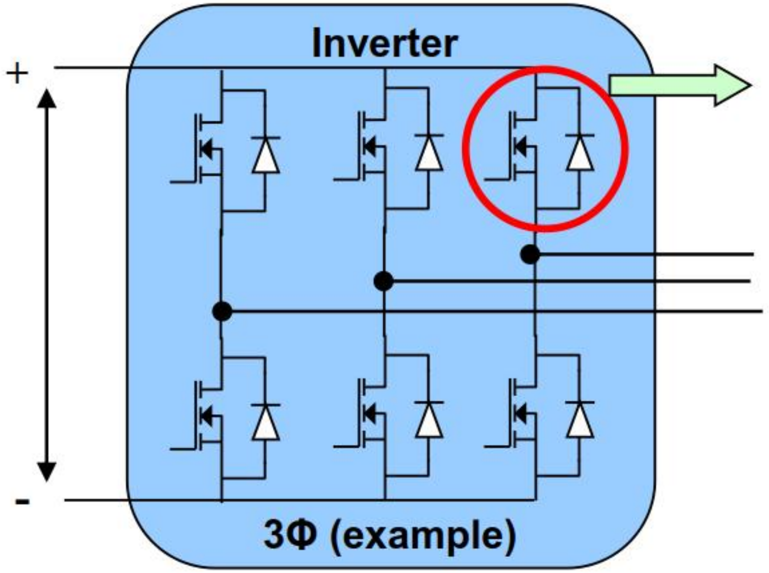
Semiconducting Materials and applications
Learning outcome

At the end of this lecture you will be able to:

- List different applications of semiconductor materials
- Explain the physics behind semiconductor material
- Understand how the semiconductors are manufactured
- Explain the operation of semiconductor diode
- Explain the operation of semiconductor transistor

Semiconductor applications

- Diodes and transistors
  - Low and high power
  - Electronics
  - Power electronics
  - Computer ships
- Detectors and Solar cells
  - Light and particle detection
  - Electric energy generation (PV)
- Optoelectronics
- LEDs and Lasers
  - Efficient lighting
  - Instrumentation and medical applications



Courtesy of Mark Johnson, Department of Materials Science & Engineering, NC State University

Materials bonding

- Atoms bond to each other to form material structures. Different bond are responsible for different properties
- Ionic bond: electron transferred from atom to the other
  - Hard and brittle, non conducting e.g. NaCl, CsCl, and ZnS
- Covalent bond: valence electrons shared between atoms
  - Very hard, non conducting e.g. Diamond, Silicon, Graphite
- Metallic bond: like covalence bond but electrons are delocalized
  - Varying hardness, conducting e.g. Iron, silver, Copper
- Hydrogen bond: electrostatic attraction between atoms or molecules
  - Had and brittle, non conducting e.g. Ice and organic solids
- Van der Waals bond: interaction due to charge shift within atoms or molecules
  - Weak interaction, soft and brittle, non conducting e.g. Noble gas (Ar, Ne, Xe)

Semiconductor

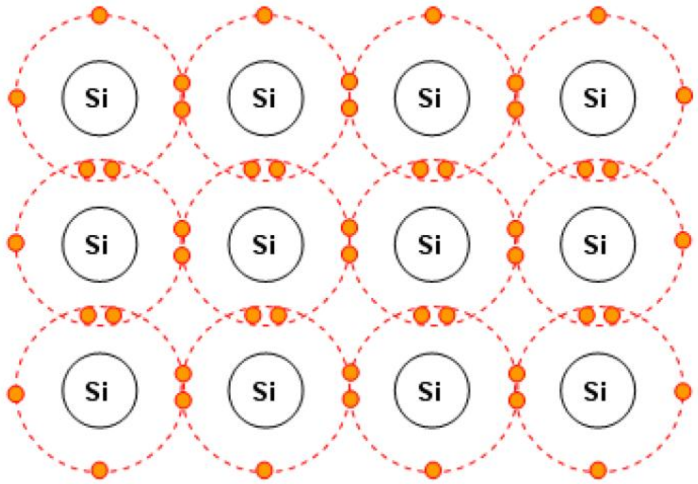
- Semiconductor materials have two kind of charge carriers
  - Doping the materials (impurities) increases the concentration of one or the other
  - Negative carriers = electrons. n-type semiconductor
  - Positive carriers = holes. p-type semiconductor

SiC = Silicon Carbide
GaAs = Gallium Arsenide
GaN = Gallium Nitride
InP = Indium Phosphide

