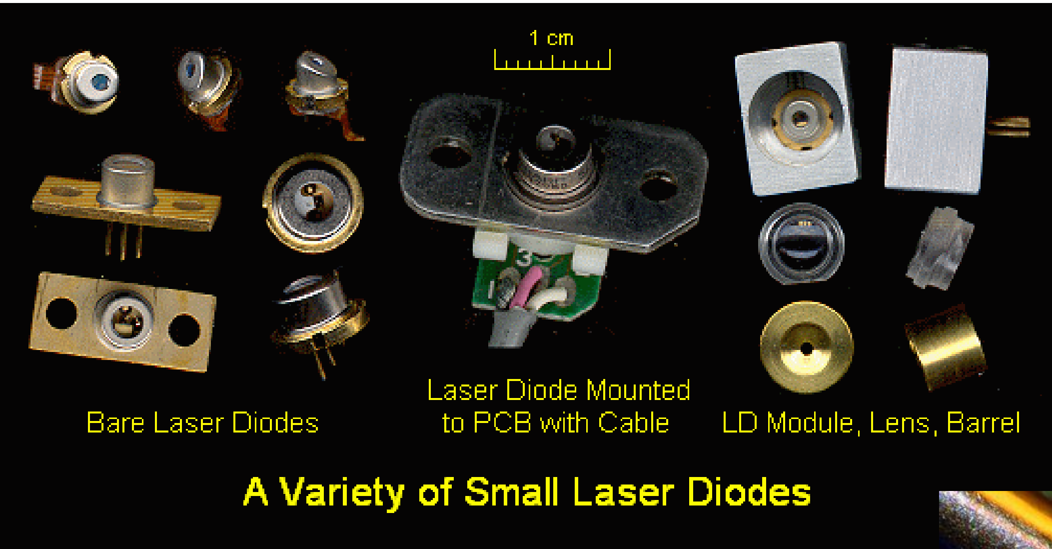
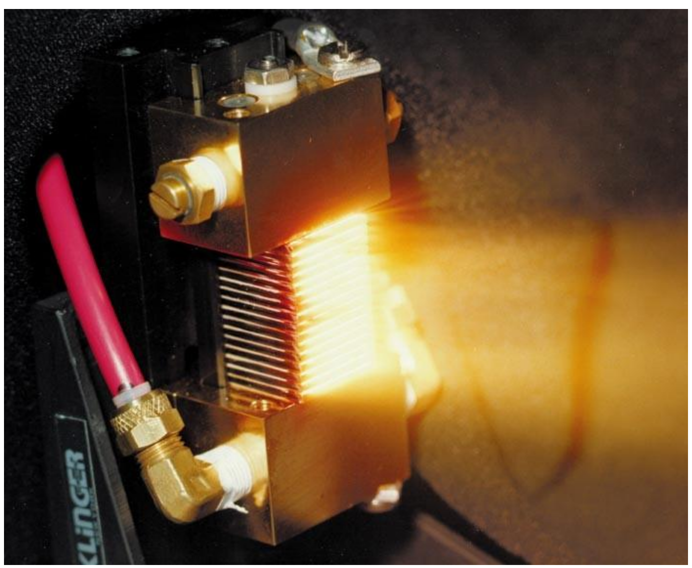
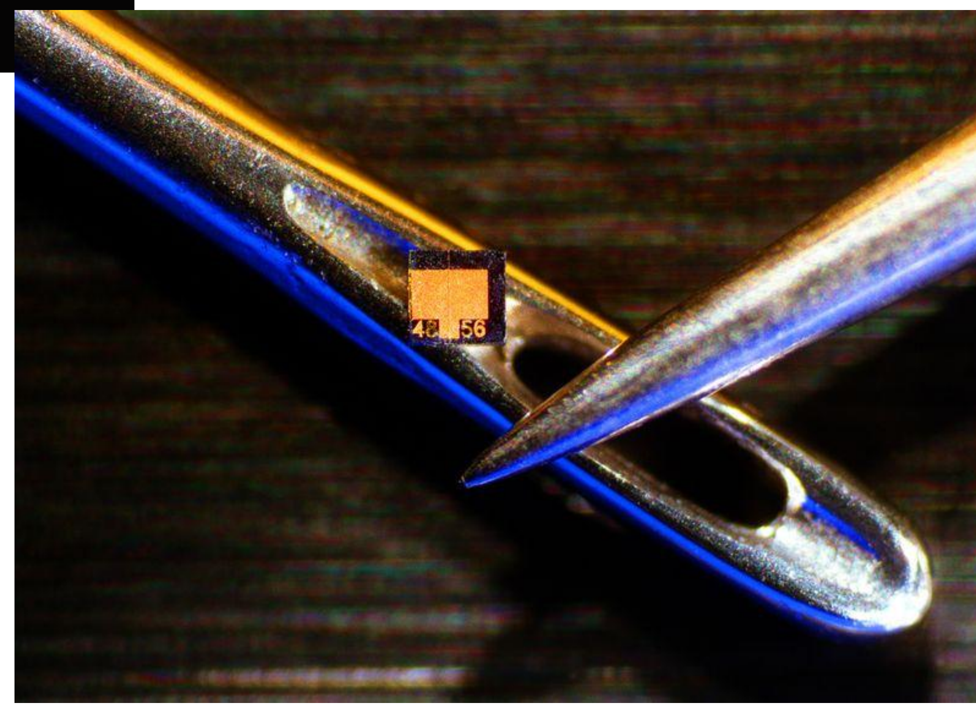
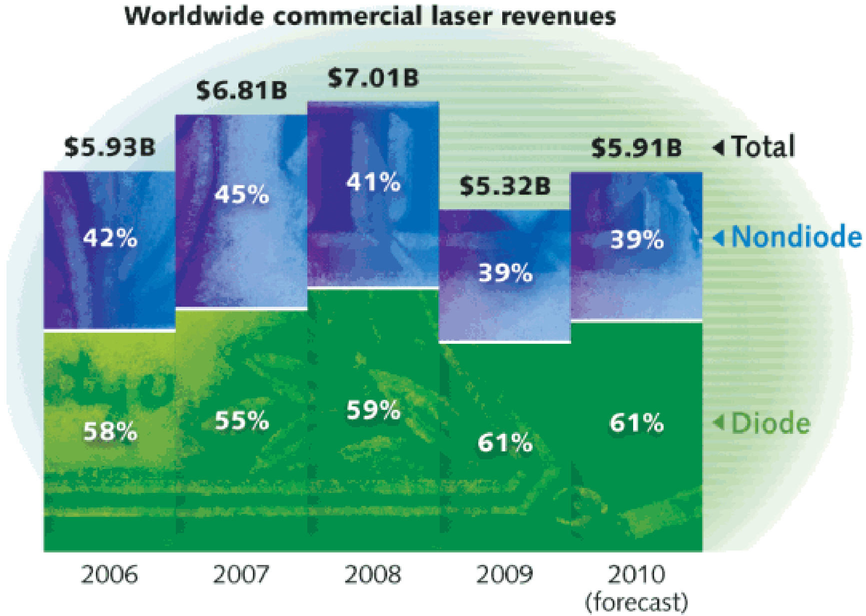
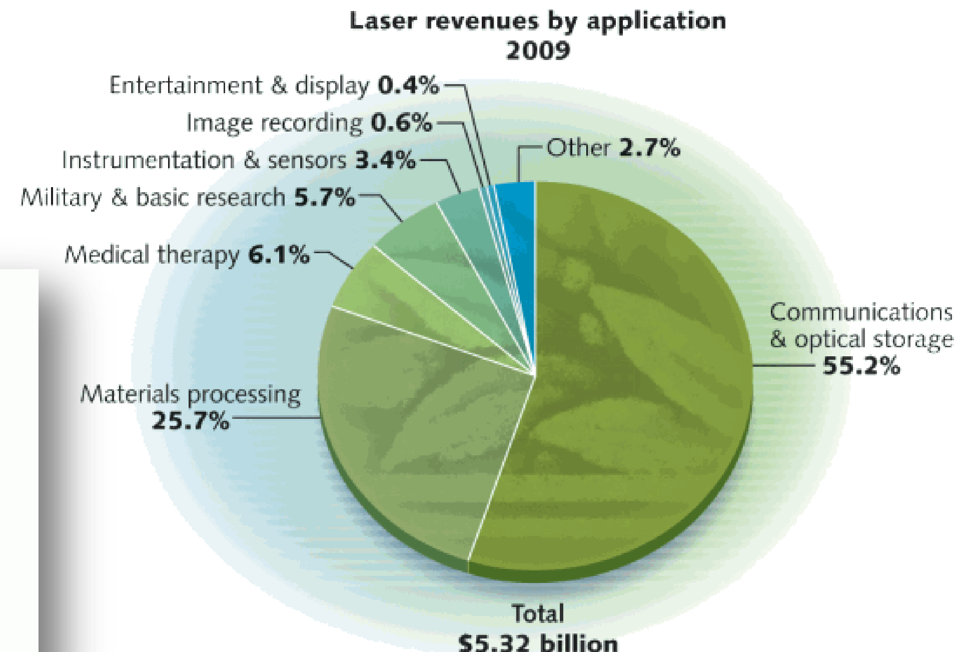
Semiconductor Lasers








