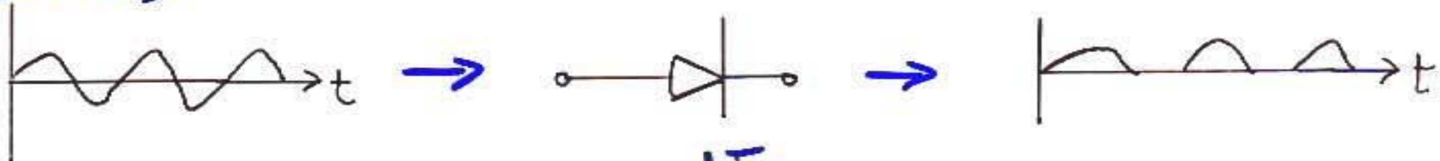
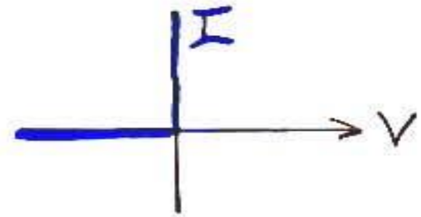
P-N Junction Applications

Basis for important devices

1) Rectifier – conducts current in 1 direction only (V>0)

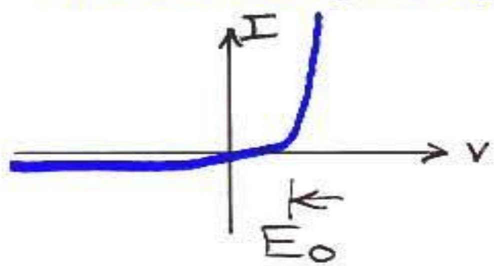


Ideal Diode:

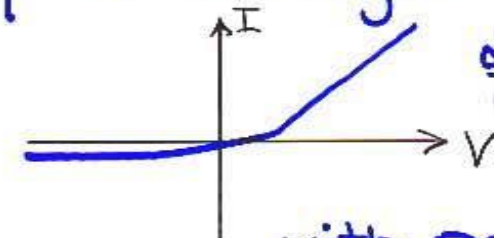


V<0 : Open
V>0 : Short

Non-Ideal Diode: Offset voltage



or



$\frac{dv}{di} = R$

with resistance

Piece-wise linear approximations of diode.

Design Considerations

a) Large band gap

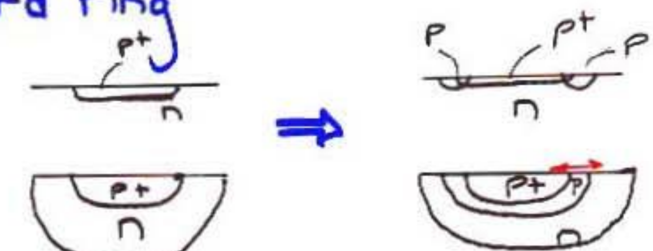
- n_i small → I_o reverse saturation small
- Can operate at high T since n_i increase small
- higher breakdown voltage V_{br} (but E_o increases)

b) Low doping

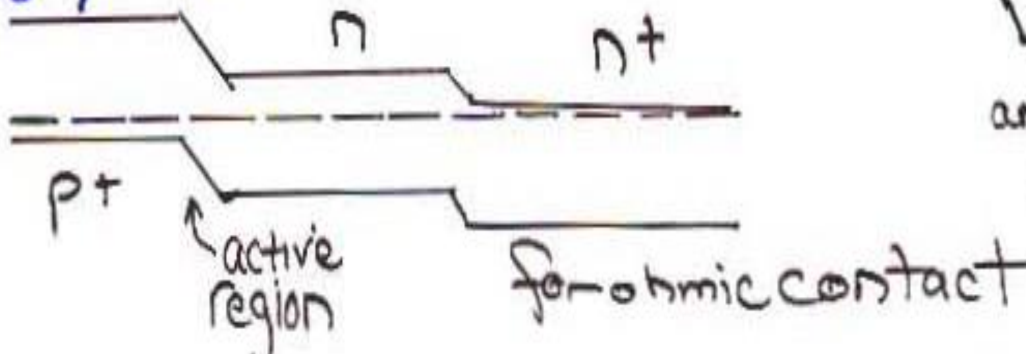
- Increase V_{br} (in lightly-doped side)
- To offset increased R, make A large and L small

