EEE105
"Electronic Devices"

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Lecture 8

- Doping Semiconductors
  - n-doping
  - p-doping
- Donor and Acceptor levels
- Defects - Deep Levels

Periodic Table – Zoom in on Si

\# Outer Electrons

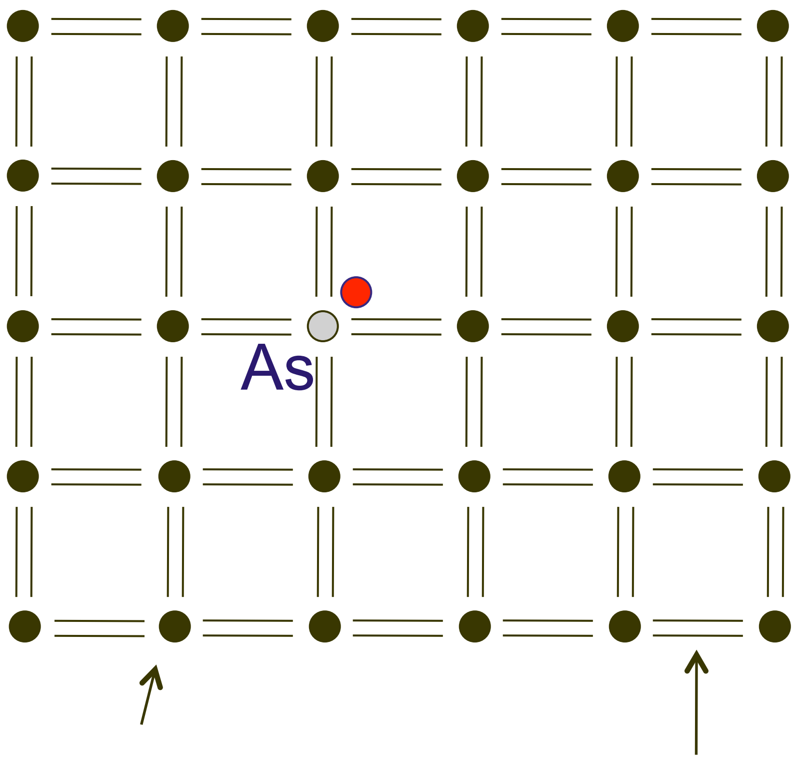
3	4	5
5 B	6 C	7 N
13 Al	14 Si	15 P
31 Ga	32 Ge	33 As
49 In	50 Sn	51 Sb
81 Ti	82 Pb	83 Bi

Semiconductor usually made up of pure material e.g. Si crystal

In extrinsic semiconductors, they are “doped” with atoms (an impurity) to increase the free electron or hole density

Doping of impurities is at the parts per million / parts per thousand level

Doping - Si with Group V (As)



Si Atom cores

Bonds with 2 shared electrons

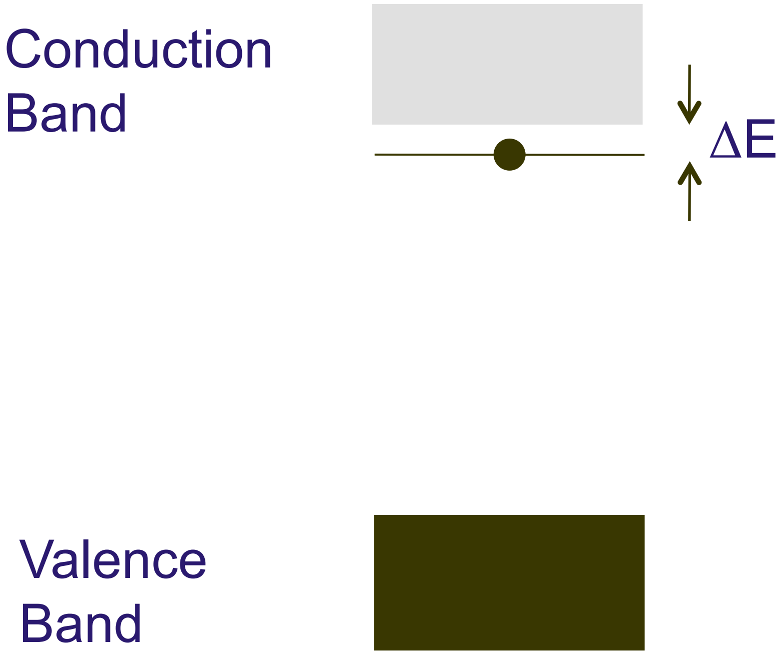
Replace a Si atom with one from group V of the periodic table (P, As, Sb) – let’s assume As

