OPTOELECTRONIC DEVICES

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What is optoelectronics?

- A field of technology that combines the physics of light with electricity.
- Optoelectronic technologies include fiber optic communications, laser systems, remote sensing systems, medical diagnostic systems and optical information systems.

Optoelectronic Devices

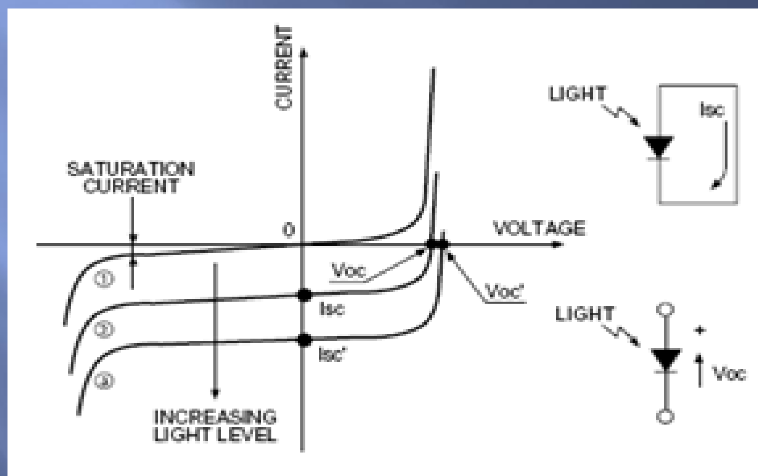
Devices that convert electrical signals into photon signals and vice versa.

- Photodiodes
- Solar cells
- LEDs
- Lasers

Photodiodes & Solar Cells

- A photodiode is a type of photo detector capable of converting light into either current or voltage.
- Solar Cells convert absorbed optical energy into useful electrical power

Current vs. Voltage Characteristic



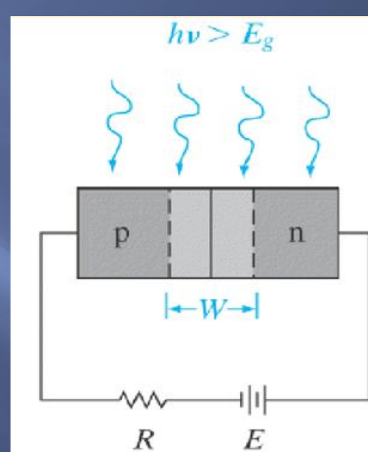
Ep = hv = hc/λ ≥ EG

h = Planck's constant (6.626 x 10^-34 Js)

λ= wavelength of optical illumination

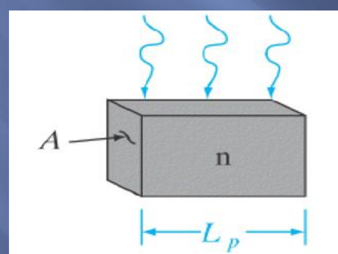
v = frequency of optical illumination

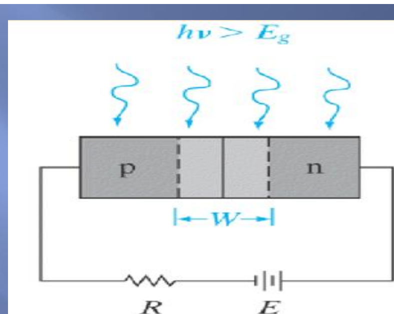
c = velocity of light (3 x 10^8 m/s)



- If the junction is uniformly illuminated by photons with $h\nu > E_g$, an added generation rate G_{op} (EHP/cm^3 s) participates in this current.

Extra holes generated on the n-side: AL_pG_{op}

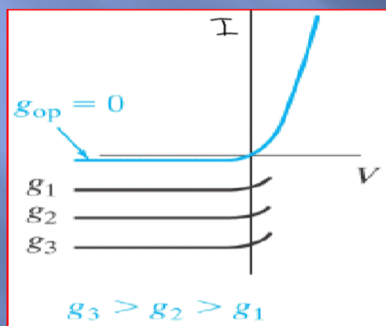




- Extra holes generated on the n-side: AL_pG_{op}
- Extra electrons generated on the p-side: AL_nG_{op}
- Extra carriers generated within the depletion region: AWG_{op}
- The resulting current:
  $I_{op} = qAG_{op}(L_p + L_n + W)$

