

Session 1: Solid State Devices

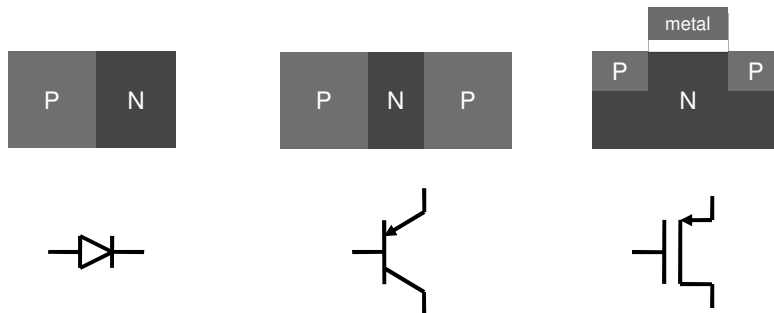
From Atoms to Transistors

FROM ATOMS TO TRANSISTORS

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Objective

To Understand: how “Diodes,” and “Transistors” operate!



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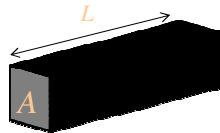
Periodic Table of the Elements

Alkali metals
Alkaline earth metals
Transition metals
Lanthanide series
Actinide series
Hydrogen
Halogens
Noble gases

1 H Hydrogen
 2 He Helium
 3 Li Lithium
 4 Be Beryllium
 5 B Boron
 6 C Carbon
 7 N Nitrogen
 8 O Oxygen
 9 F Fluorine
 10 Ne Neon
 11 Na Sodium
 12 Mg Magnesium
 13 Al Aluminum
 14 Si Silicon
 15 P Phosphorus
 16 S Sulfur
 17 Cl Chlorine
 18 Ar Argon
 19 K Potassium
 20 Ca Calcium
 21 Sc Scandium
 22 Ti Titanium
 23 V Vanadium
 24 Cr Chromium
 25 Mn Manganese
 26 Fe Iron
 27 Co Cobalt
 28 Ni Nickel
 29 Cu Copper
 30 Zn Zinc
 31 Ga Gallium
 32 Ge Germanium
 33 As Arsenic
 34 Se Selenium
 35 Br Bromine
 36 Kr Krypton
 37 Rb Rubidium
 38 Sr Strontium
 39 Y Yttrium
 40 Zr Zirconium
 41 Nb Niobium
 42 Mo Molybdenum
 43 Tc Technetium
 44 Ru Ruthenium
 45 Rh Rhodium
 46 Pd Palladium
 47 Ag Silver
 48 Cd Cadmium
 49 In Indium
 50 Sn Tin
 51 Sb Antimony
 52 Te Tellurium
 53 I Iodine
 54 Xe Xenon
 55 Cs Cesium
 56 Ba Barium
 57 La Lanthanum
 58 Ce Cerium
 59 Pr Praseodymium
 60 Nd Neodymium
 61 Pm Promethium
 62 Sm Samarium
 63 Eu Europium
 64 Gd Gadolinium
 65 Tb Terbium
 66 Dy Dysprosium
 67 Ho Holmium
 68 Er Erbium
 69 Tm Thulium
 70 Yb Ytterbium
 71 Lu Lutetium
 72 Hf Hafnium
 73 Ta Tantalum
 74 W Tungsten
 75 Re Rhenium
 76 Os Osmium
 77 Ir Iridium
 78 Pt Platinum
 79 Au Gold
 80 Hg Mercury
 81 Tl Thallium
 82 Pb Lead
 83 Bi Bismuth
 84 Po Polonium
 85 At Astatine
 86 Rn Radon
 87 Fr Francium
 88 Ra Radium
 89 Ac Actinium
 90 Th Thorium
 91 Pa Protactinium
 92 U Uranium
 93 Np Neptunium
 94 Pu Plutonium
 95 Am Americium
 96 Cm Curium
 97 Bk Berkelium
 98 Cf Californium
 99 Es Einsteinium
 100 Fm Fermium
 101 Md Mendelevium
 102 No Nihonium
 103 Lr Lawrencium

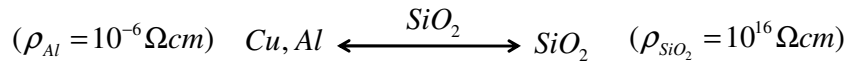
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21 Century Alchemy !



$$R = \frac{V}{I} = \rho \frac{L}{A}$$

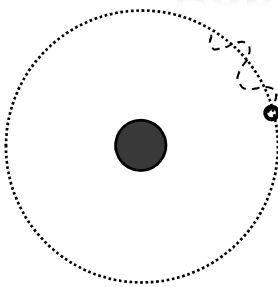
Resistivity is characteristic of the material



- Intel Core i7
- Today
- Clock rate 2.66GHz-3.33GHz
- 64 bit processor
- 4 cores
- 731M Transistors at 45 nm
- Oregon 32 nm plant
- Price 273-562 \$
- 283 mm² die size

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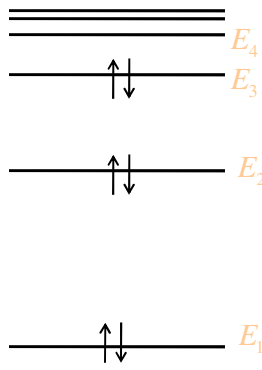
Bohr Atomic Model



wave-particle duality $\lambda = \frac{h}{p}$


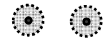
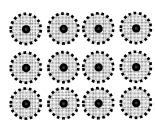
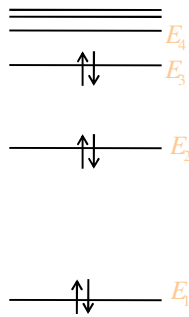
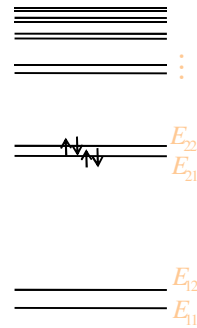
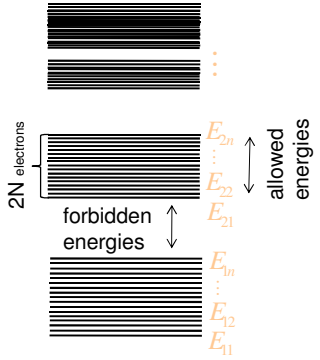
$mvr = n\hbar$

Energy Bands:

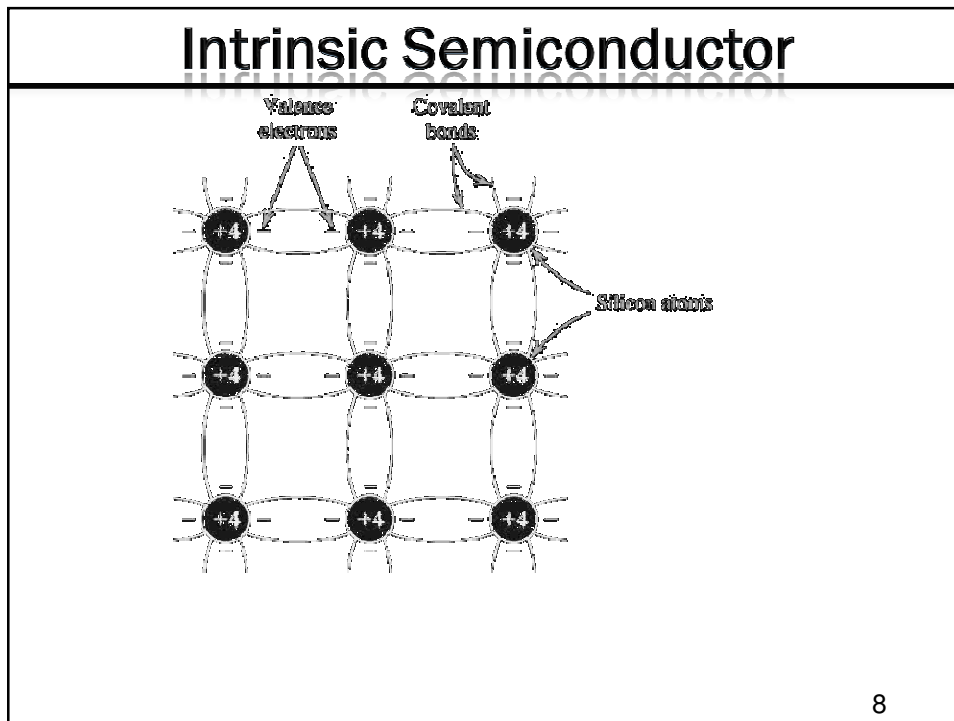
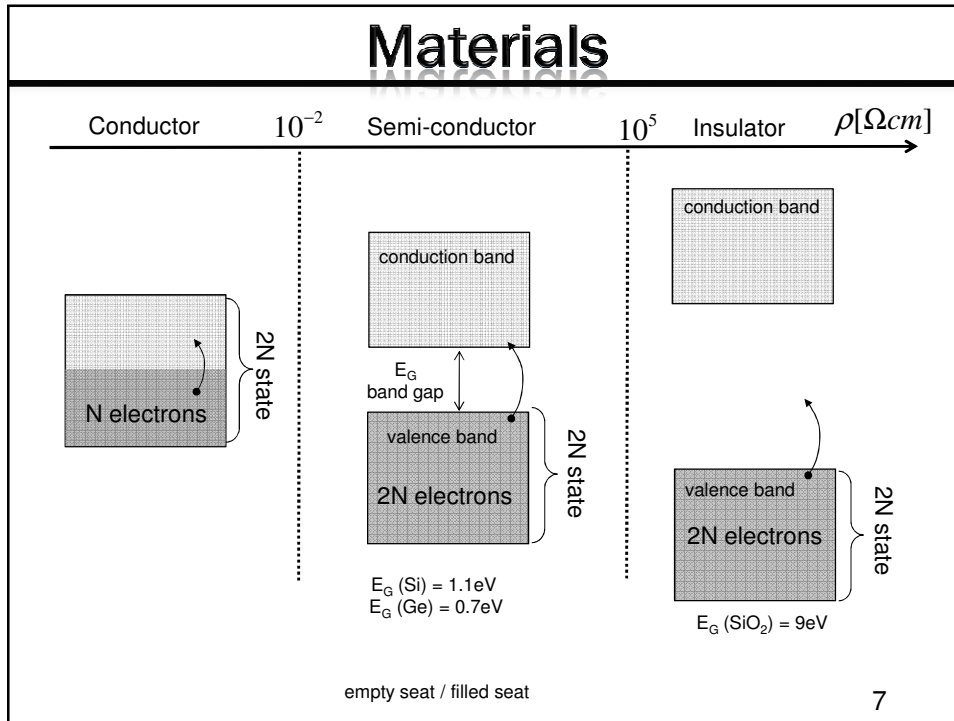


