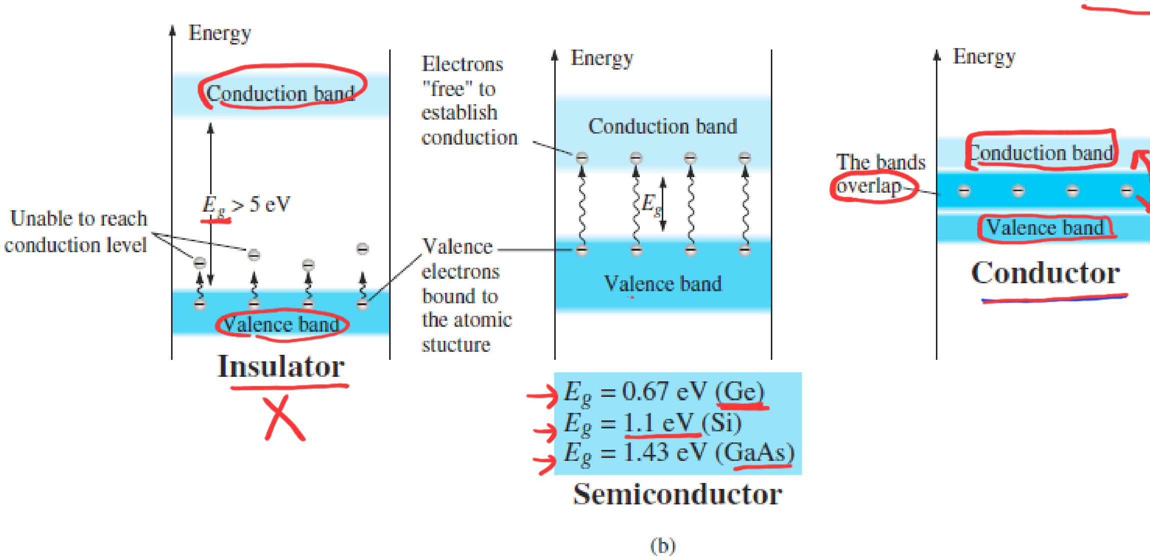
Energy Gap



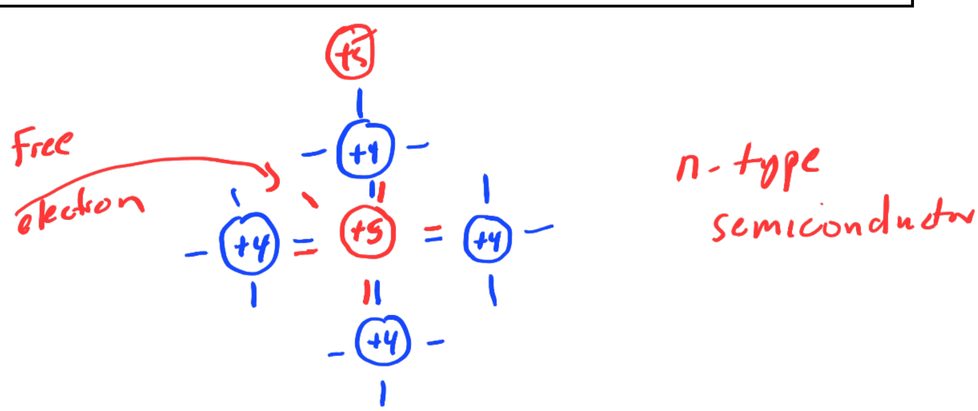
Sports

Doping Test →

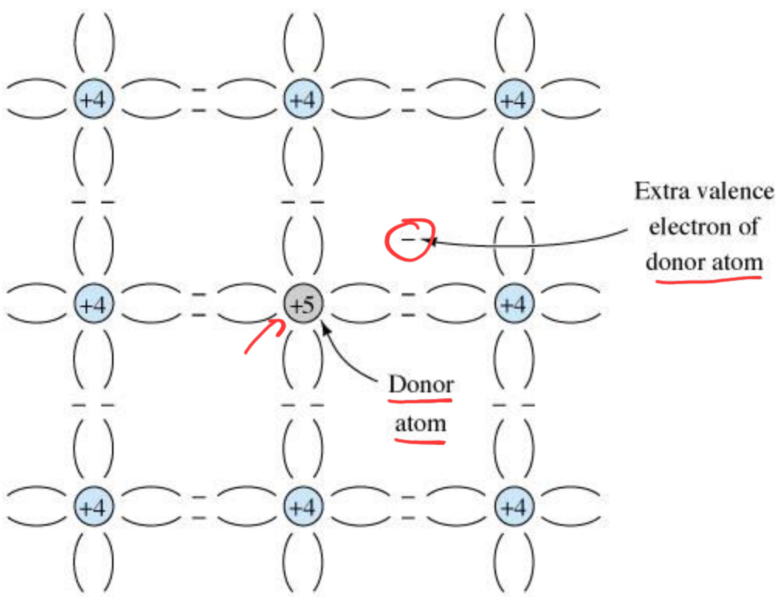
Doping

- A manufacturing process that adds free charge carriers (free electron or hole) into a pure semiconductor material to increase its conductivity
- There is two categories of impurities: n-type or p-type

- **N-Type Semiconductor**
- Pentavalent impurity (one which has 5 valence electrons) atom is added such as phosphorus
- This atom forms covalent bonds with 4 adjacent silicon atoms, while the fifth becomes a conduction electron since it is not attached to any atom



n-type silicon

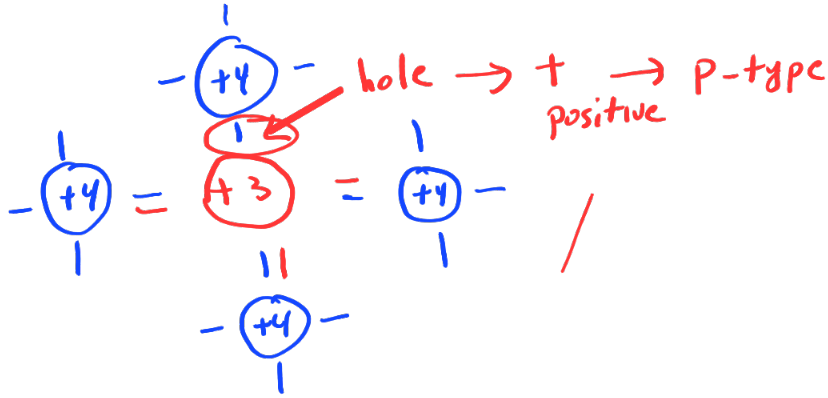


n-type silicon is created by adding valence five impurity atoms.

With the number of electrons increasing, the rate of recombination between free electrons and holes also increase

- Number of conduction electrons can be carefully controlled by the number of impurities added
- Since most of the current carriers are electrons, this type of material doped with pentavalent impurities is an n-type semiconductor
- The majority current carriers in n-type material is electrons, but there are few holes created when electron-hole pair are thermally generated, these holes are minority carriers

temp



P-Type Semiconductor

- To increase number of holes in intrinsic silicon, trivalent impurity atoms are added (atoms with three valence electrons) such as boron (B) or gallium (Ga)
- Valence electrons (3) of the impurity atom create covalent bonds with three adjacent atoms of silicon and a fourth electron is missing, creating a hole with each added impurity atom
- Majority carriers in P-type material are holes
- Also there are few free electrons that are created when electron-hole pair are thermally generated, these electrons are minority carriers