I-V in an Illuminated Junction

$I = I_{th}(e^{(qV/kT)} - 1) - I_{op}$

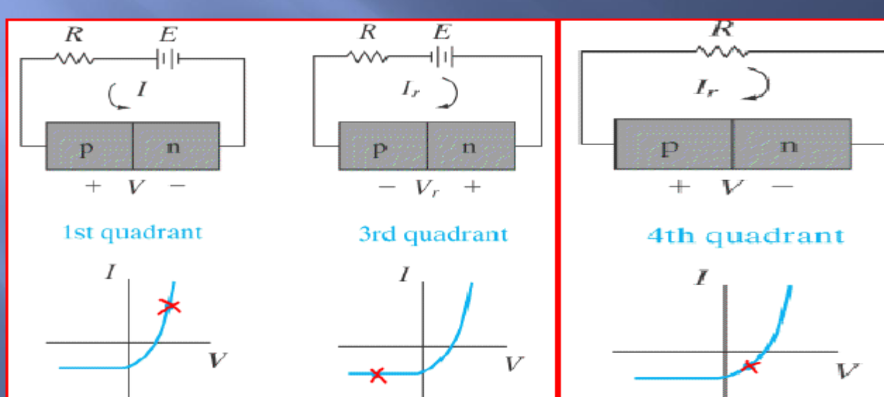


The I-V curve will be lowered in an amount proportional to the added generation rate (G_{op}).

I-V responses under Illumination

POWER IS DELIVERED TO THE DEVICE

THE DEVICE DELIVERS POWER TO THE LOAD

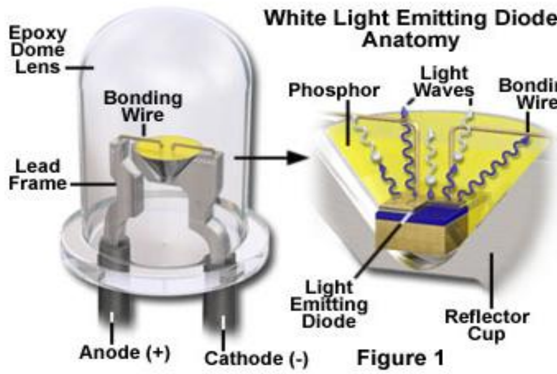


Solar Cells

- Operate in the 4^{th} quadrant where the device gives energy to the circuit.
- Current generated is in the 10-100mA for 1 cm^2 illuminated area.
- We need large area to collect light with a junction located near the surface.
- We must coat the surface with anti-reflective coating.

Solar Panel

- Short clip

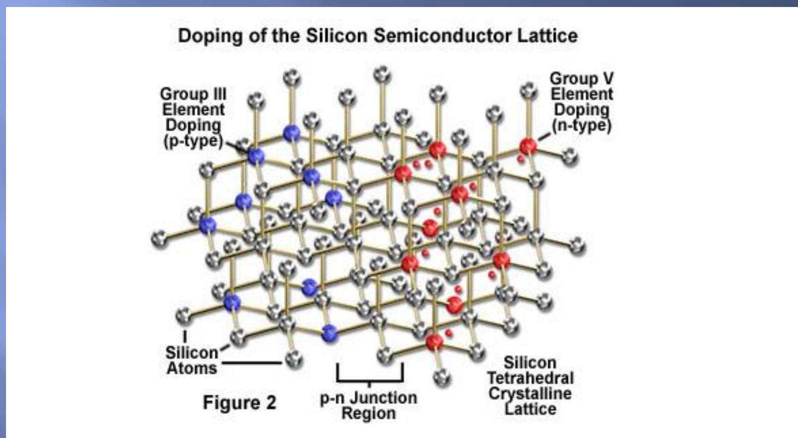


http://micro.magnet.fsu.edu/primer/lightandcolor/ledsintro.html

Table 1–1. Common semiconductor materials: (a) the portion of the periodic table where semiconductors occur; (b) elemental and compound semiconductors.