- Most semiconductors are Si-based
  - Easy and established processing methods
  - Cheap and abundant material (4” wafer of Si @30€ vs. 2” wafer of InP @300€)
- High speed electronics, up to 600 GHz requires GaAs, InP, or SiGe
- High voltage applications require GaN or SiC

Semiconductors

- Si has 4 valence electrons and 4 are missing from the outer shell
  - Most electrons have low mobility and thus do not participate in the conduction
  - Pure Si is a poor conductor

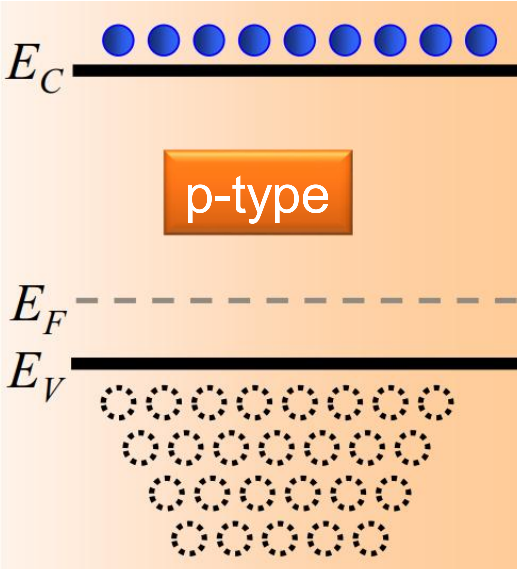


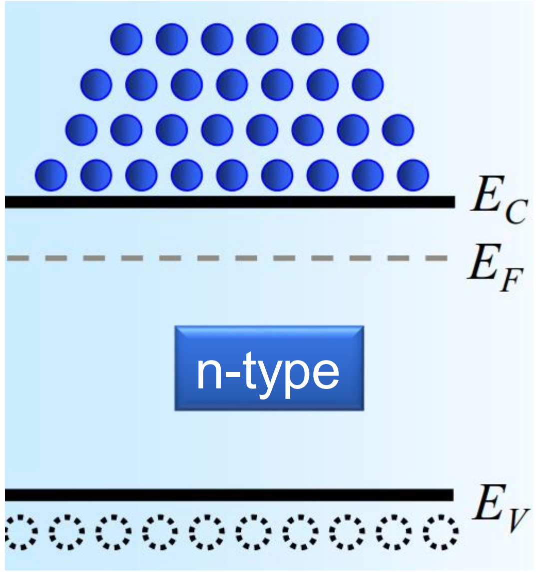
Figures: Courtesy of Prof. Hele Savin

- In normal temperature, some electrons jump from the valence band to the conducting band leaving a hole
  - A hole can also be a current carrier just as the electron
  - Note that there is an energy bandgap between the two states
  - In intrinsic semiconductors (Si, Ge) the concentration of electrons and holes is the same

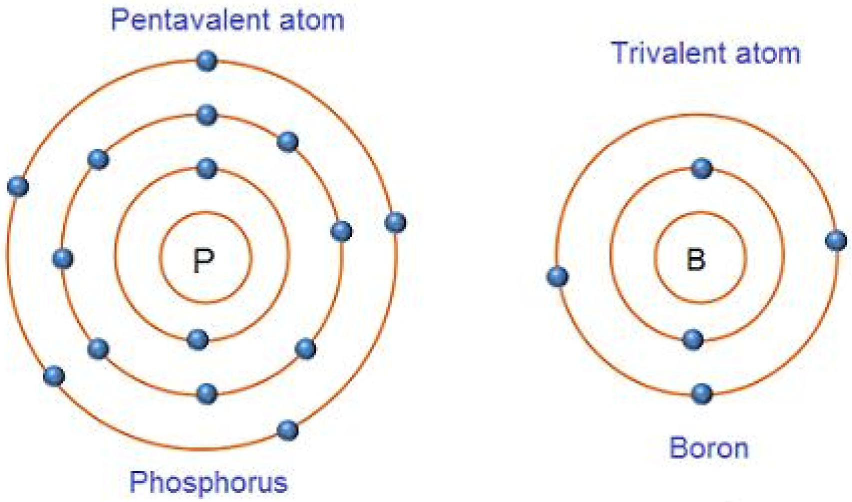
Semiconductors

- Intrinsic semiconductors like Si can be doped
  - the concentration of holes or electrons is higher p and n-type
- Pentavalent impurities: Phosphorus (P), Arsenic (As), Antimony (Sb)
- Trivalent impurities: Boron (B), Gallium (G), Indium(In), Aluminium(Al)