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Bohr Atomic Model

single atom	2 atoms	N atoms
		
		
Pauli exclusion principle		

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Intrinsic Semiconductor

Valence electrons

Free electron

Broken covalent bond

Covalent bond

Si-Si covalent bonds

n_0 electron density
 p_0 hole density
 $n_0 = p_0 = n_i$
 $n_i = AT^{3/2}e^{-E_G/KT}$

$n_i|_{T=300^{\circ}K} = 10^{10} / cm^3 \ll n(Si) = 2 \times 10^{23} / cm^3$
 ☹️ useless!!!

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n-type Semiconductor

Valence electrons

Covalent bonds

Donor: P, As, Sb

n_0 electron density
 p_0 hole density
 $n_0 = N_D$
 $n_0 p_0 = n_i^2$

Free electron donated by impurity atom

Penta-valent impurity atom (donor)

Silicon atoms

N_D up to $10^{19} / cm^3$ ☺️ $n(Si) = 2 \times 10^{23} / cm^3$

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p-type Semiconductor

Acceptor: B, Ga, In

n_0 electron density

p_0 hole density

$p_0 = N_A$

$n_0 p_0 = n_i^2$

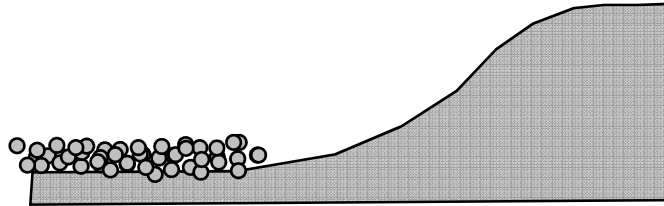
N_A up to $10^{19} / \text{cm}^3$ 😊 $n(\text{Si}) = 2 \times 10^{23} / \text{cm}^3$

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Energy Diagrams

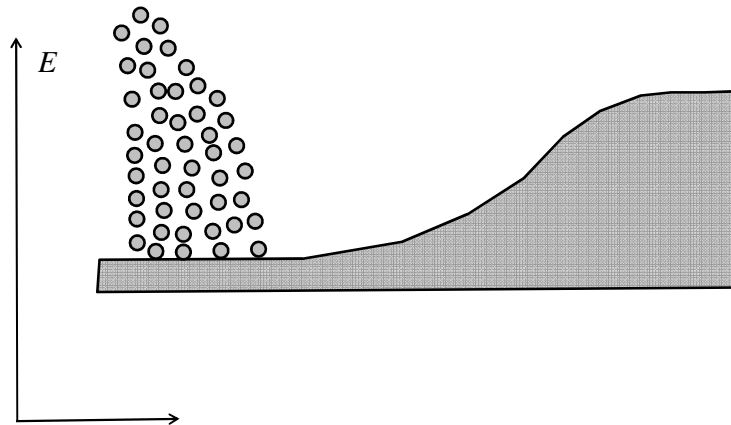
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Energy Diagrams



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Energy Diagrams



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Density of States

Azadi stadium



Boxing stadium



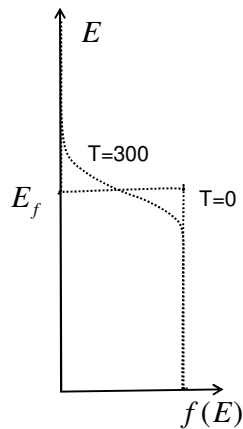
In Stadium: Number of available seats could be a function of distance from the center so

N: number of available states for the electrons could be function of "Energy" : $N(E)$

Seats are not the same for fans so empty states for electrons!

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Fermi Distribution



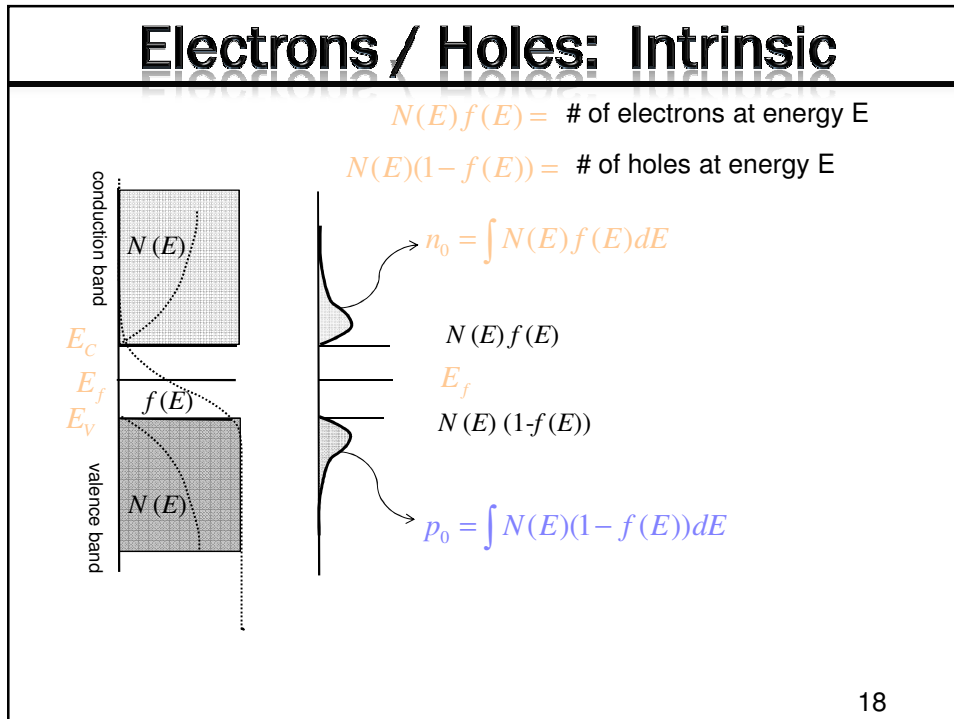
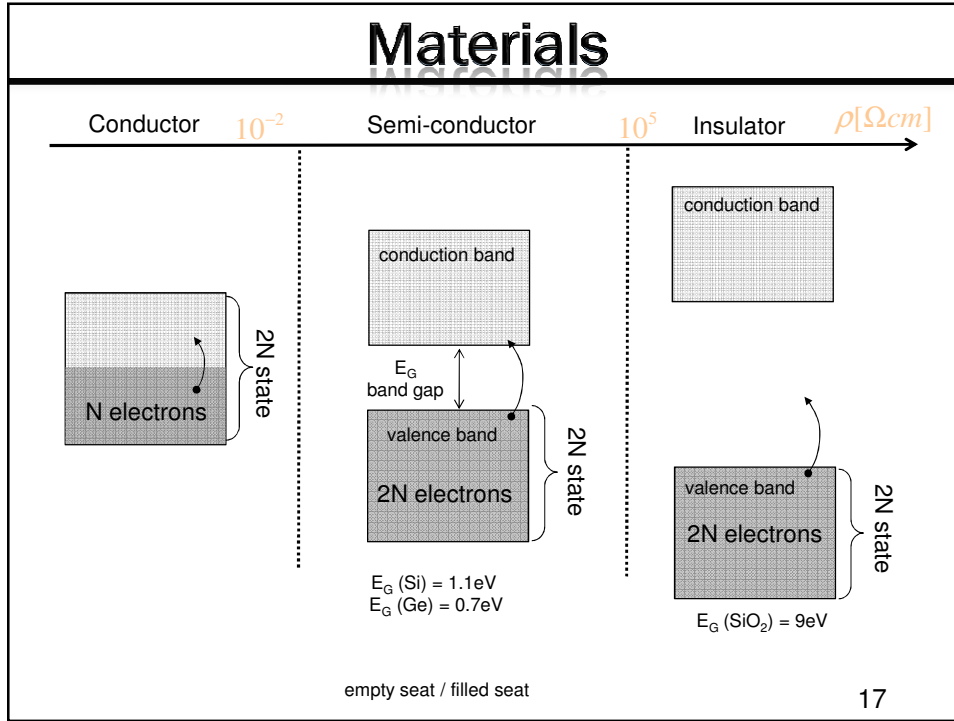
$f(E)$ probability of occupation of state at energy E by electrons