Worldwide commercial laser revenues
$5.93B
$6.81B
$7.01B
$5.32B
$5.91B
Total
Nondiode
Diode
42%
45%
41%
39%
39%
58%
55%
59%
61%
61%
2006
2007
2008
2009
2010 (forecast)


Laser revenues by application 2009
Entertainment & display 0.4%
Image recording 0.6%
Instrumentation & sensors 3.4%
Military & basic research 5.7%
Medical therapy 6.1%
Other 2.7%
Communications & optical storage 55.2%
Materials processing 25.7%
Total $5.32 billion

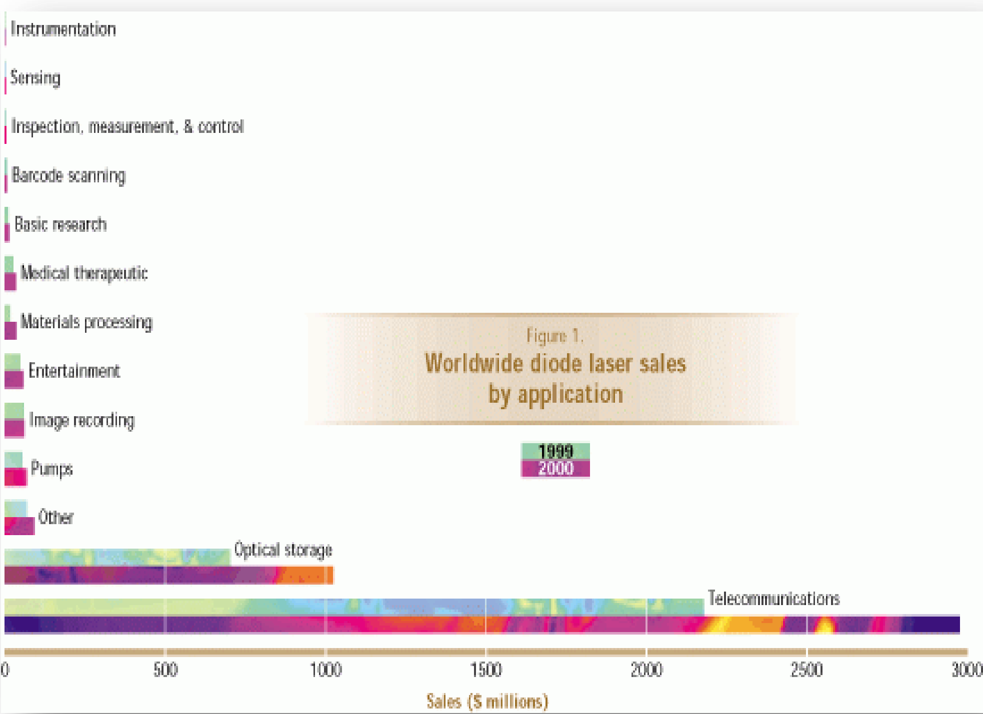
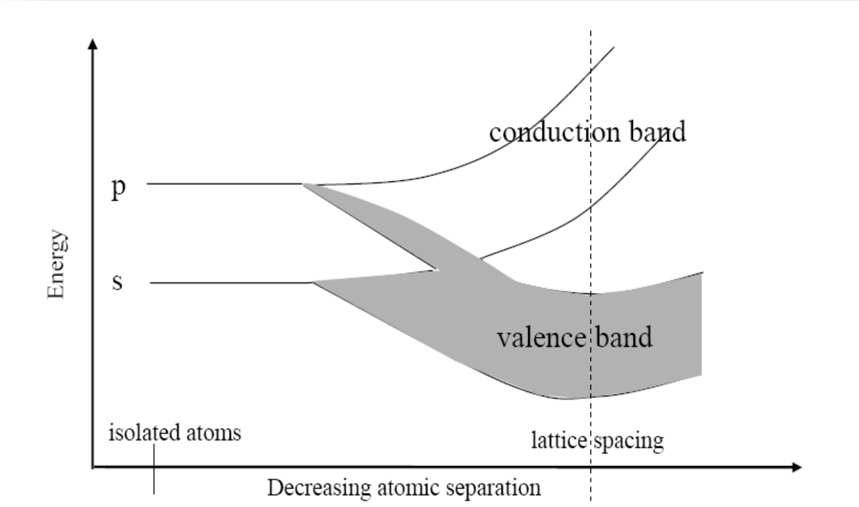
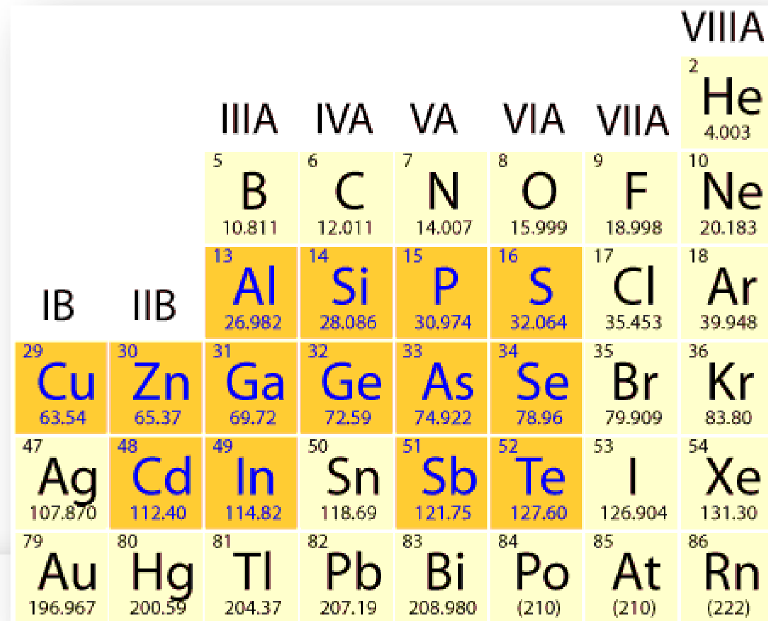
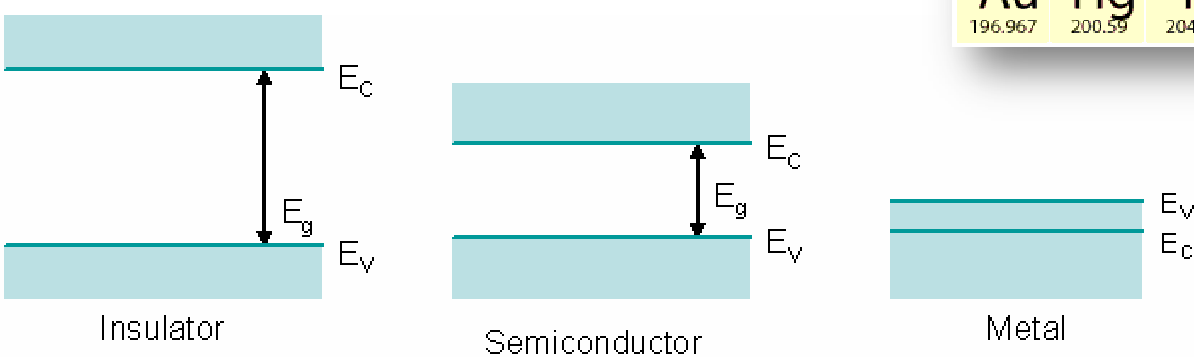


Figure 1.
Worldwide diode laser sales by application
Instrumentation
Sensing
Inspection, measurement, & control
Barcode scanning
Basic research
Medical therapeutic
Materials processing
Entertainment
Image recording
Pumps
Other
Optical storage
Telecommunications
1999
2000
0
500
1000
1500
2000
2500
3000
Sales ($ millions)

What is a semiconductor?