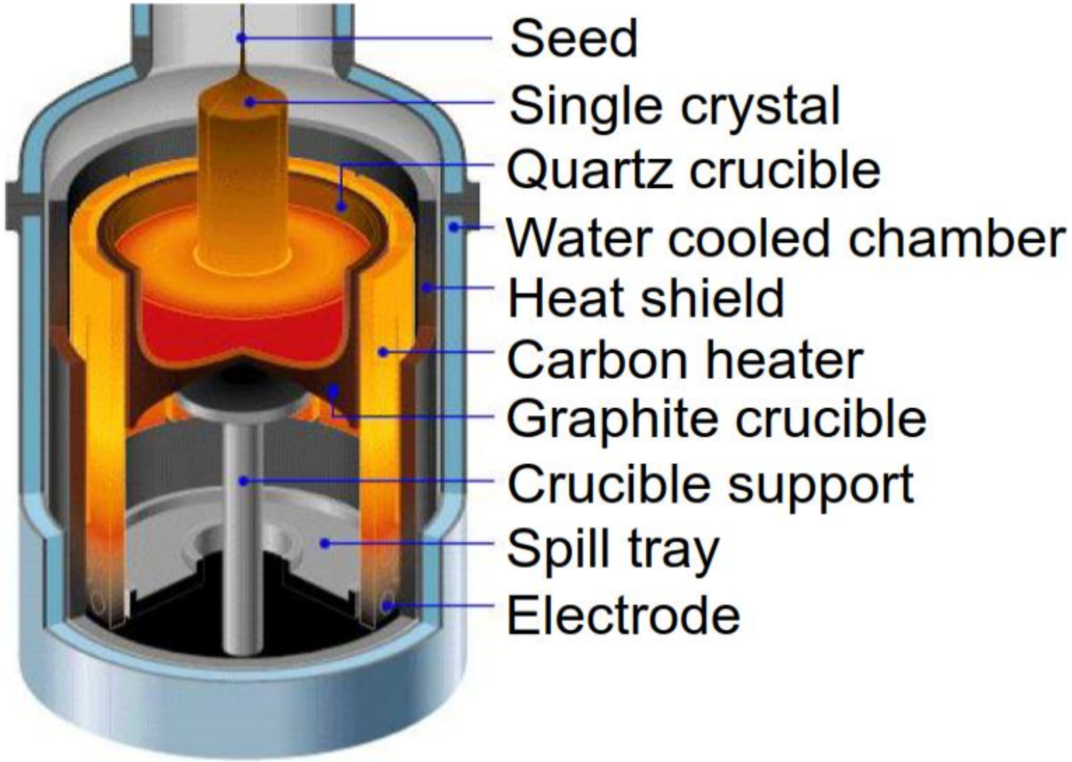


Figures: Courtesy of Prof. Hele Savin

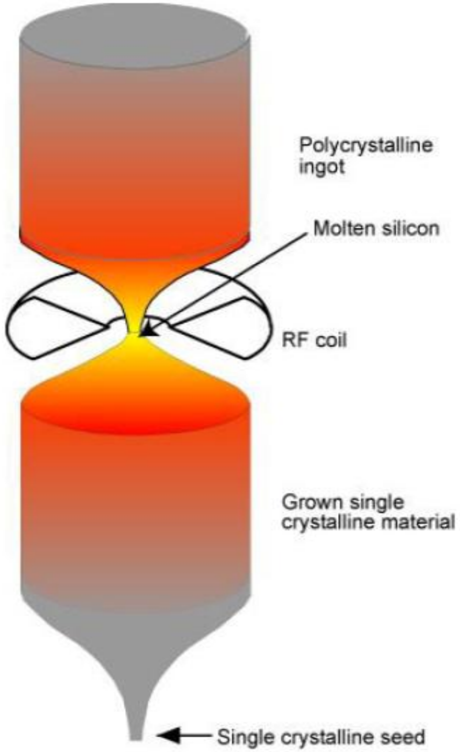


Manufacturing of Semiconductors

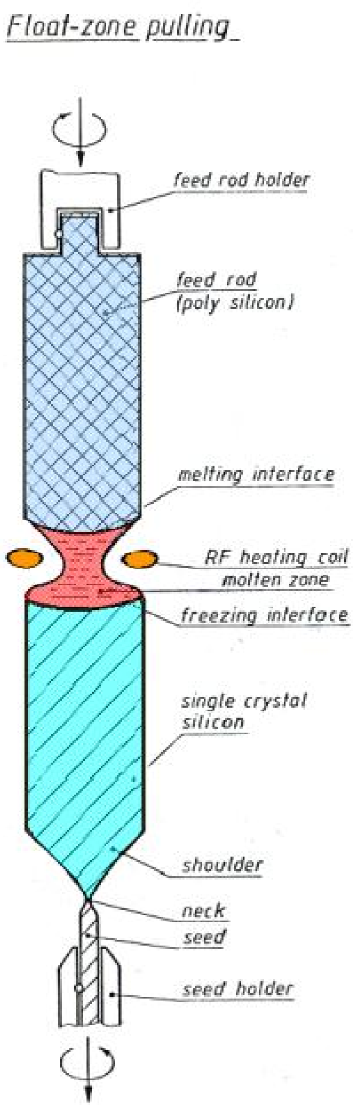
Growing a silicon ingot can take from one week to one month



Crystal pulling method