$$f(E) = \frac{1}{1 + e^{(E-E_f)/kT}}$$

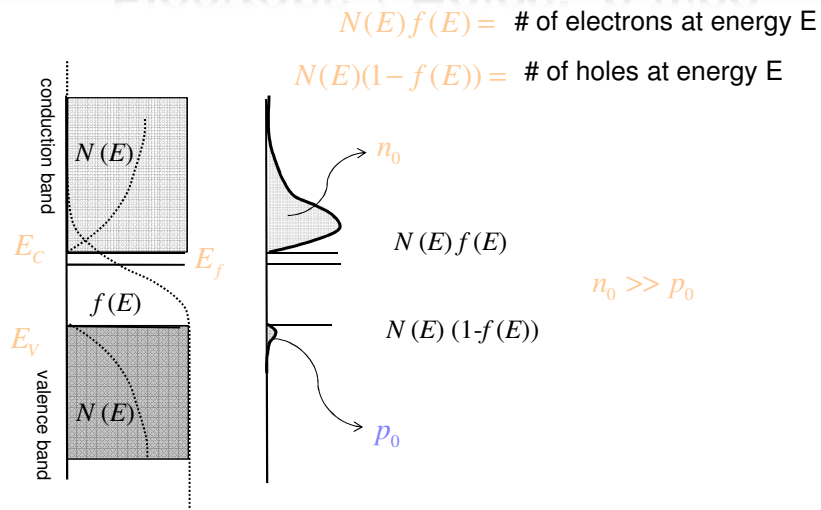
$N(E)f(E) =$ # of electrons at energy E

$N(E)(1 - f(E)) =$ # of holes at energy E

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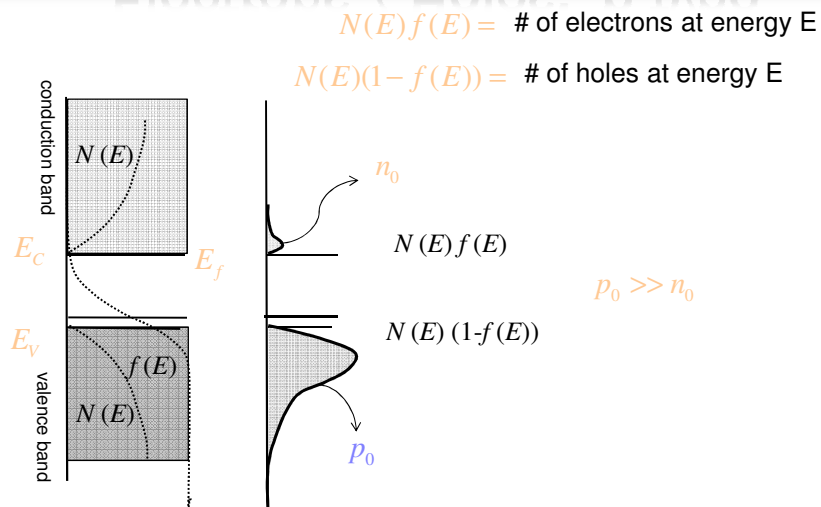


Electrons / Holes: n-type

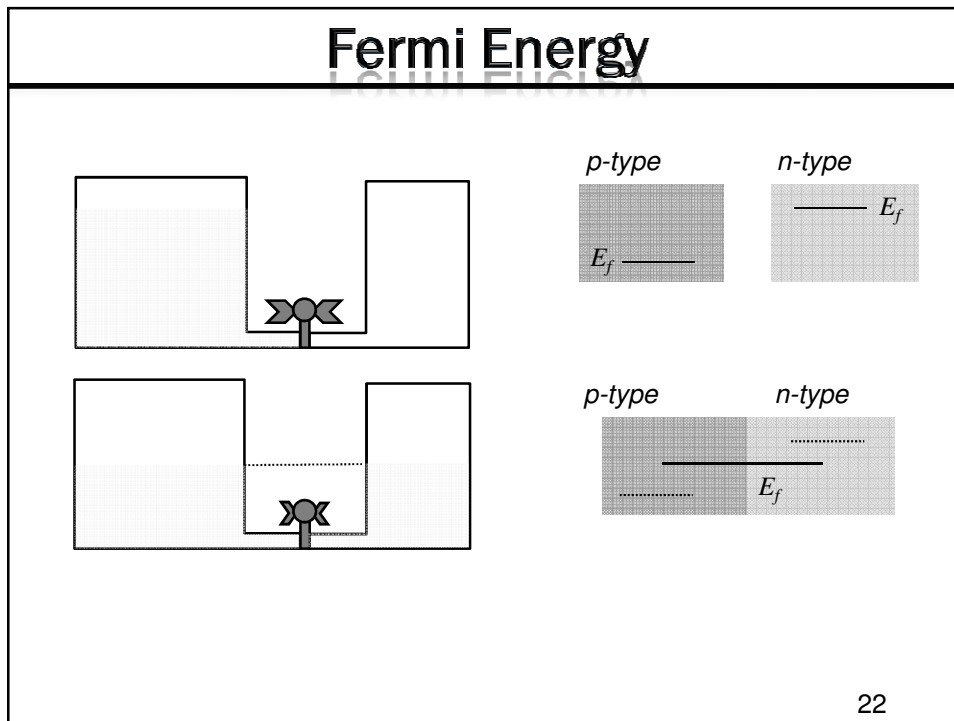
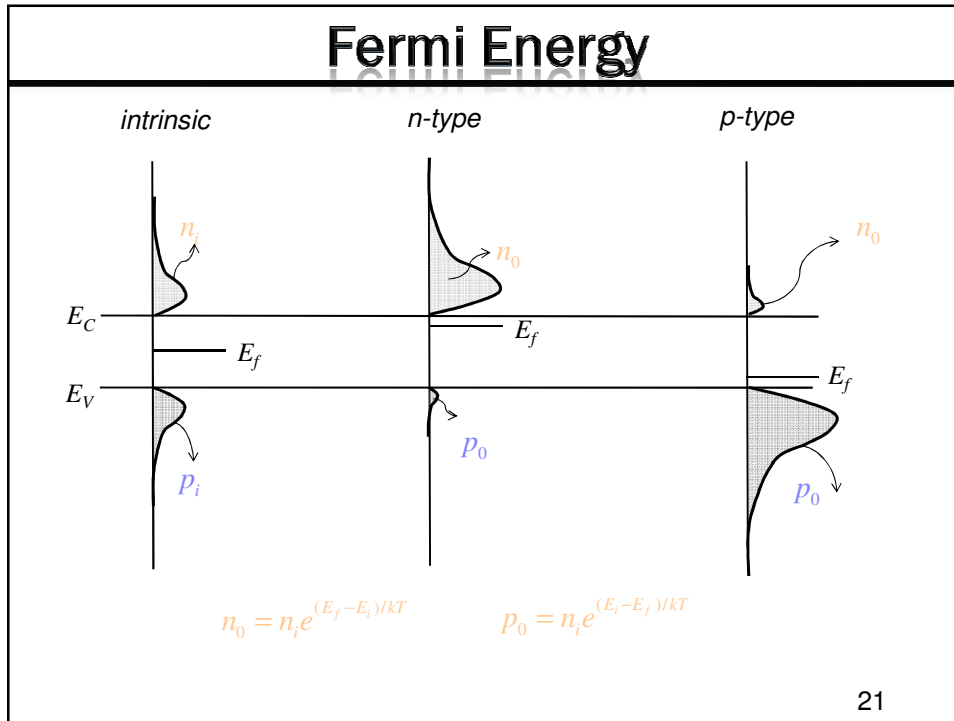


