Semiconductors and Silicon

A Basic Summary

Semiconductor Devices

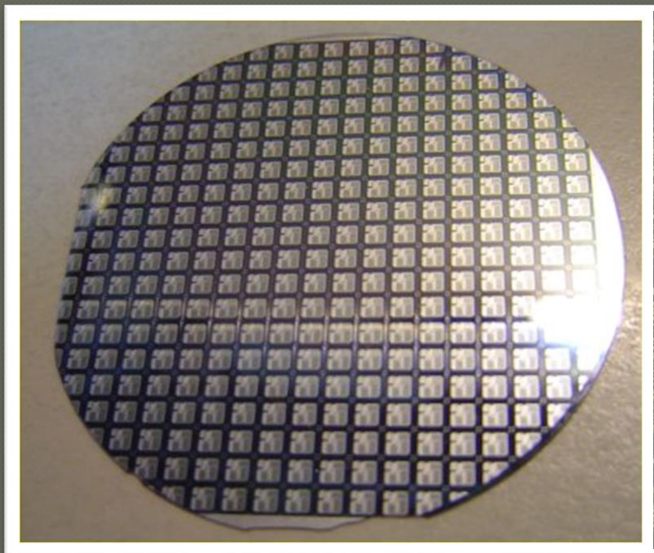
- Diodes (pn junctions)
- MOSFETs (Metal-Oxide-Semiconductor Field Effect Transistors)
- BJTs (Bipolar Junction Transistors)

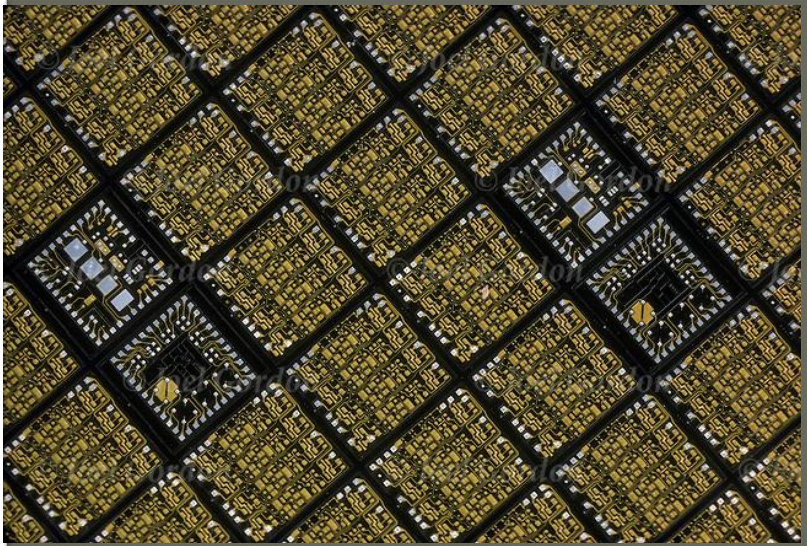
These devices are made using semiconductor materials (primarily silicon) and are very, very small.

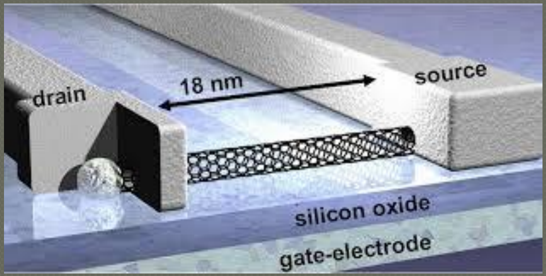
What is a semiconductor?