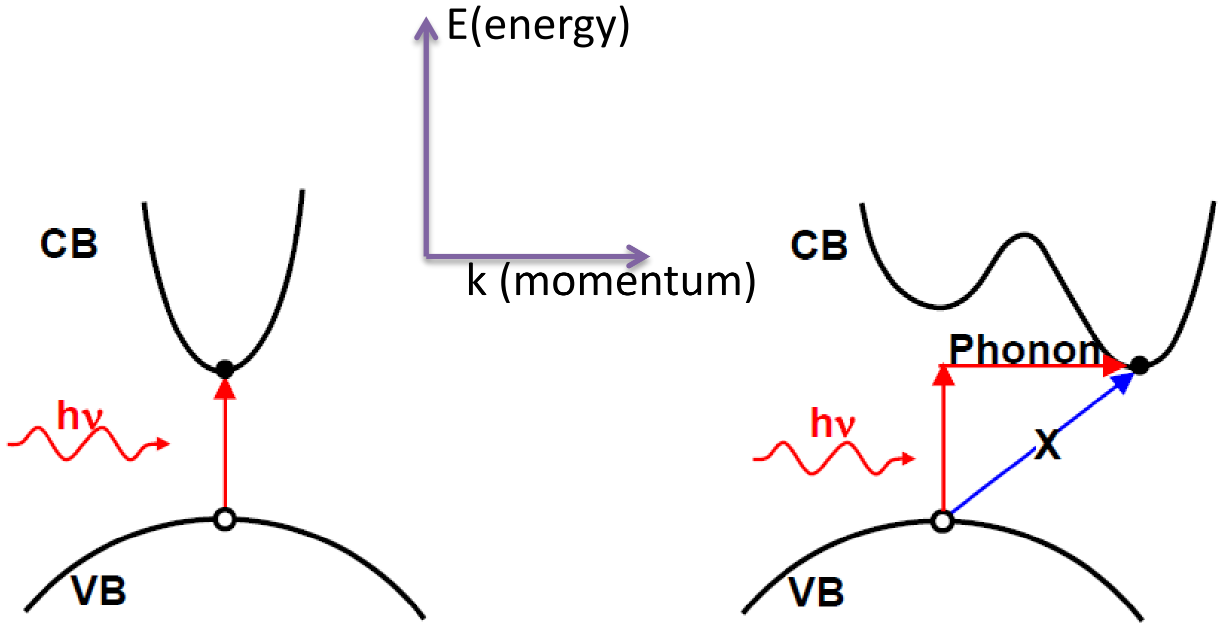


If ↑T → ↑R METAL
→ ↓R SEMICONDUCTOR

Band gap values for some semiconductors →

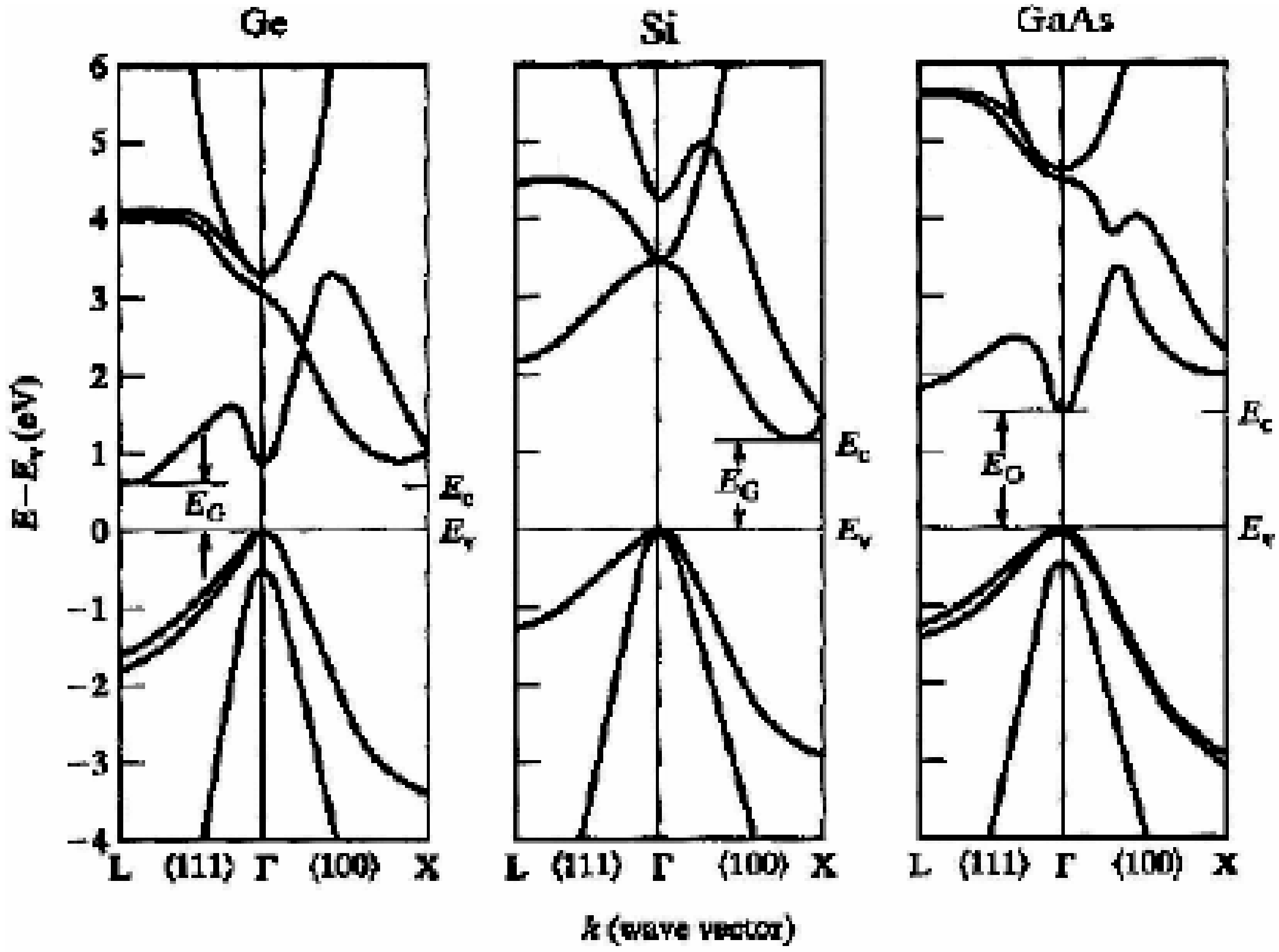
	Ge	Si	GaAs	GaN
E_g (eV)	0,66	1,12	1,42	3,44

Direct-Gap vs. Indirect-Gap



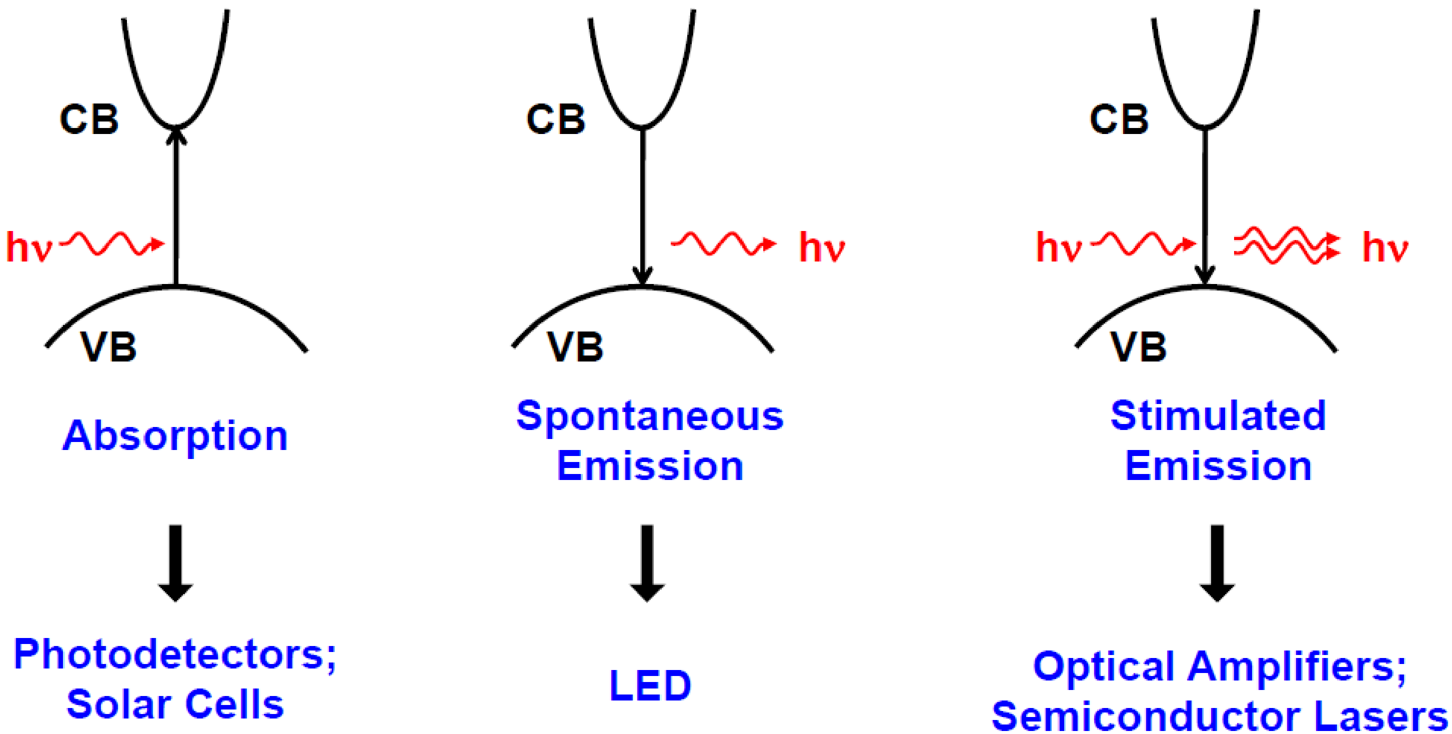
- Direct bandgap materials
  - CB minimum and VB maximum occur at the same k
  - Examples
    - GaAs, InP, InGaAsP
    - $(Al_xGa_{1-x})As$, $x < 0.45$
- Indirect bandgap materials
  - CB minimum and VB maximum occur at different k
  - Example
    - Si, Ge
    - $(Al_xGa_{1-x})As$, $x > 0.45$
  - Not “optically active”