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Electrons / Holes: p-type



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Flow of Charge

Drift

$v_p = \mu_p E$ $v_n = \mu_n E$

$$J = q(n\mu_n + p\mu_p)E$$

Diffusion

Charges move to be evenly distributed throughout space
Similar to perfume in room or heat in a solid

$$J_n = qD_n \frac{dn}{dx}$$

$$J_p = -qD_p \frac{dp}{dx}$$

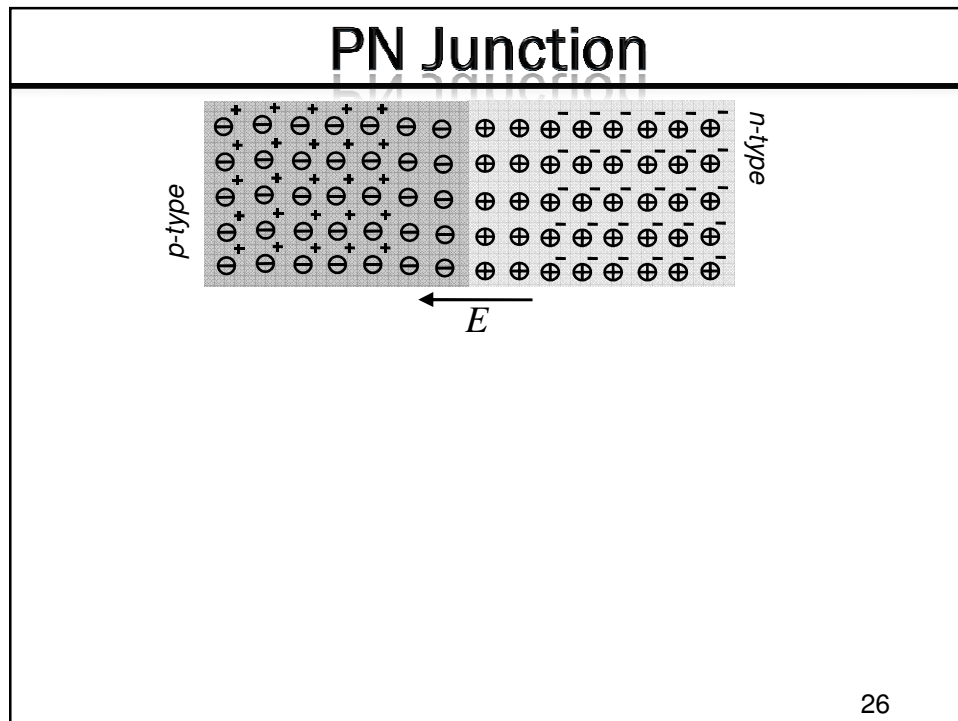
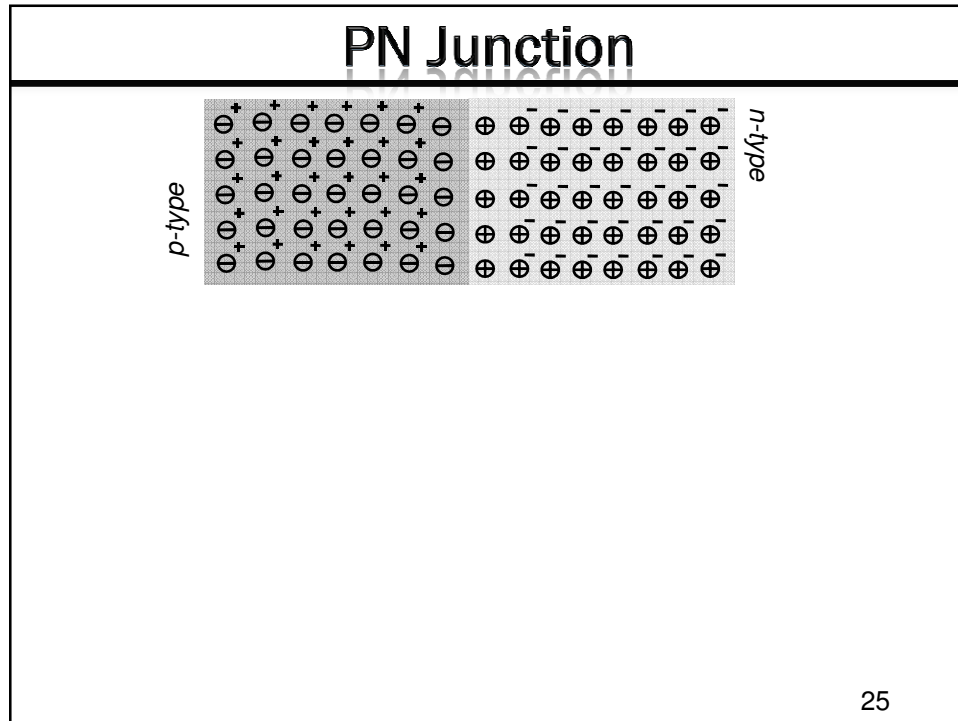
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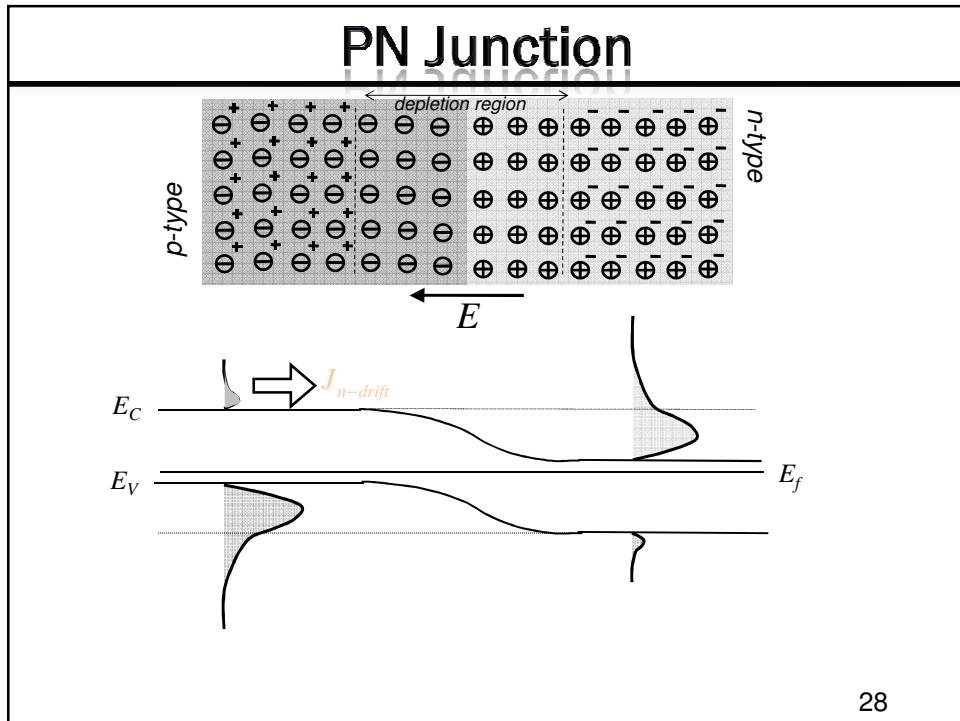
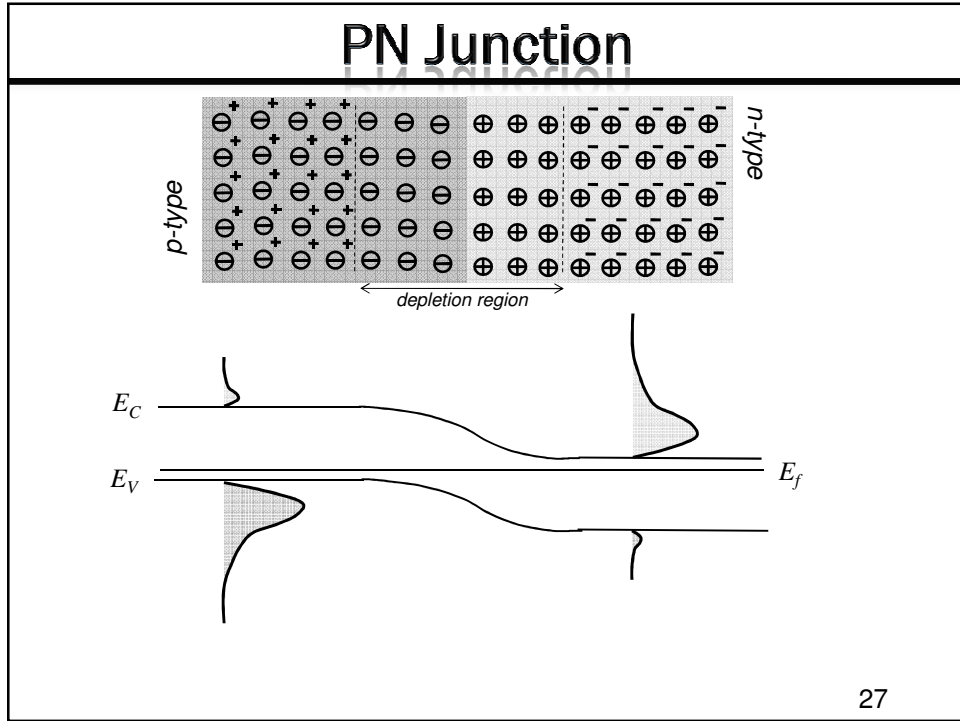
PN Junction