(a)	II	III	IV	V	VI
		B	C	N	
		Al	Si	P	S
	Zn	Ga	Ge	As	Se
	Cd	In		Sb	Te

(b)	Elemental	IV compounds	Binary III–V compounds	Binary II–VI compounds
	Si	SiC	AlP	ZnS
	Ge	SiGe	AlAs	ZnSe
			AlSb	ZnTe
			GaN	CdS
			GaP	CdSe
			GaAs	CdTe
			GaSb	
			InP	
			InAs	
			InSb	



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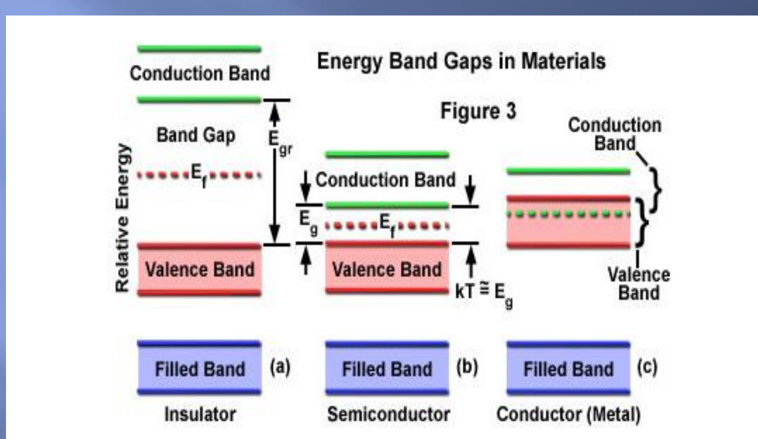

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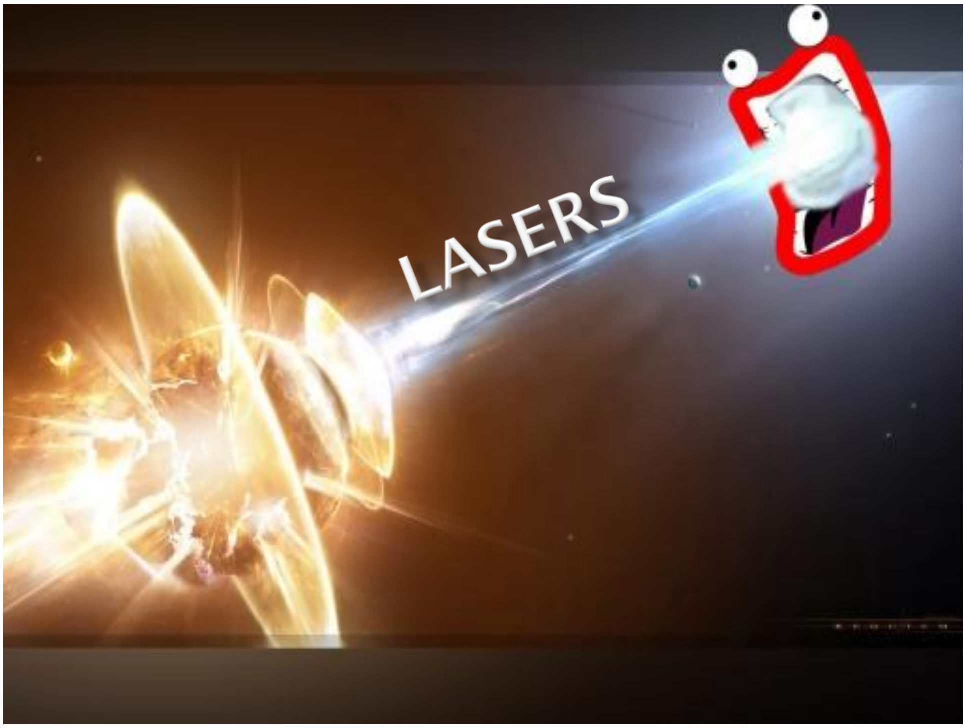
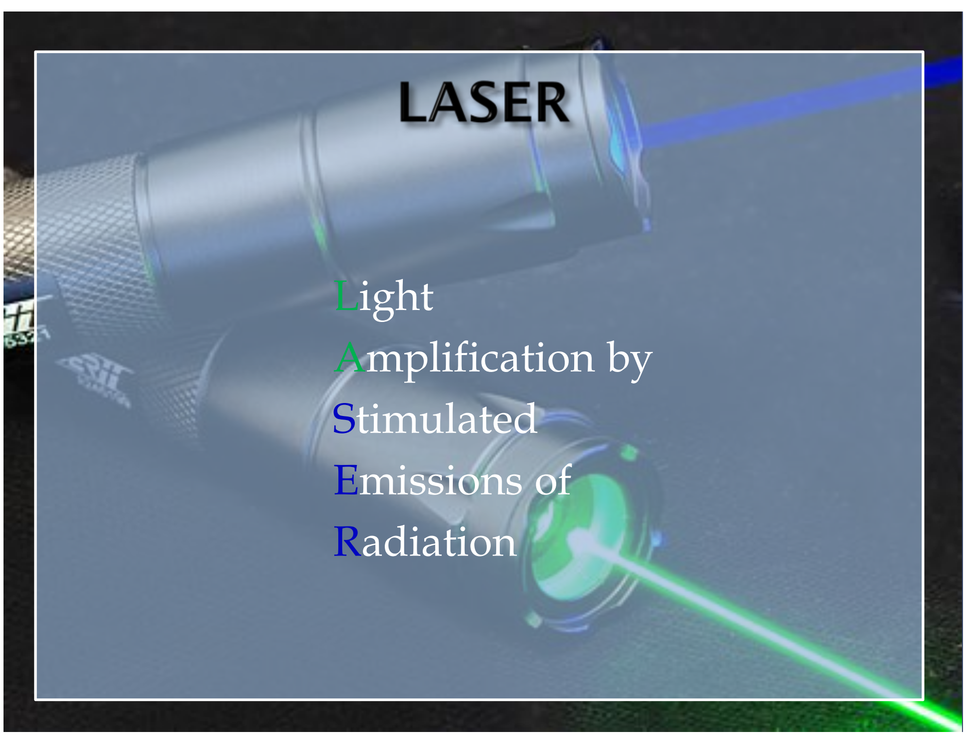

