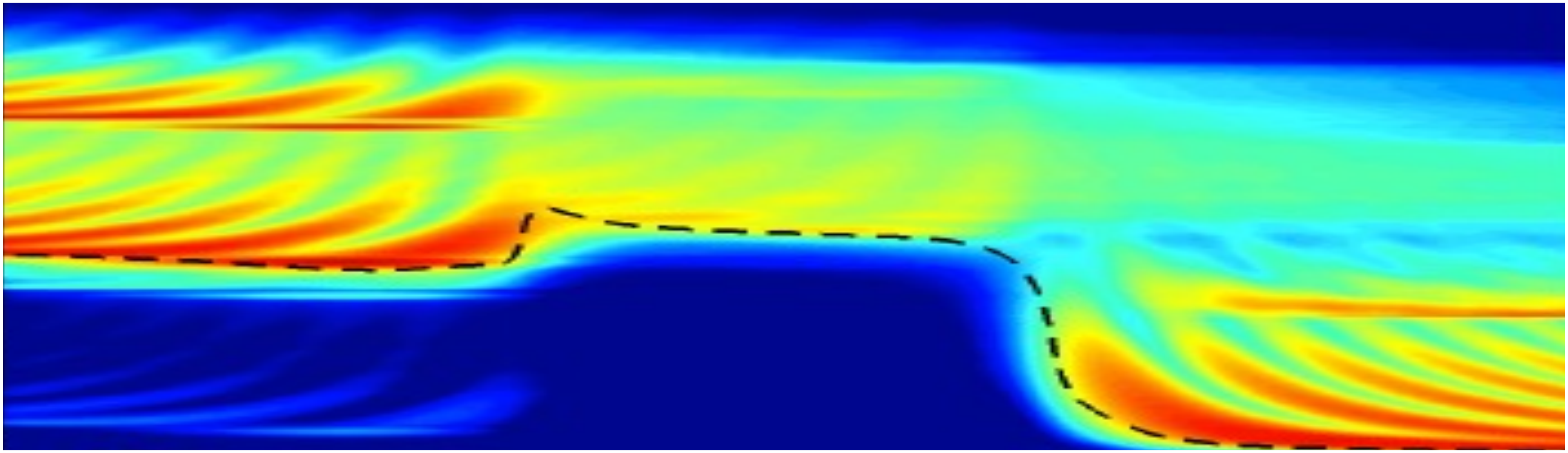

EECS 16B
Designing Information Devices and Systems II
Lecture 9

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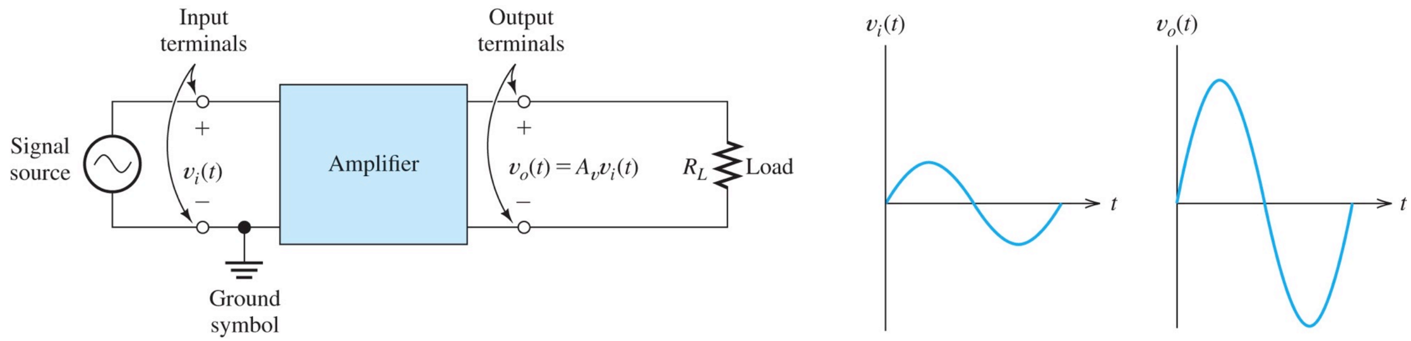
Devices

- Outline
  - Amplifiers and Devices

- Reading-slides

Active Devices



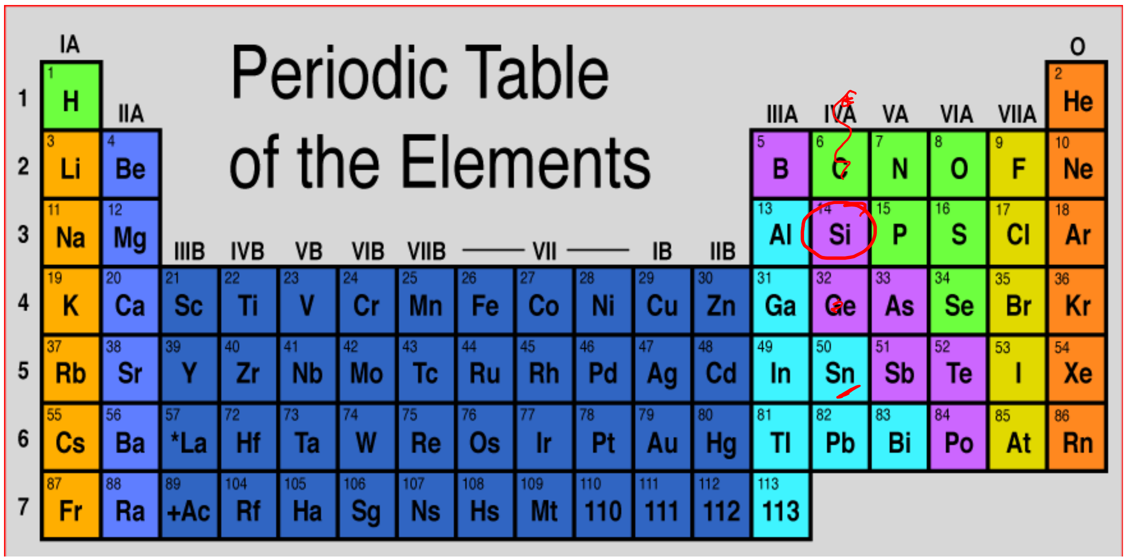
- Active devices are made of semiconductors
- Semi-conductors are materials whose resistance is in between a metal and insulator

Half

- More interestingly, one is able to change the resistance of the semiconductor materials by using external control such as voltage or current

