pn Junction based Devices

Chapters 6 and 9 of the textbook, and then 10

Question

A *pn* junction, whether it flows current or not, is basically neutral in total charge everywhere except in the depletion region.

A. True
B. False

Ans: A
Why? Majority carrier screening.

Question

When a current is flowing through a *pn* junction the minority/majority character of the hole current (or the electron current) changes as the current passes through the depletion region.

A. True

B. False

Ans: A

Question

When a current is flowing through a *pn* junction only the minority carrier carries the current just outside the depletion region.

A. True
B. False

Ans: B
Pure logic combined with the previous Q.

Question

When a current is flowing through a *pn* junction only the majority carrier carries the current far from the depletion region.

A. True

B. False

Ans: A
Why? The minority current is exponentially damped.

Question

When a current is flowing through a p^+n junction ($p^+ \gg n$), and if the n part is narrow (compared to the diffusion length), then the current is basically carried by the hole carriers alone throughout this device.

A. True

B. False

Ans: A

See Eqs. 16.11-16.14 ($J_{p,0} \gg J_{n,0}$ because $L_p N_D \ll L_n N_A$ (prove it!))

Note that $N_A \gg N_D$ but $L_p \gg L_n$!
<u>Not</u> $L_p \gg L_n$ as might have been stated(?) during lecture.
Still $J_{p,0} \gg J_{n,0}$ is true.

Question

On forward bias ($|V_A| \gg k_B T/e$), the current can be thought to occur by net ________ through the depletion region.

A. diffusion
B. drift

Ans: A

Question

On reverse bias ($|V_A| \gg k_B T/e$), the current can be thought to occur by net ________ through the depletion region.