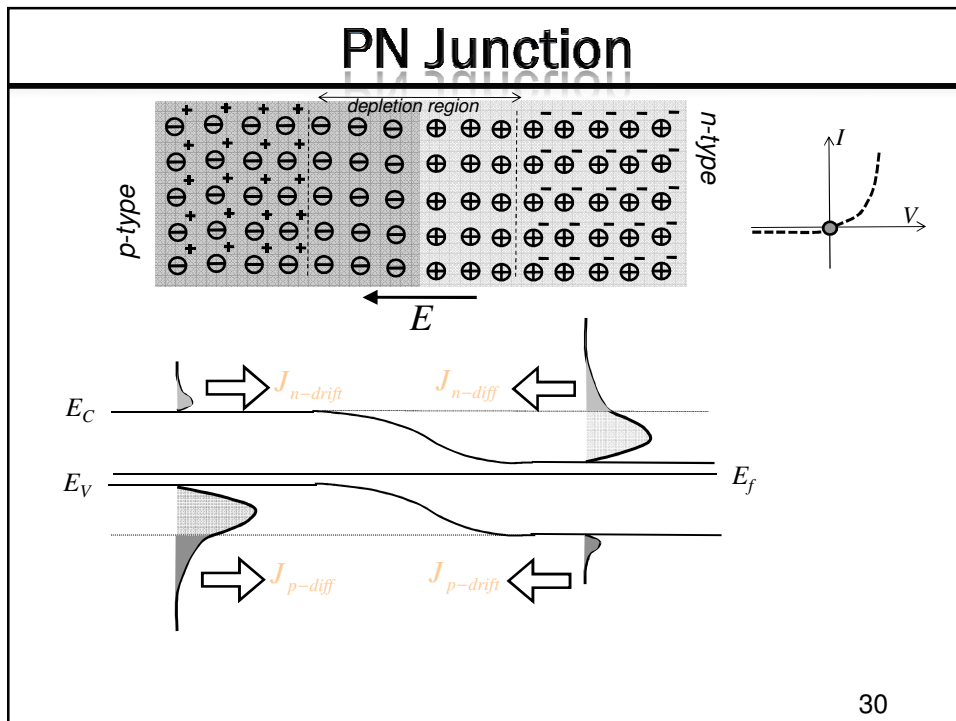
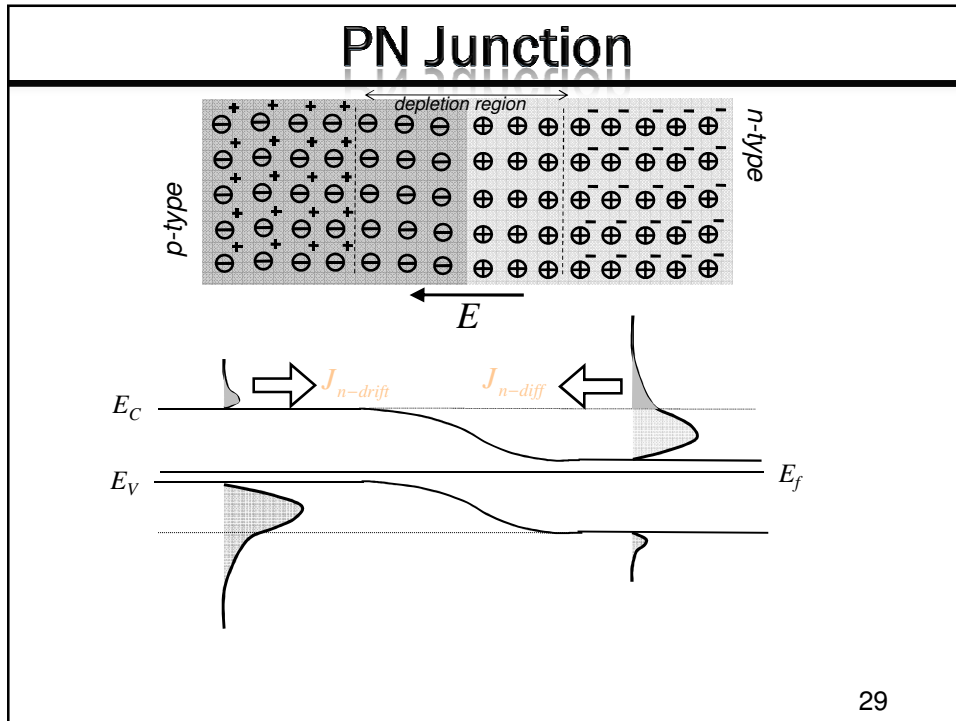
p-type

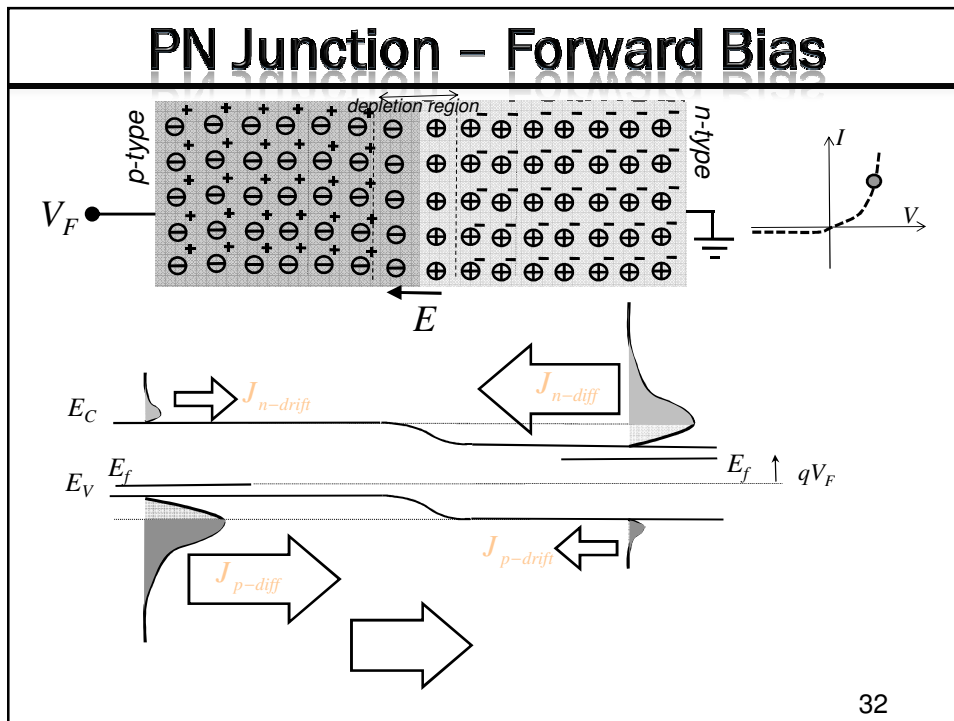
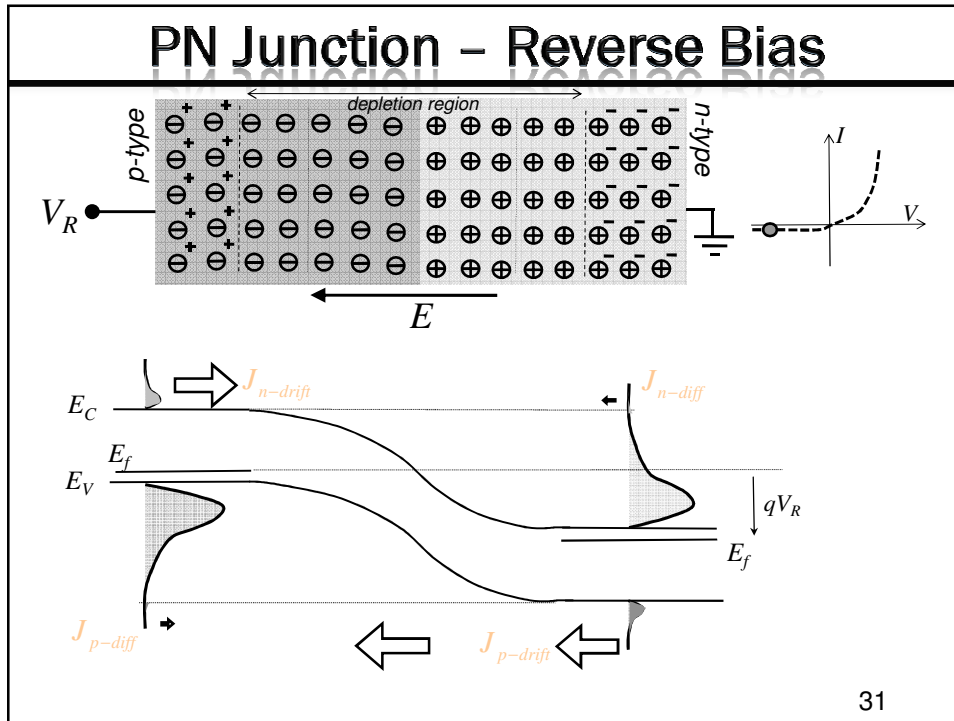
n-type

