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OPTI 380A
Intermediate Optics Lab 11:
LASER

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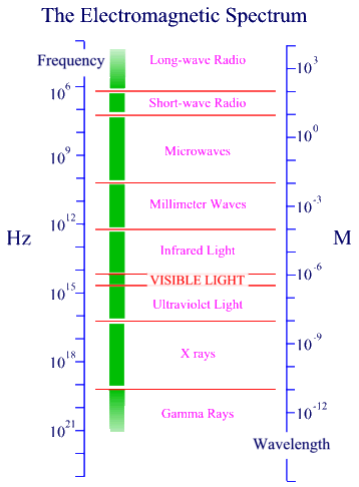
Wavelength Spectrum of Light



MASER: Microwave Amplification by Stimulated Emission of Radiation

LASER: Light Amplification by Stimulated Emission of Radiation

Laser History

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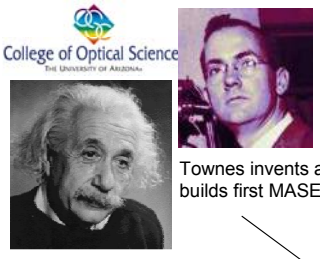
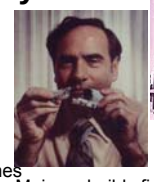


Einstein predicts stimulated emission

Townes invents and builds first MASER

Schawlow and Townes propose LASER



Maiman builds first (ruby) LASER

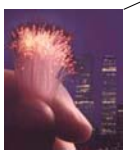
Javan invents He-Ne laser

Hall builds semiconductor laser

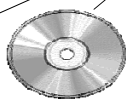
1910 1920 1930 1940 1950 1960 1970 1980 1990 2000

Alferov builds first heterostructure laser

IBM builds first laser printer



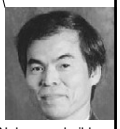
first fiber optic communication system (Chicago)



CD player

Spectra introduces Ti:Sapphire laser

Faist builds quantum cascade laser



Nakamura builds blue laser diode

Laser Characteristics

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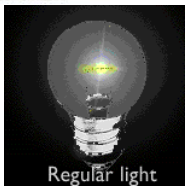
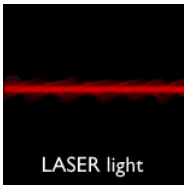
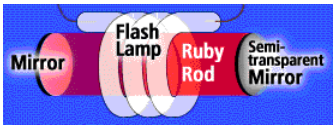




- spectrally broad
- divergent
- can't be focused tightly
- low efficiency, intensity
- incoherent

- very monochromatic
- does not diverge as fast
- can be focused tightly
- can be extremely intense
- spatial coherence (interference)
- temporally coherent (beat notes)

What is needed ?



More generally:

- active medium
- pump -> far from thermal equilibrium
- feedback (resonator, mirrors)

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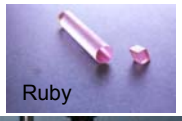
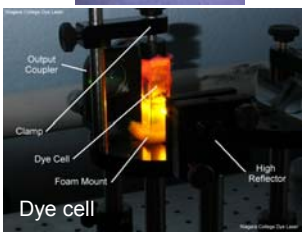
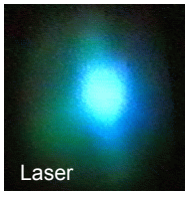
- Three essential components of a LASER