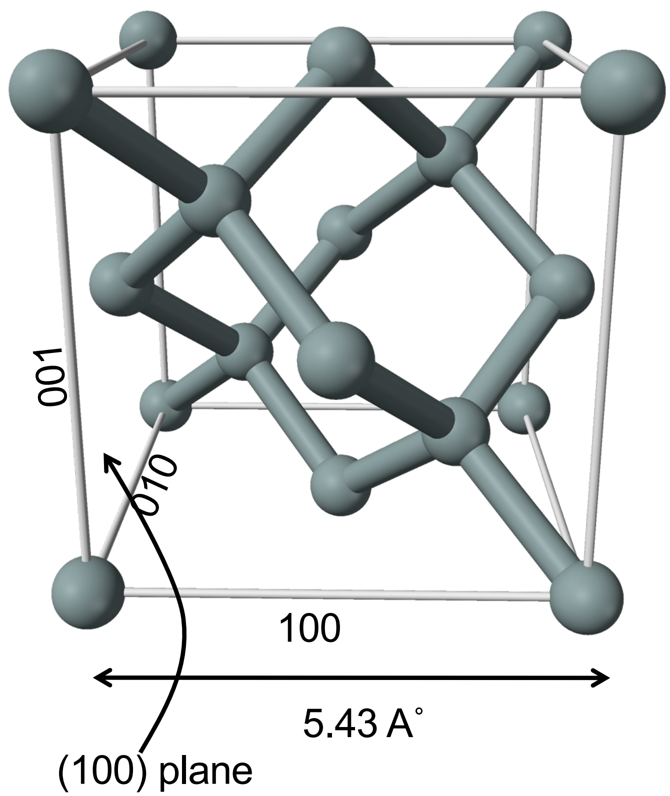
Semiconductors

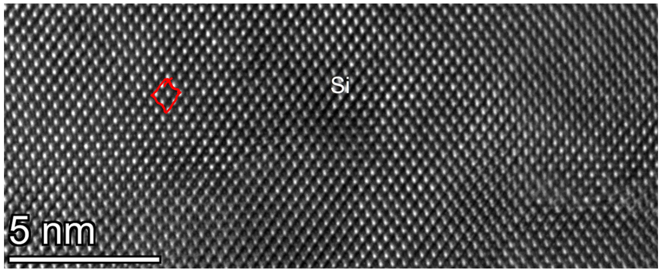
- Semiconductors are **usually** made of group IV elements- atoms that contain, on average, four valence electrons
- Most Common semiconductor used in electronic devices is **Silicon**



Crystal Structure of Si

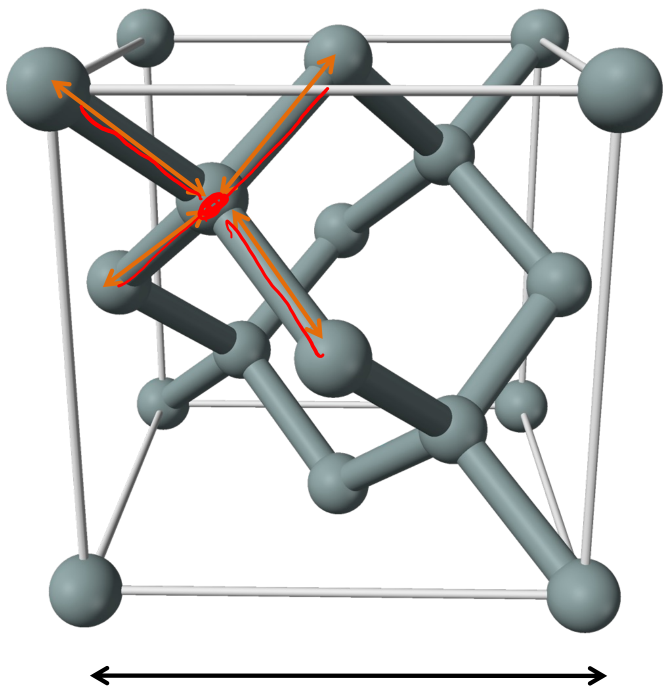
Often known as the diamond lattice





Transmission Electron Microscopy Image of Si taken at Lawrence Berkeley National Laboratorys

Crystal Structure of Si



5.43 A°

Each atom has 4 nearest neighbors

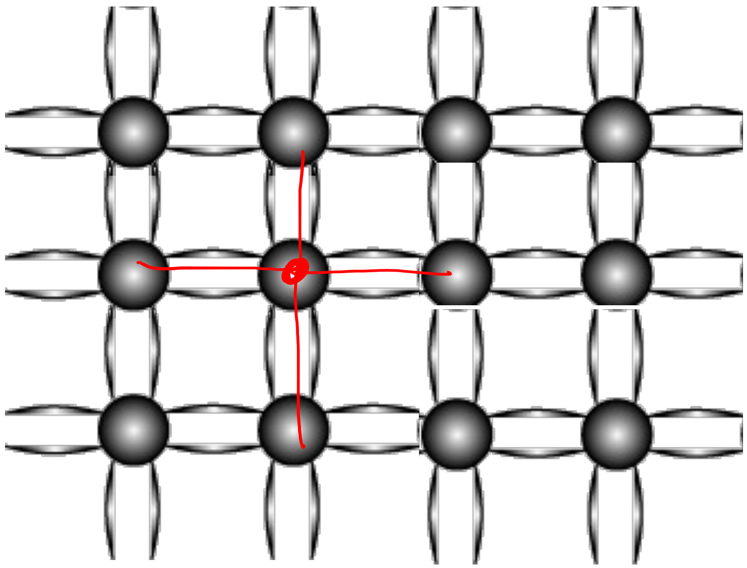
Si(14)=$1S^2 2S^2 2P^6 3S^2 3P^2$

4 valence electrons

Each atom shares 2 electrons with 4 nearest neighbors to form a covalent bond

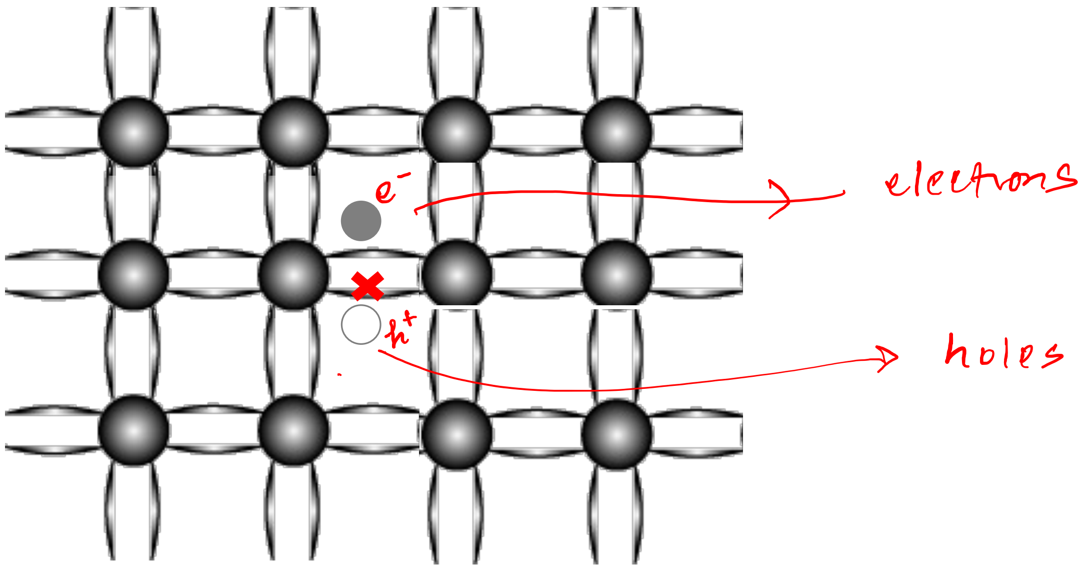
The Bond Model

Each atom shares 2 electrons with 4 nearest neighbors to form a covalent bond



At T=0K, all bonds are satisfied, there are no **free** carriers, no current flows, looks like an insulator