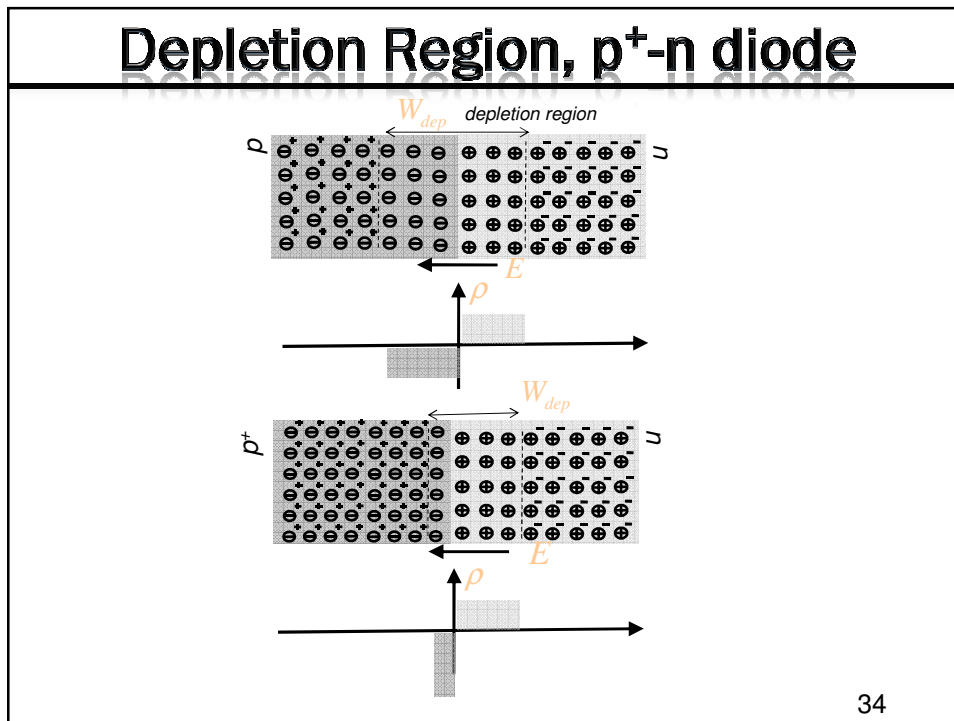
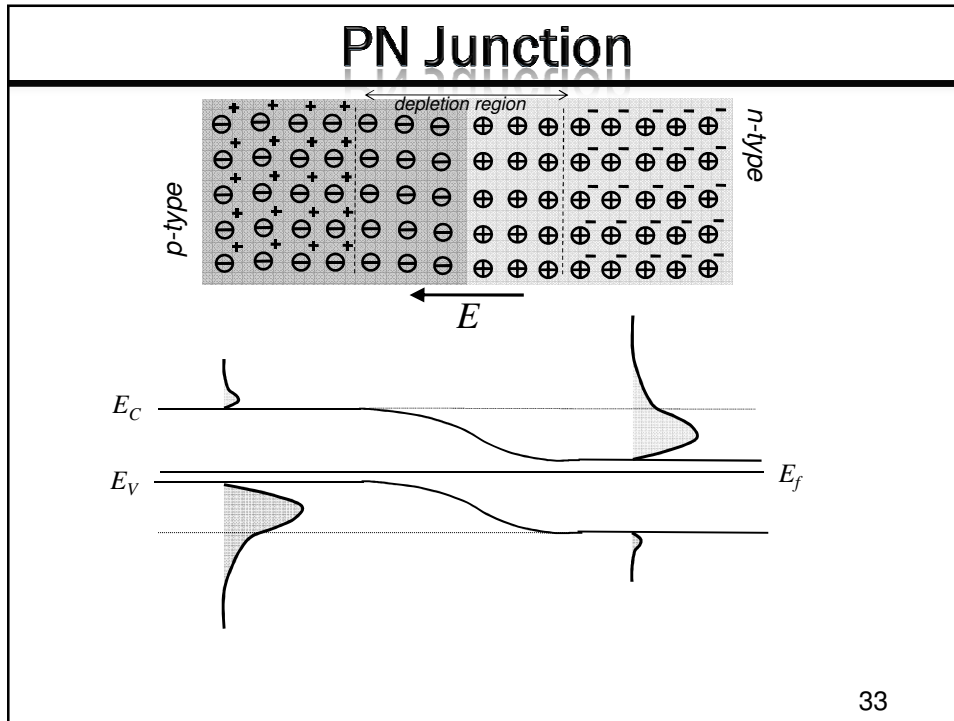
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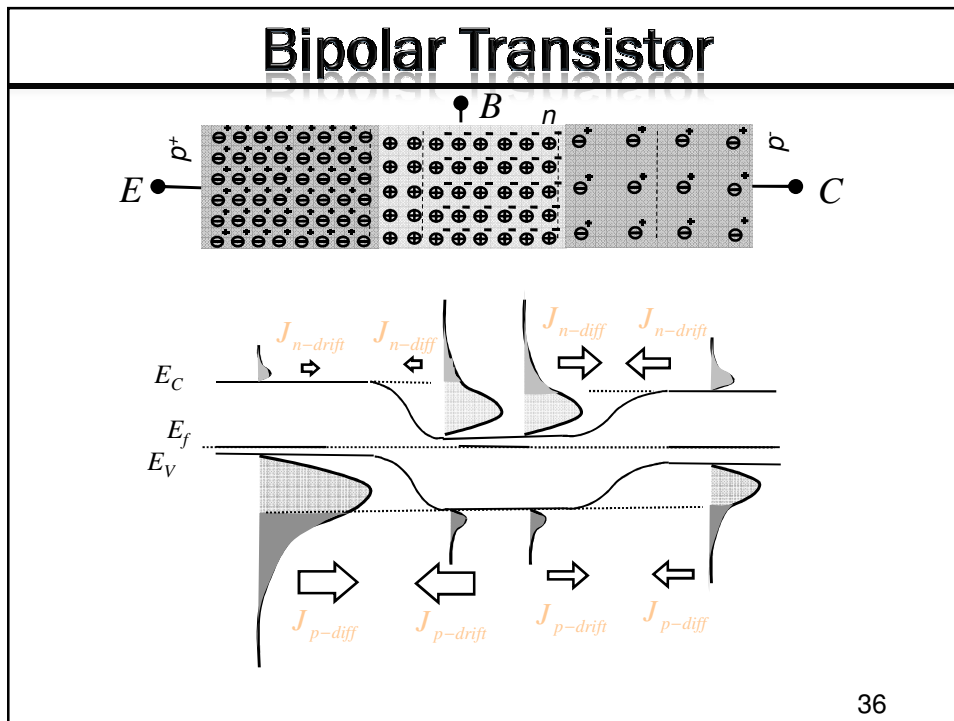
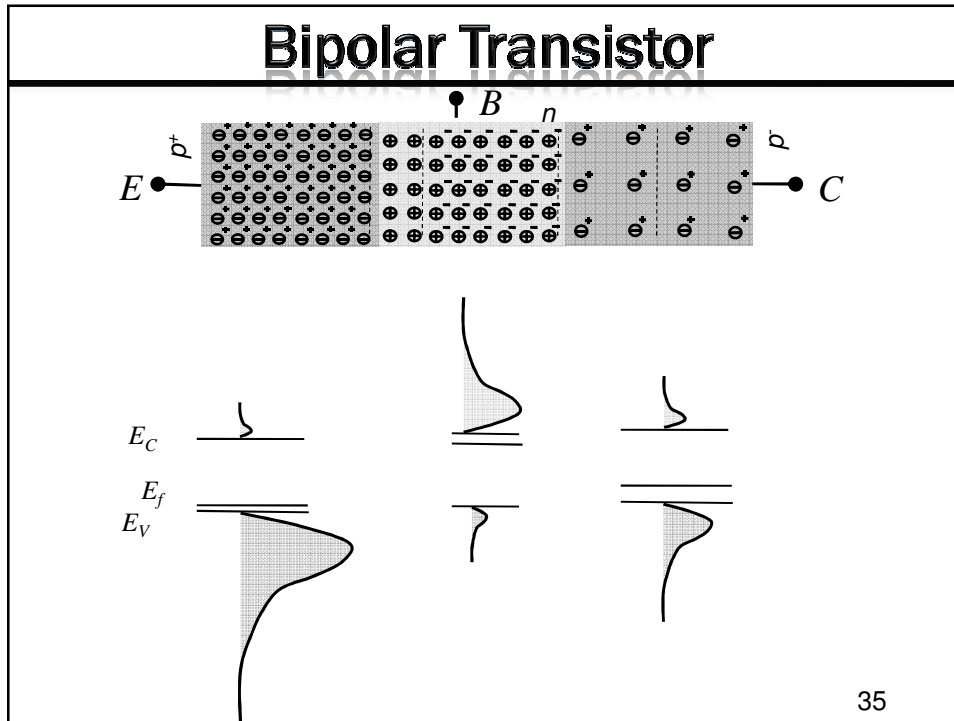