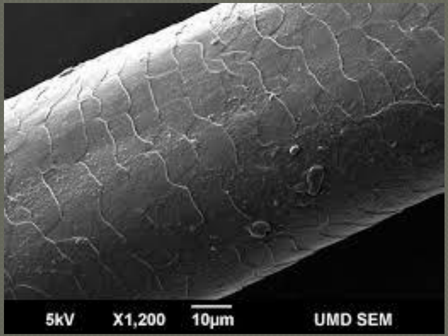
- A material whose conductivity falls between a metal and an insulator.
- Has a crystalline or poly-crystalline structure.
- Electrical conductivity is strongly dependent on temperature and impurity concentration.
- Silicon is most common because it’s cheap and easy to process

Silicon Integrated Circuits





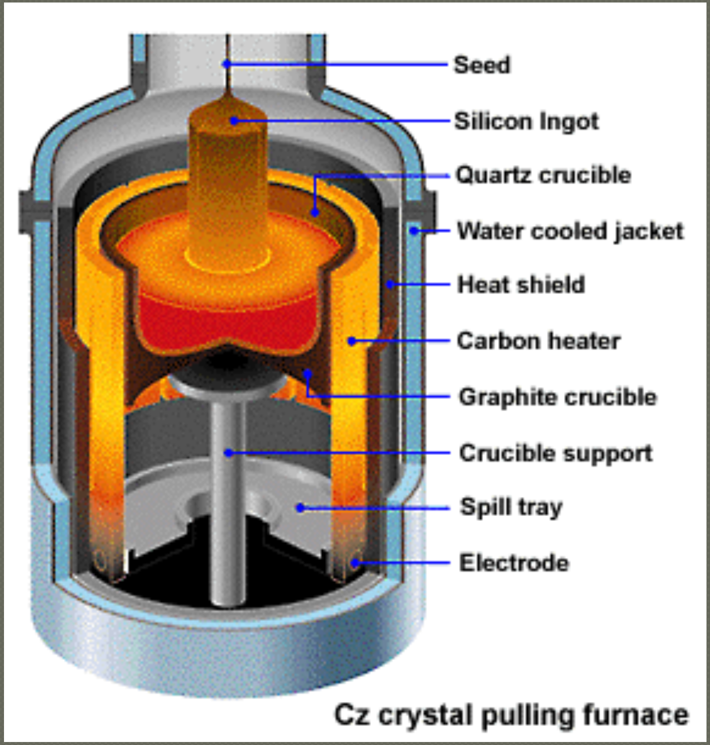




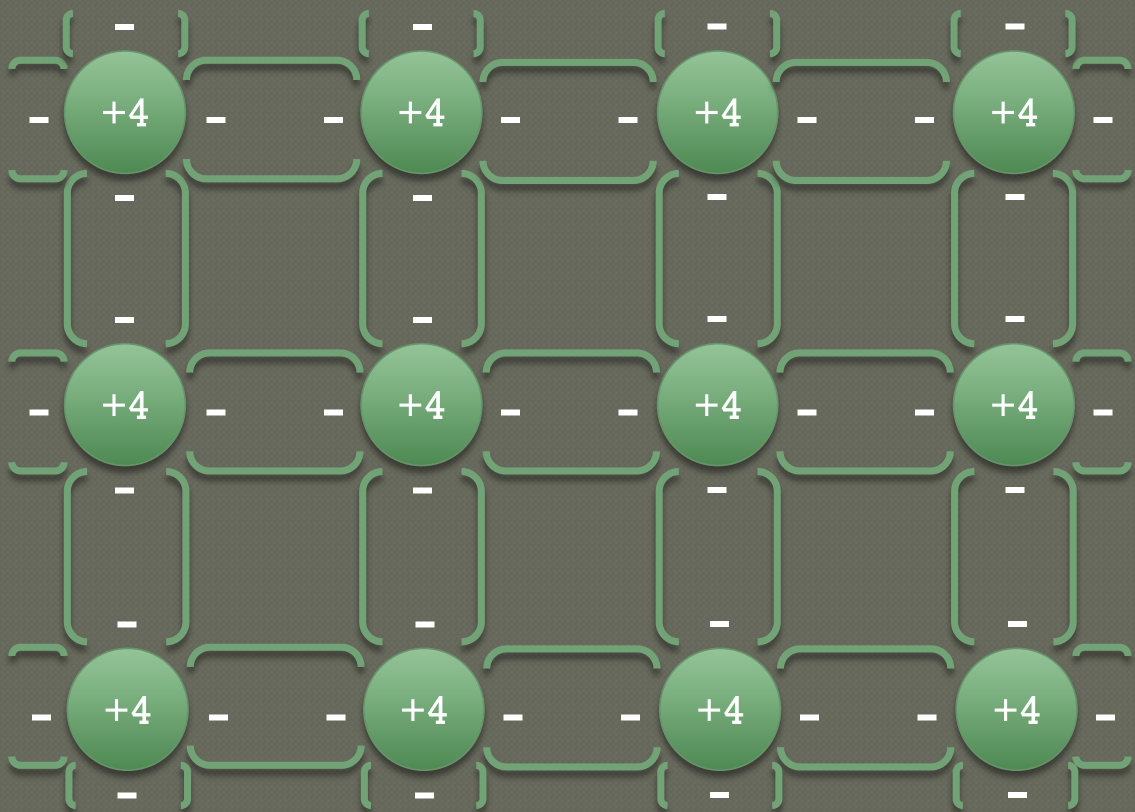
10 μm=10000 nm
Thickness of a human hair is .04mm or 40 μm