Intrinsic Si: The Bond Model: Electrons

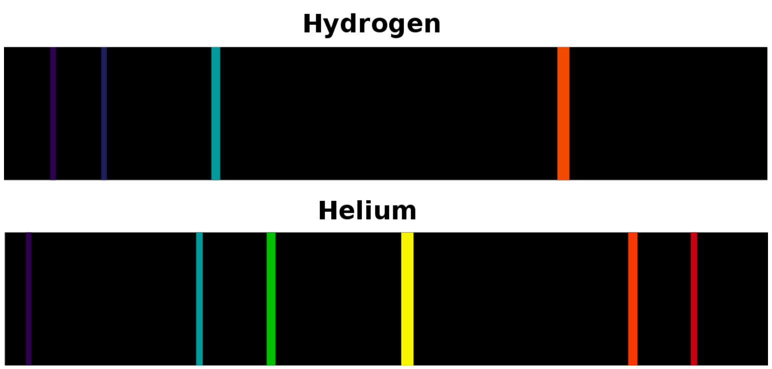


At finite temperature, an electron may gain enough energy to break the covalent bond, become **free** and move around.

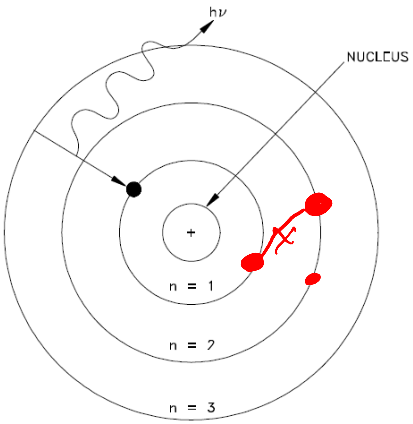
Energy Band Model

Electrons around nucleus

It was known from John Herschel's experiment in (1826) that heated gas emits a unique combination of colors

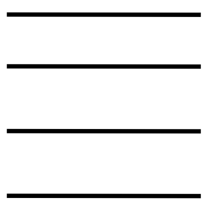


- In 1913 Niels Bohr proposed an atomic model that assumes electrons are orbiting around a positively charged nucleus in **specific shells**

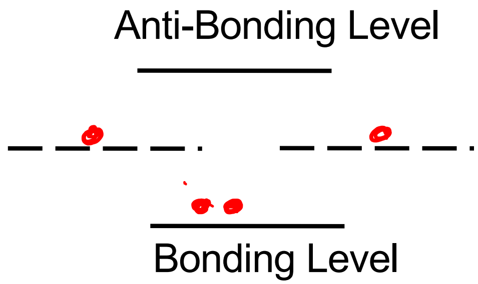


- When heated electrons can absorb the energy and go from shell 1 to 2. When cooling down, it comes down to 1, **emitting** the specific energy difference between 2 and 1 giving a specific color of light.

Energy Levels and Formation of a Molecule



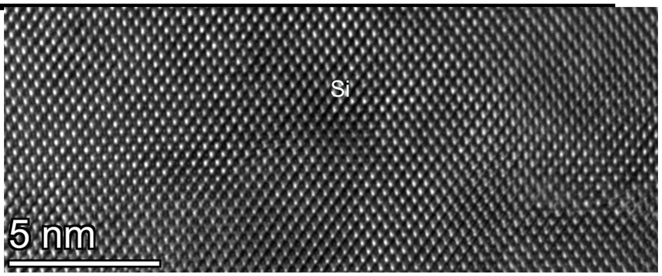
Discrete energy levels in an atom

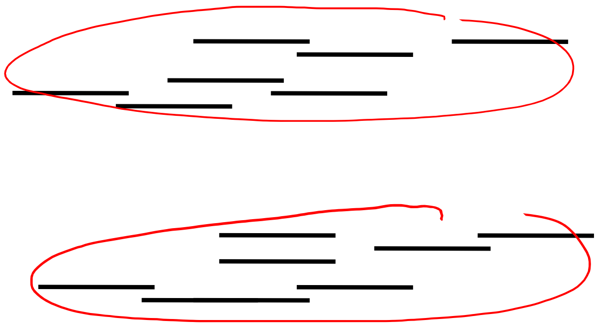


When energy levels of two atoms interact, they create one bonding and one anti-bonding level

Energy Bands

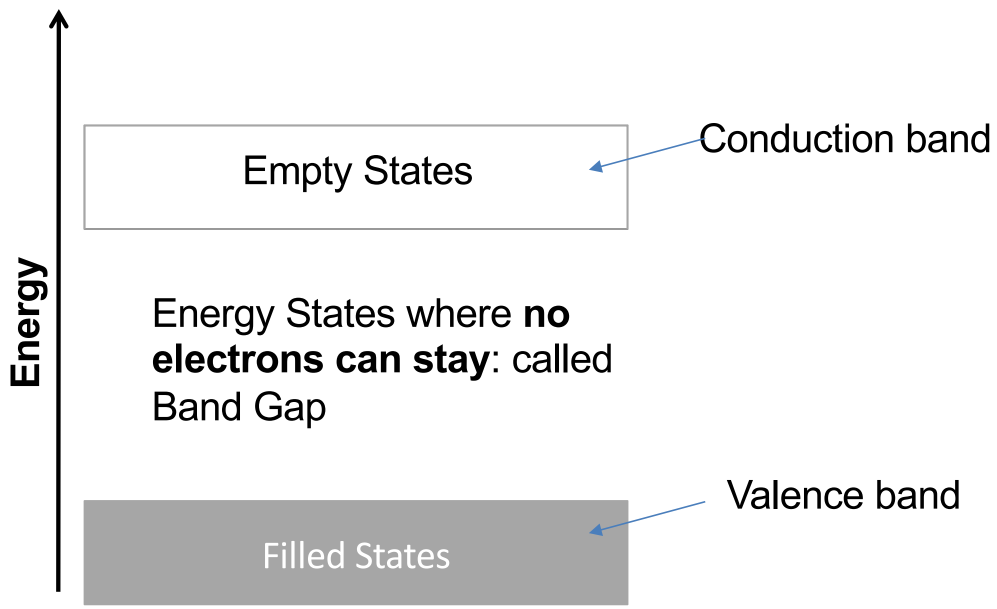
In a solid as many atoms are brought close to each other they create many many bonding and anti-bonding levels