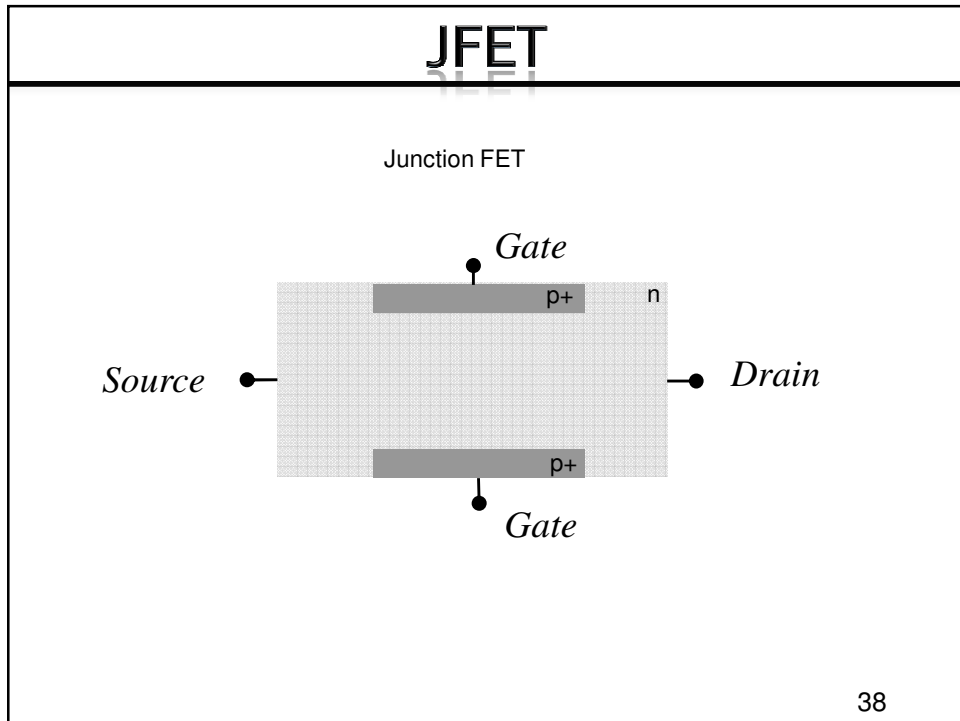
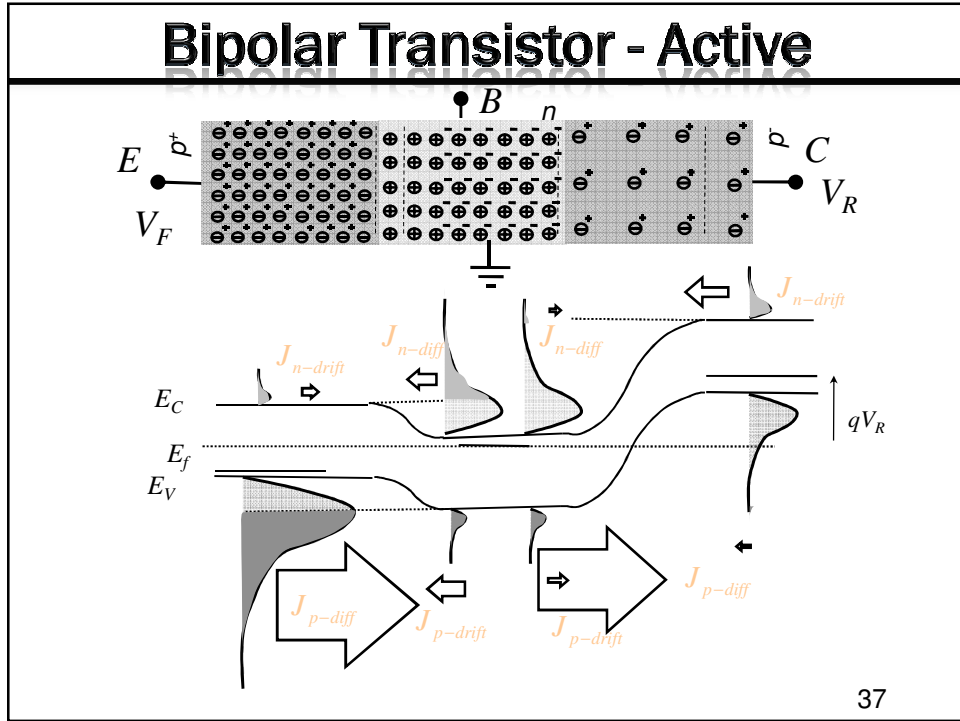