E-k diagrams



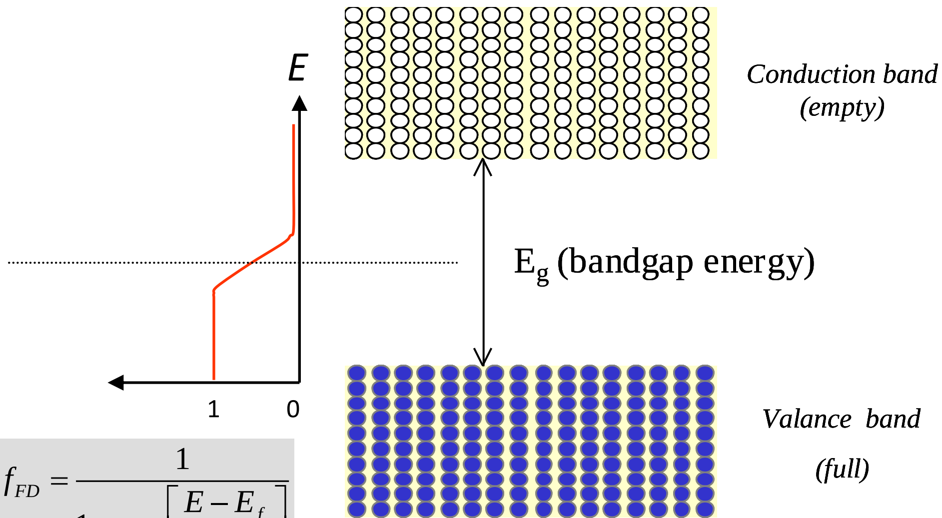
Ge
Si
GaAs
6
5
4
3
2
1
0
−1
−2
−3
−4
E − E_v (eV)
E_G
E_c
E_v
E_G
E_c
E_v
E_G
E_c
E_v
L (111) Γ (100) X
L (111) Γ (100) X
L (111) Γ (100) X
k (wave vector)

Optical Interactions in a Direct-Gap Semiconductor



A Brief Introduction to Semiconductors

Energy Bands

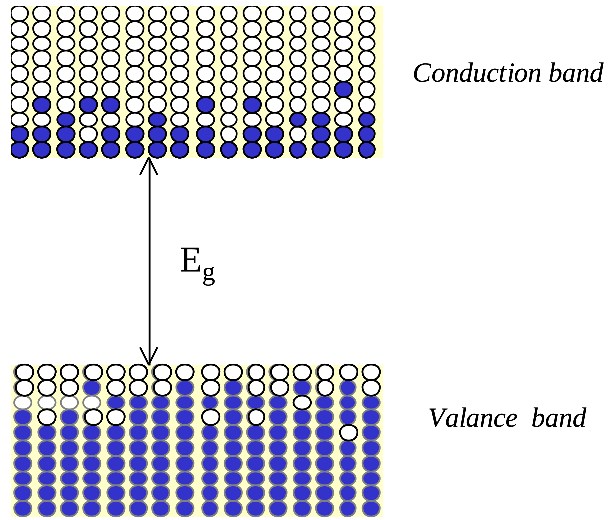


$$f_{FD} = \frac{1}{1 + \exp\left[\frac{E - E_f}{kT}\right]}$$

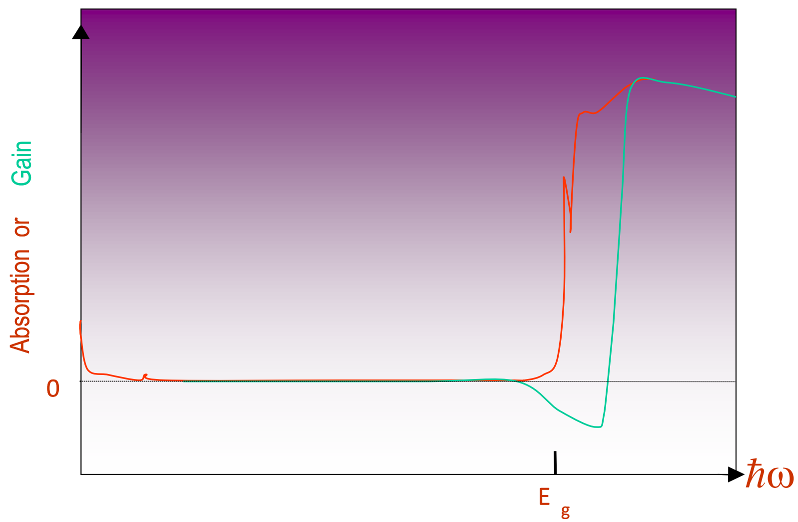
Fermi-Dirac Statistics

Equilibrium

http://britneyspears.ac/lasers.htm !!!???



Nonequilibrium Electron-Hole Injection



Example

GaAs

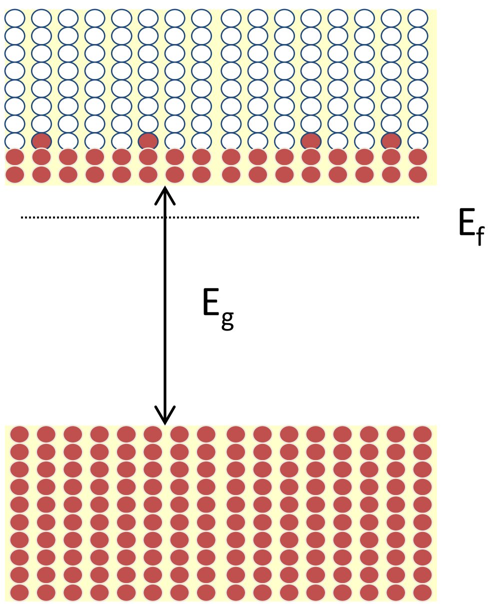
E_g=1.4 eV

(λ_g=850 nm)