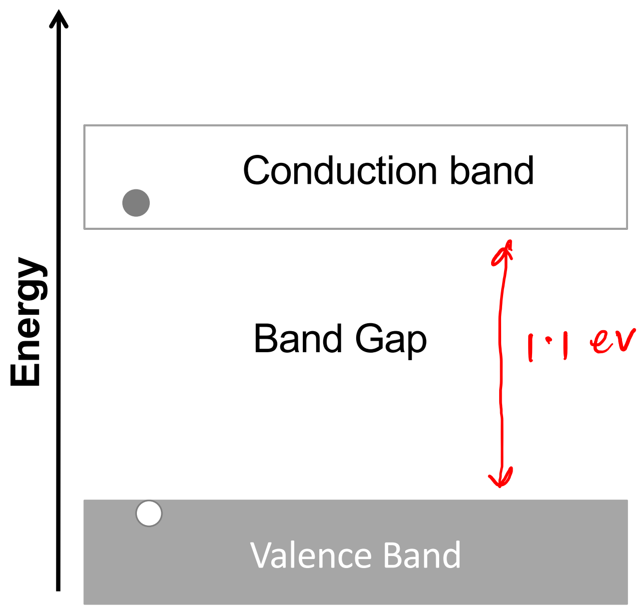


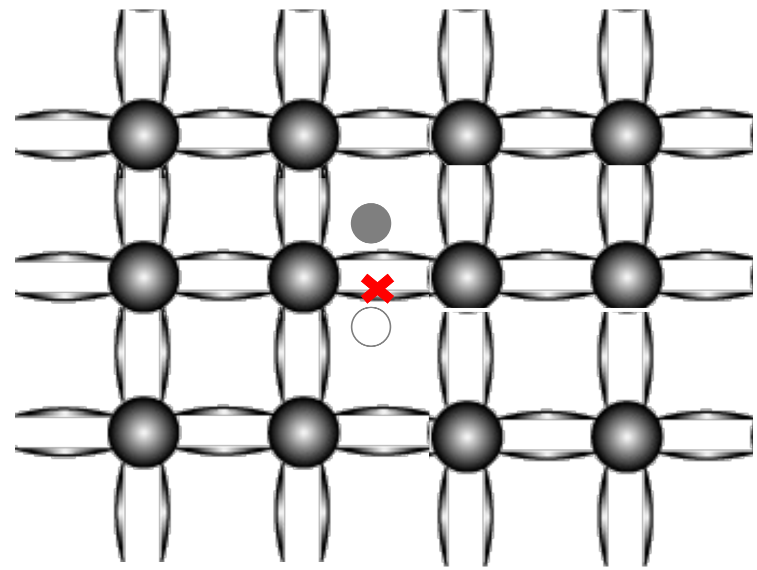
Energy Bands

Energy Bands



Energy Bands

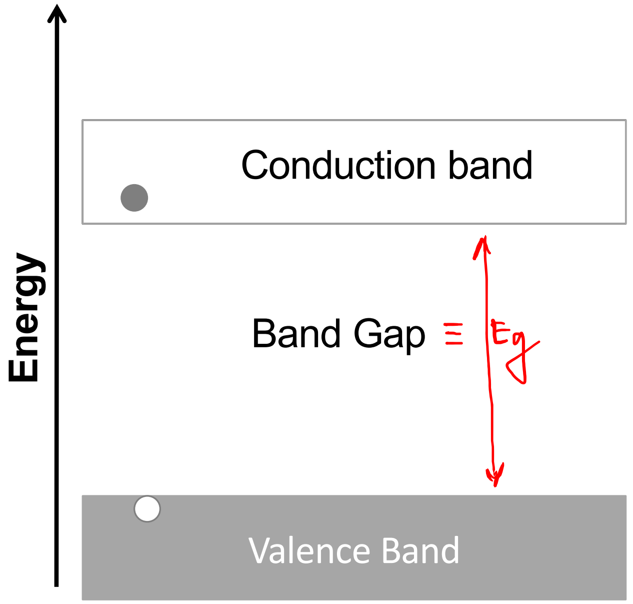




$k_B T \sim 26$ meV

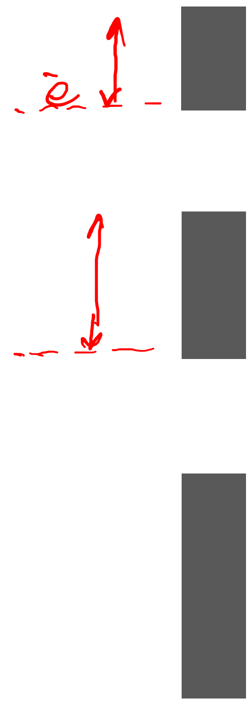
→ Boltzmann constant

Probability of an electron being free



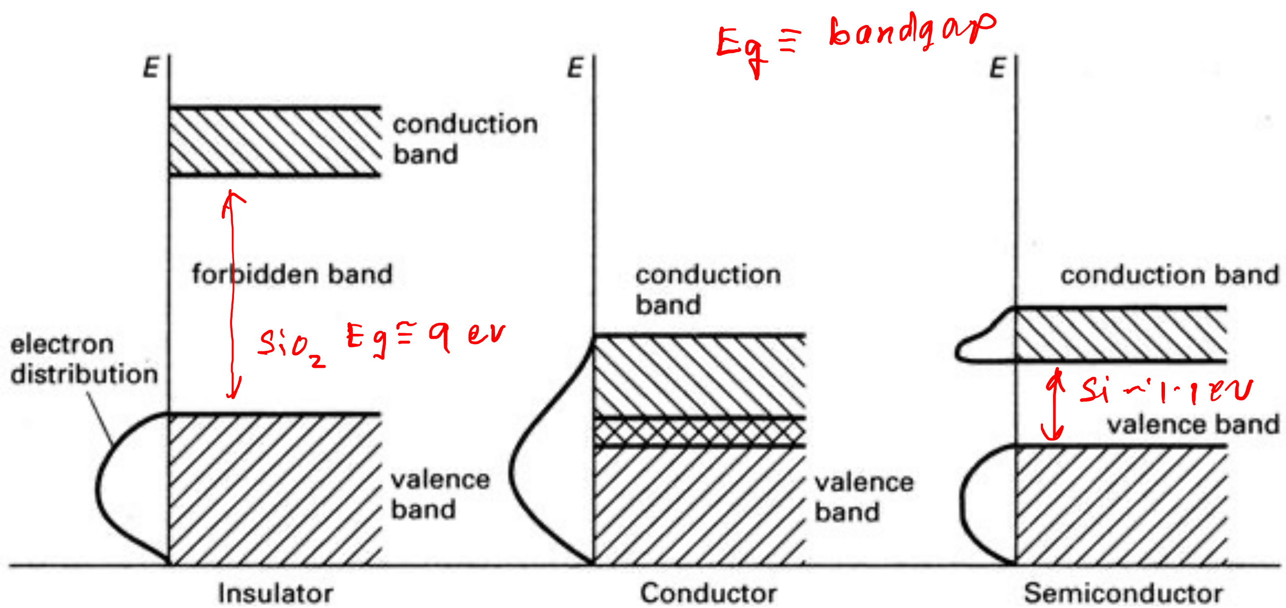
Probability of finding an electron in the conduction band