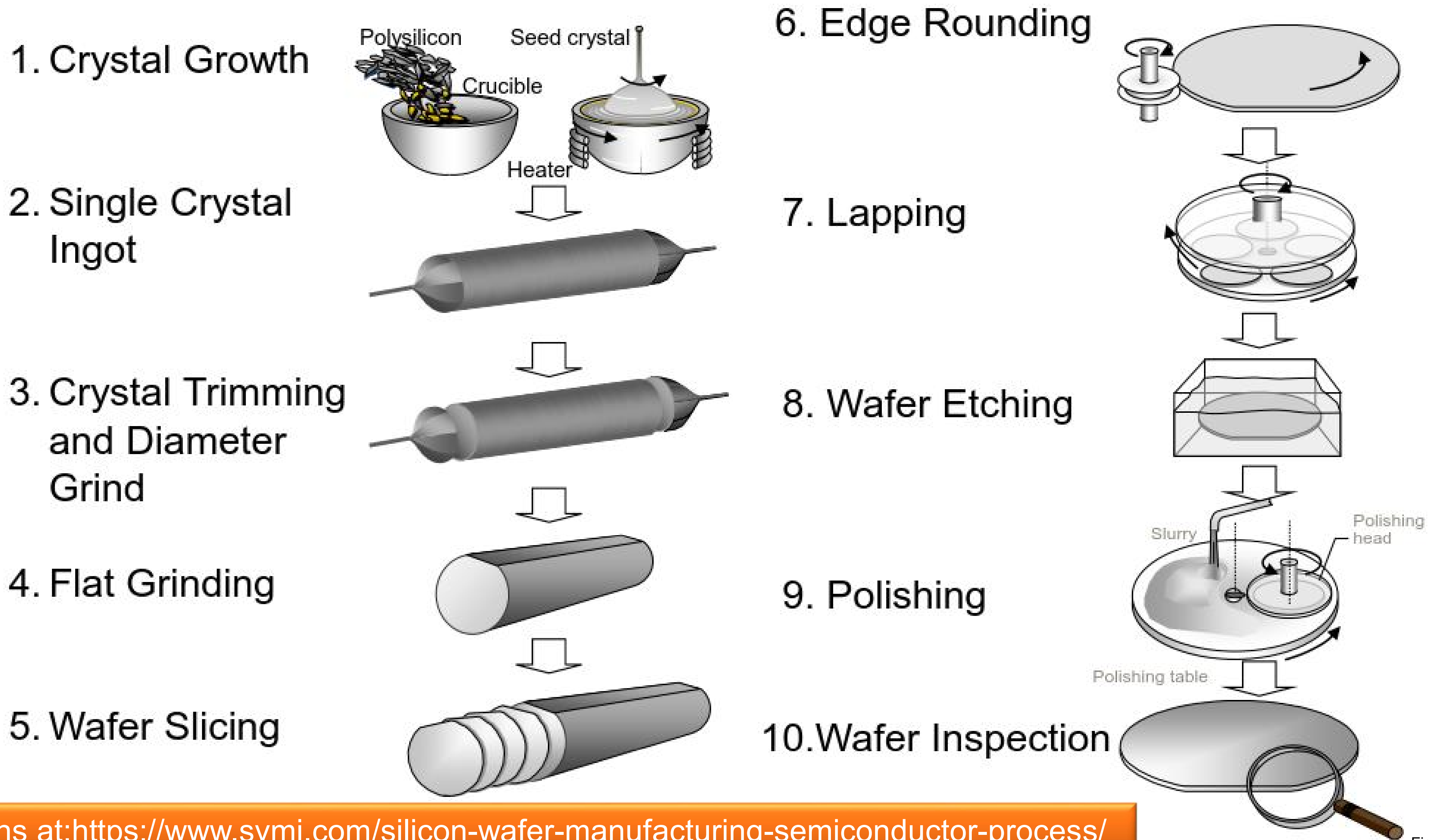
Float-zone method



Figures: Courtesy of Prof. Hele Savin

Manufacturing of silicon wafer

Boron: P type
Phosphorus, Antimony, Arsenic: N type



Explanations at:https://www.svmi.com/silicon-wafer-manufacturing-semiconductor-process/

