Recall, carrier densities:

$$n = N_c(T)e^{-(\varepsilon_c - \mu)/kT}$$

$$p = P_v(T)e^{-(\mu - \varepsilon_v)/kT}$$

n & *p* adjusted by changes in μ.
OK far from band edges (used MB approx.)

product
independent of μ

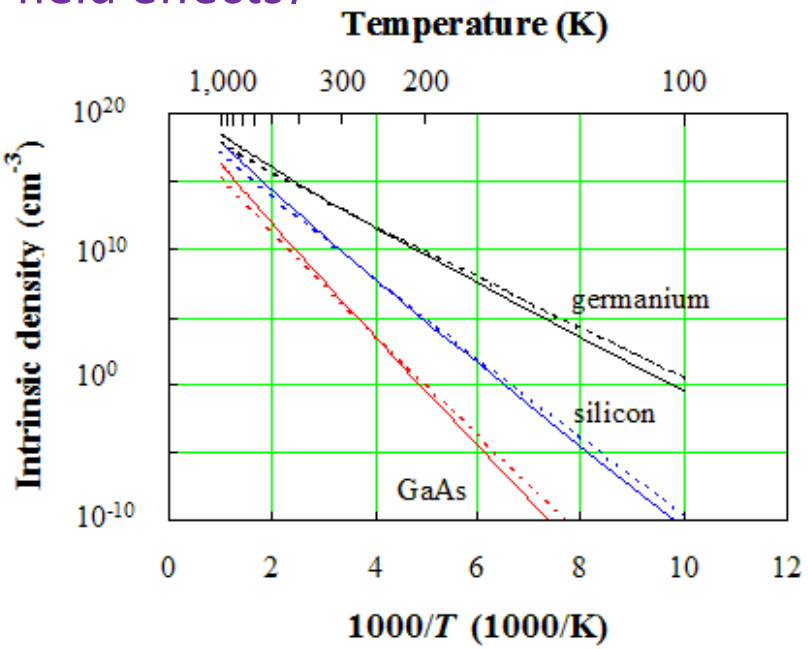
$$np = N_c(T)P_v(T)e^{-(\varepsilon_g)/kT}$$

Silicon, RT $N_cP_v = (2.8 \times 1.0) \times 10^{38}$ cm^{-6}

- Intrinsic: ultra-pure (no impurities, or field effects)
- *n* = *p* by charge conservation.
- μ near mid-gap position.

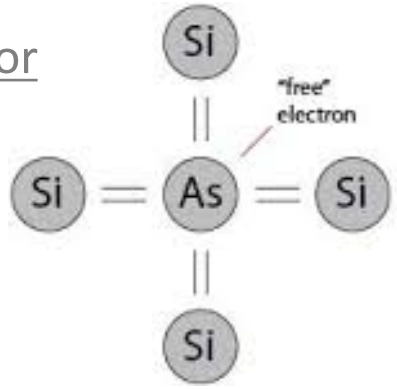
$$n_i = \sqrt{N_c(T)P_v(T)}e^{-(\varepsilon_g)/2kT}$$

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

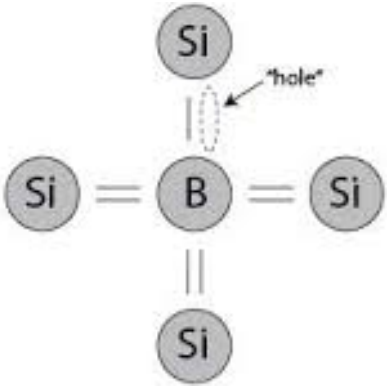


Donors / acceptors

donor



acceptor

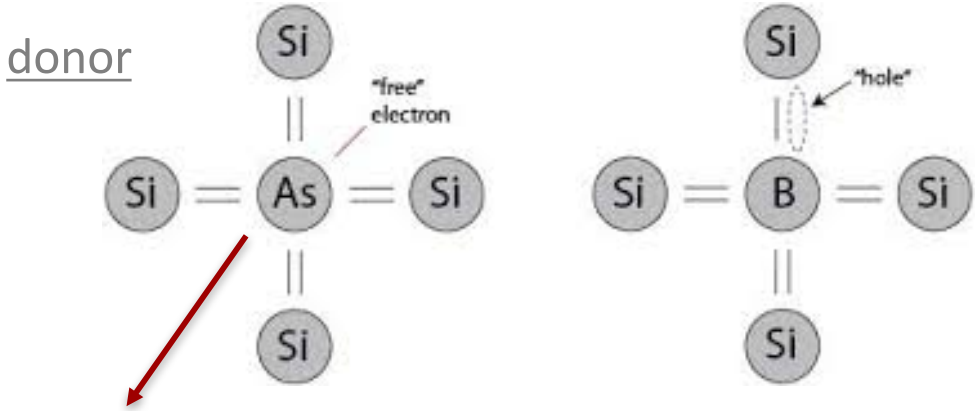


boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007
aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974
gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922
indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76

impurities:

- Electronic states mixed with band states - *not so important.*
- States in gap: localized.
- deep traps (near mid-gap) various practical effects, e.g. pinned chemical potential detrimental to some devices.
- Shallow donors/acceptors: similar to hydrogen states.

Donors / acceptors



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Assume ionized into C.B.

Ground state: localized "Bohr orbit", composed of CB states.

(Result shows this is consistent picture)

$$U = \frac{1}{\kappa}\frac{e}{r}$$

$$r = \frac{\hbar^2}{m_c^* e}\kappa \approx 60 a_o$$

silicon

$$E_n = 13.6\text{eV}\,\frac{m_c^*/m}{\kappa^2}\frac{1}{n^2} \approx 20\text{meV}/n^2$$

But coulomb interactions may limit this to one occupied state (HW)

Donors / acceptors:

boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007
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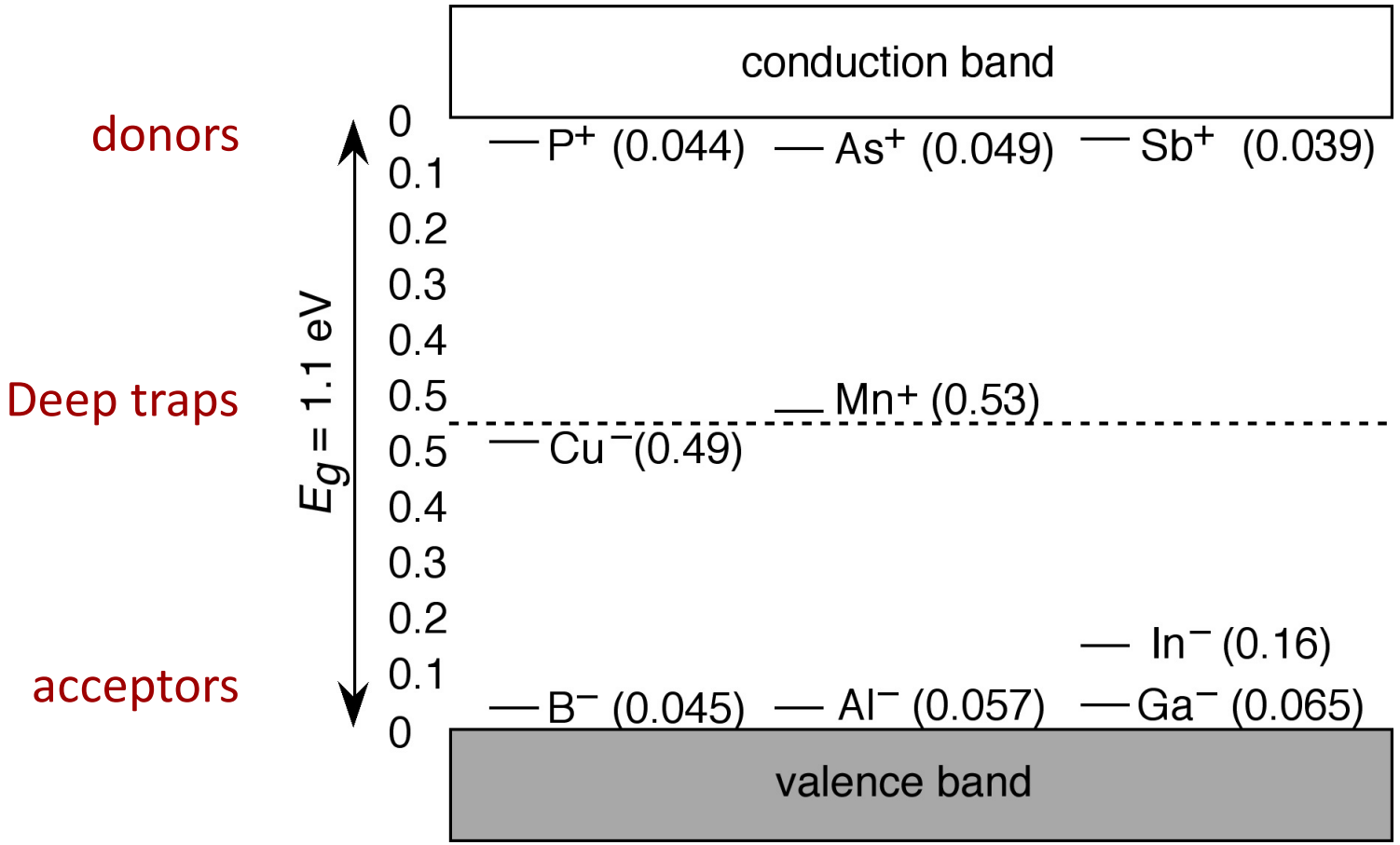
Results:



Silicon impurity states

Donors / acceptors:

Equilibrium :

typically all ionized, wide range of T

(density not too big)

Donors: pull μ toward CB edge.

Notation:

n = electron density (CB)

p = hole density (VB)

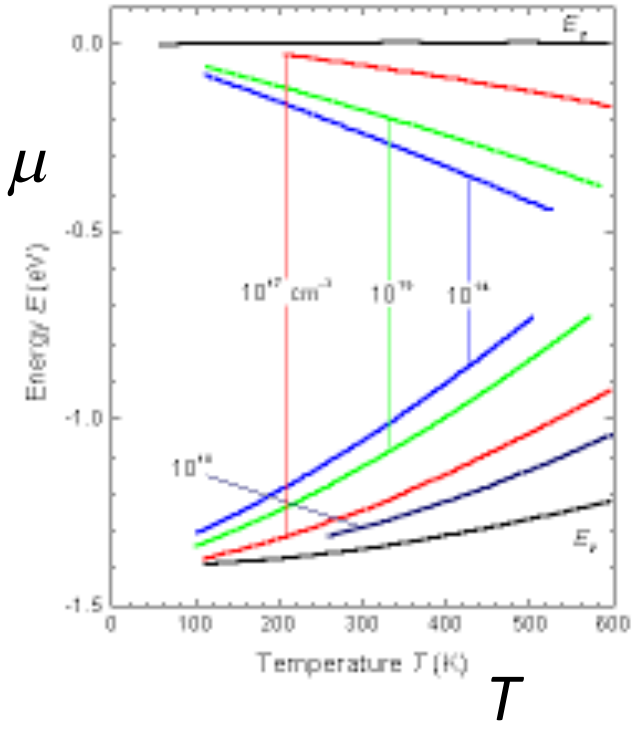
N_D = donor atom density

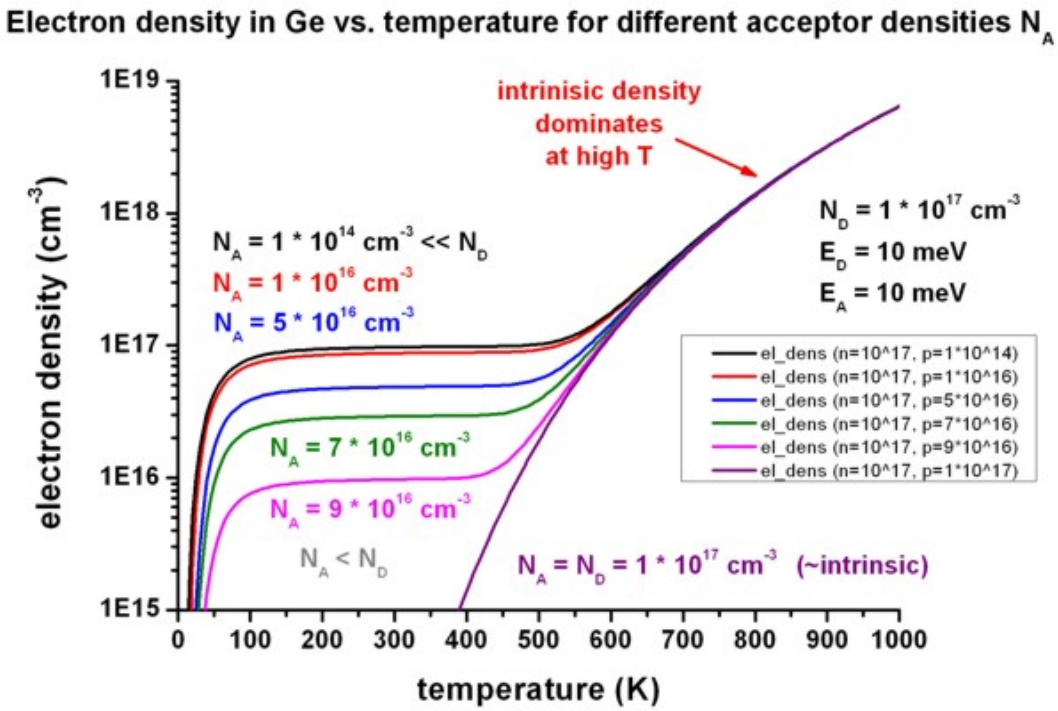
n_D = density, electrons on donors (*neutral*)