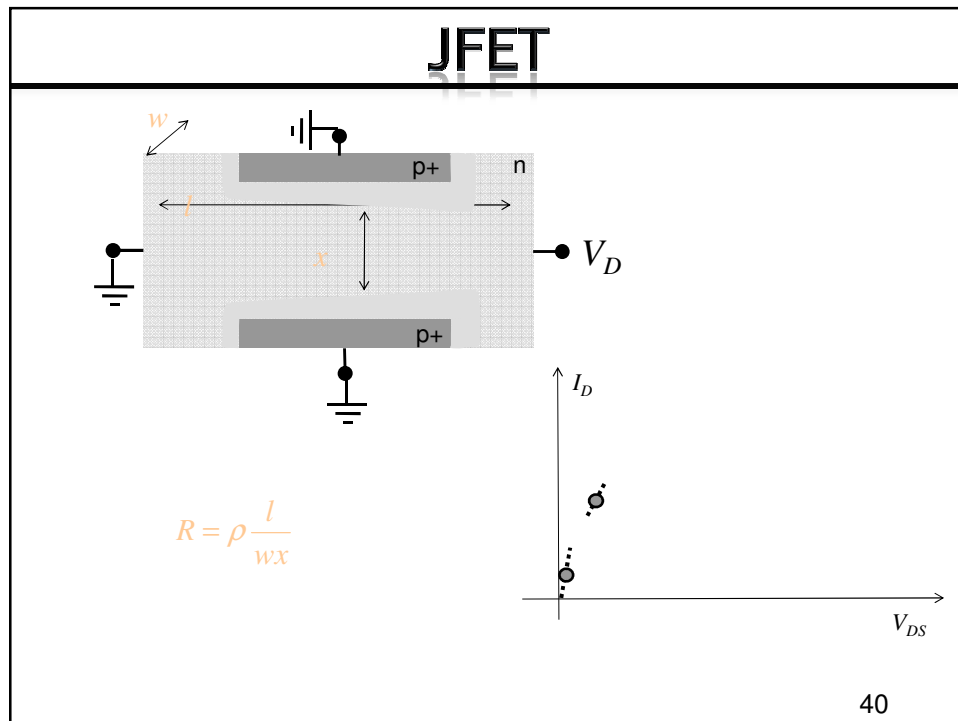
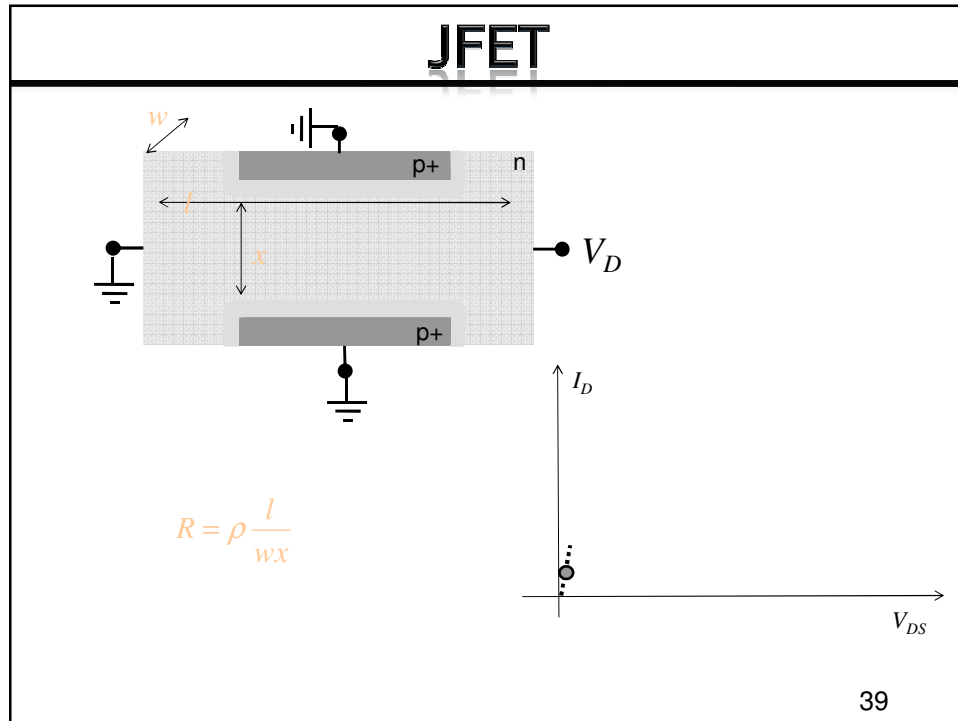


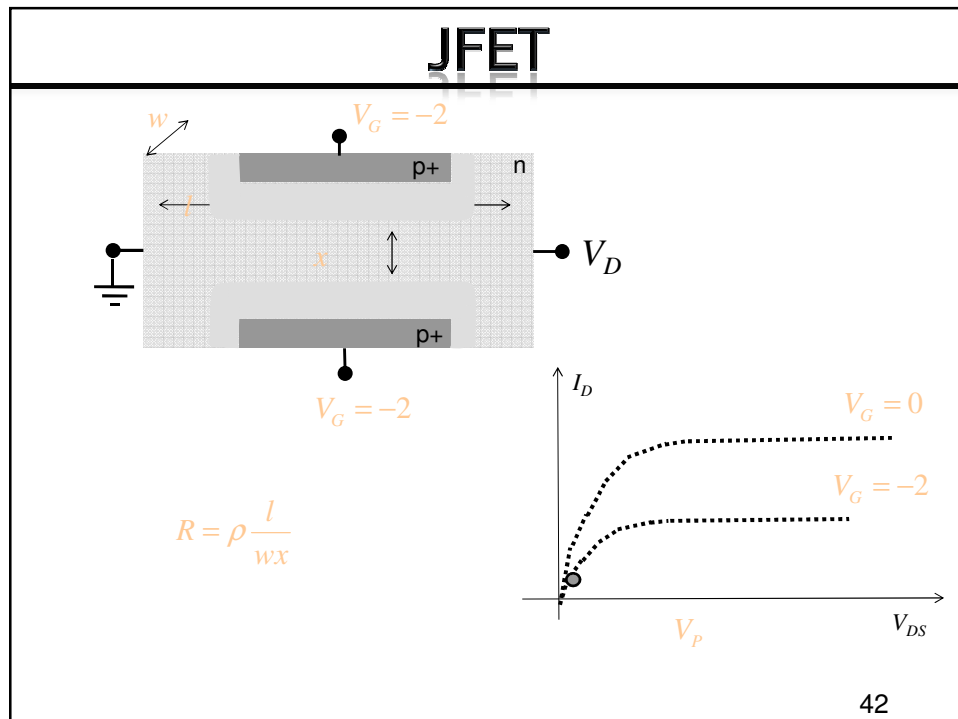
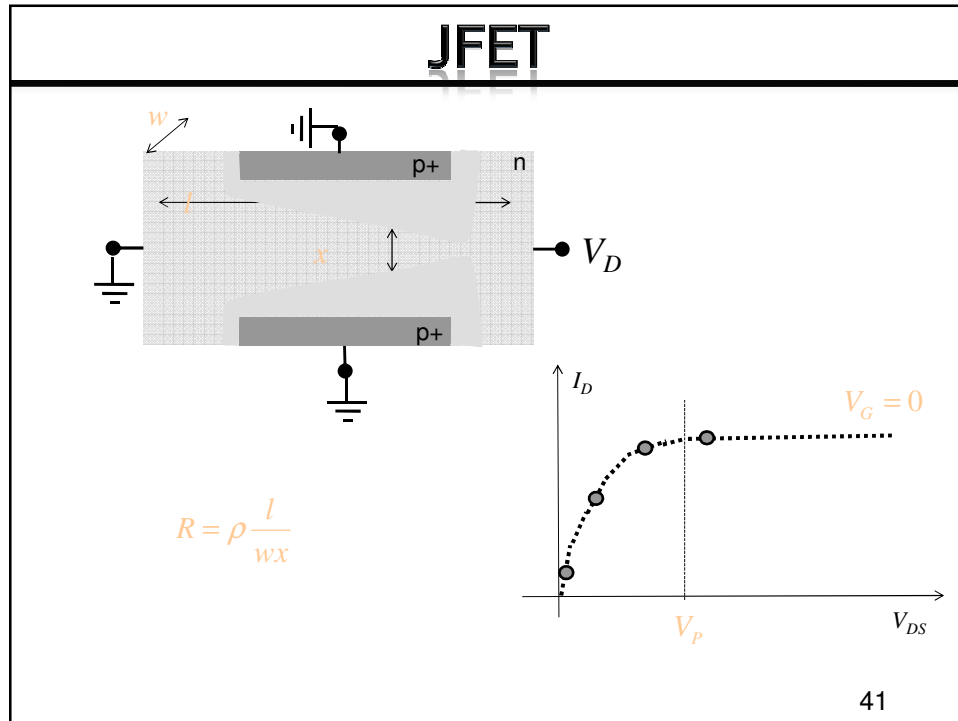




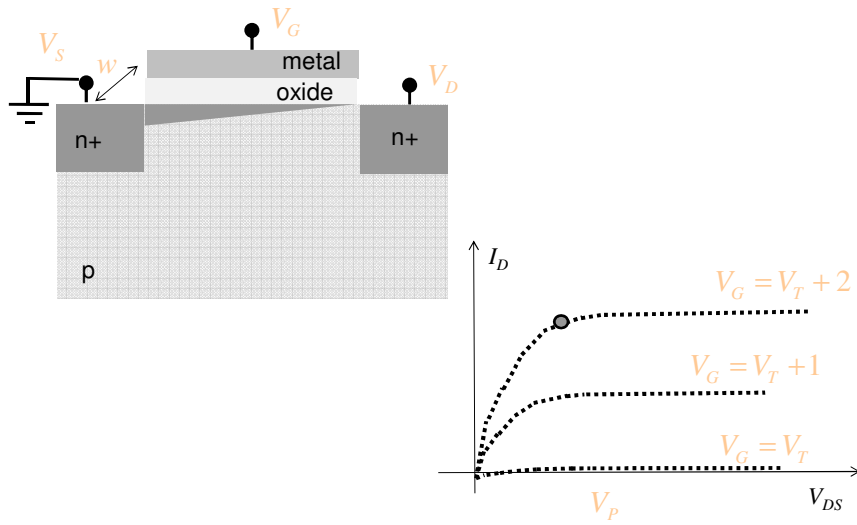








MOSFET



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Thank you

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