p-n junctions

Doping with Impurities

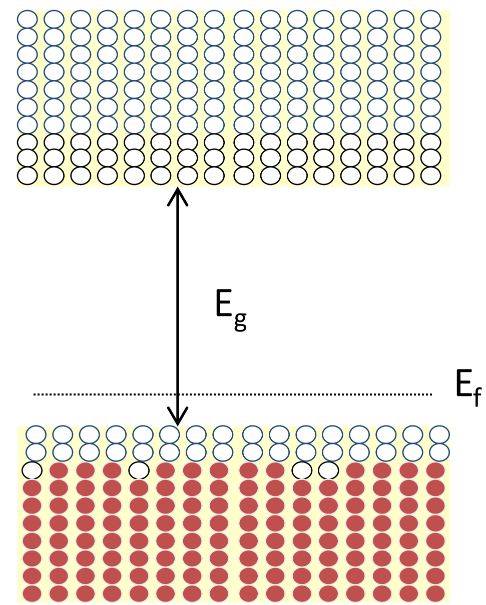
n-type



Examples: GaAs doped with Br

Si doped with P

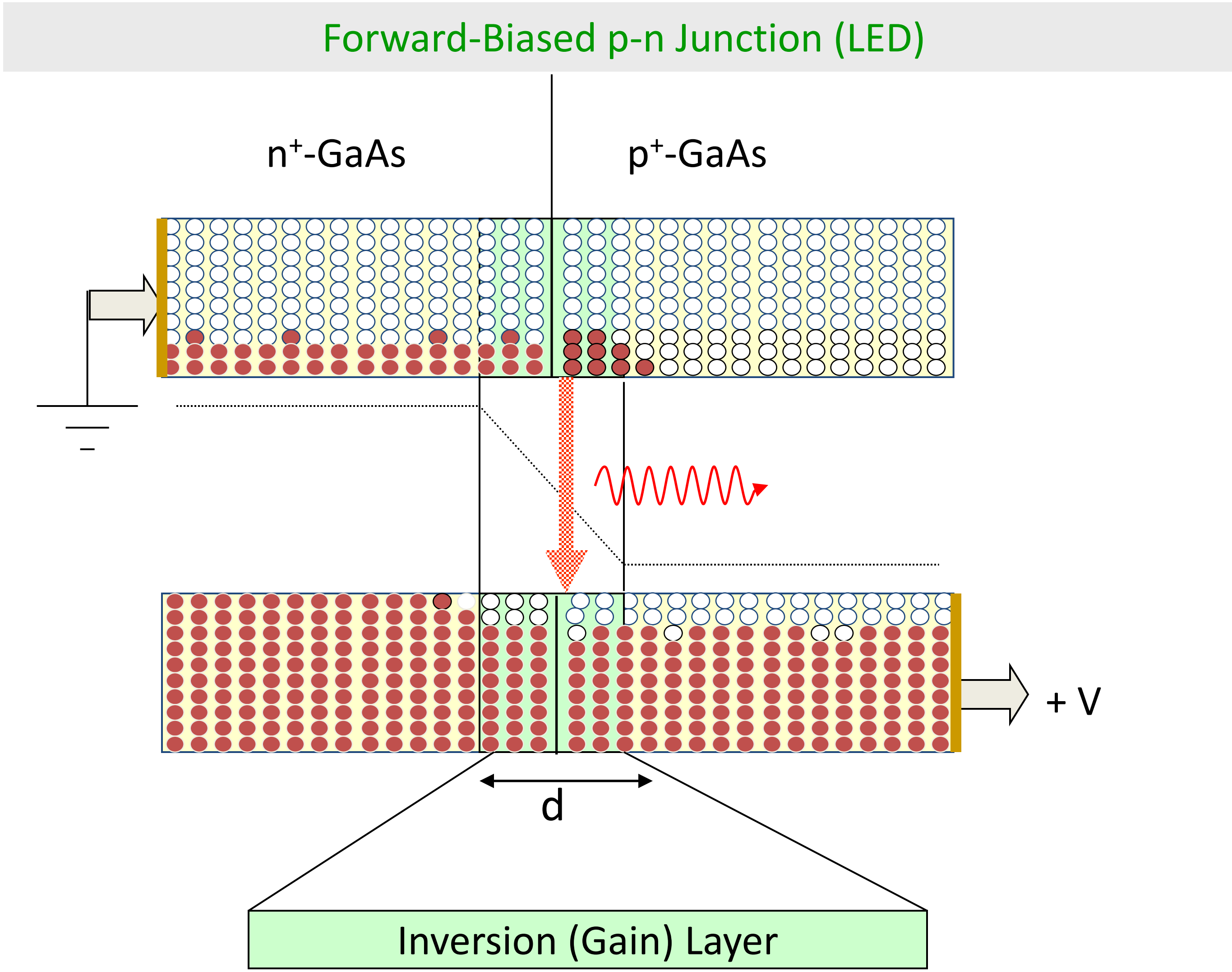
p-type



Examples: GaAs doped with Zn

Si doped with Al

Semiconductor junction lasers

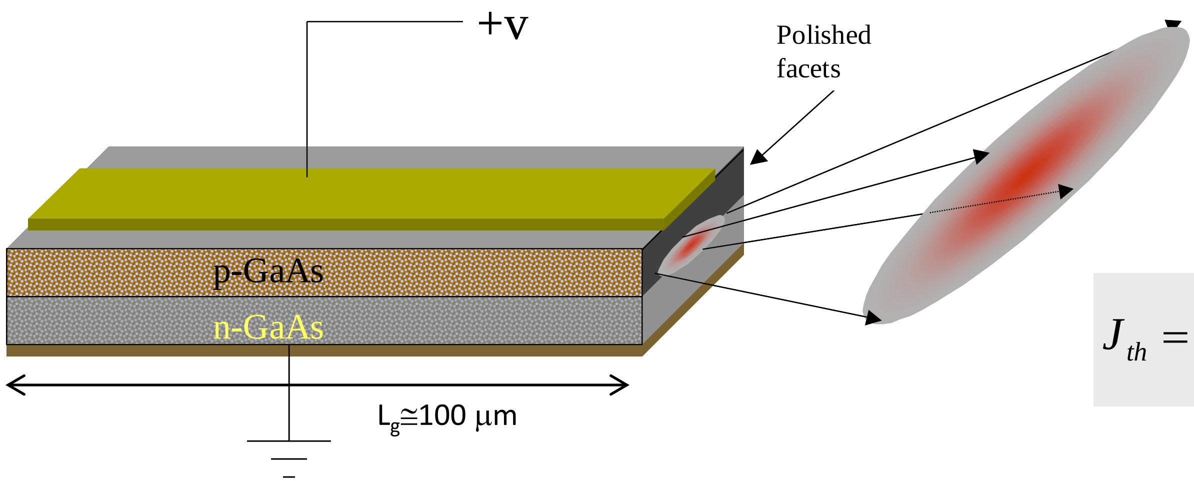


Current Density Threshold

$$J_{th} = \frac{N_{e,h} e d}{\tau_r}$$

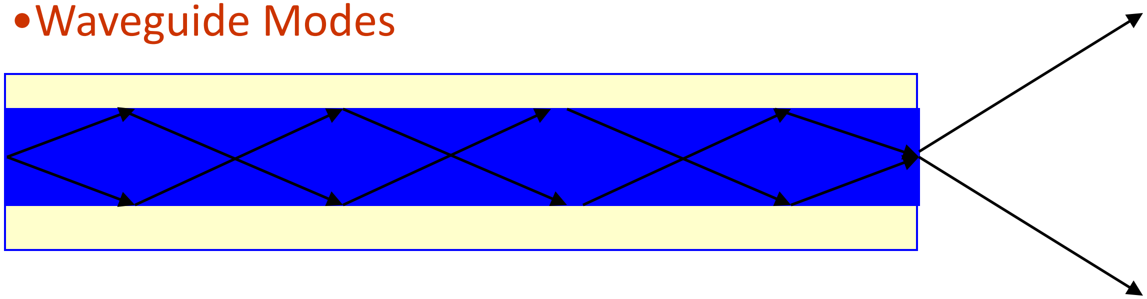
Recombination time

Edge-Emitting Homojunction Laser Diodes



$$J_{th} = \frac{N_{e,h}ed}{\tau_r}$$

•Waveguide Modes

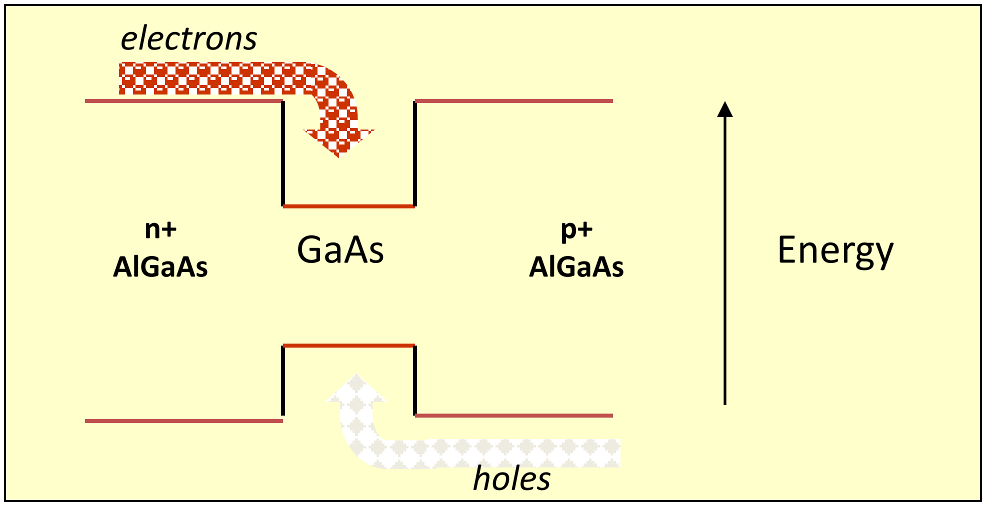


Homojunction Lasers have very high current threshold mainly because.

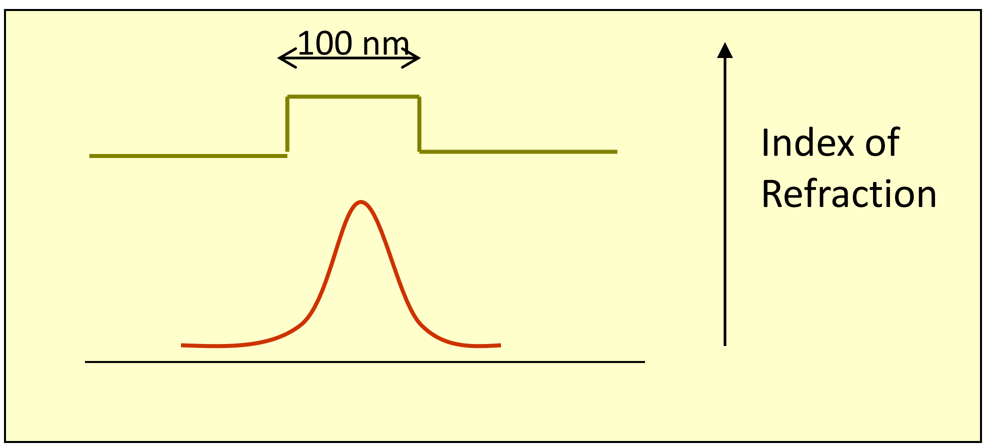
- *Electrons and holes are free to diffuse and therefore dilute the gain (no carrier confinement)*
- *Optical mode has poor overlap with gain (no optical confinement or guiding)*