c) Beveled edge/guard ring

Lower edge fields



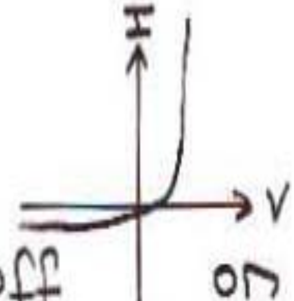
d) Highly doped ohmic contacts



lowers resistance and voltage across all but p+n transition region and n region.

---

2) Switching Diode



(well, almost)

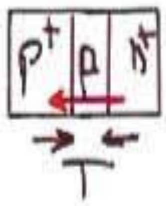
Minimize responsetime between on/off states

Need: a) Very low stored charge

b) Very short carrier lifetime, (τ_n, τ_p)

a) How? shorten lightly-doped neutral region

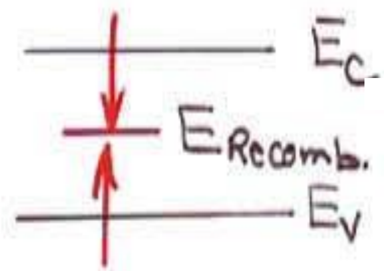
Less charge in smaller volume.



$T < L_n$

b) How?

Add recombination centers.

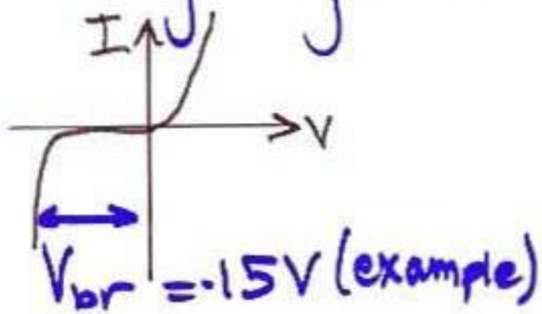


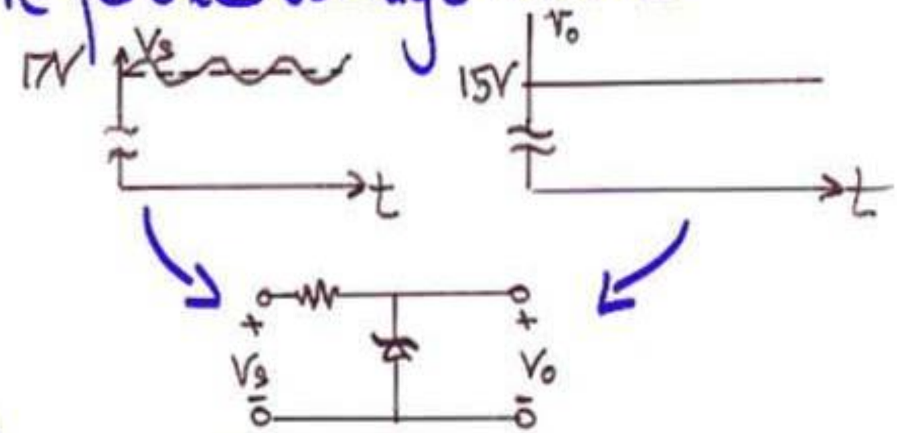
example: Au in Si $10^{15}\,cm^{-3}$

$\tau_p \sim 0.01\,\mu sec$

3) Breakdown Diode (Zener effect - tunneling)

Voltage regulators, reference voltage diodes





Design in specific voltage.

4) Varactor Diode (Variable Reactor

(voltage-variable capacitor)

Recall: $C = C(V)$

$C_j = V_r^{-1/2}$ abrupt $V_r >> V_0$

$C_j = V_r^{-n}$ Linearly graded $n = \frac{1}{3}$

Can be used in resonant circuit

→ vary ω with applied V

$\omega_r = \frac{1}{\sqrt{LC}} \propto V_r$ for $n=2$ (hyperabrupt)

Use in place of bulky variable plate capacitors.

other applications : active filters, μwave mult.