These atoms have 5 outer electrons

4 of the outer electrons covalently bond with the neighbouring Si atoms

Weakly bound additional electron
In this case the dopant impurity has zero charge

Donor States, T = 0 K



The additional electronic level of the group V impurity dopant forms an electronic level in the band-gap sitting (just) below the conduction band

ΔE ~5meV

This is referred to as a donor level

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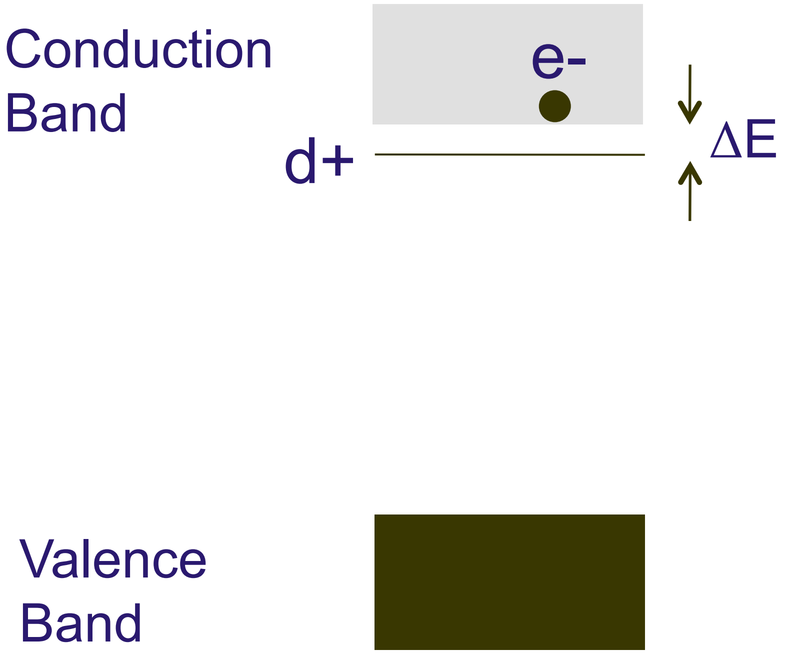
Donor States, T = 300K



At room temperature the average thermal energy $= K_BT = 25\text{meV}$

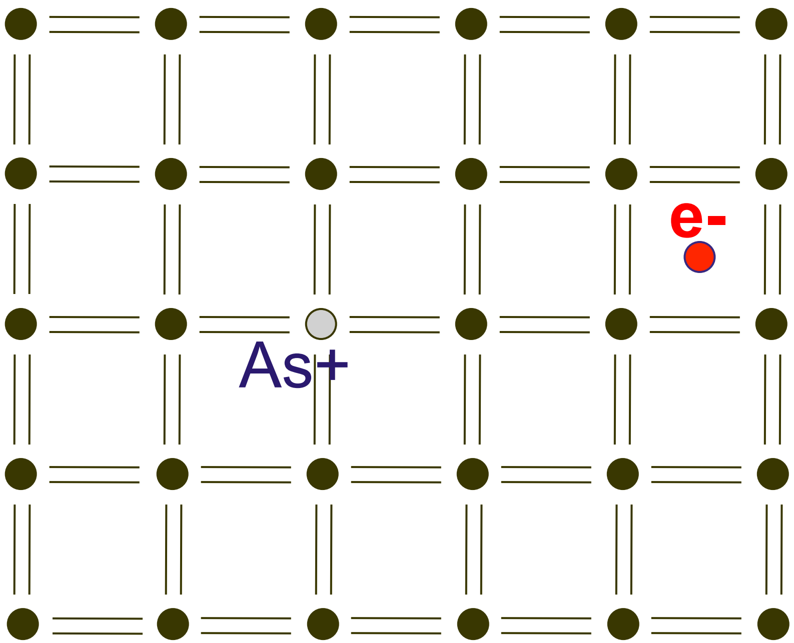
As $K_BT >> \Delta E$

An electron is "donated" to the conduction band by each donor impurity atom

Dopant atom density = free electron density

Termed "n-type doping" or "n-doping"

Ionized Donor



Freeing the weekly bound electron leaves a positively charged donor atom (As)

