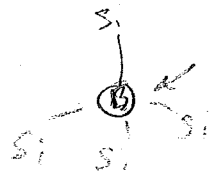
"Acceptor"



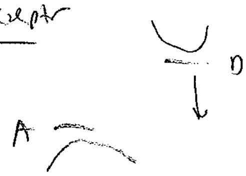
← 4 electrons to conduction band + 1 extra hole (and neg. charged nucleus)

(ie p-type)

hole binding to neg. nucleus → same ionize. energy + Bohr radius (except hole m^*, not electron m^*)

Acceptor Binding E

Donor + Acceptor



electrons drop down to A level

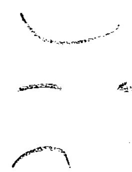
if $N_D > N_A$ n-type

$N_A < N_D$ p-type

"compensated" → roughly equal. or at least, lots of both types

Amphoteric - ex. Si in GaAs, could be either

Nonhydrogenic



← states deep in band

tend to happen when big lattice distortion because dopant not very like host

Background - unintentional $\simeq 10^{14}$ cm^{-3} ($\approx$ 1 part in 10^9) for best samples

intentional: often $\approx 10^{17}$–10^{18} cm^{-3}

(my own samples $3\cdot10^{15}$–$3\cdot10^{16}$ cm^{-3})

What happens at room temp? ($kT \approx 25$ meV)

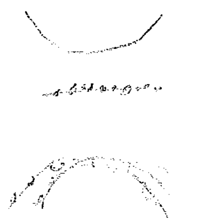
GaAs ≅ 6 meV (both theory + exp)

(≅ 26 meV (theory), 30-40 meV exp)

if n-type: practically all donor electrons → to CB

(if p-type: some (not all) acceptor holes → to VB)

At 0K



← E_F must be in here

$$E_F \approx \frac{E_{CB}+E_{donor}}{2}$$

exponential population of CB

~~Boltzmann statistics~~

~~E_d ... N_d ... $e^{-E_d/kT}$ ... $n = \frac{\dots}{1+e^{\dots}}$ ... Think about!~~

~~$n \cong \sqrt{n_0 N_d}\; e^{-E_d/2kT}$ ... $n_0 = 2\left(\frac{m_e kT}{2\pi\hbar^2}\right)^{3/2}$ ... concentration~~

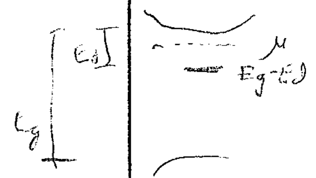
~~Handout S.M. Sze (Yu Notes)~~

~~Fig 8, 20 → concentration vs temp.~~

~~See ... doping ...~~

~~... Thermal ...~~

Derivation: we find $\rightarrow n = \underbrace{2\left(\frac{m^* kT}{2\pi\hbar^2}\right)^{3/2}}_{n_0} e^{-(E_c-\mu)/kT}$



$$n = n_0 e^{-(E_c-\mu)/kT} = n_0 e^{-(E_g-\mu)/kT}$$

$$p = p_0 e^{-(\mu-E_v)/kT} = p_0 e^{-\mu/kT}$$

Let $E_v = 0$, then $E_c = E_g$

Before $n = p$

Now $n = p + \underbrace{\#\text{ ionized donors}}_{\#\text{ donors} \times \text{Prob of ionizing}}$

$$N_d e^{-[\mu-(E_g-E_d)]/kT}$$

(just like for valence band. Probably implies Boltzmann statistics)

$$n = \underbrace{p_0 e^{-\mu/kT}} + N_d e^{-(\mu+E_d-E_g)/kT}$$

$\times n \qquad \times n_0 e^{-(E_g-\mu)/kT}$

$$n^2 = n_0 p_0 e^{-E_g/kT} + n_0 N_d e^{-(\cancel{\mu}+E_d-\cancel{E_g})/kT} e^{-(\cancel{E_g}-\cancel{\mu})/kT}$$

$$\boxed{n^2 = n_0 p_0 e^{-E_g/kT} + n_0 N_d e^{-E_d/kT}}$$

typically small at room T — typically this dominates

$$\boxed{n = \sqrt{n_0 N_d}\, e^{-E_d/2kT}}$$

Handout from Sze

Alloys

concentration 1% + → not dopants any more

"average" atom

bandgap engineering handout

→ discussion of quantum wells

Type 1 vs Type 2

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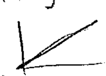
day 38 pg 1

End of Ch. 8

→ skipping misc topics at end

- Thermoelectric
- Superlattices
  - o Bloch oscillator
  - o Zener tunneling ← actually, maybe explain

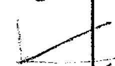
Applied $\vec{E}$ → tilts bands

because $V =$  space

for const $\vec{E}$

then $U \sim V$

$U =$ existing U

\+ 

potential vs space