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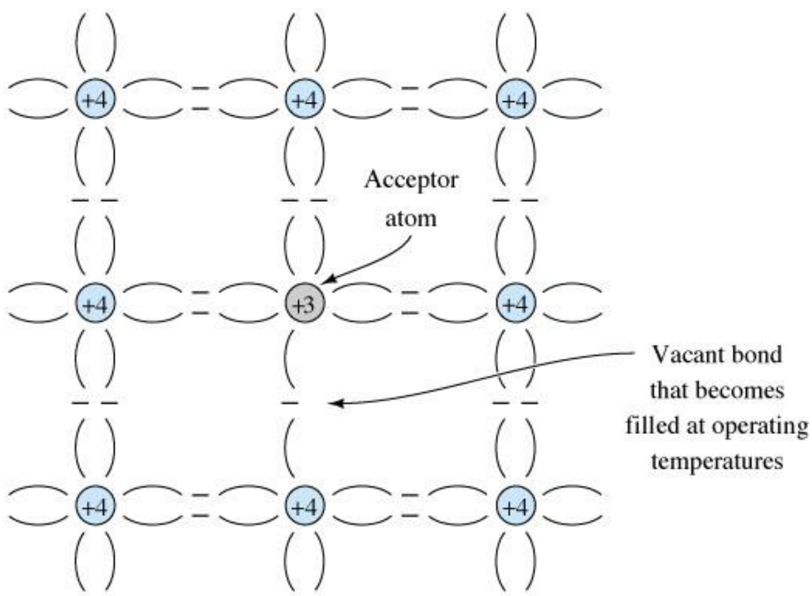
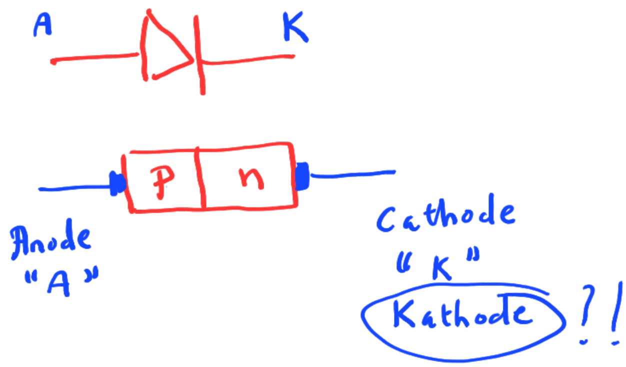
p-type silicon

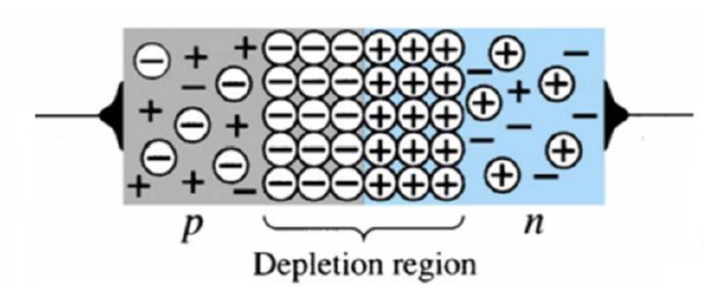


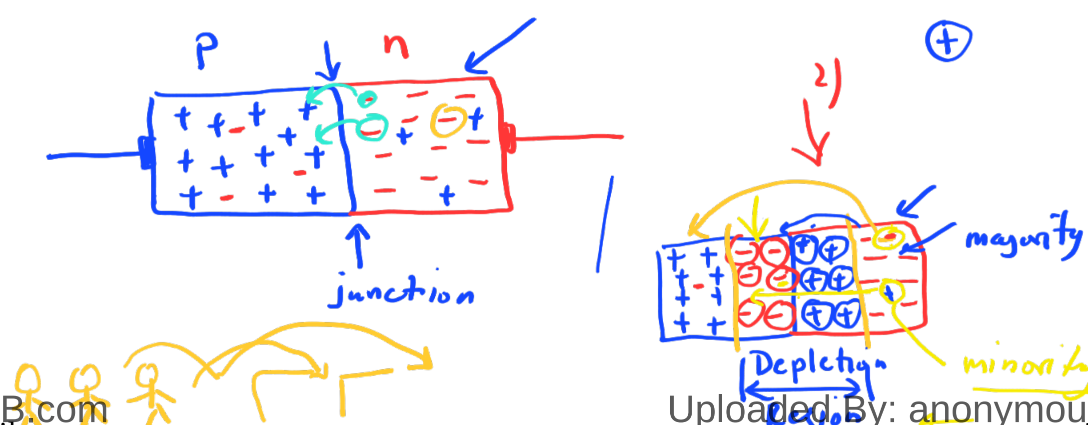
p-type silicon is created by adding valence three impurity atoms.



Pn junction

- The p-n junction is the basis for diodes, certain transistors ,and other devices.





Formation of Depletion Region

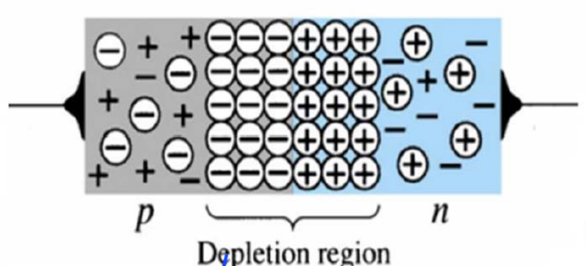
1) Electrons from the n-type material near the junction diffuse a cross the junction.