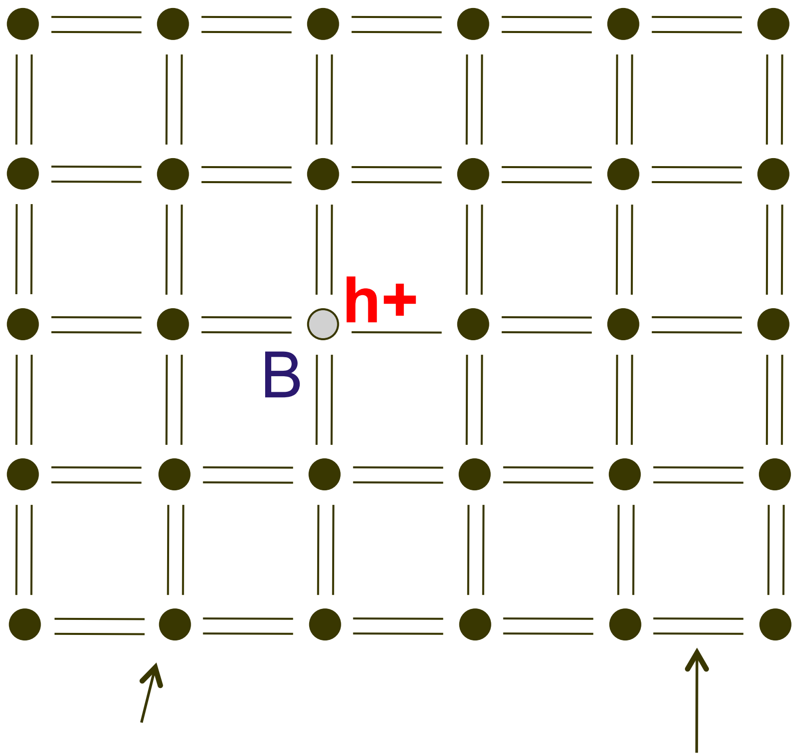
If concentration of donors is high – electrons are majority carriers, holes are minority carriers

The atom is locked into the crystal and ***cannot*** move to contribute to conduction

The ionized impurity is a scattering centre

Increased Ionized impurity density tends to decrease τ , decrease vd, decrease μ

Doping - Si with Group III (B)



Si Atom cores

Bonds with 2 shared electrons

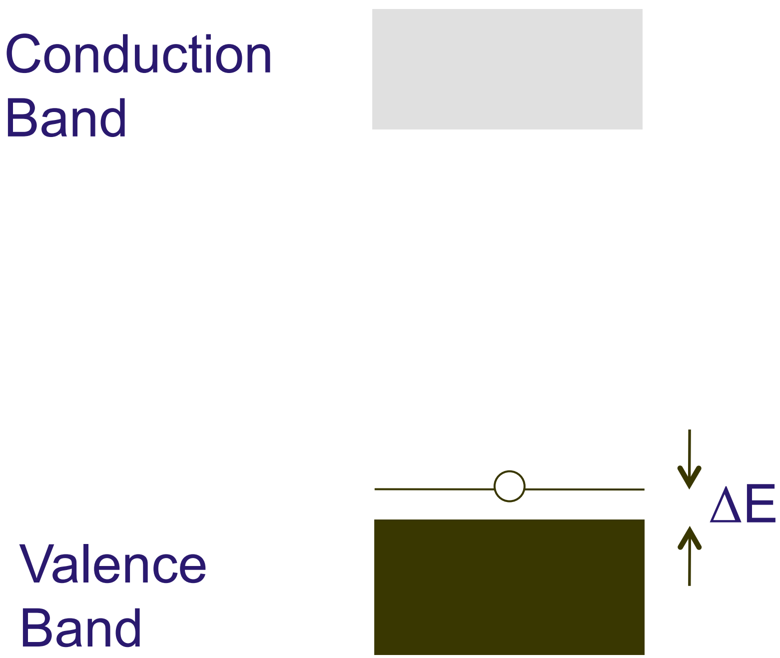
Replace a Si atom with one from group III of the periodic table (Ga, B) – let's assume B (it is easier to use practically)