$p \propto e^{-A E_g}$



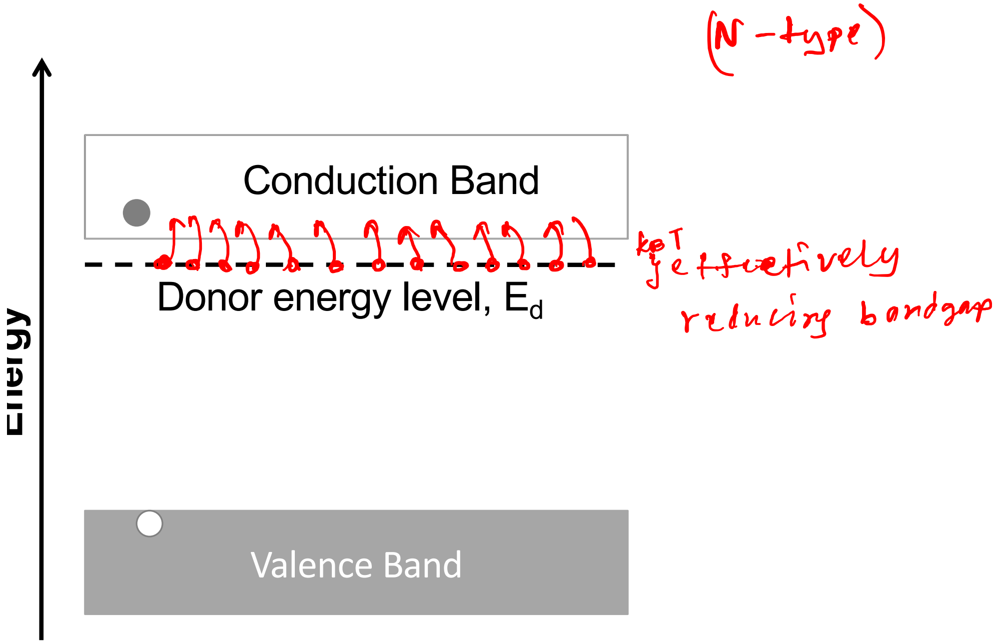
Probability of an electron being able to find itself in the conduction band becomes **exponentially smaller** with **increasing bandgap**

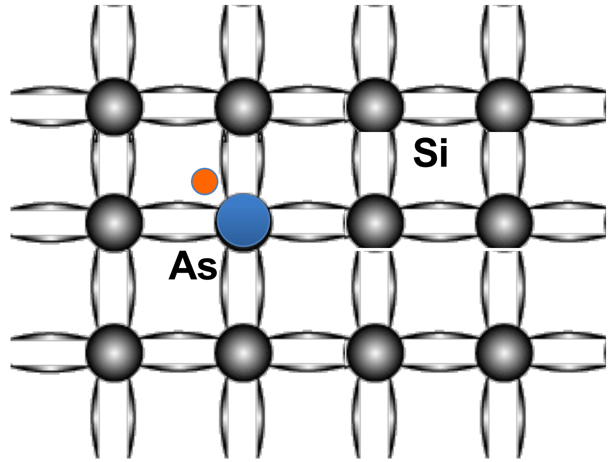
Semiconductors, Insulators and Conductors



✓Conductors have half filled bands
✓Semiconductors have lower energy gap compared to insulators and can be doped

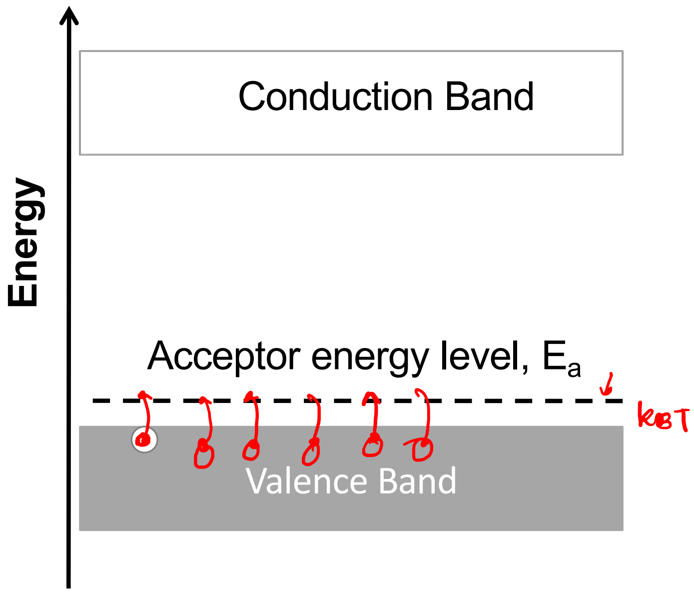
Doping

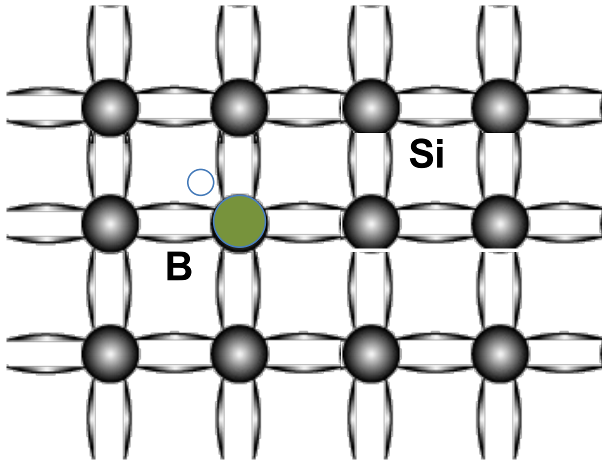




	III	IV	V	
	Boron (B)	Carbon (C)		
. . .	Aluminum (Al)	Silicon (Si)	Phosphorous (P)	. . .
	Galium (Al)	Germanium (Ge)	Arsenic (As)	
		. . .		

