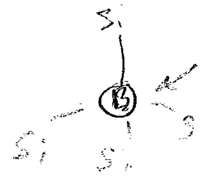
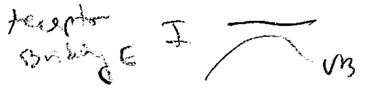
"Acceptor"



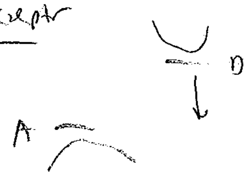
← 4 electrons to conduction band + 1 extra hole (and neg. charged nucleus)

[illegible]

hole binding to neg. nucleus → same ioniz. energy + [illegible] radius (except hole m^*, not electron m^*)



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

day 35 pg 1

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

intentional: often ~ 10^{17} - 10^{18} cm^{-3}
(my own samples $3 \cdot 10^{14}$ - $3 \cdot 10^{15}$ cm^{-3})

Growth techniques
- bulk (melt)
- layers (MOCVD, MBE) → QWs, Type I vs Type 2 (bandgap engineering handout)

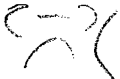
Alloys: when ≥1% "impurity"

day 33 pg 2

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

GaAs

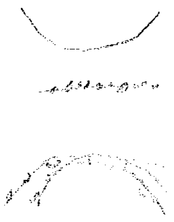
$\lesssim 6$ meV (both theory & exp)


($\lesssim 26$ meV (theory) / 30–40 meV exp)

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

(if p-type: some (small) acceptor holes ↓ to VB)

At 0K n type


← filled up to here ← 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 ... $e^{-E_d/kT}$ ... $e^0 = 1$ ... $n = \frac{e^{-E_d/kT}}{1+e^{-E_d/kT}}$~~ ~~think about!~~

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

~~$n_0 = 2\left(\frac{m_e kT}{2\pi\hbar^2}\right)^{3/2}$ ... concentration~~

~~Handout S.M. S2e (Yu Notes)~~

~~1, 8, 2b → concentration vs temp.~~

~~Switched donor → acceptor~~

Derivation: we found

$$n = n_0 e^{-(E_c-\mu)/kT} \qquad n_0 = 2\left(\frac{m_e kT}{2\pi\hbar^2}\right)^{3/2}$$

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

Before $n = p$

Now $n = p + \#$ ionized donors

$\hookrightarrow = \#$ donors × Prob of ionizing

$\#$ donors $= N_d$

Prob of ionizing $\hookrightarrow$ 1 − Prob of occupied

$$1 - \frac{1}{e^{+(E-\mu)/kT}+1} \qquad \text{(Fermi Dirac)}$$

Kittel Thermal Physics pg 369: FD is not correct. Oh well.

$$\frac{e^{(E-\mu)/kT} \cancel{+1} \cancel{-1}}{e^{(E-\mu)/kT}+1} \times \frac{e^{-(\ )}}{e^{-(\ )}}$$

$$\frac{1}{e^{-(E-\mu)/kT}+1}$$

Note that μ is above E

so $E - \mu$ = negative

— E_c

← μ

— $E = E_c - E_d$

— E_v

$$\frac{1}{e^{(\mu-E)/kT}+1}$$

↑ big??

$$\simeq e^{-(\mu-E)/kT}$$

$$n = \underbrace{p_0 e^{(-\mu+E_v)/kT} + N_d e^{(-\mu+E_c-E_d)/kT}}_{\times n_0 e^{(-E_c+\mu)/kT}}$$

× n

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

→ typically very small at room T

→ typically dominates

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

Kittel
pg 213
Eqn 8.53

Handout from Sze

Aug 25 | pg 4

~~Alloys~~

~~concentration 1% + → not dopants any more~~

~~"average" atom~~

~~bandgap engineering handout~~

~~→ discussion of quantum wells~~

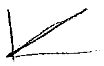
~~Type 1 vs Type 2~~

End of Ch 8

→ skipping misc. topics at end of chapter

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

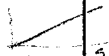
Applied $\vec{E}$ → tilts bands

because $V =$  space

for const E

then $U \sim V$

$U =$ existing U

\+ 

plotted vs. space