12.3 Heterojunction Lasers Diodes

A fortunate coincidence: n ↑ when E_g ↓

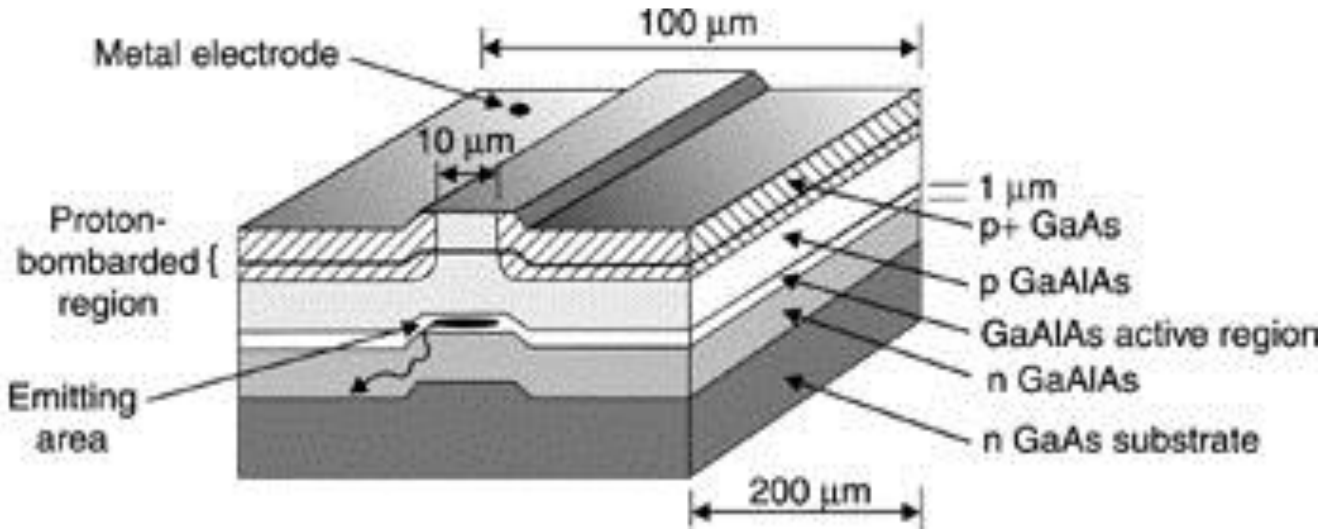


Carrier confinement

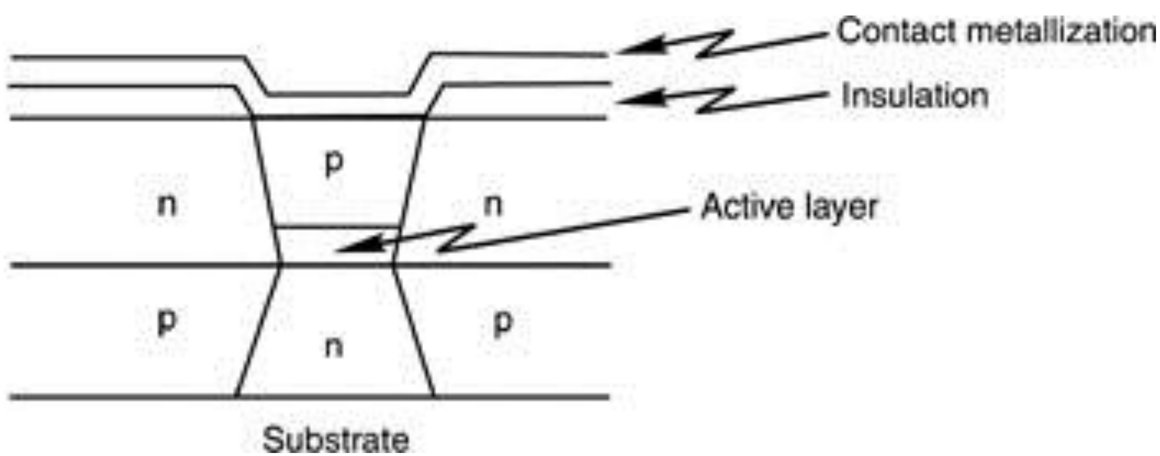


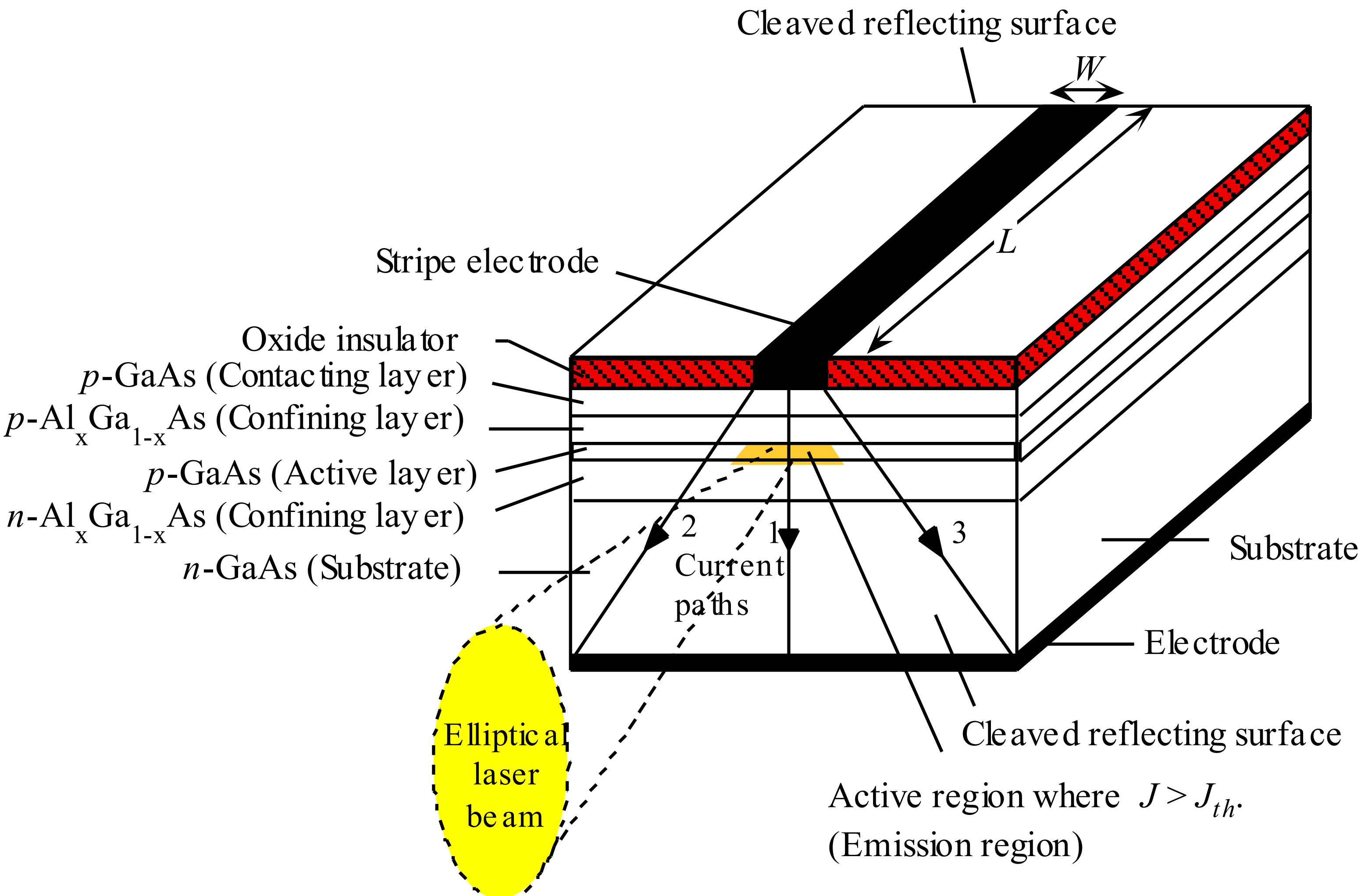
Mode confinement

Edge-Emitting Heterojunction Laser Diodes



Edge-Emitting Buried Heterojunction Laser Diodes

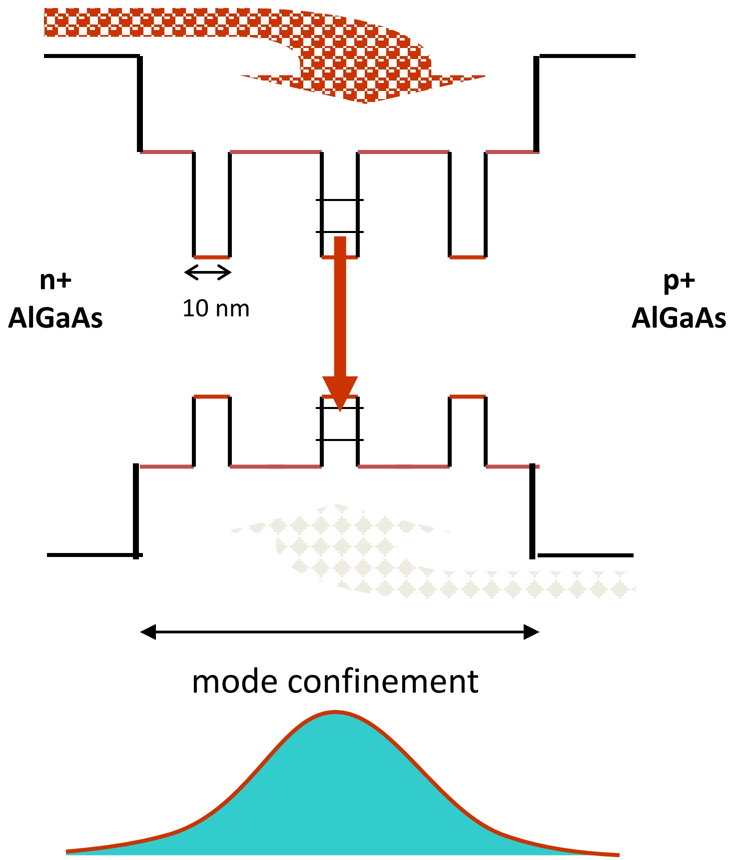


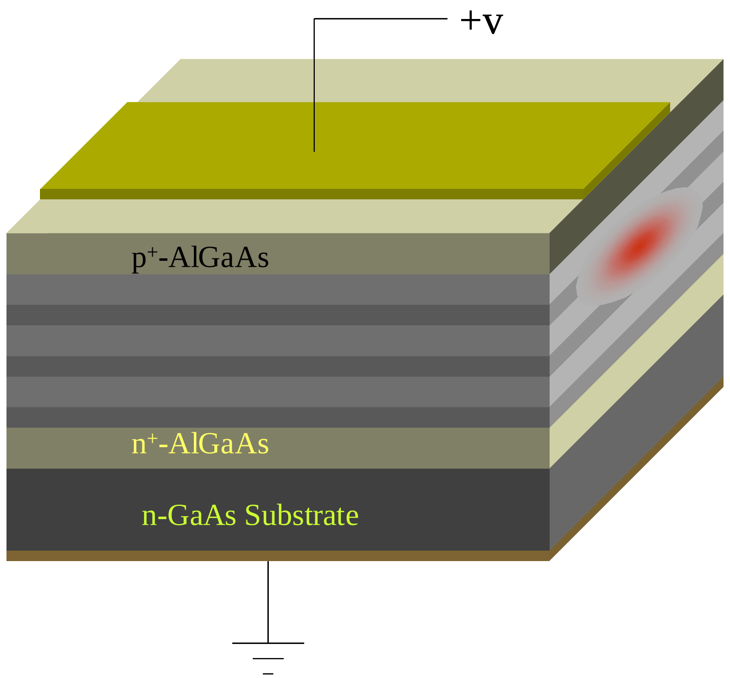


Schematic illustration of the the structure of a double heterojunction stripe contact laser diode