A. diffusion
B. drift

Ans: B

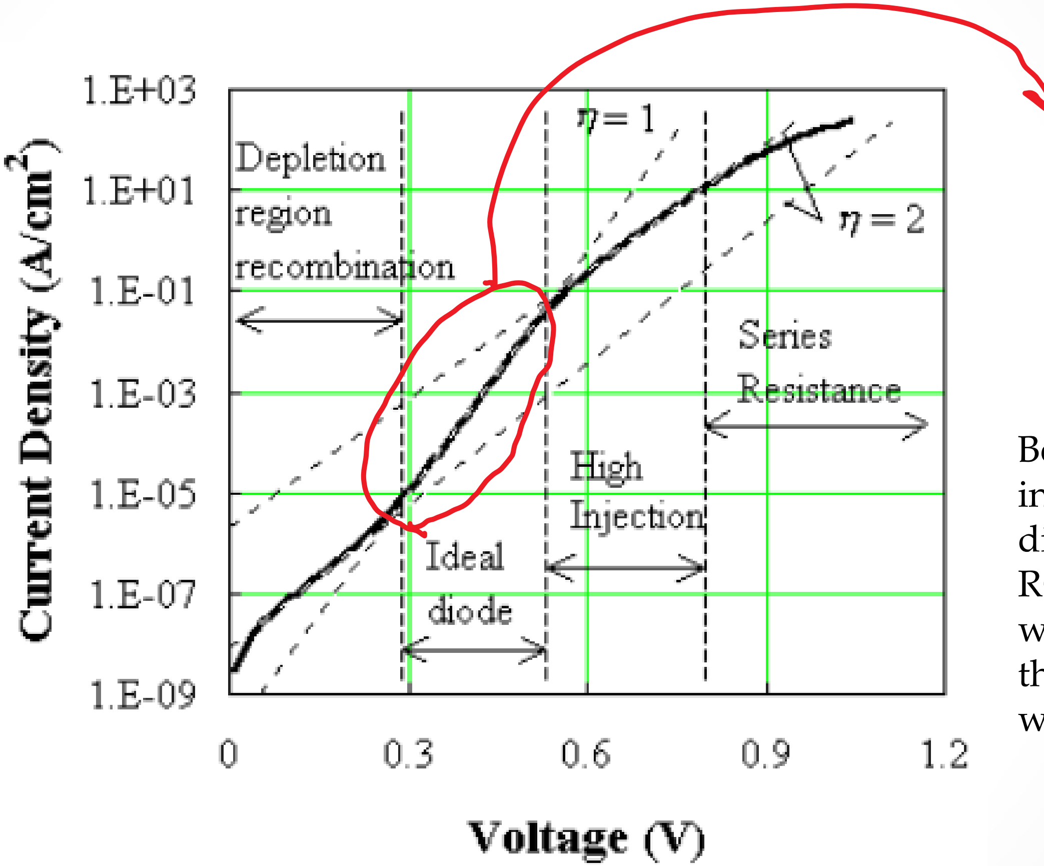
Question

The Ideal Diode Equation (“Shockley Equation”) is useless as far as the quantity of the current is concerned.

A. True
B. False

Ans: B
Quantitatively useful in some range! (Next slide.)

Summary of Forward Bias (Si)



Ideal diode equation does work here!!

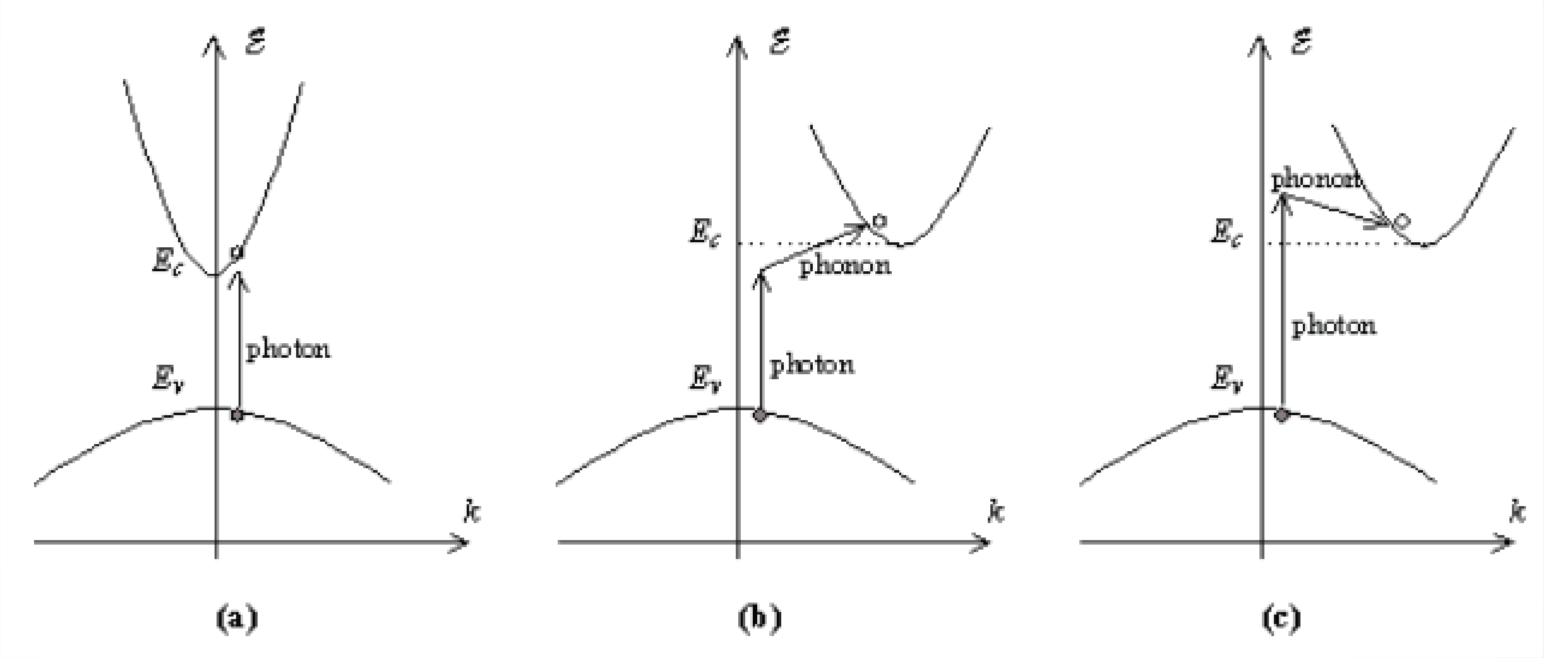
Because of the indirect gap of Si, direct band-to-band RG process, which would contribute to the $\eta = 1$ behavior as well, is not important!