LASERS


LASER
Light
Amplification by
Stimulated
Emissions of
Radiation

LASER

- Lets break it down:

- Light Amplification :
  Refers to the devices use of light to 'amplify' a beam of light (I'll explain further later)
- Stimulated Emissions of Radiation:
  Refers to the unique way a coherent and directed beam of light can be created.

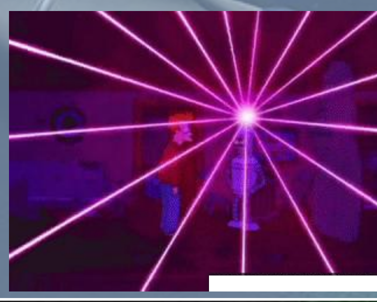
LASER

- So what is so special about light from stimulated emission as opposed to spontaneous emission?

[5]

LASER

- Typically in nature, light is emitted by spontaneous emission.
  - This light is incoherent, non directional, and can be of random wavelengths depending on other factors
- In lasers the emission of light is by means of stimulated emission
  - This light is ideally monochromatic, coherent, and highly directional



[6]

LASER

- LEDs, Photo Diodes, and LASERS Rely on the same basic equation to describe the light the emit or detect:

$$hv_{12}=E_2-E_1$$

E_2=upper electron energy level

E_1=lower electron energy level

hv_{12}=photon energy

LASER

- However stimulated emission occurs instantly where as spontaneous emission which occurs exponentially over time (think RC curves).

$$hv_{12}=E_2-E_1$$

E_2=upper electron energy level

E_1=lower electron energy level

hv_{12}=photon energy

LASER

- Assuming n_1 is the charge carrier concentration in E_1
- Assuming n_2 is the charge carrier concentration in E_2

Then at <u>equilibrium</u> $n_2 << n_1$ and:

$$\frac{n2}{n1} = e^{\frac{E1-E2}{kT}} = e^{\frac{hv\ 12}{kT}}$$

*Given that $hv_{12}=E_2-E_1$

LASER

- To describe Absorption, Stimulated emission and Spontaneous emission in detail would require quantum mechanics so to keep things simple the next few sections do not give any derivations or detailed explanations as to why.
- Now: in order for stimulated emission to occur, there must be a light density $\rho(v_{12})$. This just means that there must be light present in the laser generation medium.

LASER

- All of these effects can be described using some relations made by Einstein, but first we have to know some coefficients:
- B_{12}= Proportionality factor of absorption
- A_{21}= Proportionality factor of emission
- B_{21}= Proportionality factor of stimulated

LASER

- B_{12}= Proportionality factor of absorption
- A_{21}= Proportionality factor of emission
- B_{21}= Proportionality factor of stimulated

<u>Under equilibrium</u>

Absorption Spontaneous Stimulated

$$B_{12}n_1\ \rho(v_{12}) = A_{21}n_2 + B_{12}n_2\ \rho(v_{12})$$

(Light absorbed = light emitted by both types of emission)

LASER

- B_{12}= Proportionality factor of absorption
- A_{21}= Proportionality factor of emission
- B_{21}= Proportionality factor of stimulated

<u>Under equilibrium</u>

Absorption Spontaneous **Stimulated**

$$B_{12}n_1\ \rho(v_{12}) = A_{21}n_2 + B_{12}n_2\ \boldsymbol{\rho(v_{12})}$$

- In-order to get laser light we want the rate of stimulated emission to be much higher then spontaneous emission so we increase the light density.