Figures: Courtesy of Prof. Hele Savin

Semiconductor applications

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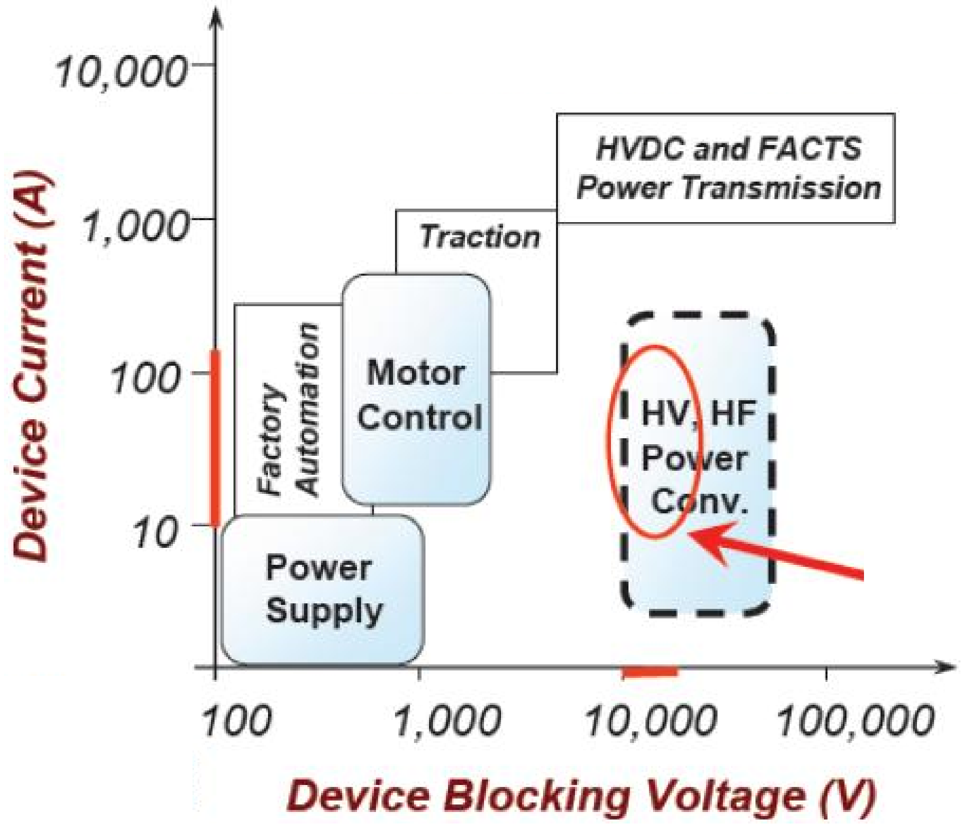

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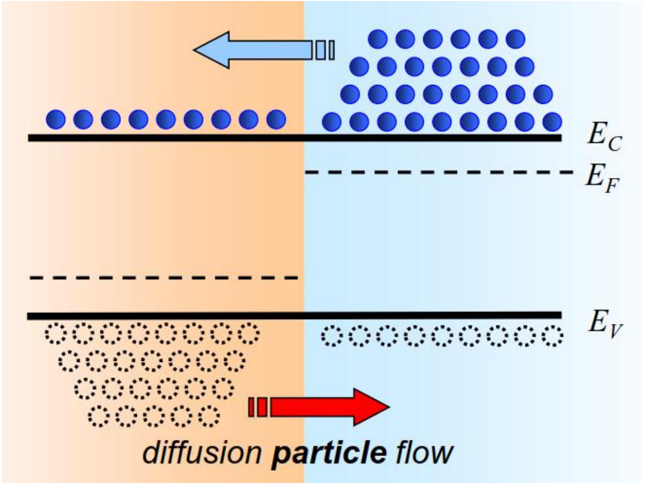
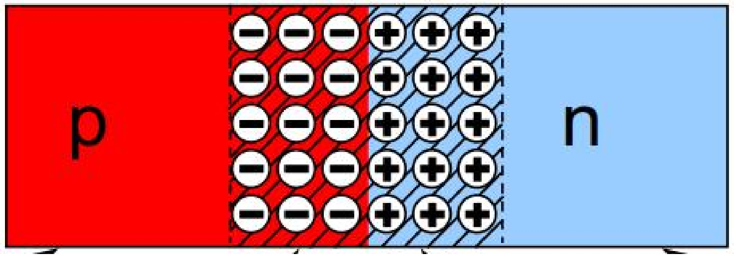
n-p Junction and diode