$\eta?$

$$I \propto \exp\left(\frac{V_A}{\eta k_B T}\right)$$

Image from http://ecee.colorado.edu/~bart/book/
(this and other unlabeled figures in this file)

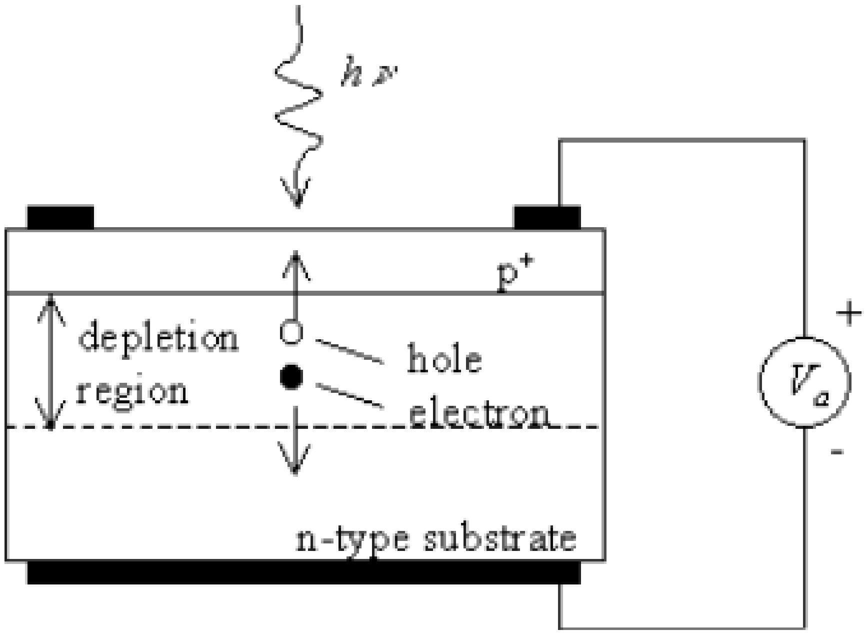
Optoelectronic Device



Direct semiconductor

Indirect semi-conductor

pn Junction under Illumination



pn Junction under Illumination

When illuminated, the electron-hole pairs will be created everywhere. Which pairs will contribute the most? (assuming small V_A) Why?

A. e-h pairs created in the depletion region.

B. e-h pairs created in the quasi-neutral region, far away from the depletion region.

C. e-h pairs created in the quasi-neutral region, within L_p or L_n away from the depletion region.

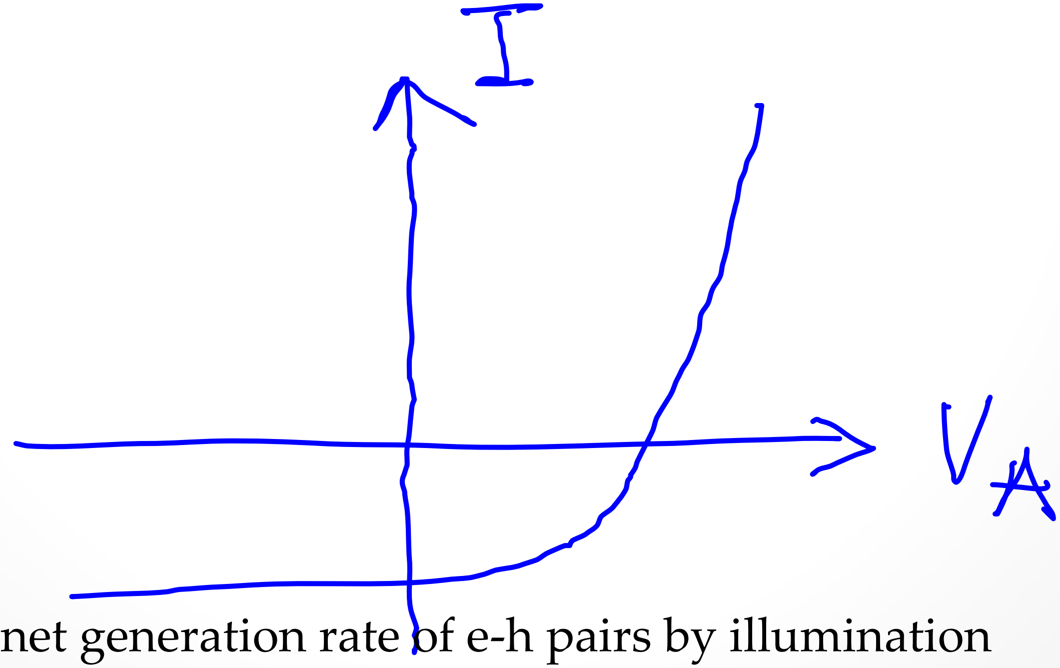
Ans: C
Why? $L_p + L_n > W$. The answer would be A for large reverse bias.