12.4 Quantum Well Lasers

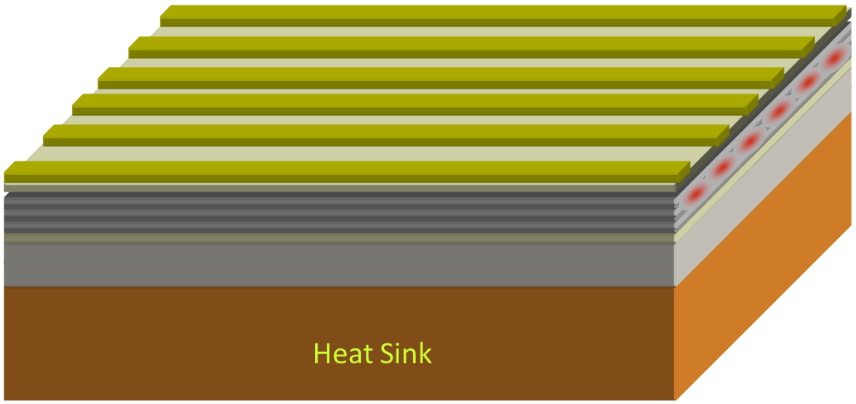
Multiple Quantum Well (MQW) Lasers

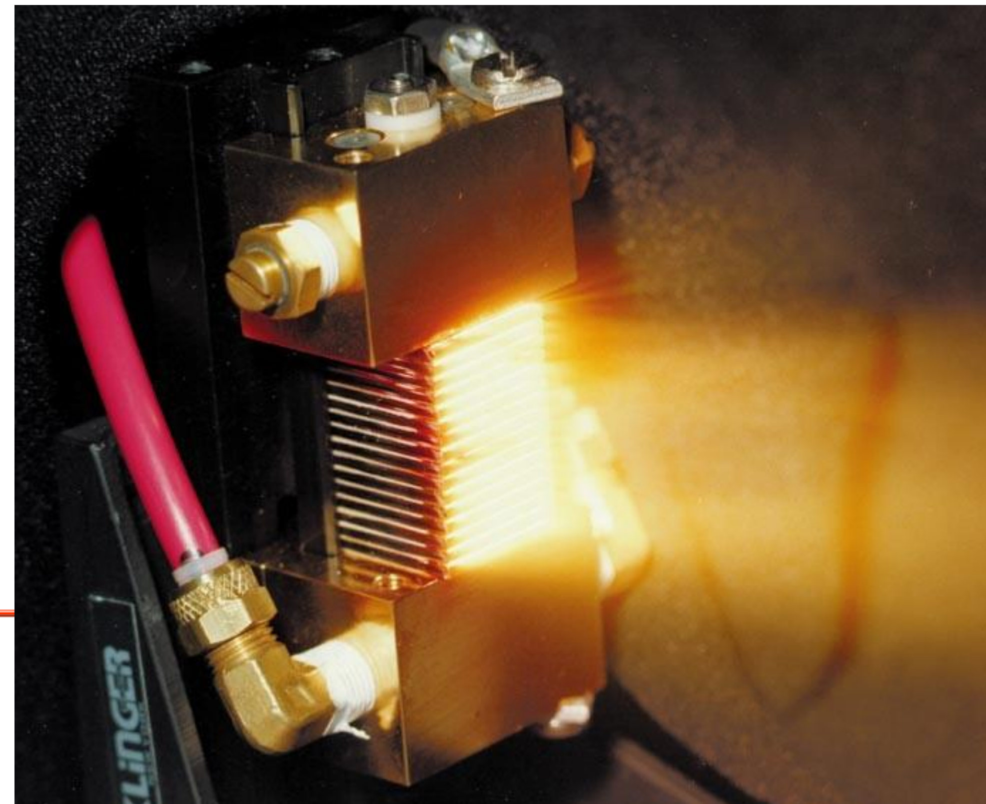




Epitaxial Growth

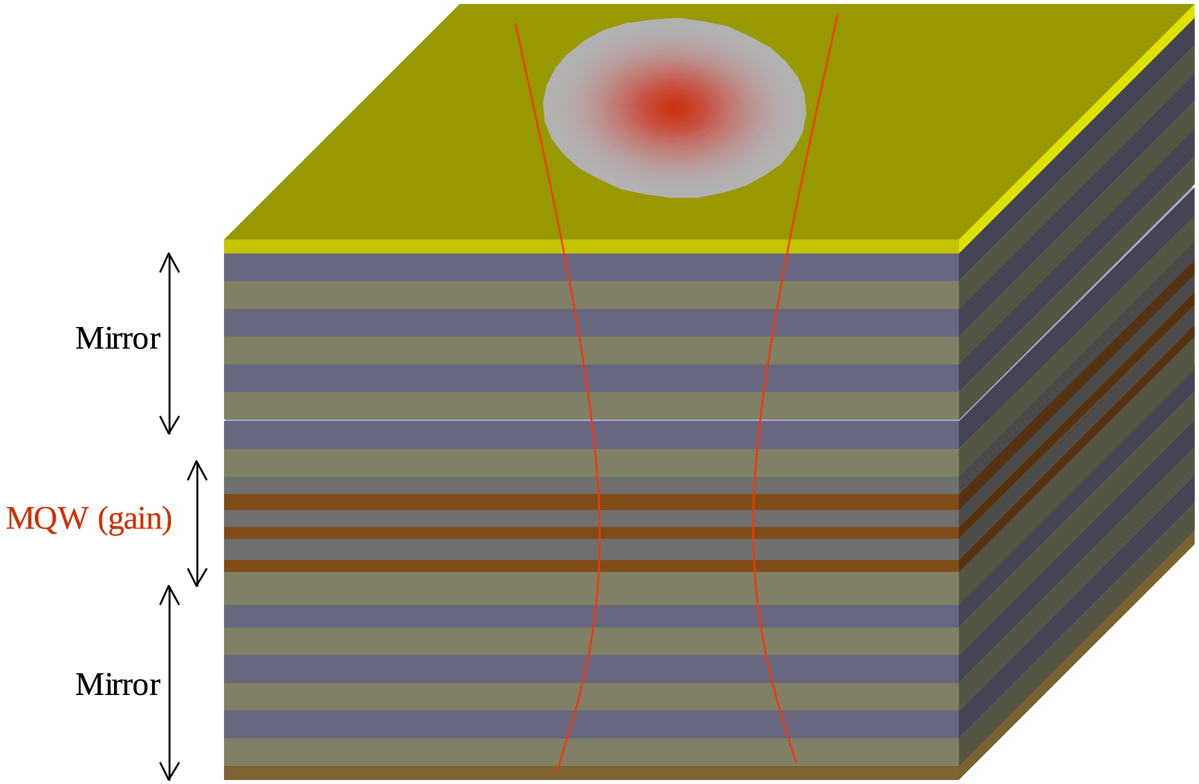
High Power Diode Bars





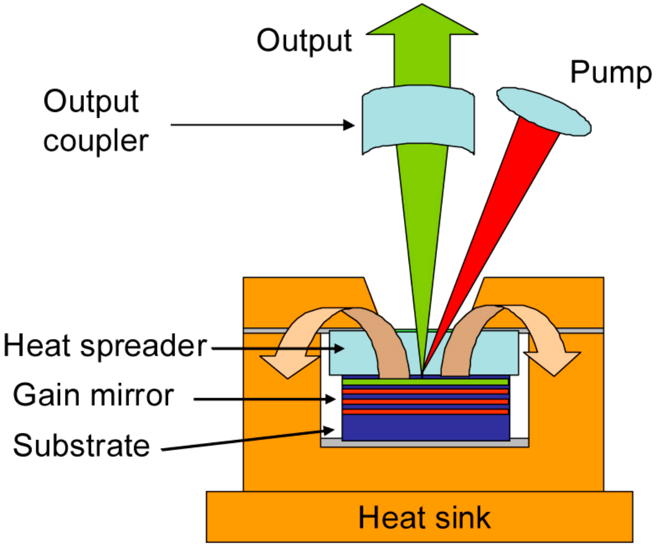
- P>100 W (cw)
- Diode-pumping solid-state lasers (DPSS)
- Material Processing
- …

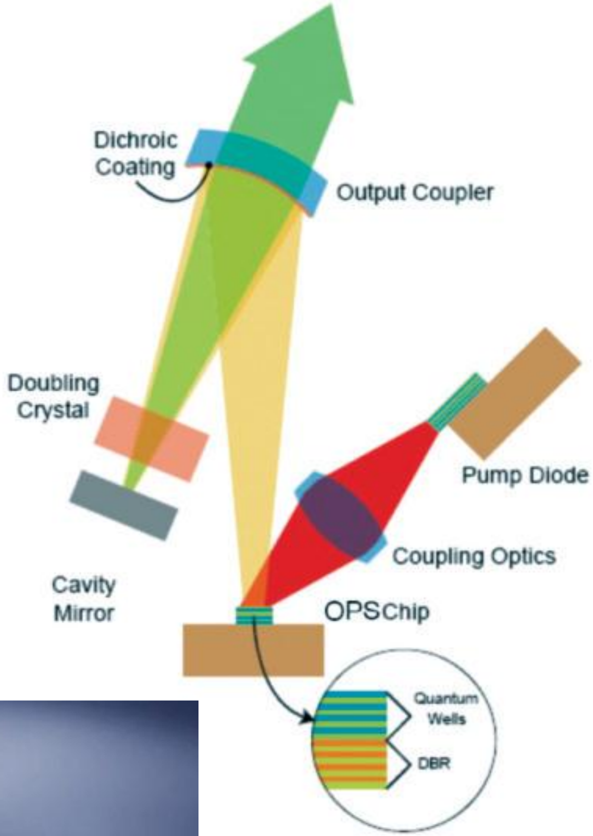
Vertical Cavity Surface Emitting Lasers (VCSEL)

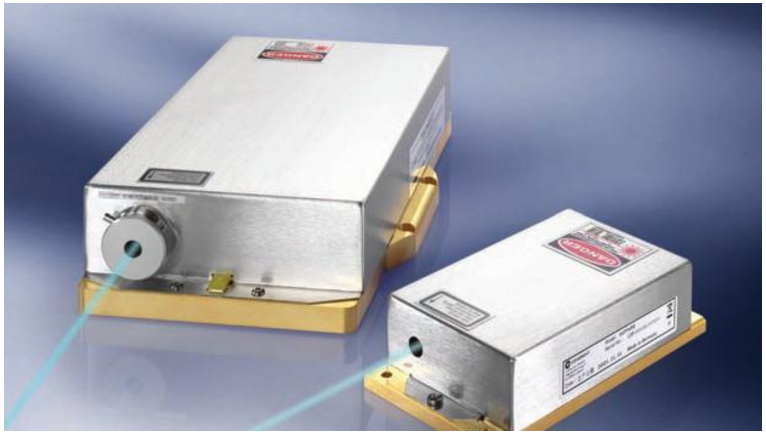


- Good mode quality couples to fiber efficiently for telecom applications
- Single mode operation
- 2-D structures cam be made
- Low power

Optically-Pumped Semiconductor Lasers (OPSL)







Laser Diodes Cover the Spectrum

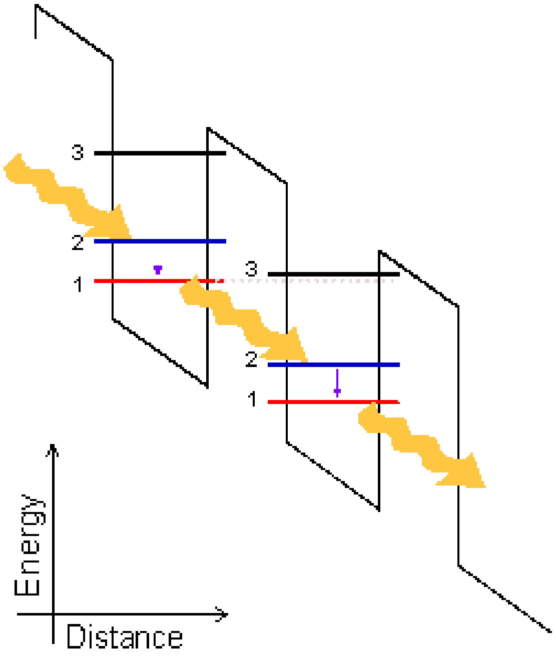
Compound	Spectral Region	Notes
$Al_xGa_{1-x}N$ GaN $In_xGa_{1-x}N$	*uv* *uv (350 nm)* *blue (480-400 nm)*	 data storage, display
$Ga_xI_{1-x}P$ (x=0.5) $Ga_xAl_{1-x}As$ (x=0-0.45)	*670 nm* *620-895 nm*	display
GaAs $In_xGa_{1-x}As$ (x=0.2)	*904 nm* *980 nm*	diode pumping solid-state and fiber lasers.