- n-p junction diodes are made by putting side-by-side n- and p-type semiconductors
- Diffusion phenomena occurs in the conduction and valence bands
  - In conduction band, electrons diffuse from n- to p-region
  - In valence band, holes diffuse from p- to n-region
- Diffusion is limited by the remaining charges creating an electric field
  - A region of recombined holes-electrons is formed: depletion Region





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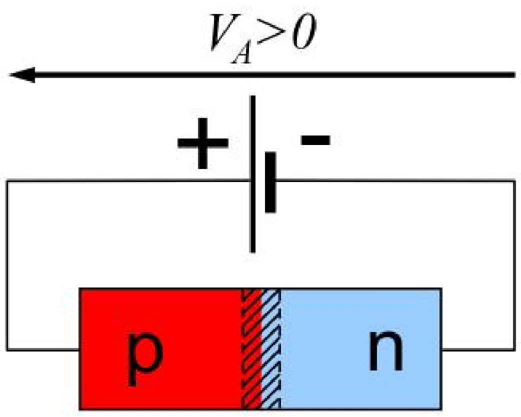
n-p Junction and diode

- Depletion region forms an equivalent of an insulation layer
- Positive voltage applied over the p-n junction
  - The depletion region get thinner and a current start flowing → forward conduction
- Negative voltage applied over p-n junction
  - The depletion region get wider and thus no current can flow → reverse blocking
- Excessive negative voltage over p-n junction
  - Breakdown of the insulation layer and current flow



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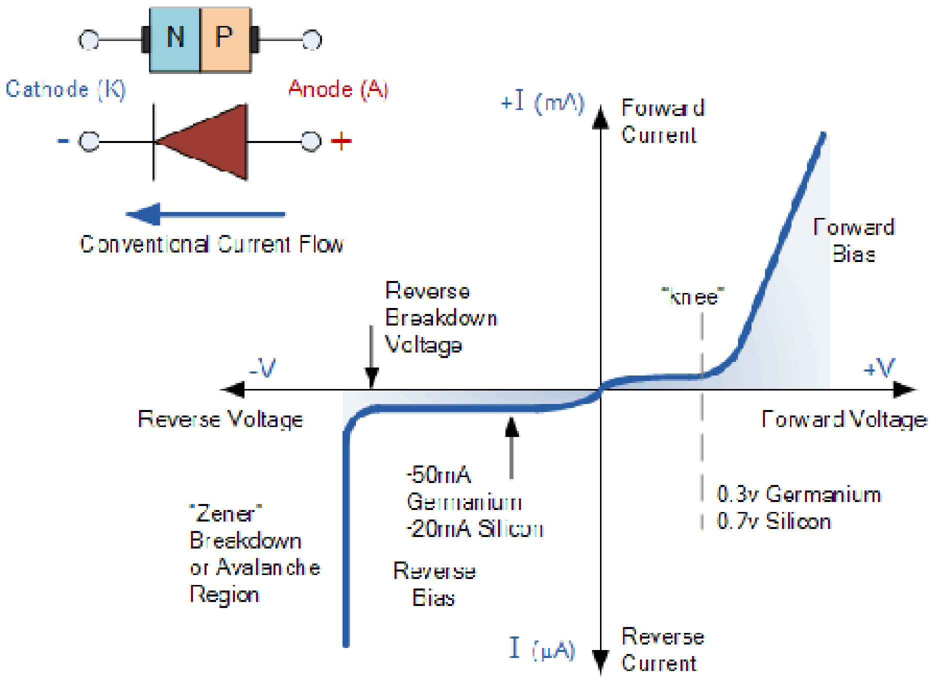
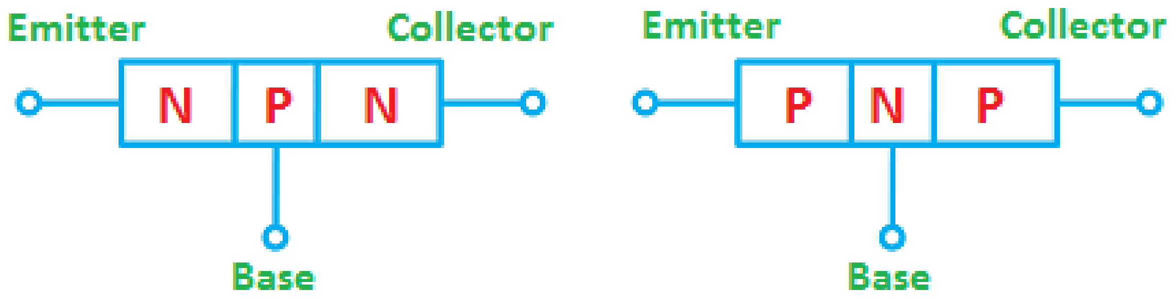
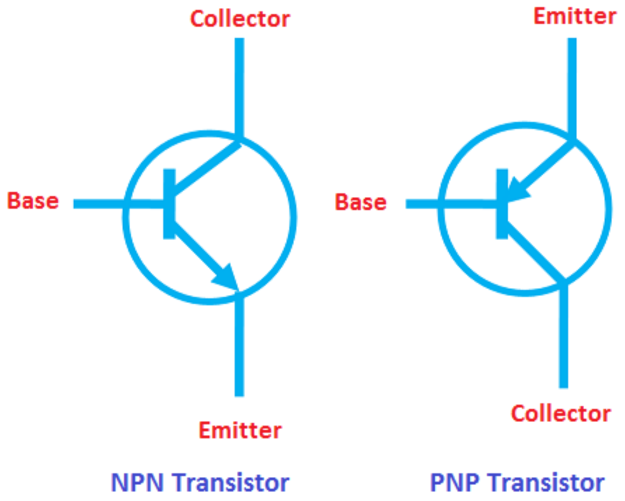


