LASER – Short Nots.

(1) Introduction

(2) Laser beam Characteristics — Monochromatic / Coherence / Divergence

(3) Atomic Process — Spontaneous / Stimulated / Absorption.

(4) Thermal Eq.

(5) Population Inversion

(6) Three level & four level Laser.

(7) Laser Cavity

(8) Amplification

(9) Standing Wave.

(10) Mods — Longitudinal Mods / Transverse Mode

(11) Longitudinal Mode & Laser gain bandwidth
$\Delta \nu$, $\delta \nu$.

(12) Single Mode & Multi Mode Laser

(13) Pulsed Lasers — Mode Locked / Q Switched.

(14) Peak Power, Irradiance, Fluence
Average Power

(15) Types of Laser – Ruby Laser, He-Ne Laser,
CO_2 Laser, Argon Ion Laser, Nd:YAG Laser,
Excimer Laser, Dye Laser, FEL.

(For any doubt ring me at 9413839224)

Introduction

Achronym for Laser:

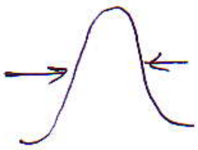
- Light amplification by Stimulated emission of Radiation

- Invention:
    - ~~Ab~~ Theoretical Background - Albert Einstein in 1916.
    - Theodore Maiman built first Laser in 1960: Ruby Laser.

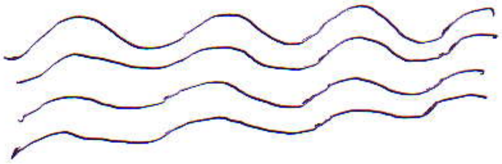
- Major Applications.
    1) Optoelectronics - Reading & Writing CD disk, DVD, 3d printer, bar code scanner
    2) Medicine.
    3) Materials Working - drilling, Welding
    4) Military Applications.
    5) Most Imp - Communication. Fiber Optic Communication - Mobile phone, Internet.

Laser beam Characteristics

- **Monochromatic** – Single wavelength

Concept of Spectral Width.  $\Delta\nu$ (FWHM)

- Single Mode laser – much narrower.
- $\Delta\nu$ = V-Imp in dispersion in Optical fibers. This determines data rate / bandwidth.

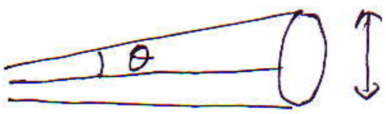
- **Coherence** :  Phase relations remain const in with time.

  - Spatial Coherence
  - Temporal Coherence. ⇒ Coherence time.

Coherence length = c × Coherence time = $\frac{c}{\Delta\nu}$

- ord light = 400 nm
- He Ne Laser ≈ 10 cm.
- In exp Sem Laser = 0.3 mm.
- Single Mode Laser = 100 m

- **Divergence** (m.rad).

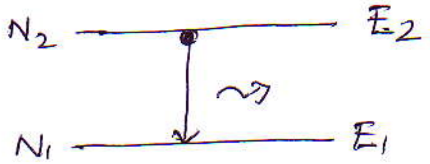
 $2L\sin\theta$ for small θ $\tan\theta \simeq \sin\theta$.

spot size.

Atomic Processes.

- spontaneous Emission
- stimulated Emission
- Absorption.

Spontaneous Emission.

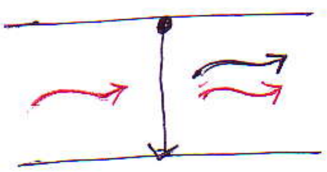


$E_2 - E_1 = h\nu$

Random emission of photon.

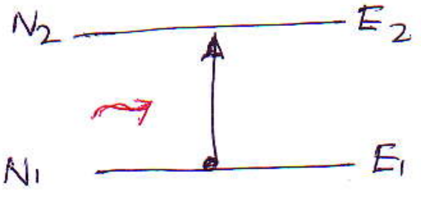
N_1 atoms in state E_1
N_2 atoms in state E_2

Stimulated Emission.