LASER

- B_{12}= Proportionality factor of absorption
- A_{21}= Proportionality factor of emission
- B_{21}= Proportionality factor of stimulated

Under equilibrium

Absorption Spontaneous **Stimulated**

$$B_{12}n_1 \, \rho(v_{12}) = A_{21}n_2 + B_{12}n_2 \, \rho(v_{12})$$

- Unfortunately this is a double edged sword in that the rate of absorption increase proportionally as well.

LASER

- B_{12}= Proportionality factor of absorption
- A_{21}= Proportionality factor of emission
- B_{21}= Proportionality factor of stimulated

Under equilibrium

Absorption Spontaneous **Stimulated**

$$B_{12}n_1 \, \rho(v_{12}) = A_{21}n_2 + B_{12}n_2 \, \rho(v_{12})$$

- Because of this we must also increase the amount of free charge carriers (the number of carriers in n_2)

LASER

- B_{12}= Proportionality factor of absorption
- A_{21}= Proportionality factor of emission
- B_{21}= Proportionality factor of stimulated

Absorption Spontaneous **Stimulated**

$$B_{12}n_1 \, \rho(v_{12}) + A_{21}n_2 << B_{12}n_2 \, \rho(v_{12})$$

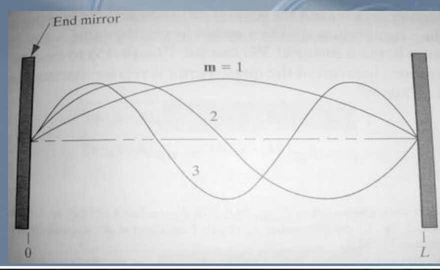
- Now that the light density as well as number of free charge carriers has been increased laser light can be created!

LASER

- We already know that applying a voltage bias to a material will alter the number of free charge carriers.
- What we don't know is how to alter the light density within a material

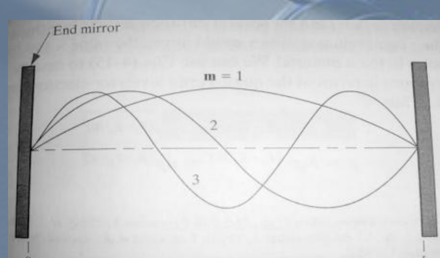
LASER

- In LASERs a resonance cavity for light is used to increase the light density $\rho(v_{12})$
- This cavity is of length $L = m\lambda/2$ where m is some integer multiple of the wavelength (λ) of the stimulated light emission.



LASER

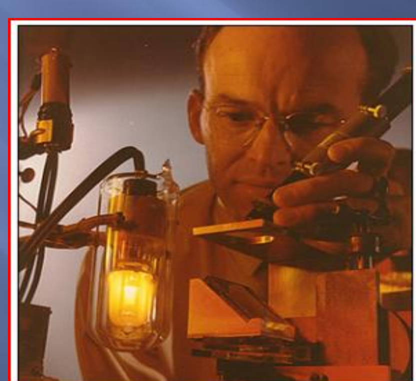
- The light actually emitted from a laser diode comes through one of the mirrors which is only partially reflective.
- The amount of light leaving the resonance chamber must be less then the light created within it in order for stimulated emission to continue.