These atoms have 3 outer electrons

Absence of a bond = hole

In this case a hole is weakly bound to the impurity

Acceptor States, T = 0 K

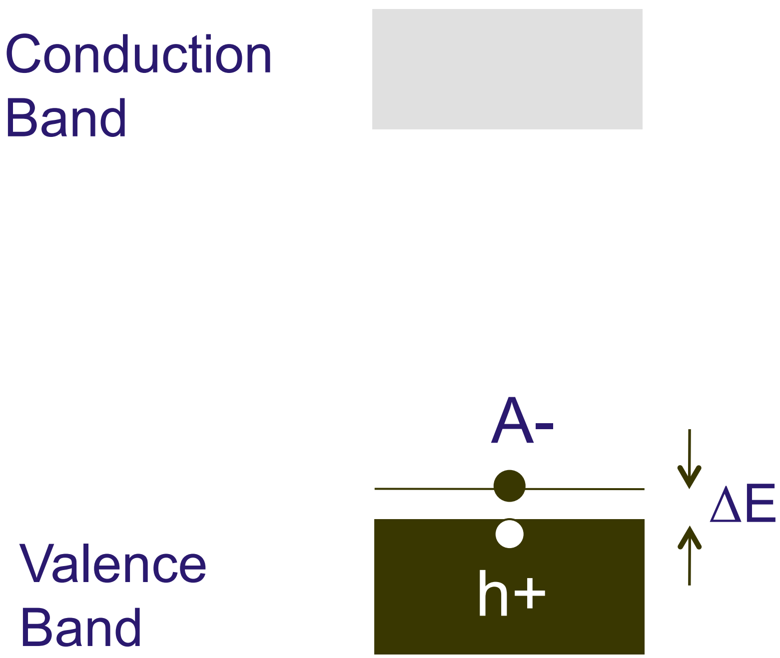


The additional electronic level of the group III impurity dopant forms an electronic level in the band-gap sitting (just) above the valence band

ΔE ~5meV (Si) ~(can be 20-30meV other semiconductors)

This is referred to as an acceptor level

Acceptor States, T = 300K



At room temperature the average thermal energy
$= K_BT = 25meV$

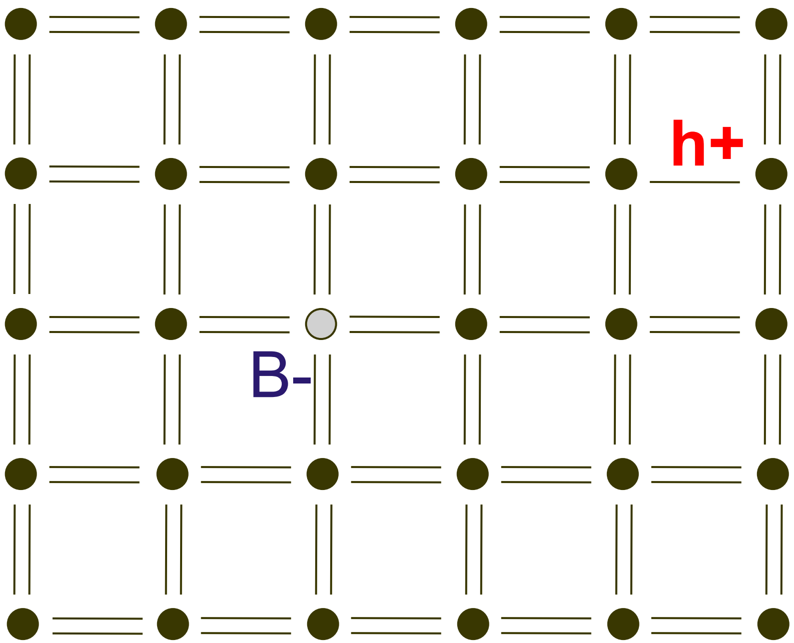
As $K_BT >> \Delta E$ for B in Si

The level "accepts" an electron from the valence band - creating a hole in the valence band

Dopant atom density = free hole density (if $K_BT >> \Delta E$)

Termed "p-type doping" or "p-doping"