N_A = acceptor atom density

n_A = holes on acceptors

$$n - p = N_d\left[1 - \frac{1}{1 + \frac{1}{2}e^{(\varepsilon_d - \mu)/kT}}\right]$$ general case





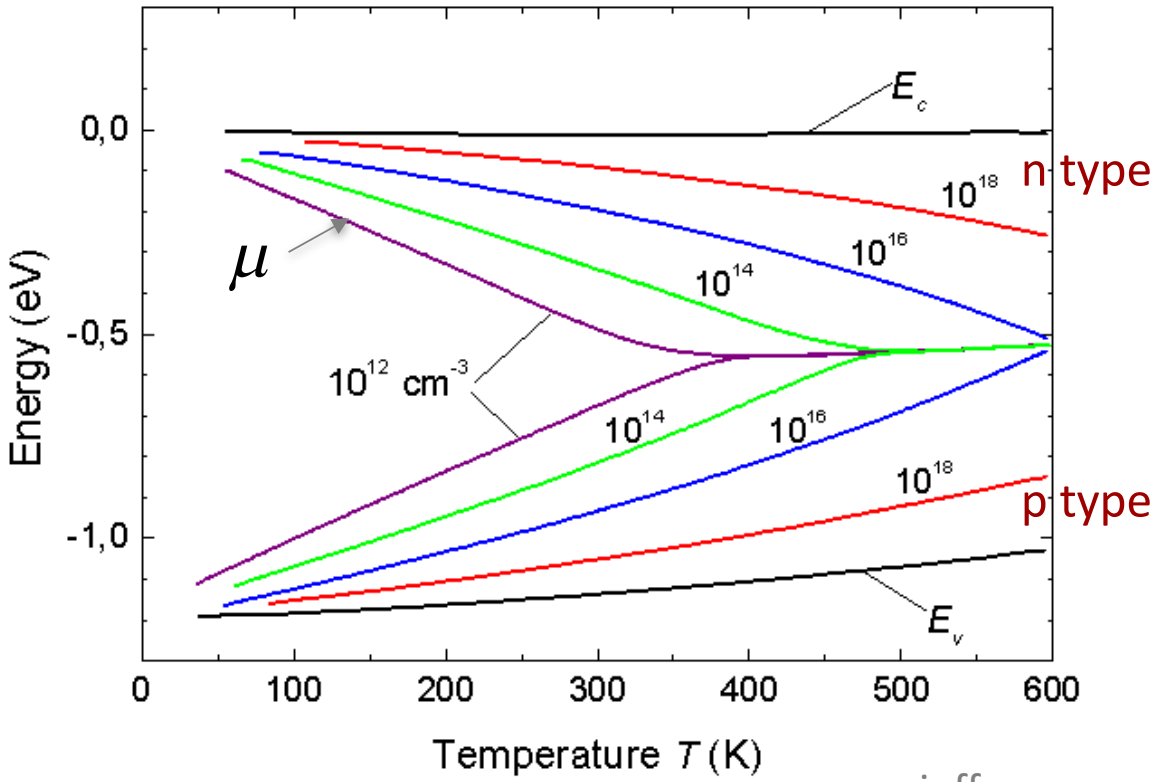
Donors / acceptors:

Equilibrium :

typically all ionized, wide range of *T*

(density not too big)

Donors: pull μ toward CB edge.



$$n - p = N_d\left[1 - \frac{1}{1 + \frac{1}{2}e^{(\varepsilon_d - \mu)/kT}}\right]$$

$$n \approx N_c(T)e^{-(\varepsilon_c - \mu)/kT}$$

$$p \approx P_v(T)e^{-(\mu - \varepsilon_v)/kT}$$

Solve for μ.