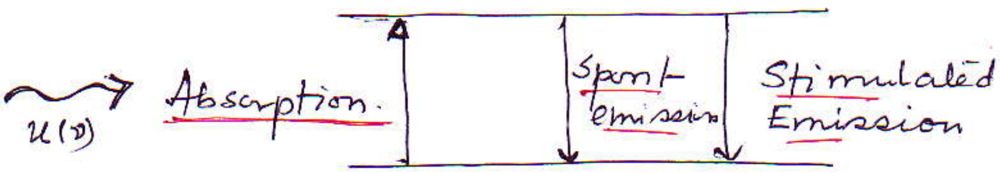


perturbed by a photon
Both the photon have same phase, frequency, polarization state & direction of travel. ⇒ Cause of Laser Light.

Absorption:



In Thermal equilibrium (const T) or in a steady state condition, upward transition must balance all downward transition.



Population Inversion

$N_2 > N_1$ Such that stimulated emission dominates.

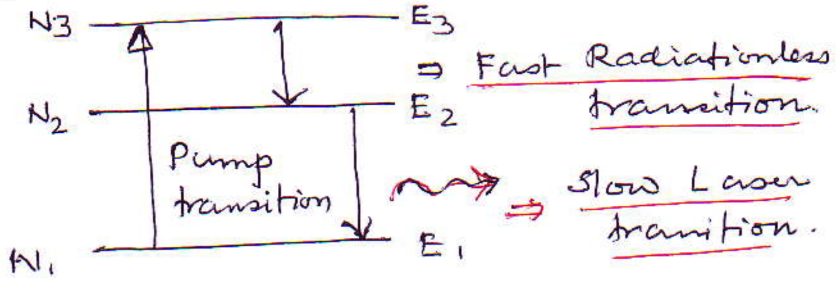
Maxwell Bolzman distribution.

$$\frac{N_2}{N_1} = \frac{g_2}{g_1} e^{-(E_2 - E_1)/k_B T}$$

(This is something $\frac{N_2}{N_1} = e^{-x}$. The N_2 can be larger than N_1 only when T is $-$ve)

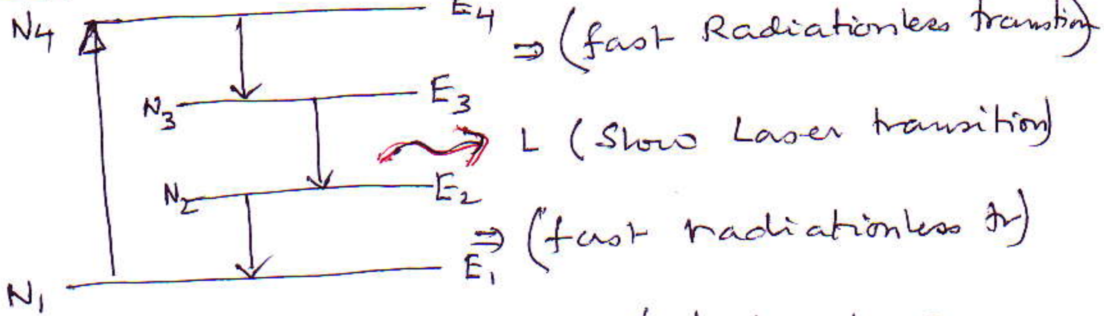
So in two level ~~laser~~ it is not possible.

Three Level Laser.



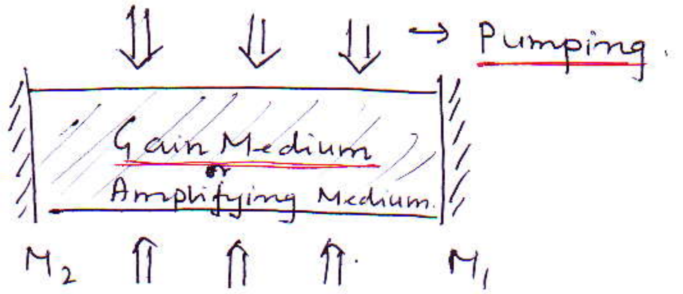
- population Inversion achieved in Level 2
- $\tau_{21} >> \tau_{32}$

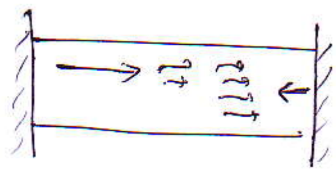
Four Level Laser



- population Inversion achieved bet Level 3 & lev 2
- $\tau_{32} >> \tau_{43}, \tau_{21}$

LASER Cavity.