http://www.electronics-tutorials.ws/diode/diode5.gif?x98918

Semiconductor transistor construction and operation

- Transistors are the basic component of the contemporary industry
  - Computers, electronic devices, power electronics, etc.
  - Before the discovery of transistors in 1947, vacuum tubes were used to build amplifiers
- Transistors are semiconductor device with 3 terminals
  - They are used to switch or control the current flow
  - The basic construction and operation of a transistor is similar to that of a diode
  - Instead of a single junction, transistors have double junction: p-n-p or n-p-n

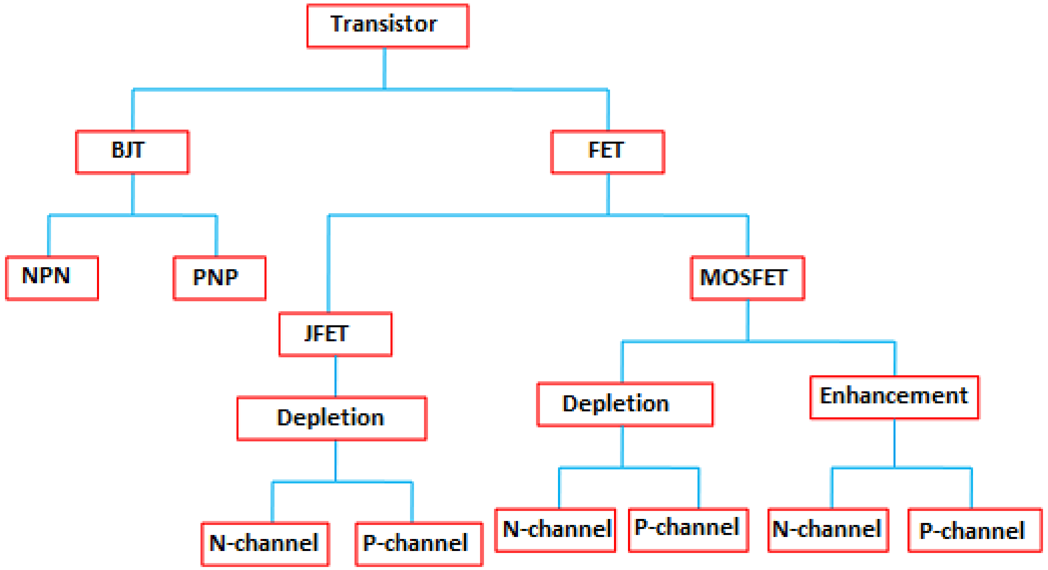




http://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/transistors/bipolarjunctiontransistor/bipolarjunctiontransistorintroduction.html

Semiconductor transistor construction and operation

- Transistors are classified according to their mode of operation
  - Bipolar Junction Transistor (BJT) : both electrons and holes ensure conduction
  - Field Effect Transistor (FET): either electrons or holes ensure conduction.
    - JFET = Junction Field Effect Transistor
    - MOSFET = Metal Oxide Semiconductor Field Effect Transistor.