SEMICONDUCTOR LASERS

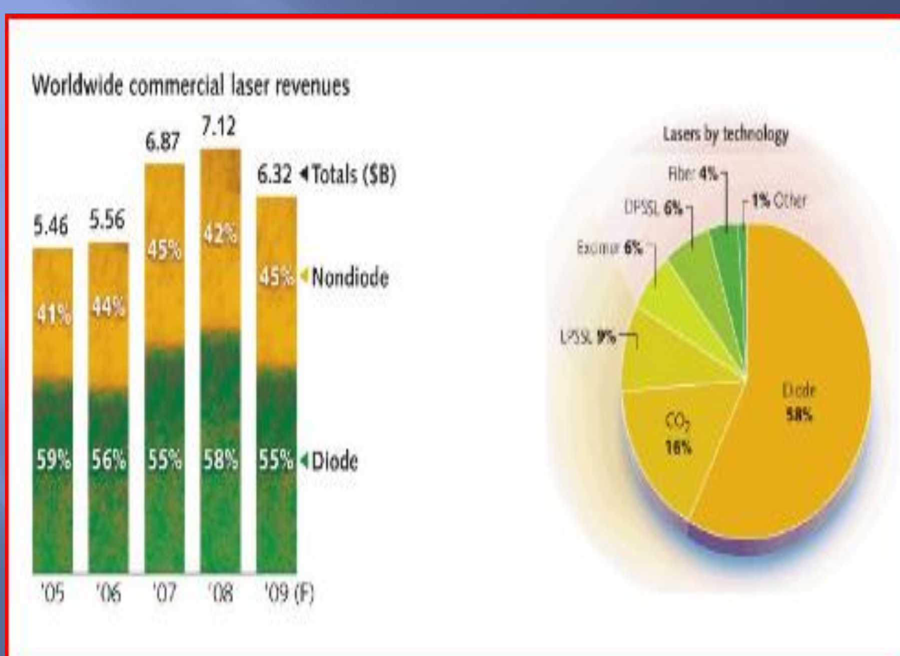
Semiconductor Laser Background:

- Discovered in 1962
  - Robert N. Hall revealed invention in Physics Review Letters

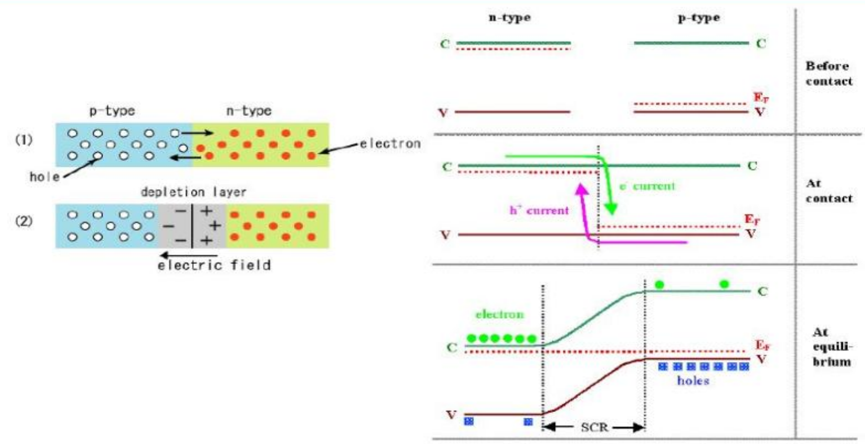


Markets

- ~55% of the laser market (revenues) are derived from semiconductor lasers
- ~58% of lasers produced are semiconductor lasers
  - source:laserfocusworld.com

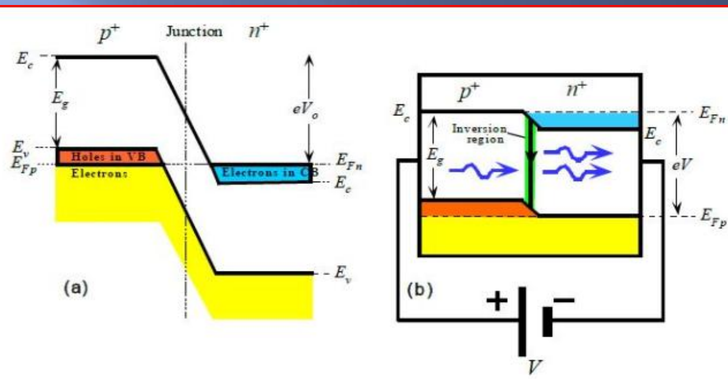


Semiconductor Laser Junction Physics



1999 S.O. Kasap, Optoelectronics (Prentice Hall)

Inversion



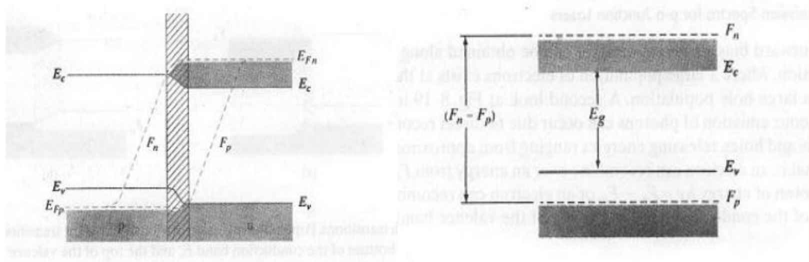
More electrons in the Conduction Band at energies near Ec than electrons in Valence Band near Ev.