pn Junction under Illumination

$$I = I_{dark} + I_L$$

$$I_{dark} = I_0(\exp(e\beta V_A) - 1) \quad (if\ ideal)$$

$$I_L = -eA\left(L_n + W + L_p\right)G_L$$



A=crossection, G_L=net generation rate of e-h pairs by illumination

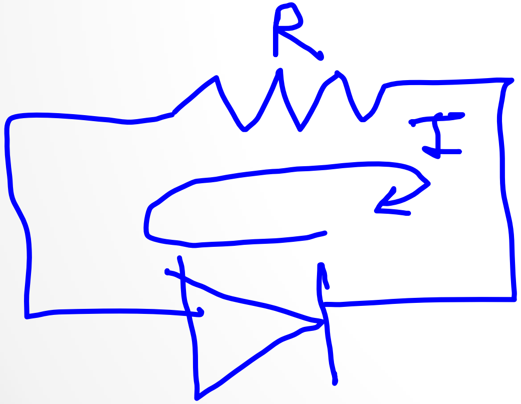
Photo-diode

- *pn* junction, illuminated.
- Under reverse bias.
- Used as a sensor of light.
- On reverse bias, the junction capacitance decreases, and thus a shorter response time results.

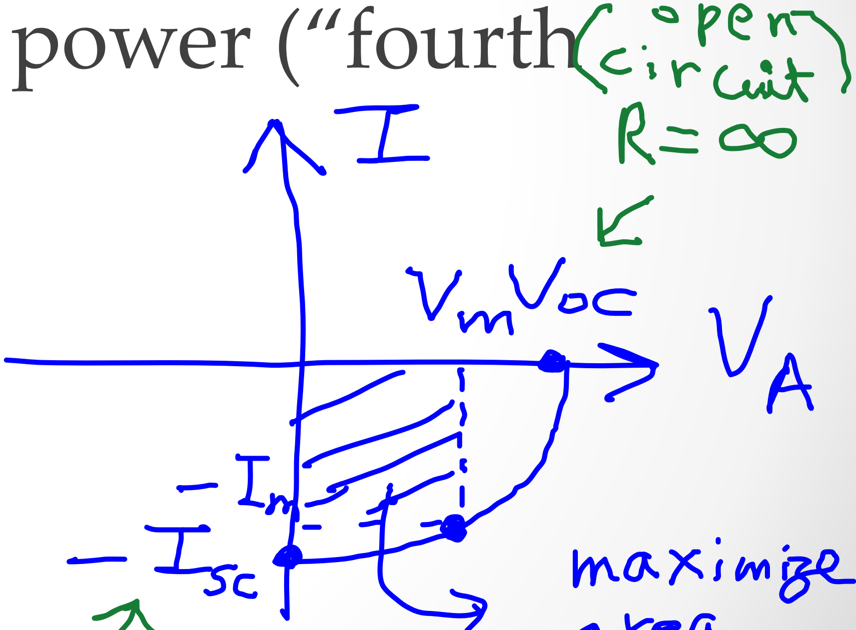
Photo-voltaic Device

- *pn* Junction, illuminated.
- No external bias.
- Self-generates bias and power ("fourth quadrant operation").

$$\frac{I_m V_m}{I_{sc} V_{oc}} = \text{fill factor}$$



$V > 0$ $I < 0$!