Ionized Acceptor



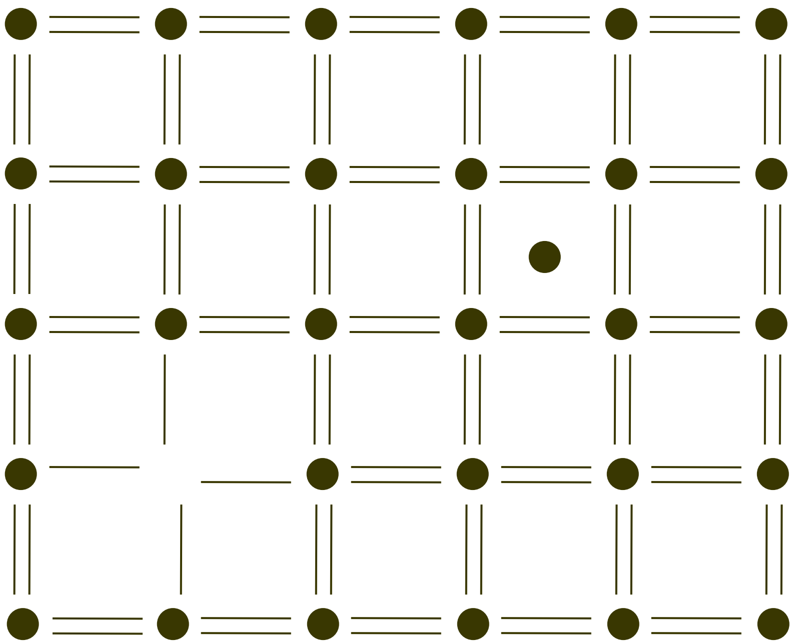
Free the weakly bound hole

If concentration of acceptors is high – holes are majority carriers, electrons are minority carriers

Leaving a negatively charged ionized acceptor

Again – these act as scattering centres like ionized donors

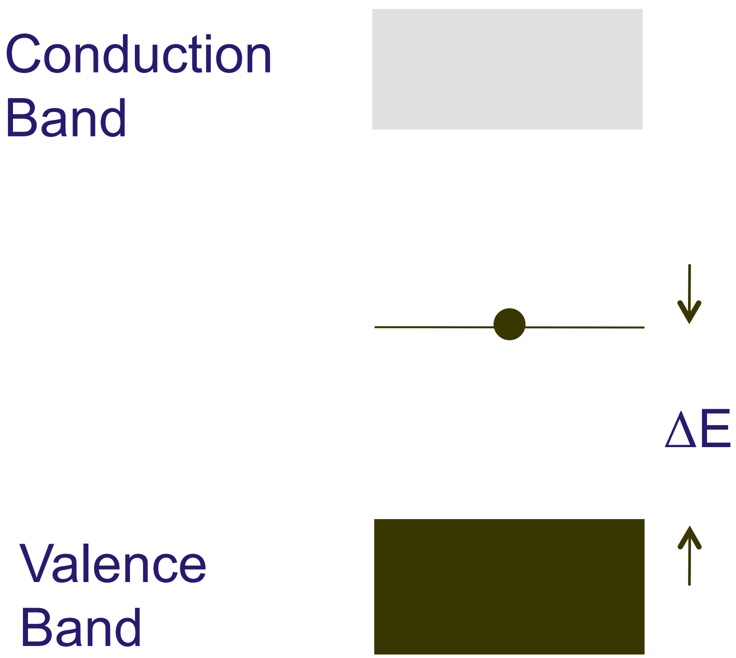
Defect Levels



Vacancies and interstitials and defect complexes can tend to form levels in the mid part of the band-gap

Such states are not useful electrically and serve only to trap and scatter charge carriers – tending to decrease τ , decrease vd, decrease μ

Deep Donor States, T = 300K



e.g. Interstitials, vacancies

For deep donor

$\Delta E >> K_B T$

Charge effectively trapped

Additional unwanted scattering centre

Summary

- A pure semiconductor is termed an intrinsic semiconductor – at room temperature there are a relatively small number of electrons and holes
- It is possible to increase the density of electrons or holes by doping the semiconductor with different atoms – here we consider Si
- Adding atoms from Group V, where there are 5 outer electrons, results in the "donation" of a free electron and an ionized atom ("donor"). At room temperature all donors are ionized. This is termed n-type doping or n-doping as the charge carriers are negatively charged.

Summary (2)

- Adding atoms from Group III, where there are 3 outer electrons, results in the atom “accepting” an electron from the valence band resulting in the creation of a free hole and an ionized atom (“acceptor”). At room temperature all acceptors are ionized. This is termed p-type doping or p-doping as the charge carriers are positively charged.
- The dopant atoms have electronic levels close to the conduction (donors) and valence band (acceptors)
- Ionized impurities act to scatter carriers, reducing mobility
- Other impurities and defects can form levels close to the middle of the band-gap