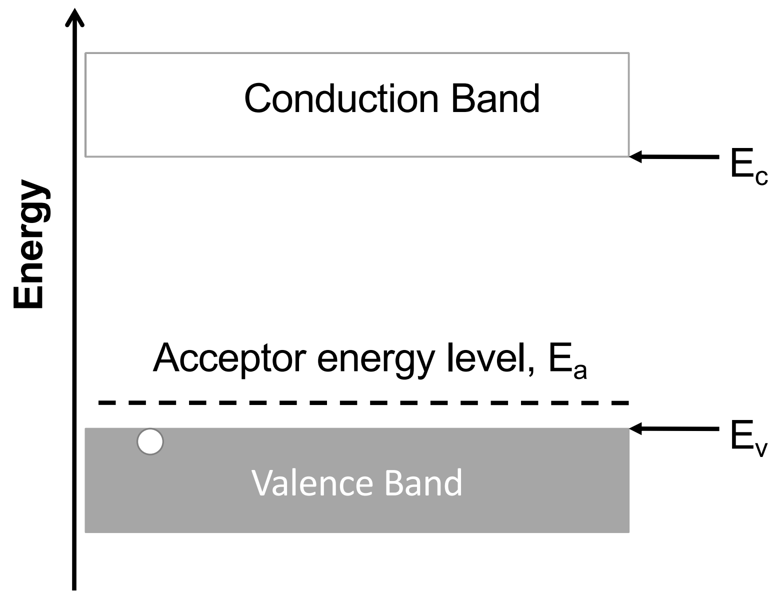
Doping





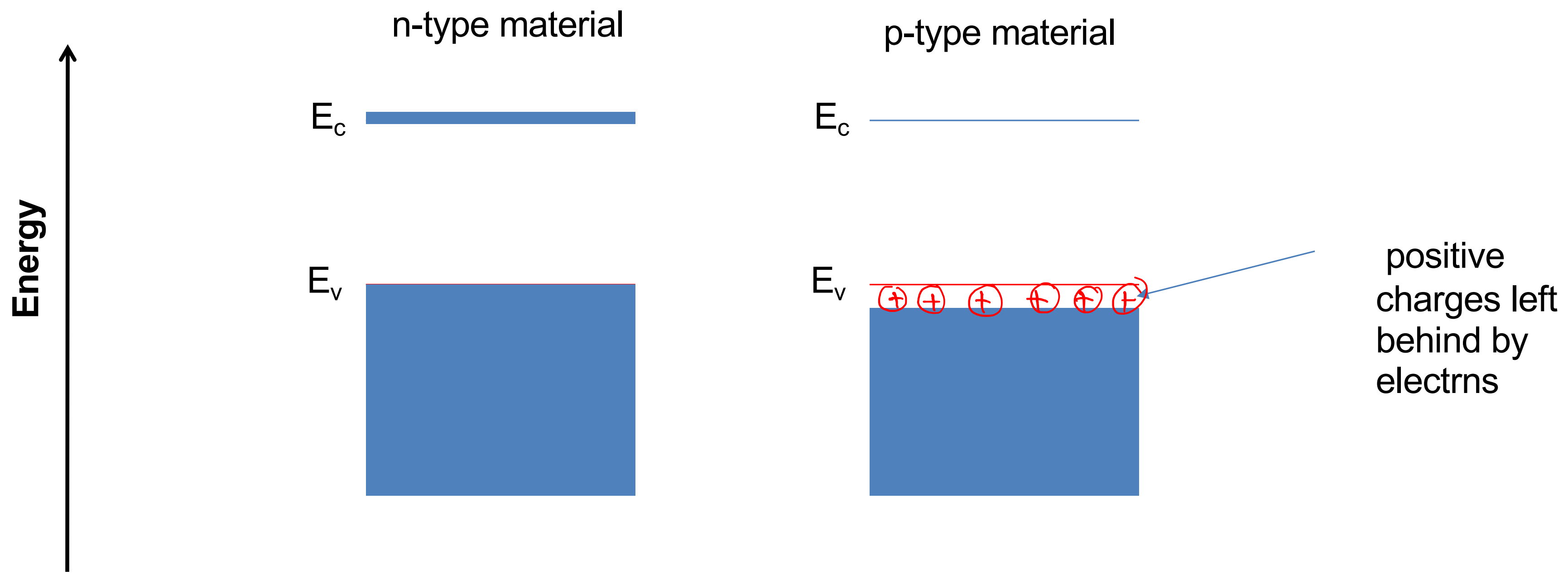
	III	IV	V	
	Boron (B)	Carbon (C)		
. . .	Aluminum (Al)	Silicon (Si)	Phosphorous (P)	. . .
	Galium (Al)	Germanium (Ge)	Arsenic (As)	
		⋮		

A convention about energy bands



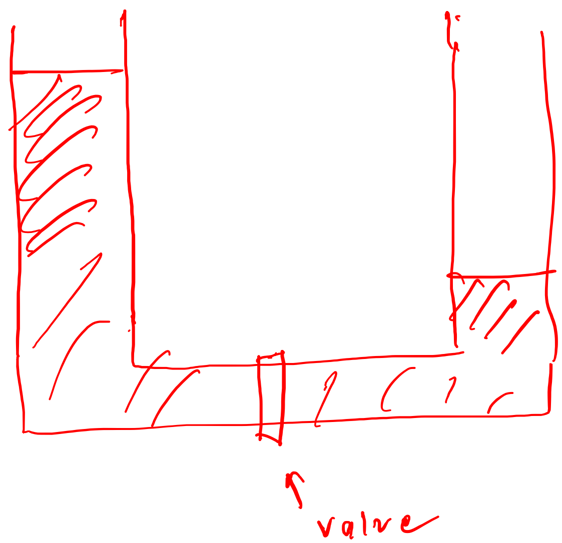
Only the edge of the bands are shown where the difference between the two edges is the bandgap