2) These electrons fill the holes in the p-type material adjacent to the junction.

3) As a result of electrons leaving the n-type material , **donor ions are created** on the n side of the junction .

4) When these electrons fill holes in the p side of the junction , **accepter ions** are produced.

5) A wall of stationary positive ions is aligned with a wall of n egative ions along the n and p sides of the junction .

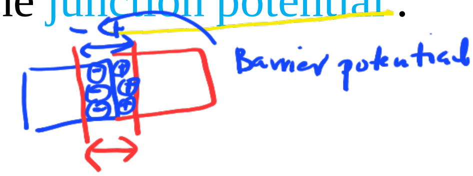


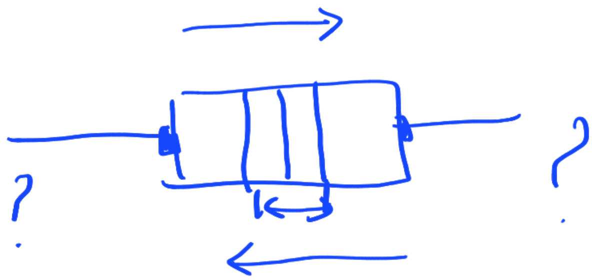
6) The space occupied between the ion walls is called depletion region.

7)Whenever there exists a positive charge with respect to a negative charge , a voltage difference is set between charges ;(Junction potential, Junction barrier).

8) The junction potential acts as potential barrier that tend to prevent majority carriers from crossing the junction.

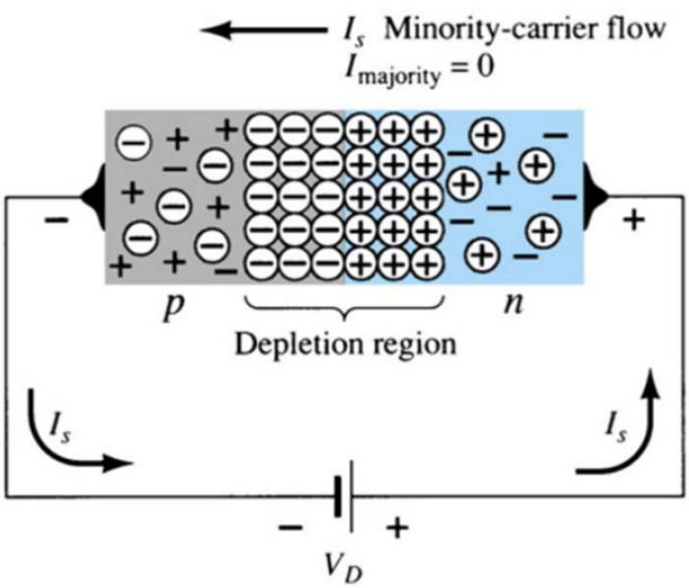
9) Minority carriers are aided by the junction potential .