$R = 0$ (short circuit)

maximize area = max power out

Laser Diode

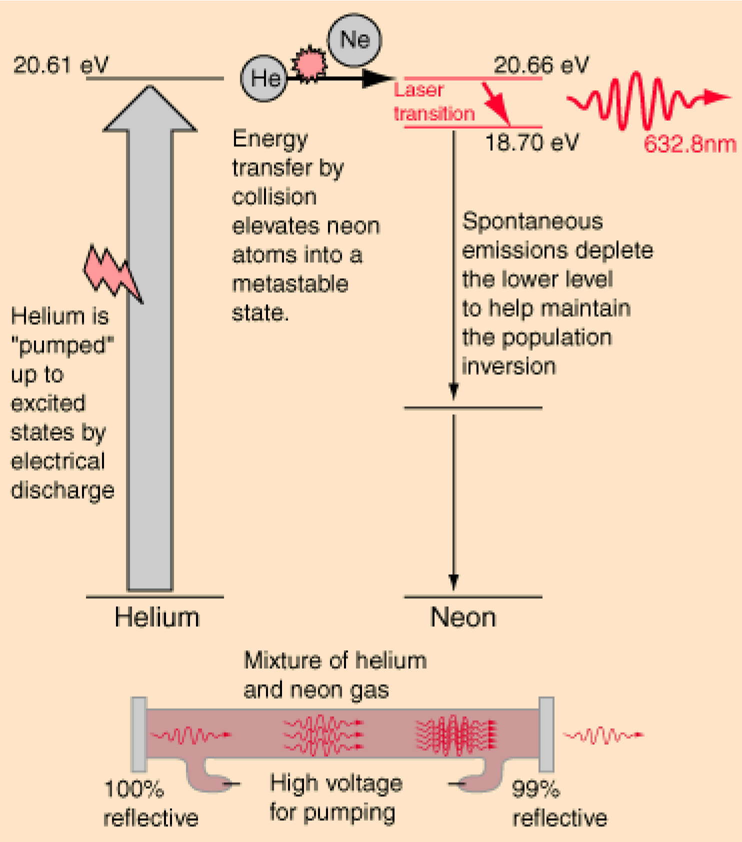
- Laser = Light Amplification by Stimulated Emission of Radiation
- Stimulated Emission? (Einstein)

  Light shakes atoms and becomes more intense!

- Opposite of Absorption

  Light shakes atoms and become less intense.

Laser Example (He-Ne)



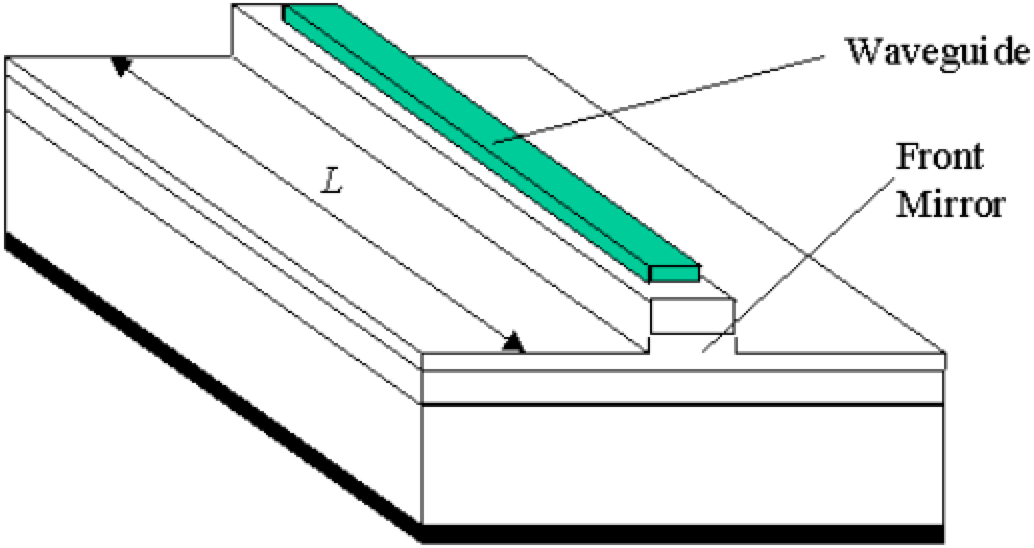
http://hyperphysics.phy-astr.gsu.edu/hbase/optmod/lasgas.html