• Light oscillating back & forth – to give amplification.

So the Laser Cavity Consists of

(1) Gain Medium – Medium in which the light oscillats back & forth & give rise to laser light. The medium may be 1) gas mixture like. He Ne Laser

2) Solid = Nd: YAG Laser

3) Liquid = Dye Laser.

Accordingly the Laser is termed as Gas Laser, solid state laser or a liquid Laser.

(2) There are two mirrors on both sides. – There may be many different kind of arrangement of mirrors but the most Common is when both the mirrors are parallel to each other. ~~On~~ one side the Laser light coms out, that is 99% reflecting.

(3) Pumping – There are different pumping mechanism to pump energy to a Laser. The most Common of them are (1) Optical pumping (2) Electrical pumping

In He-Ne Laser there is electrical pumping — The He atoms get energy due to some electrical discharge.

Amplification: As the light undergoes multiple reflection, the photons are multiplied because of stimulated emission.

Standing Waves: As the light oscillate back & forth standing waves are formed. In standing wave because of Constructive Interference only certain discrete frequencies/ wavelengths are allowed. They are given by

$$n \times \frac{\lambda}{2} = L \implies \boxed{\nu_n = \frac{nV}{2L}} = \frac{nc}{2L}$$

$$\Rightarrow \boxed{\lambda_n = \frac{2L}{n}}$$

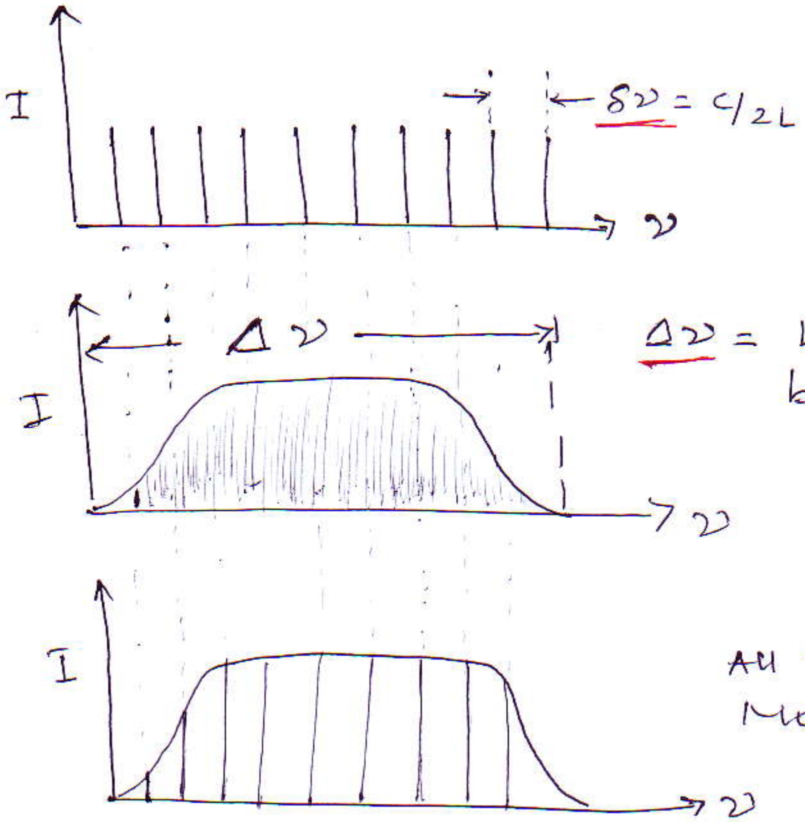
In wavelength. In frequency term.

Mods: These stable frequency / electromagnetic waves which occur because of constructive interference are known as Mods.

Mods
- Longitudinal Mods = differ in freq
- Transverse Mods. = differ in freq as well as Intensity pattern of light.

Here we will not discuss about Transverse Mode.