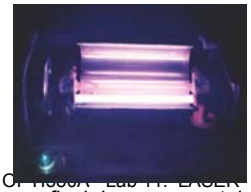
Gain Medium



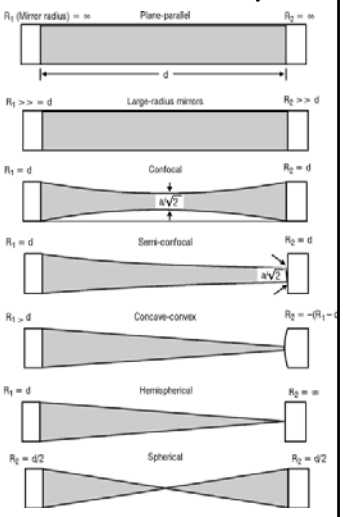


Pump: flash lamp, current, laser





Feedback, laser cavity



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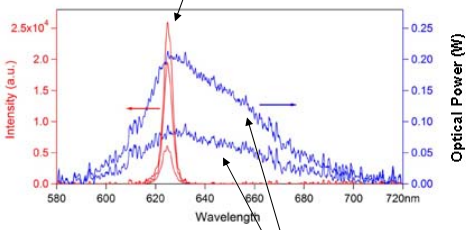
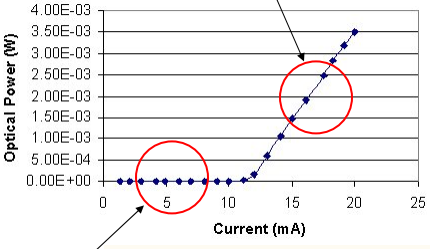
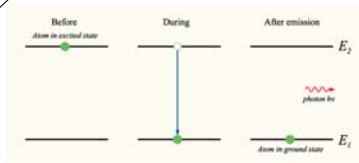
Laser Threshold

Threshold = Gain > Loss

Above threshold, stimulated emission into dominant mode with lowest loss







Below threshold, spontaneous emission in all directions

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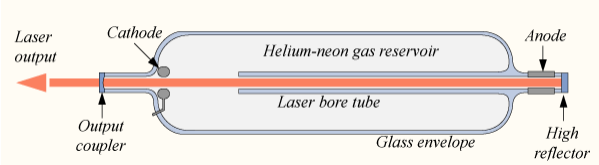
HeNe Laser

- Gas Laser at 632.8nm
  - Gain medium is helium and neon gas in 5:1 to 20:1 ratio
  - Pump by electrodischarge at around 1000V
  - Feedback provided by two mirrors

$$He(2^1S)^* + Ne + \Delta E \rightarrow He(1^1S) + Ne3s_2^*$$



Laser transition from $3s_2$ and $2p_4$

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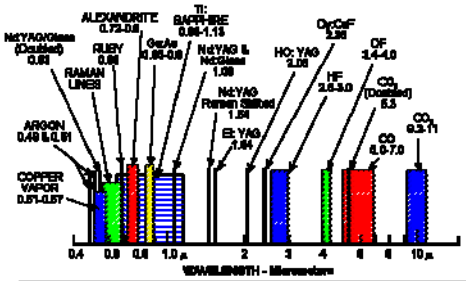
Characteristics of well known lasers

(1) Need transitions that emit light at the right wavelength
(2) Need mirrors that is good at that wavelength to form a low loss cavity
(3) Need a way to excite the transition



Laser Medium	Transition Wavelength λ_o	Single Mode (S) or Multimode (M)	CW or Pulsed[a]	Approximate Overall Efficiency $\eta(\%)$[b]	Output Power or Energy[c]
C^{6+} (p)	18.2 nm	M	Pulsed	10^{-5}	2 mJ
ArF excimer (g)	193 nm	M	Pulsed	1.	500 mJ
KrF excimer (g)	248 nm	M	Pulsed	1.	500 mJ
He–Cd (g)	442 nm	S/M	CW	0.1	10 mW
Ar^+ (g)	515 nm	S/M	CW	0.05	10 W
Rhodamine-6G dye (l)	560–640 nm	S/M	CW	0.005	100 mW
He–Ne (g)	633 nm	S/M	CW	0.05	1 mW
Kr^+ (g)	647 nm	S/M	CW	0.01	500 mW
Ruby (s)	694 nm	M	Pulsed	0.1	5 J
$Ti^{3+}:Al_2O_3$ (s)	0.66–1.18 μm	S/M	CW	0.01	10 W
Nd^{3+}:glass (s)	1.06 μm	M	Pulsed	1.	50 J
Nd^{3+}:YAG (s)	1.064 μm	S/M	CW	0.5	10 W
KF color center (s)	1.25–1.45 μm	S/M	CW	0.005	500 mW
He–Ne (g)	3.39 μm	S/M	CW	0.05	1 mW
FEL (LANL)	9–40 μm	M	Pulsed	0.5	1 mJ
CO_2 (g)	10.6 μm	S/M	CW	10.	100 W
H_2O (g)	118.7 μm	S/M	CW	0.001	10 μW
HCN (g)	336.8 μm	S/M	CW	0.001	1 mW