Current min feature is 7 nm

Silicon Ingots and Wafers

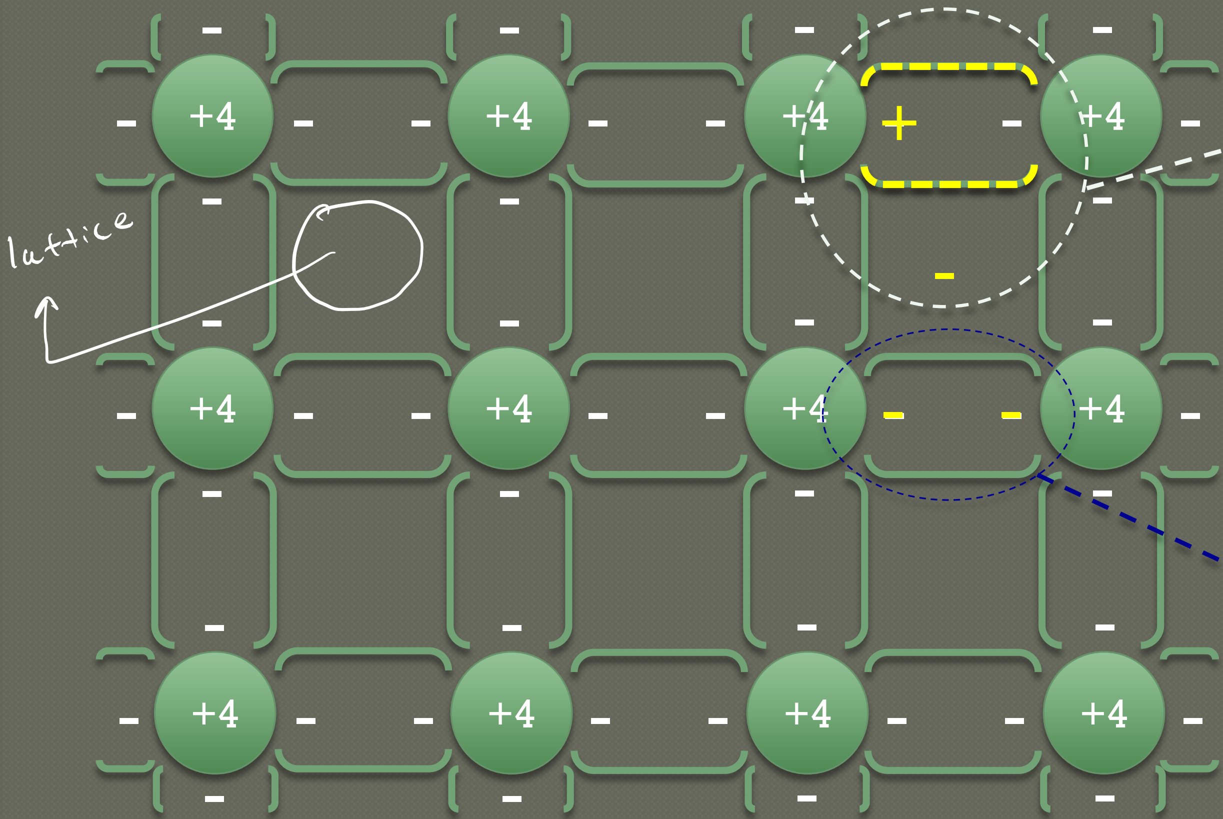


Silicon Crystal Structure



Covalent bonds w/ it's nearest neighbor

Electrons and Holes in the Lattice



- Covalent bond broken
- A "hole" appears in the valence position
- Electron is free in the lattice