5.) Tunnel Diodes (p. 486ff. 5th ed.)

Like Zener diode, but doesn't require large V_r to get band overlap

Also — Negative dV/dI !

key: Requires degenerate semiconductors

So far: semiconductors N_a or N_d << atomic density ($\approx 10^{22} cm^{-3}$)

so dopants don't interact.

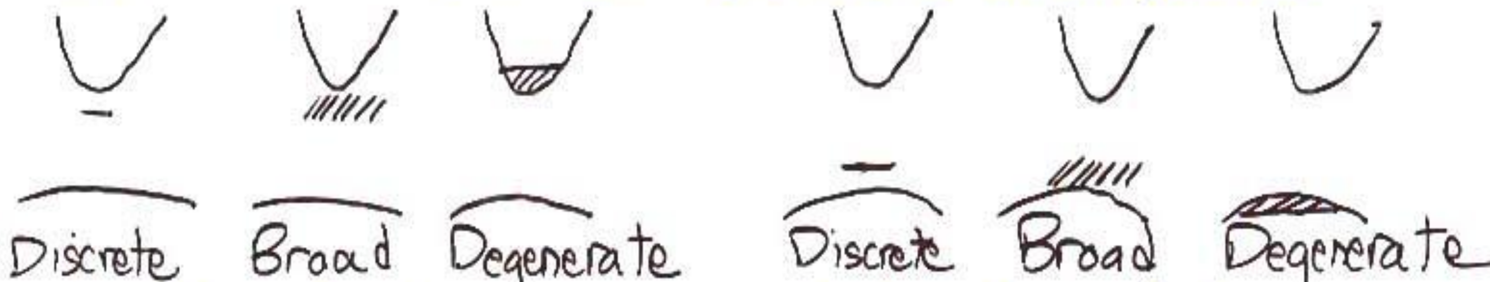
At high concentrations ($\geq 10^{19}$-10^{20} cm^{-3})

→ Dopants overlap ψ's + interact

→ Form a band ($N_a, N_d > N_c, N_v$)

