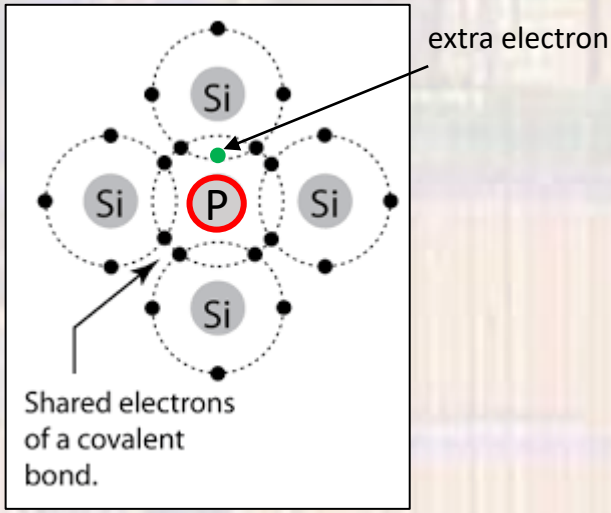
Silicon Doping

Last updated 2/4/22

These concepts have been greatly simplified

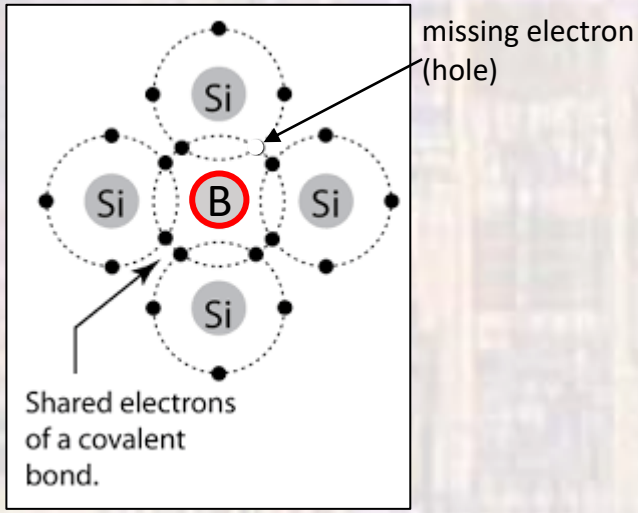
Silicon Doping

- Replace some of the Si atoms in the crystal with another atom



Phosphorus
5 e- in its outer shell
"donor"

excess e- is easily freed

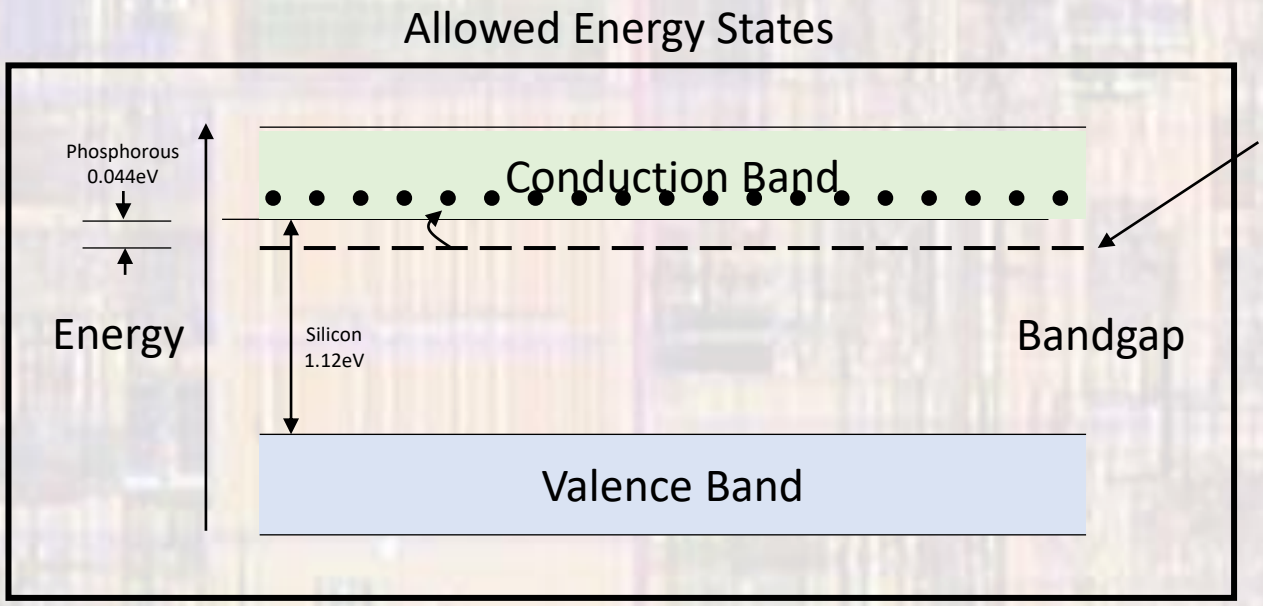


Boron
3 e- in its outer shell
"acceptor"