What is Inversion?

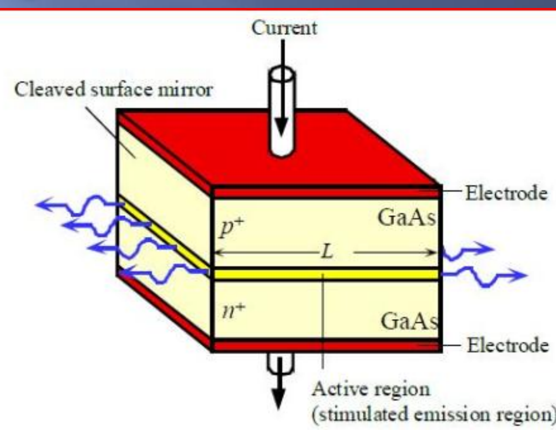
Inversion best explained using quasi-fermi levels:

$$n = N_c e^{-(E_c - F_n)/kT} = n_i e^{(F_n - E_i)/kT} \quad (8\text{-}12a)$$

$$p = N_v e^{-(F_p - E_v)/kT} = n_i e^{(E_i - F_p)/kT} \quad (8\text{-}12b)$$



Homojunction Diode Laser



A schematic illustration of a GaAs homojunction laserdiode. The cleaved surfaces act as reflecting mirrors.

Limitations of Homojunction Diode Laser

- High current density required to reach threshold required for inversion.
  - Generates too much heat and cannot operate at room temperature.
  - Solution: apply bias in pulses
  - Solution: try to channel thermal energy away from laser (i.e. heat transfer)
- Another solution: change laser configuration
  - double heterostructure laser

Emission Wavelength Associated with Laser Diodes

Laser diode material (active region / substrate)	Typical emission wavelengths	Typical application
InGaN / GaN, SiC	380, 405, 450, 470 nm	data storage
AlGaInP / GaAs	635, 650, 670 nm	laser pointers, DVD players
AlGaAs / GaAs	720–850 nm	CD players, laser printers
InGaAs / GaAs	900–1100 nm	pumping EDFAs; high-power VECSELs
InGaAsP / InP	1000–1650 nm	optical fiber communications

www.rp-photonics.com

50 years later…

Many types of lasers.

Wide array of applications:

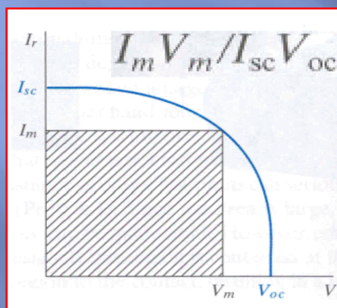
- Telecommunication
- Data storage
- Material processing
- Laser pumping
- Medicine
- Laser Printers, bar-code readers

HW Questions

Q1. What does the acronym LASER stand for?

Q2. What are the three distinctive traits of light from stimulated emission?

HW Questions



Q3. This figure shows the fourth quadrant portion of a solar cell characteristic, with I_r plotted upward for convenience of illustration. A Si solar cell has a I_{sc} = 100mA, V_{oc} = 0.7V under solar illumination. The ratio $I_m V_m / I_{sc} V_{oc}$ is 0.7. What is the maximum power delivered to a load by this cell?

(Hint: P_{max} = fill factor*I_{sc}*V_{oc})

References

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http://www.webopedia.com/TERM/O/optoelectronics.html

[2] "Photodiode Technical Guide"
http://sales.hamamatsu.com/assets/html/ssd/si-photodiode/index.htm

[3] "LASERS intro page"
http://files.sharenator.com/Shoop_Imma_Firin_Mah_Laser-s1024x640-34243-580.jpg

[4] "LASERS slide background"
http://hacknmod.com/wp-content/uploads/2008/08/lasers.jpg

[5] "Stimulated emission"
http://plaza.ufl.edu/dwhahn/LaserPhoto5.jpg

[6] "monochromatic, direct, coherent light"
http://27.media.tumblr.com/tumblr_lifjmgpZ9N1qcqljxo1_500.gif