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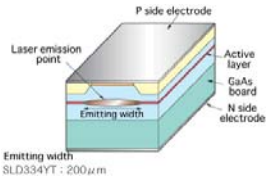
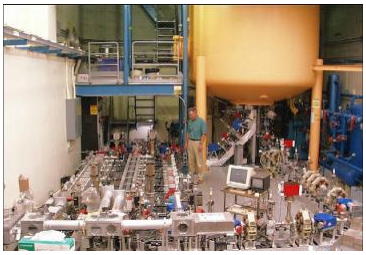
Examples of Laser

Laser diodes

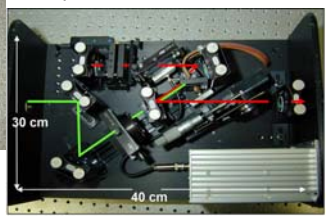


Free electron laser at UCSB

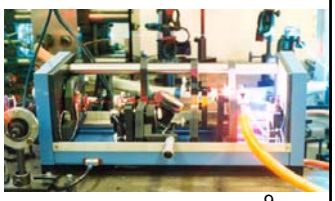


HeNe gas laser

Solid state Ti:Sapphire pulse laser



Single frequency dye laser



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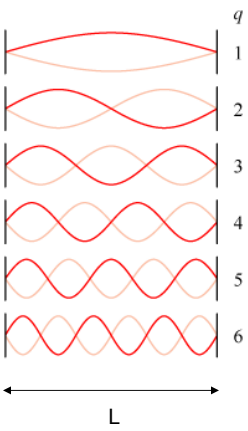
Longitudinal modes

Allowed modes of the cavity are those where mirror separation is equal to multiple of half wavelength.



$$L = q\frac{\lambda}{2}$$ q is an integer

Frequency separation

$$\Delta\nu = \frac{c}{2L}$$ for L >> λ (For gas cavity)

$$L = q\frac{\lambda}{2n_{cav}}$$ (For cavity with index n_{cav})

$$\Delta\nu = \frac{c}{2n_{cav}L}$$

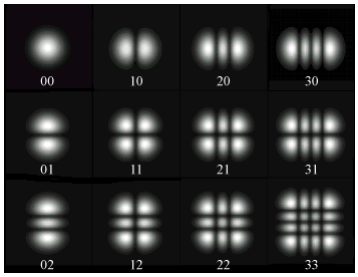
Transverse modes

Transverse modes are mode that are in a plane perpendicular (transverse) to direction of propagation (m,n).

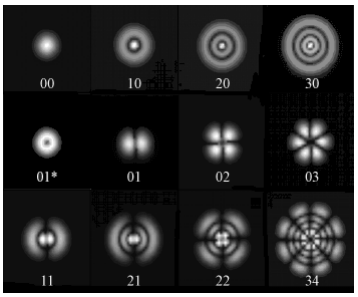
Profiles depend on the mirror shape.

Lowest order mode TE_{00} is the Gaussian beam.

Rectangular symmetric modes
Hermite polynomials



Circular symmetric modes
Laguerre polynomials



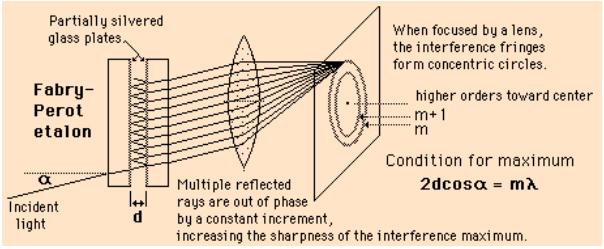
$$\nu_{mnq} = \frac{c}{2n_{cav}L}\left[q + \frac{(1+m+n)}{\pi}\cos^{-1}\sqrt{(1-\frac{L}{r_1})(1-\frac{L}{r_2})}\right]$$

Fabry-Perot Configuration

Charles Fabry (1867-1945)