Intrinsic Silicon

- Balanced lattice structure
  - Concentration of free electrons (n) equals concentration of free holes (p)
- Thermal generation of electrons and holes does not contribute to significant current flow
- To achieve current flow, n>>p or p>>n.
- This is done by adding impurities to silicon.

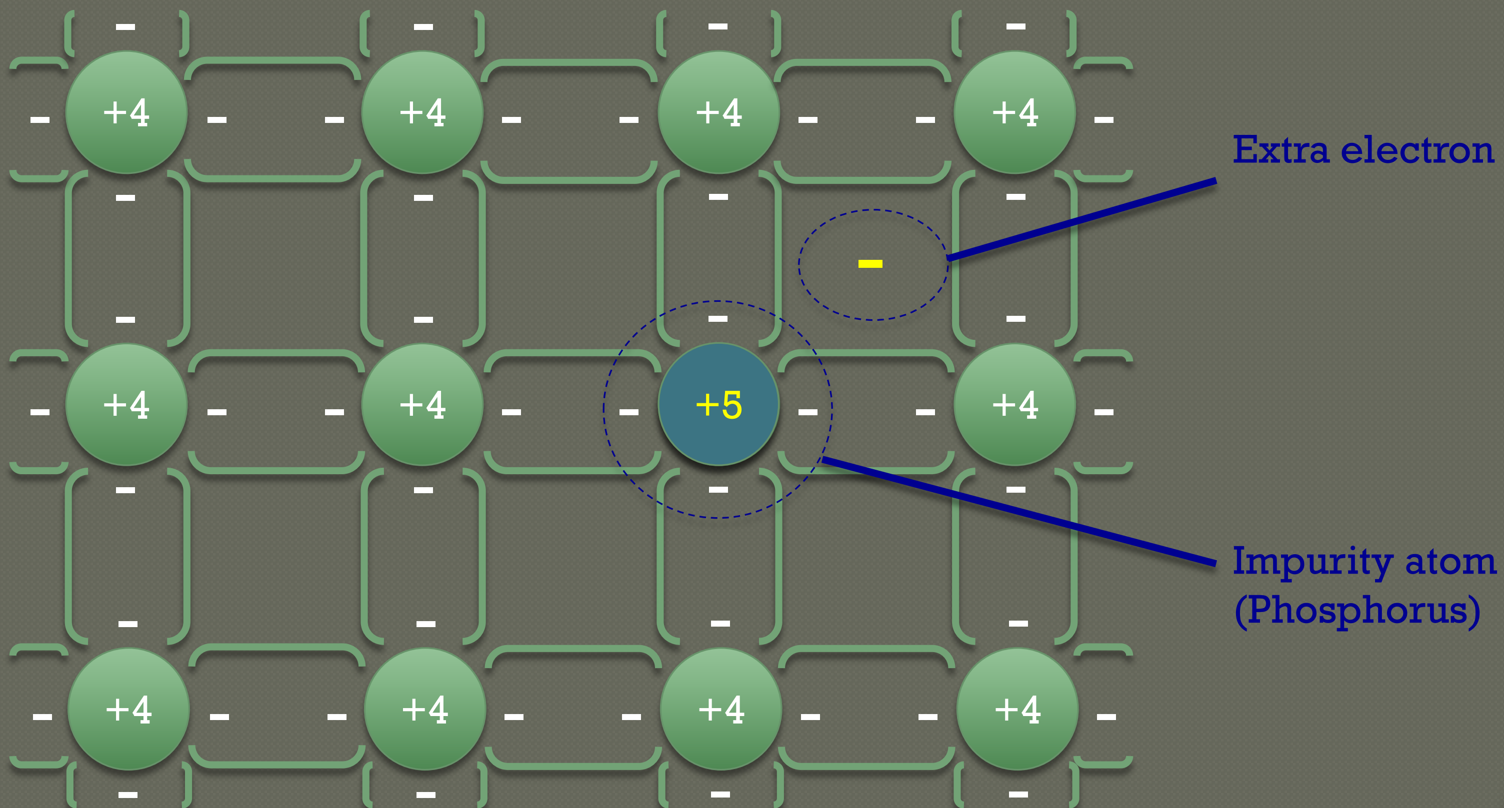
-> perfect material, this is not possible.