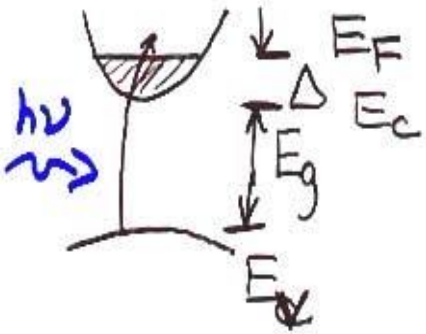
→ Overlaps E_c and E_v

E_F moves into conduction (Valence) band



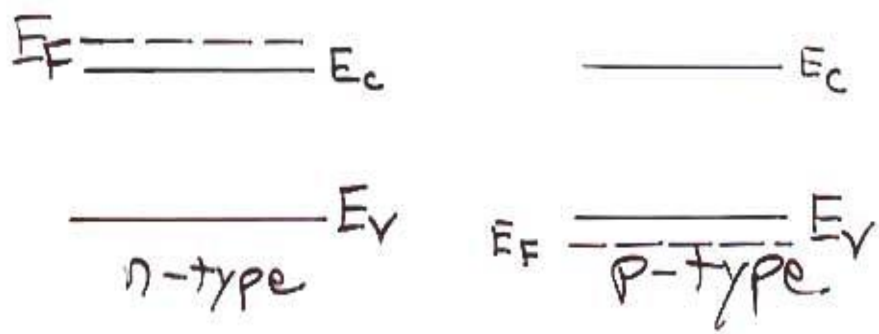
Increasing n-doping →

Increasing p-doping →

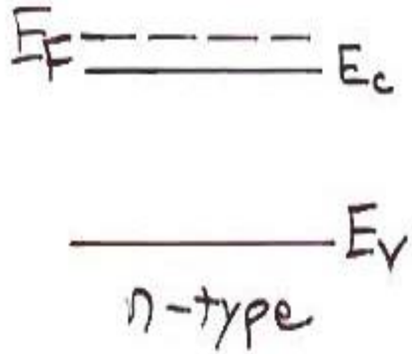


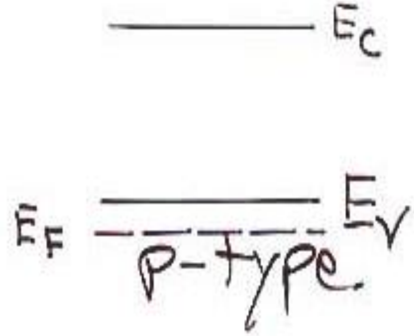
No absorption until $E_g + \Delta$
(Burstein Effect)

Band Diagram for degenerate semiconductors:

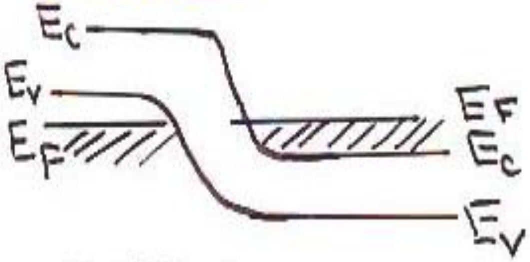


Band Diagram for degenerate semiconductors:





Tunnel diode involves p-n junction with <u>both</u> sides degenerate.



Equilibrium

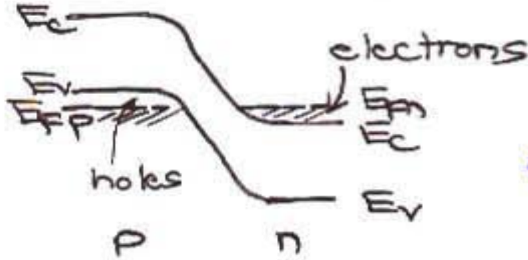
→ Bands overlap even with $V=0$!

so low voltage can give tunneling versus large V_r needed with Zener

Filled and empty states separated by thin barrier → Tunneling

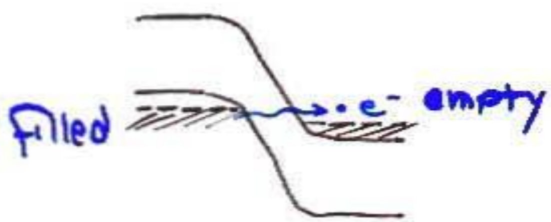
Band Diagrams and I-V

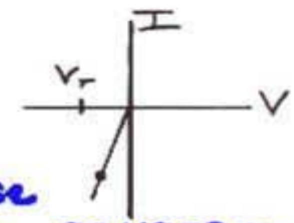
a.)



Equilibrium

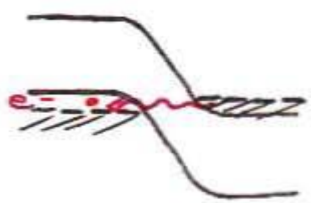
b.)



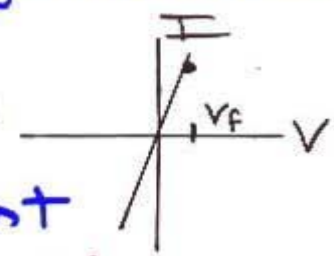


small reverse bias, large reverse current

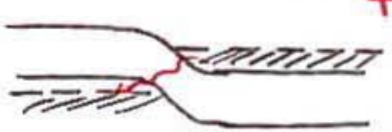
c.)

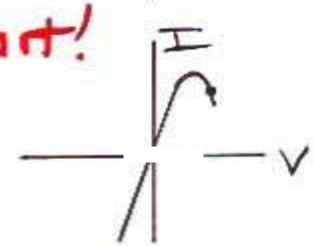


small forward bias, large forward current



d.) Now comes the interesting part!