excess hole is easily freed

Silicon Doping

- Dopant binding energies
  - Donor Atoms

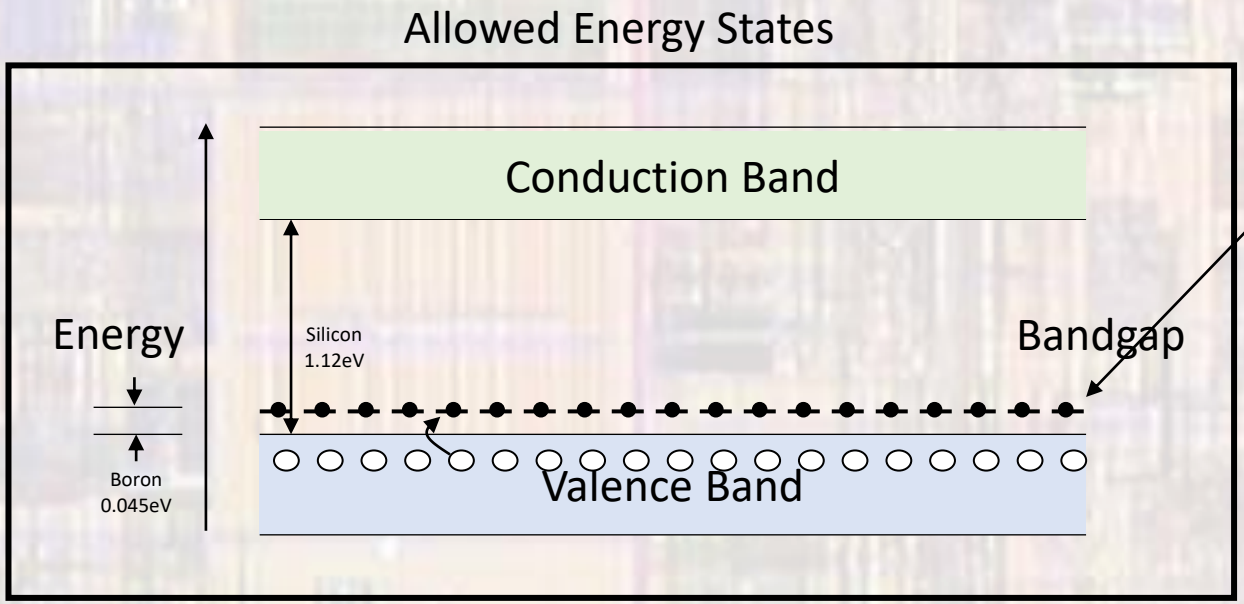


Allowed energy states due to donor atom's excess electrons

At normal operating temperatures, all the electrons will have sufficient energy to move to the conduction band

Silicon Doping

- Dopant binding energies
  - Acceptor Atoms



Allowed energy states due to acceptor atom's deficient electrons

At normal operating temperatures electrons in the valence band will have sufficient energy to move to the acceptor locations

Leaving behind holes in the valence band

Silicon Doping

- Doping Relationship
  - N_D – number of Donor atoms / cm^3
  - N_A – number of Acceptor atoms / cm^3
  - n_0 – electron concentration / cm^3 under equilibrium
  - p_0 – hole concentration / cm^3 under equilibrium

$$n_0 p_0 = n_i^2$$

$n_i = 1.5 \times 10^{10}/cm^3$, RT

N-type semiconductor
N_D (Phosphorus) = $1 \times 10^{16}/cm^3$

$n_o = N_D = 1 \times 10^{16}/cm^3$
$p_o = n_i^2/N_D = 2.25 \times 10^4/cm^3 \approx 0$

Excess electrons can travel in the conduction band

P-type semiconductor
N_A (Boron) = $2 \times 10^{16}/cm^3$

$p_o = N_A = 2 \times 10^{16}/cm^3$
$n_o = n_i^2/N_A = 1.125 \times 10^4/cm^3 \approx 0$