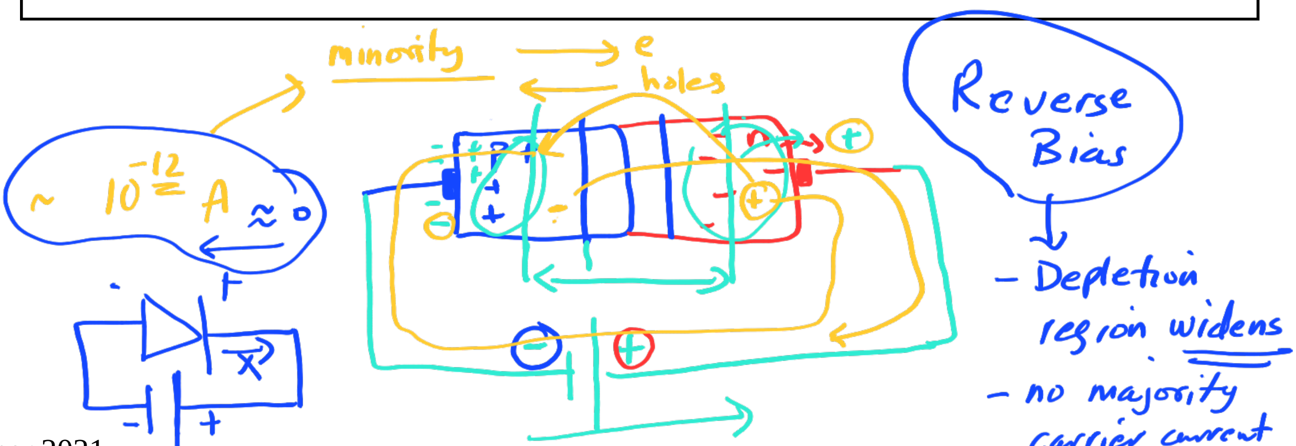




Reverse bias of a pn junction

Reverse bias is when the voltage at the n-side is higher than p-side

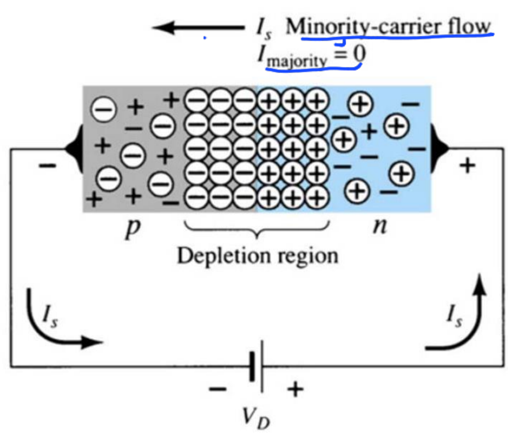




► The reverse voltage causes the depletion region to widen .

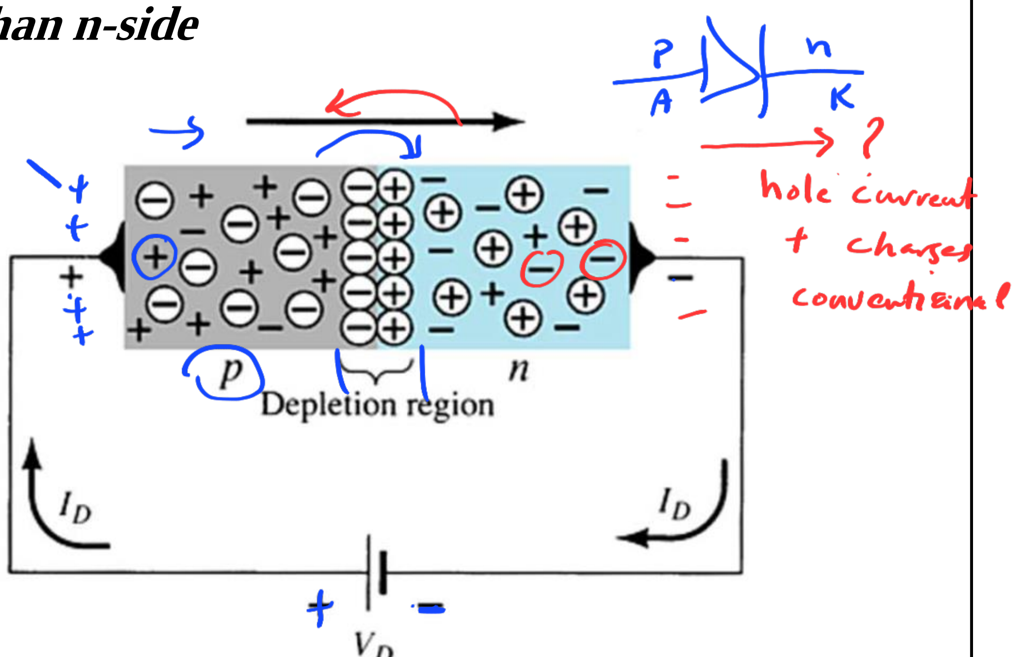
► The electrons in the n-type material are attracted toward the positive terminal of the voltage source .

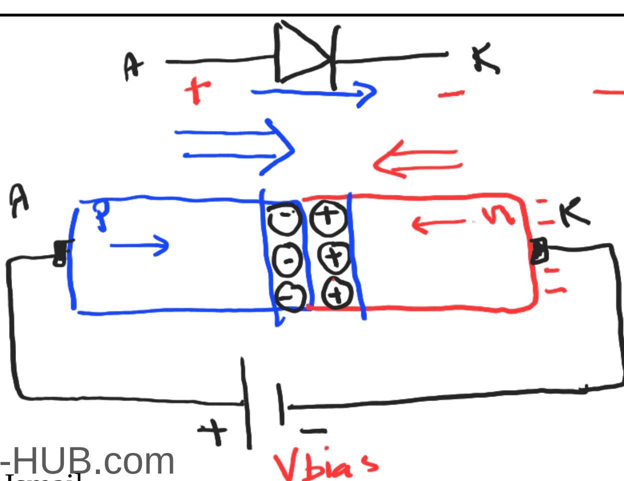
► The holes in the p-type material are attracted toward the negative terminal of the voltage source .