N and P type Materials, Junctions and Devices



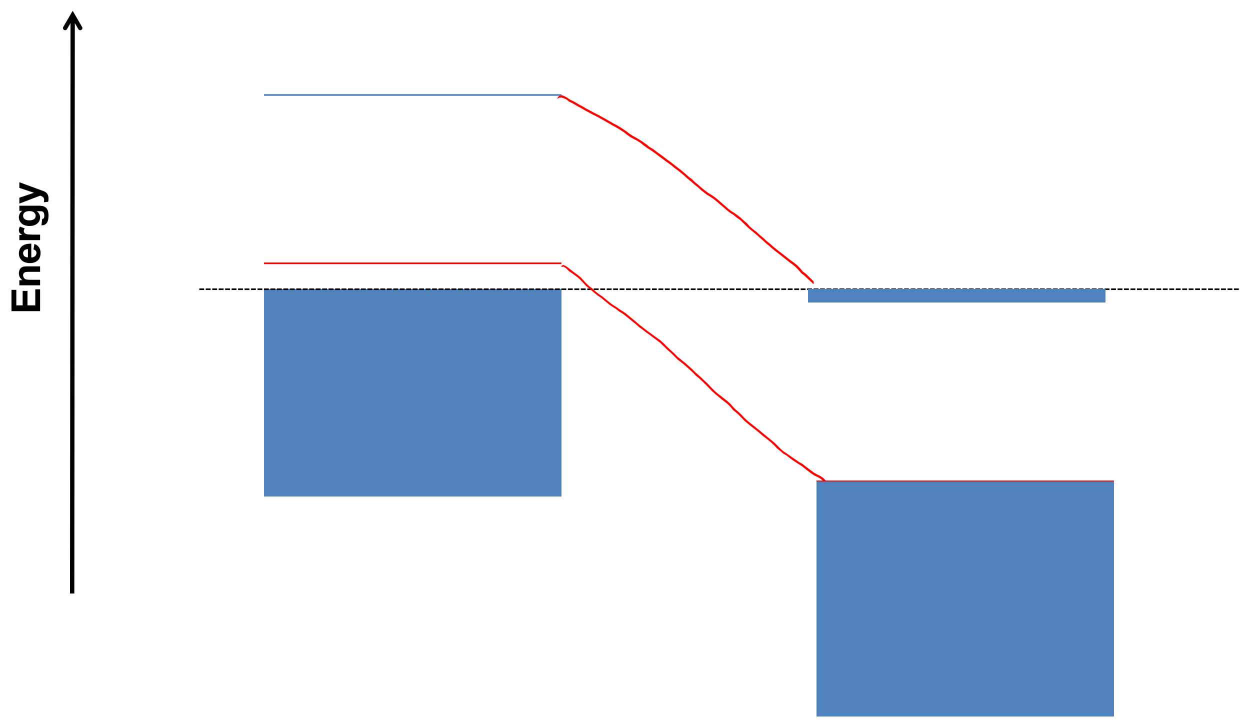
*Blue color indicates electrons

Combining N and P materials

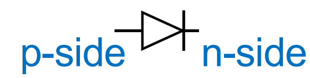


N and P type Materials, Junctions and Devices

Qualitative Picture of a Junction Formation



- When a n and p are put together, they form a p-n junction diode
  Symbol:



- Electron densities align in energy so that there is no difference in concentration

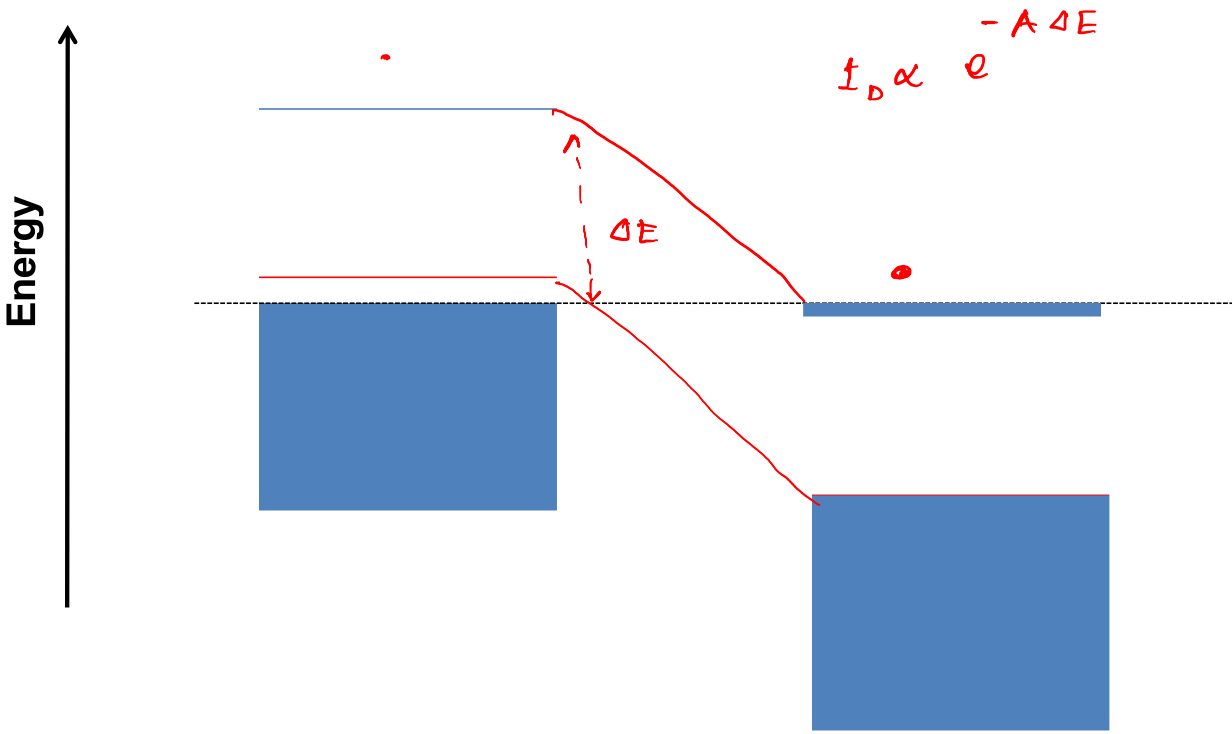
- Technically what aligns is the energy level where probability of finding an electron is ½ →to be discussed in more details in EE130

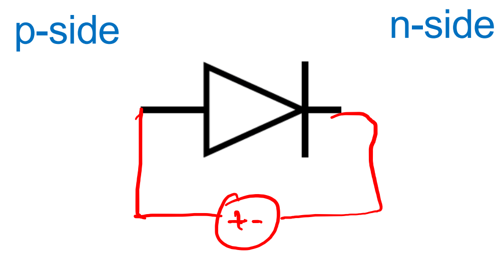
What does a voltage do?