-> Dope the silicon to get current flow.

Doping Silicon

- Doping silicon by introducing impurities to intrinsic material
- Dopants introduce extra negative (electrons) or positive (holes) charge
- The extra charge carriers contribute to significant current flow

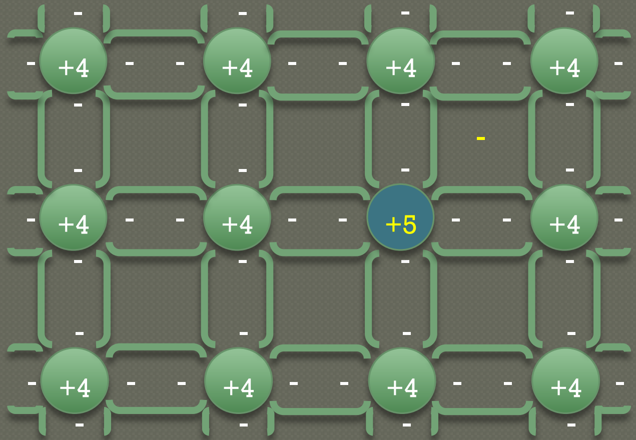
n-type Doping



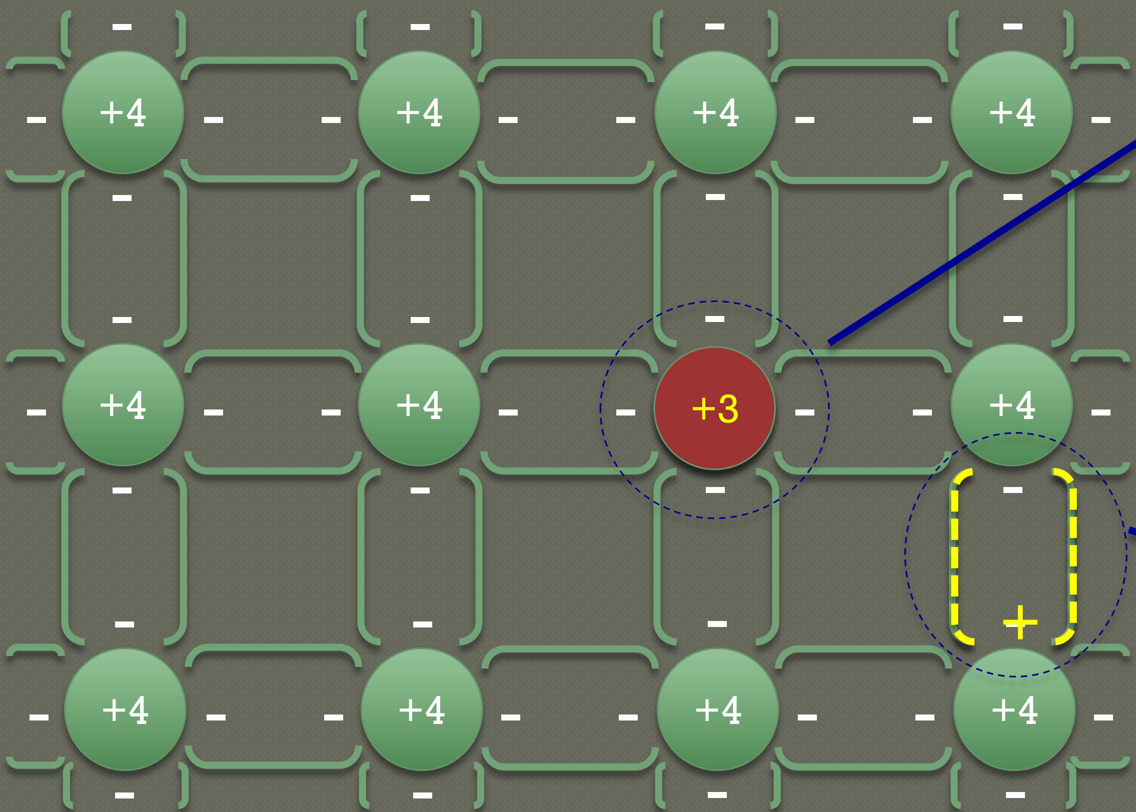
more phosphorus, more electron flow.