Forward bias of a pn junction

Forward bias is when the voltage at the p-side is higher than n-side





End of L2

Forward Bias

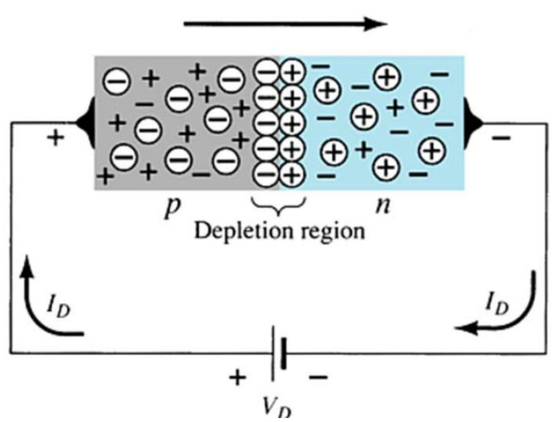
- Depletion region is reduced

start of L3
8/7/2021

► The forward voltage causes the depletion region to narrow

► The electrons and holes are pushed toward the p-n junction

► The electrons and holes have sufficient energy to cross the p-n junction



https://www.youtube.com/watch?v=OsfguONJw2Q

Please Watch

https://www.youtube.com/watch?v=ar7xDMR4P_U

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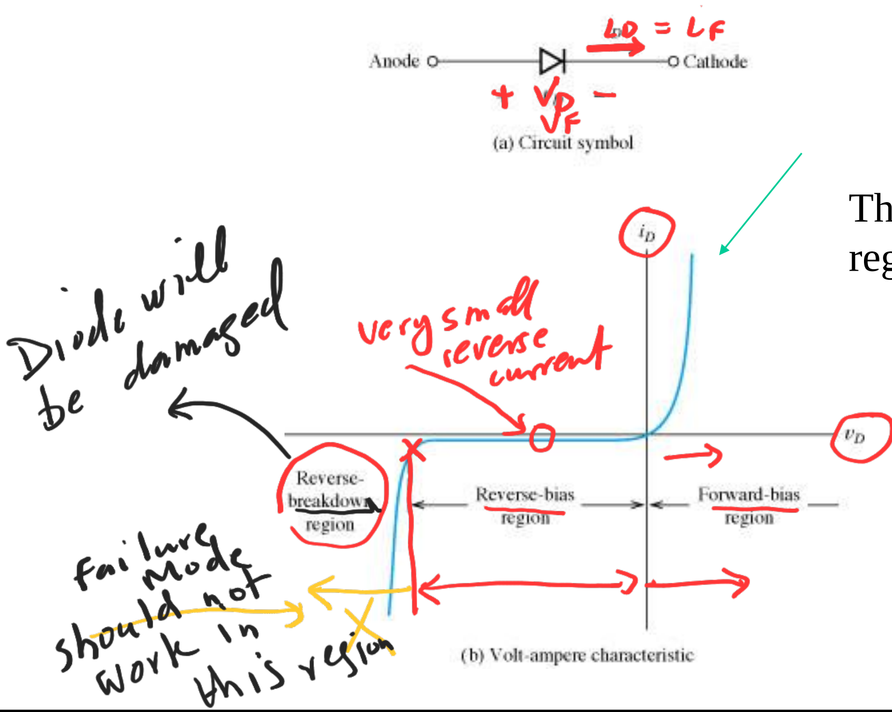
Barrier Potential

- *The barrier potential of a pn junction depends on several factors, including the type of semiconductor material, amount of doping, and the temperature*
- *Typical at 25 deg C it is ~ 0.7 for silicon and ~ 0.3 for germanium*

in this course → Si → $V_F = V_D \approx 0.7\ V$ ✓

Ge → $V_F = V_D \cong 0.3\ V$

Semiconductor Diode I-V curve



Three operating regions

T1 → L1
→ L2
→ L3 (part 1)