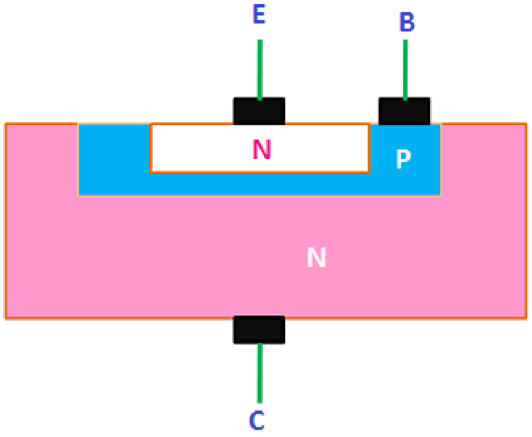


Classification of transistors

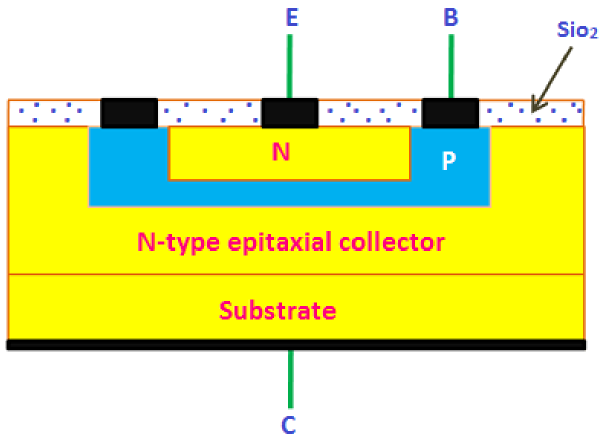
http://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/transistors/transistors-introduction.html

Semiconductor transistor construction and operation

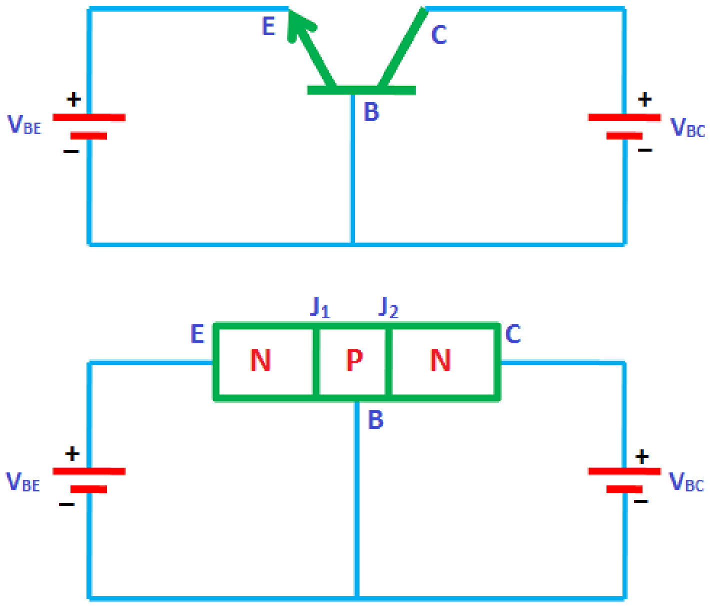
- Operation of transistor is controlled by controlling the dc input voltages:
- Cut-off mode:
  - $V_{BE}>0$, $V_{BC}>0$ → both junction blocking → switch OFF
- Saturation mode:
  - $V_{BE}<0$, $V_{BC}<0$ → both junctions conducting → switch ON
- Active mode:
  - $V_{BE}<0$, $V_{BC}>0$ → EB in conduction and CB in blocking mode
    - small E-C current causes large C-B current→ amplifier



Diffusion junction transistor



Epitaxial junction transistor



Cutoff mode

http://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/transistors/bipolarjunctiontransistor/transistorconstruction.html

Photovoltaic panels-operation

- Photons with energy higher than band gap rise electrons from valence band to conduction band. A hole is left in the valence band
- Electric field in depletion layer drives electrons to n-type and holes to p-type
  - Electric current flows, but some electrons and holes might recombine