Excess holes can travel in the valence band

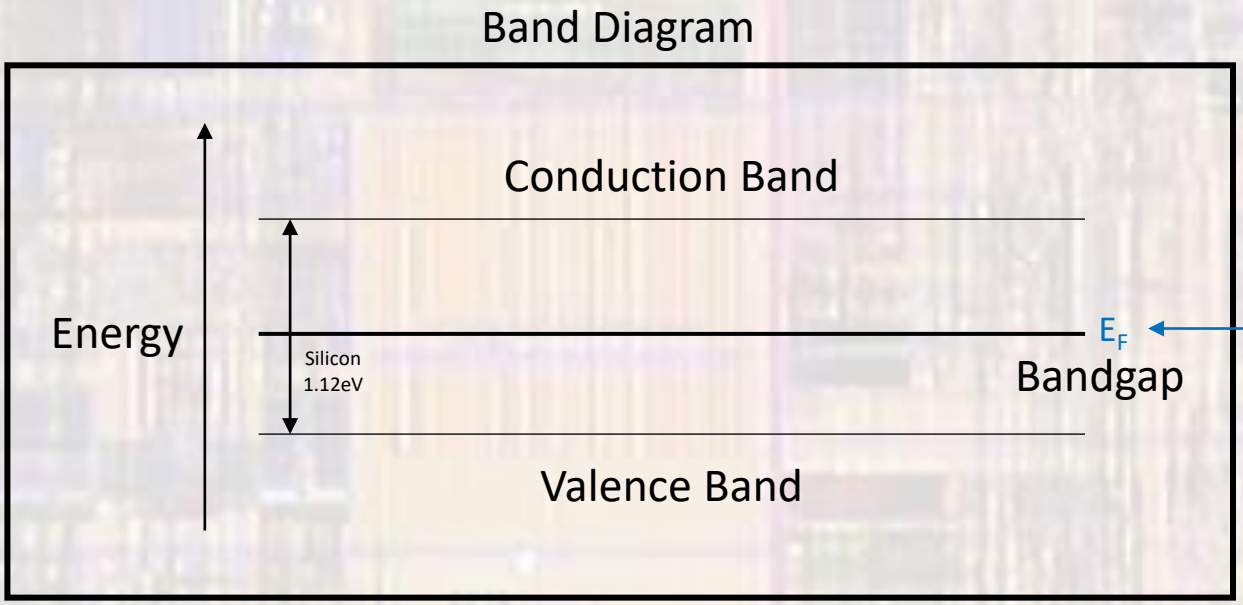
Silicon Doping

- Doping Relationship – energy bands
  - E_F – Fermi energy (level)
    - Represents the energy at which half of the available carrier energy states will be filled
    - Decreasing filled states extend approximately 3kT above E_F
    - Increasing filled states extend approximately 3kT below E_F
    - All states at energies < E_F – 3kT can be considered filled