Light Emitting Diode

- Use the population inversion caused by the minority carrier injection.
- Requirement – Large Gap (1.77 – 3.10 eV, or 0.4 – 0.7 μm) Direct Semiconductor that can be made into a *pn* junction – Very hard to meet! (Read textbook.)
- The energy gap determines the wavelength of the light emitted.
- Table T9.1

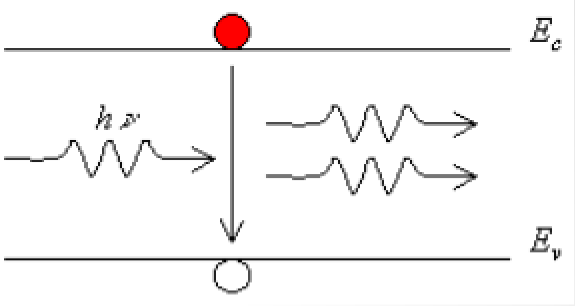
Laser Diode

Q: coherence length? -- A: See the wiki site. https://griffin.ucsc.edu/ph156/Coherence%20Length%3F



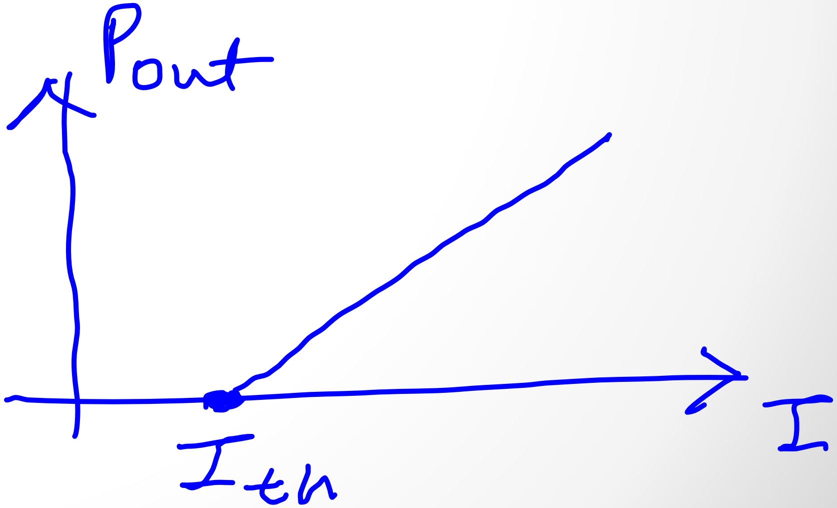
Assume that two mirrors, front and back, have the reflectivity R_1 and R_2. R is the ratio of the light reflected back into the device.

Laser Diode



- Round-trip amplification

  $$A = e^{2gL}R_1R_2$$
- g is the net gain per unit length
- $A = 1$ is the Lasing condition.
- P_{out} = power output of light turns on only above I_{th} when the lasing condition is met.



Bipolar Junction Transistor

- Back to back *pn* junctions
- p^+np or n^+pn
- Emitter-Base-Collector
- Base is thin ($< \mu$m or less than the diffusion length).
- Four configurations possible: Saturation, Active, Inverted, Cutoff.
- Active mode (p^+np): E and B are forward biased. C and B are reverse biased. Large hole current through E, B and C. Small electron current between E and B.