$In_xGa_{1-x}As_yP_{1-y}$ (x=0.73, y=0.58) (x=0.58, y=0.9)	*1100-1650* *1310 nm* *1550 nm*	Telecom

PbSSe	*4200-8000 nm*	cryogenic
PbSnTe	*6300-29,000 nm*	cryogenic

12.5 Recent Advances: Quantum Cascade Lasers

Original concept and theoretical prediction

R. F. Kazarinov and R. A. Suris, Fiz. Tekh. Poluprovodn, ***5***, *pp. 797-800, (1971).*

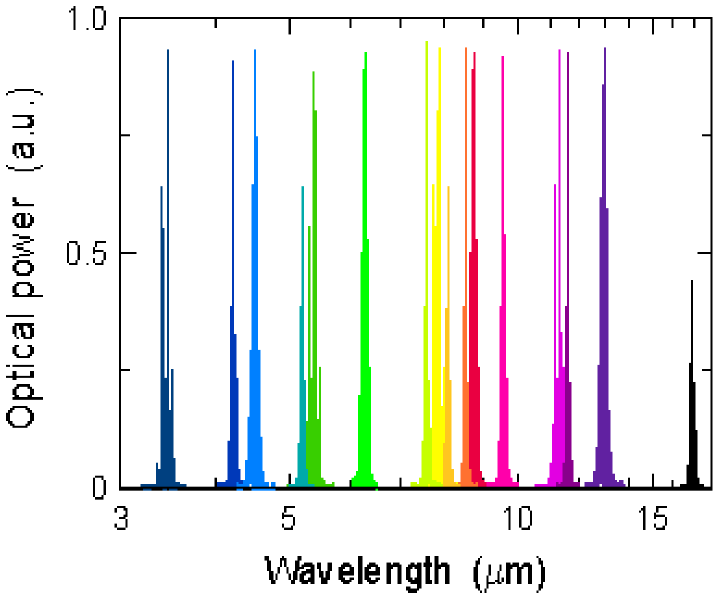


- Energy levels of electrons (3,2,1) in quantum wells strongly depend on layer thickness
- Laser photon created by an electron jumping between energy levels 1 and 2

→ therefore wavelength is determined by choice of layer thicknesses

- Many photons created by an electron cascading through many quantum wells

Wide wavelength-range of QC lasers



QC lasers cover entire mid-infrared wavelength range (3.4 - 17 μm) by tailoring layer thicknesses of the same material

THE END !

"Mr. Osborne, may I be excused? My brain is full."

Final Exam
Thursday, Dec. 16
Comprehensive, Closed Book

Review Session

Thursday, Dec. 9