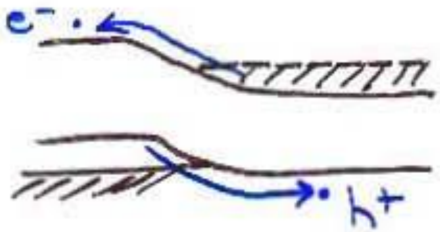


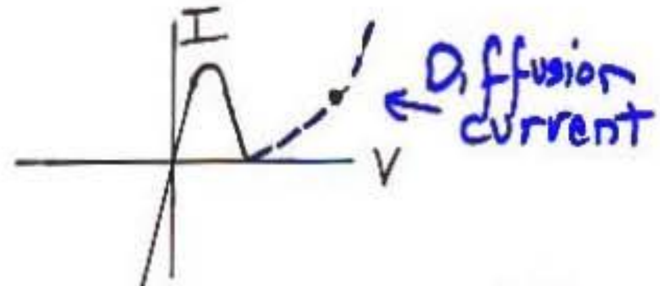
# of states "opposite" (across junction at same energy) starts to decrease.

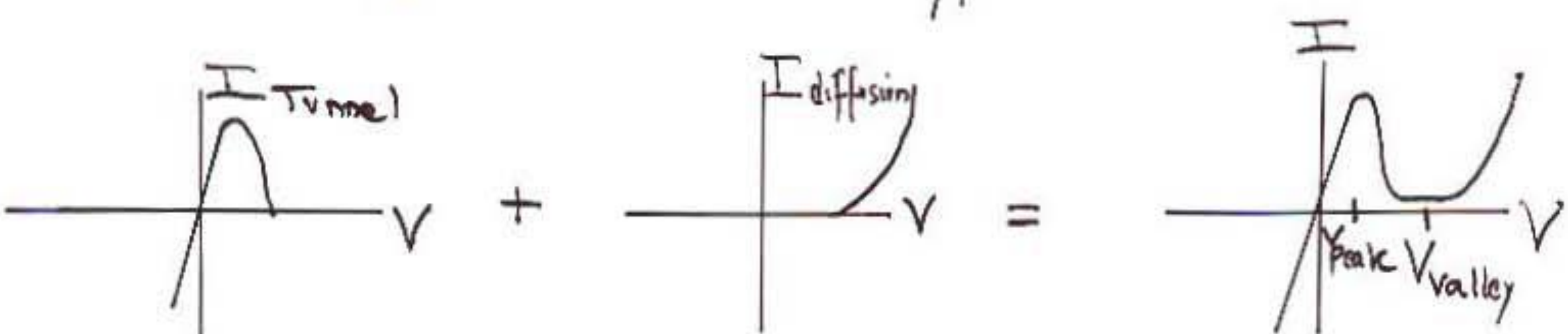
→ Tunnel current decreases with increasing forward bias.

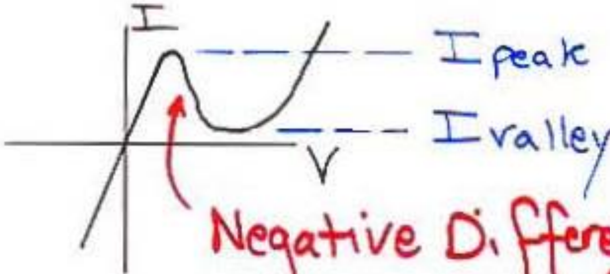
$$J_{Tunnel} \sim \underbrace{f_n(E)\, N_{cn}(E)}_{\#\text{ filled on n-side}} \left(\underbrace{1 - f_p(E)\, N_{vp}(E)}_{\#\text{ empty on p-side}} \right)$$

e.) Finally, diffusion dominates









S&B Figures 10-2, 10-3

Negative Differential Resistance (NDR) $\frac{dV}{dI} < 0$

- I_{peak}/I_{valley} is a figure of merit
- Determines slope of $\frac{dV}{dI}$ (magnitude of NDR)
- V_{peak}/V_{valley} → Voltage spread between positive dV/dI regions

Applications: high speed circuits
- no time delays
- switching
- amplification
- but currents are low → low power