Reminder: @RT, $3kT \approx 0.078eV$

Silicon Doping

- Doping Relationship – energy bands
  - Intrinsic

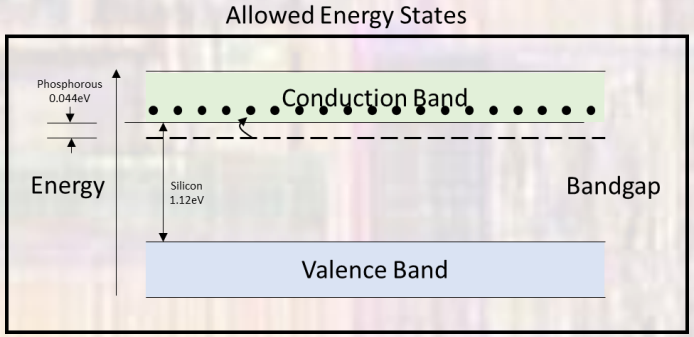


Very few electrons have moved from the valence band to the to conduction band

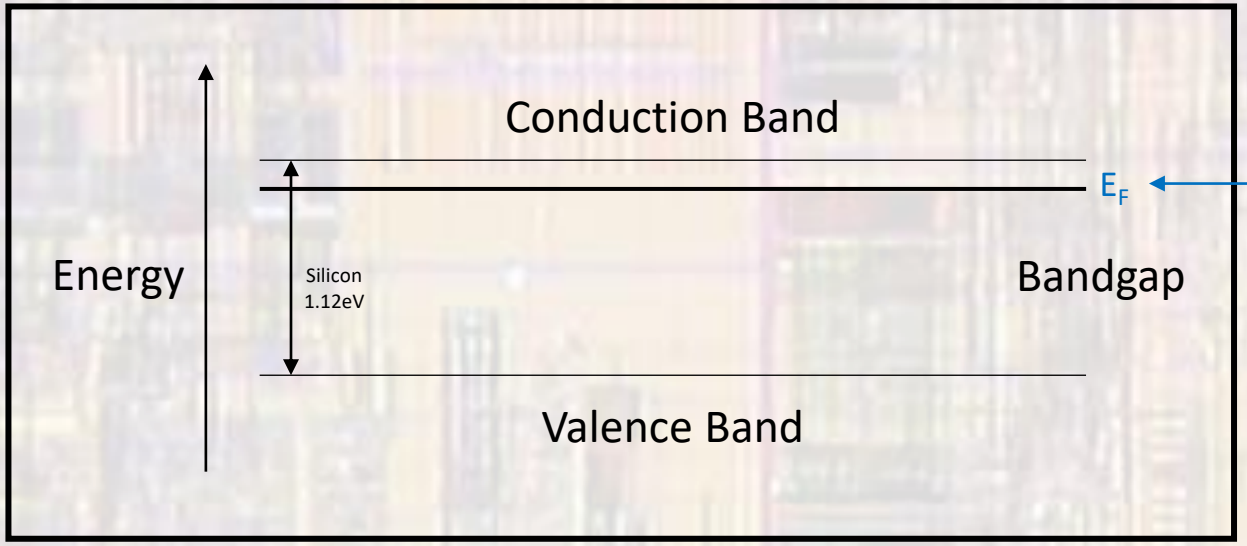
E_F is near mid band

Silicon Doping

- Doping Relationship – energy bands
  - N-Type Si



Band Diagram

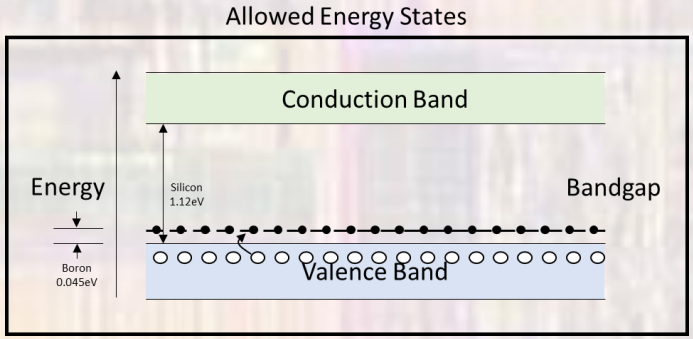


Position depends on doping density

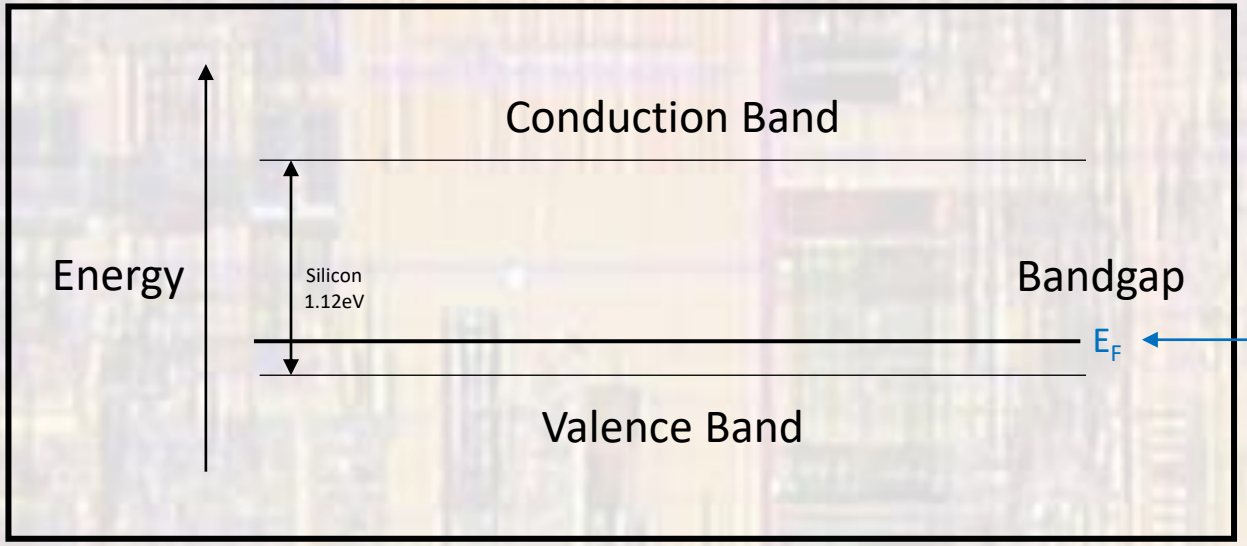
Higher doping → more electrons in conduction band → higher Fermi level

Silicon Doping

- Doping Relationship – energy bands
  - P-Type Si



Band Diagram



Position depends on doping density

Higher doping → more electrons have occupied acceptor sites → more holes in valence band → lower Fermi level