$U = qV$

$= -eV$

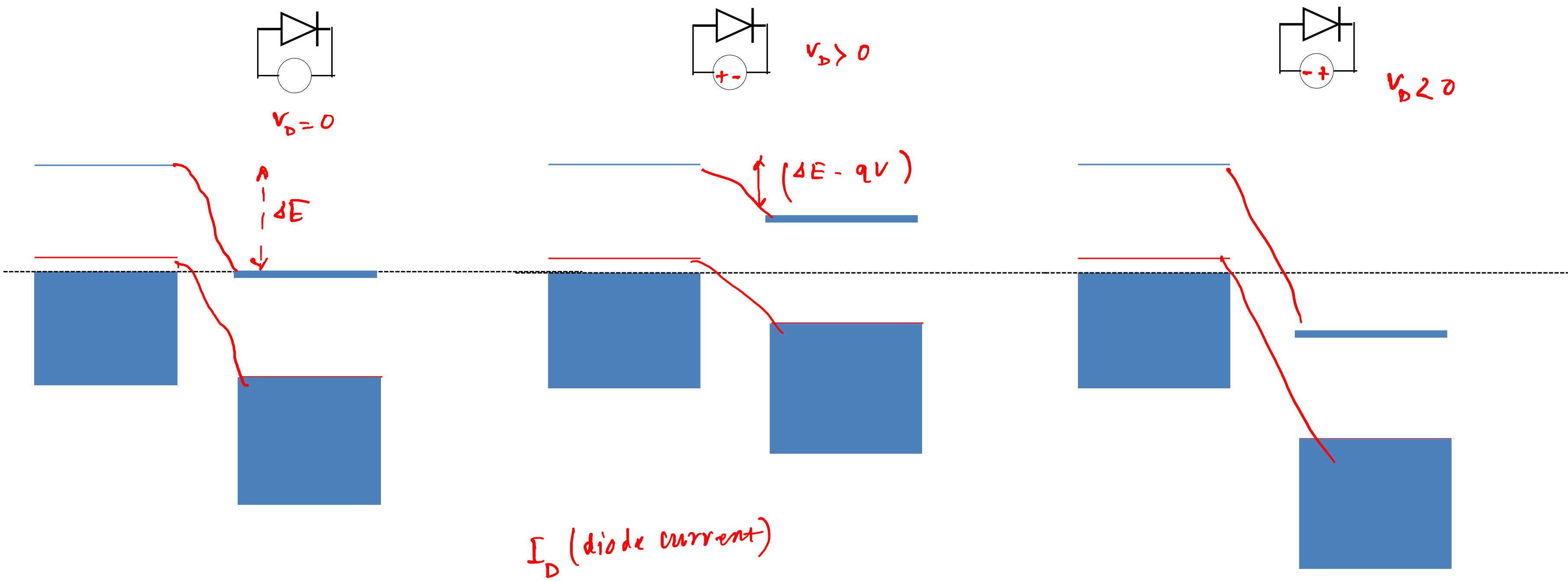
Qualitative Picture of a Junction Formation





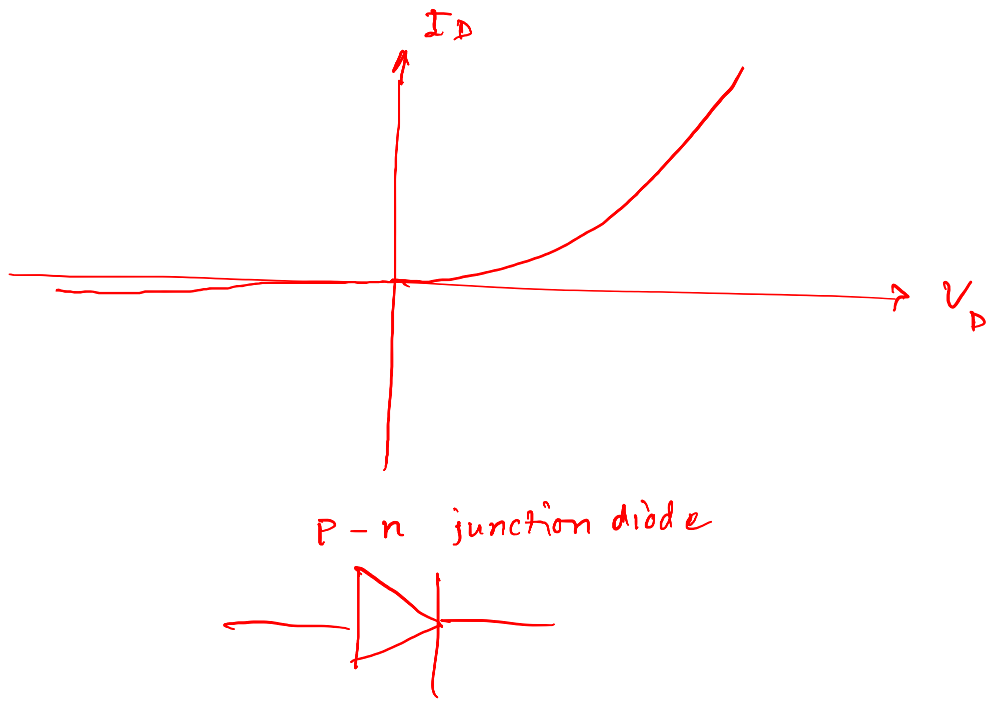
Negative terminal of a battery brings electrons and thereby **increases energy.**

N and P type Materials, Junctions and Devices

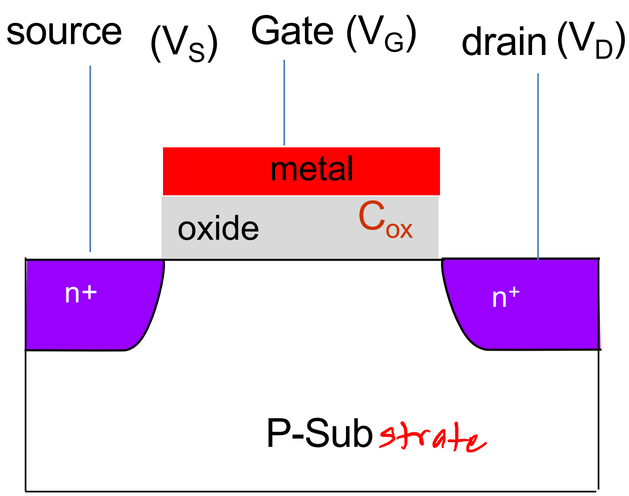


I_D (diode current) changes exponentially with V_D

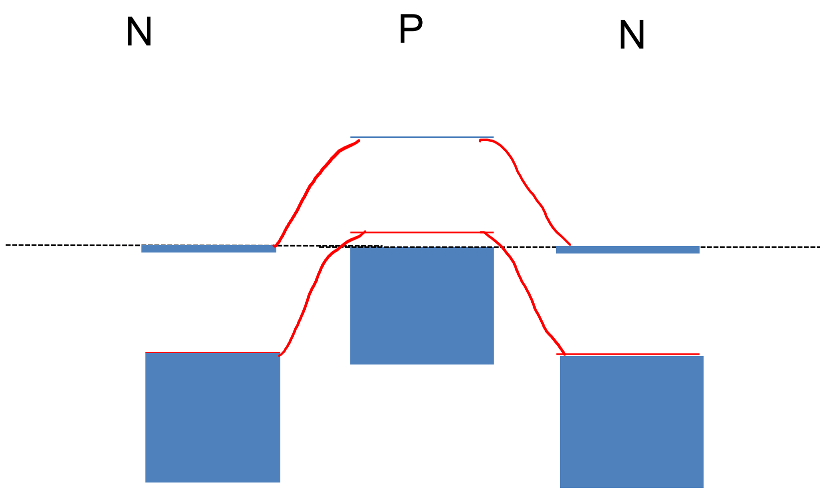
I-V of a PN junction Diode



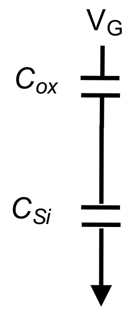
Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET)



- + or – in the name of n or p type material indicates extent of doping. N+ means doped **heavily** to n type.
- In common MOSFET source and drain voltages are interchangeable



P-type semiconductor in the middle with little to no electrons on the conduction band acts like an insulator



Recap: Capacitors (Review)