Alfred Perot (1863-1925)

- Light traverses through two reflecting surfaces after multiple reflections



Sodium doublet on Fabry-Perot

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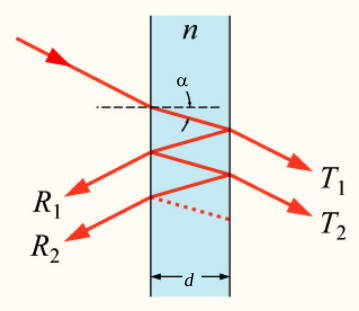
Optical properties



phase difference between succeeding reflection

$$\delta = \left(\frac{2\pi}{\lambda}\right) 2nd\cos\alpha$$

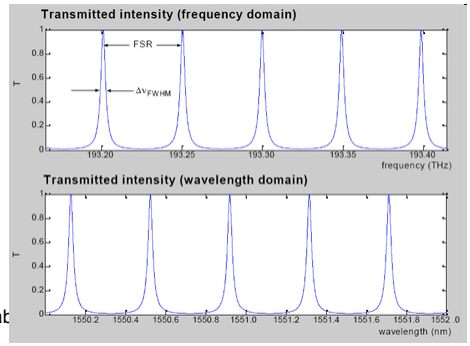
assume both surfaces have reflection coefficient R

$$T = \frac{(1-R)^2}{1+R^2-2R\cos\delta}$$

$$FSR = c/2d$$

maximum transmission $T_{\max} = 1$

maximum reflectivity $R_{\max} = \dfrac{4R}{(1+R)^2}$



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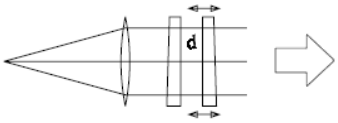
Scanning Fabry Perot Filter/Spectrometer

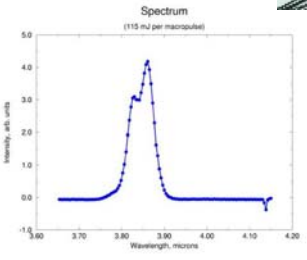
- Wavelength (color) filter
- High resolution spectroscopy (limited by FSR)

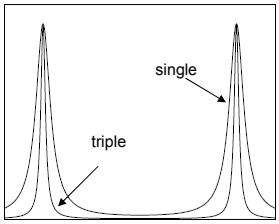
fixed gap

tunable gap

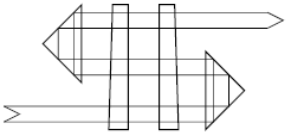
single pass tunable configuration



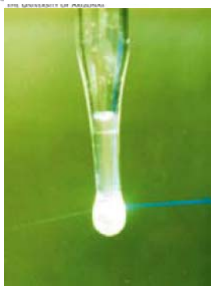




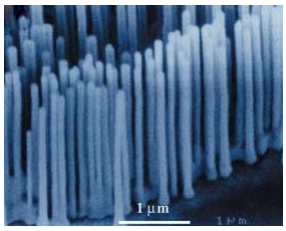
triple pass configuration



One drop dye laser



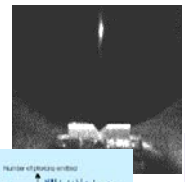
Zinc oxide nanowire laser

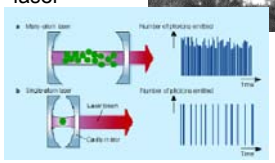


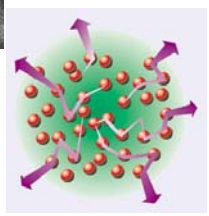
Keyhole Nebula, the only star thought to emit natural laser light

Prof. Arthur L. Schawlow (1921-1999)
"Anything will lase if you hit it hard enough."

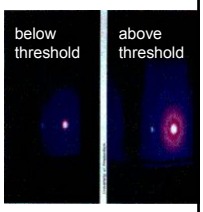
Single atom laser







Random laser: lasing in disordered media (trap by scattering)



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Research in Lasers

- New wavelength bands
- Higher output power
- Higher peak output power
- Shorter pulse
- Higher efficiency