n-type Doping

- Phosphorus (and other like elements) are donor impurities.
- Phosphorus atoms *donate* an electron to the lattice.
- The donated electrons will contribute to current flow.
- The increase in electrons makes the intrinsic silicon become n-type silicon.
- Other n-type or donor atoms include arsenic and antimony



p-type Doping



Impurity atom (Boron)

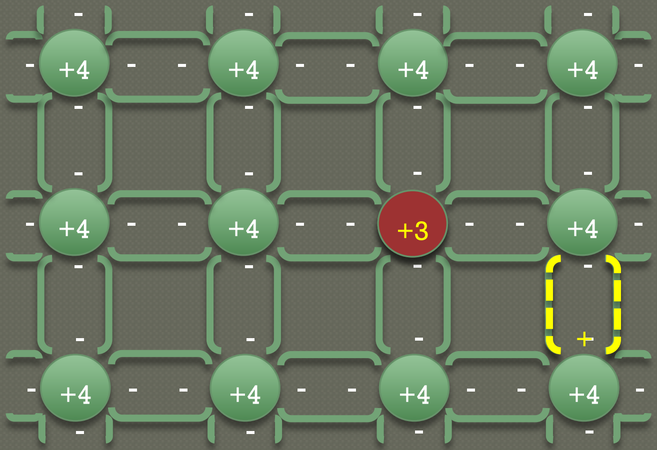
space where there is no electron, more holes.

- Broken covalent bond
- Hole created

p-type Doping

- Boron (and other like elements) are acceptor impurities.
- Boron atoms *accept* an electron from the lattice which results in a hole (or a net positive charge).
- The holes will contribute to current flow.
- The increase in holes makes the intrinsic silicon become p-type silicon.
- Other p-type or donor atoms include aluminum and gallium

primarily Boron



Doped Silicon Definitions

- n_i = concentration of electrons and holes in intrinsic Si
- At room temp (300K), $n_i = 1.5 \times 10^{10}$ carriers/cm^3
- N_D = concentration of donor atoms
- n_n = concentration of electrons in n-type silicon – determined by doping concentration
- p_n = concentration of holes in n-type silicon – determined by thermal generation
- $p_n n_n = n_i^2$ (equilibrium)
- If $N_D >> n_i$, then $n_n = N_D$
- For n-type Si, electrons are majority carriers and holes are minority carriers

Doped Silicon Definitions

- N_A = concentration of acceptor atoms
- p_p = concentration of holes in p-type silicon – determined by doping concetration
- n_p = concentration of electrons in p-type silicon – determined by thermal generation
- $p_p n_p = n_i^2$ (equilibrium)
- If $N_A >> n_i$, then $p_p = N_A$
- For p-type Si, holes are majority carriers and electrons are minority carriers

Currents in Silicon

DRIFT CURRENT

- Due to an applied electric field and a function of charge carrier velocity in Si
- Velocity of electrons and holes depends on mobility [μ]
- Electron drift current flows opposite to hole drift current

DIFFUSION CURRENT

- Due to concentration of charge carriers in Si
- Electrons and holes will diffuse from regions of higher concentrations to lower concentrations
- Electron diffusion current flows opposite to hole diffusion current.