Longitudinal Mods = Differ in freq given by the above eqn. $\nu_n = \frac{nV}{2L}$. Now only those frequencis are allowed which are falling under the laser gain bandwidth. A ~~Laser~~ particular laser say He Ne Laser will give light in a Certain frequency range known as Laser gain bandwidth but only those frequencis will be allowed which will follow $\nu_n = \frac{nV}{2L}$. That can be shown by a diagram.



(a) all possible mods.

$\Delta\nu$ = Laser Gain bandwidth

(b)

Imp

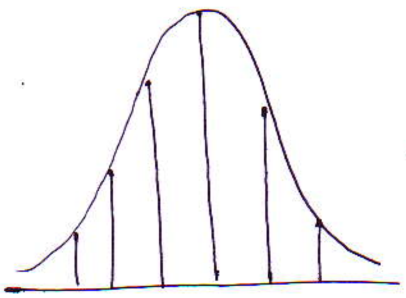
All the allowed Mods.

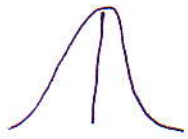
(c)

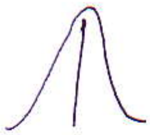
$\frac{\Delta\nu}{\delta\nu}$ = Total NO of allowed Mods.

Single Mode & MultiMode Laser.

Single Mode	MultiMode
⇓	⇓
only one frequency	Many frequencies simultaneously exist.
⇓	
$\Delta\nu$ = Spectral width is very small ⇒ Coherence length increase	$\Delta\nu$ = Spectral width decrease resulting Low Coherence length compared to Single Mode Laser.



Filter →  Single Mode Laser.

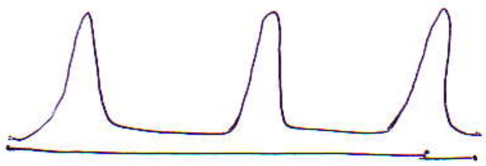
→ decrease l →  Single Mode Laser.

→ Mode locking

⇓

MultiMode – Many frequencies given by the lines simultaneously exist with Random phase.

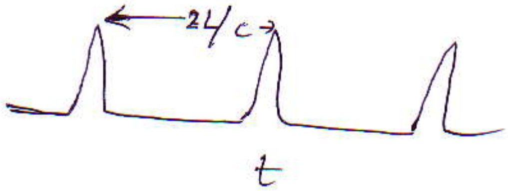
Locking their phase such that the phase have a definite relation – in AP. ⇒ pulsed Laser



Pulsed Laser.

What are pulsed Laser: ~~Theo~~ Light Coms out in pulss. The timing or FWHM of these puls are very short. So when some energy fals for a very short time th peak power is very high — so high that It can drill a hole in a metal. If it is focussed using a lens then th peak power/area becoms very hight which is known as irradiance.

Pulsed Laser
- Mode Locked pulsed Laser

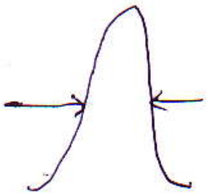


- Q switched pulse Laser

Q switching is another method of producing pulsed Laser.

V. Imp

- Peak Power = $\dfrac{\text{Pulse energy}}{\text{FWHM}}$



FWHM. Full width at half Maxima

- Irradiance = Peak Power / area.
- Fluence = Energy / area.
- Average Power = Average Energy / time.

Types of Laser

(1) Ruby Laser (solid state) First Laser in 1960 Theodore Maiman.

- $\lambda = 693.4$ nm.
- Pulsed Laser
- Three level Laser
- Ruby = (Cr^{3+} doped in Al_2O_3)

(2) He - Ne Laser

- Gas Laser
- $\lambda = 632.8$ nm. (red region) (most common)
- other λ = Infrared, Visible - Green & yellow
- Pumping ⇒ Electrical discharge $\xrightarrow{e}$ excite the He gas — Ne gas → gives the Laser.
- Four Level Laser

Standard parameters:

- Wavelength = 632.8 nm
- Output power = 0.5 — 50 (mW)
- Gain Bandwidth = 1.5 GHz.
- Beam Divergence = 0.5 - 3 (mRad)
- Coherence length = 0.1 - 2 (m)
- Beam Diameter = 0.5 - 2.0 (mm)
- lifetime > 20,000 hours.

(3) CO_2 Laser — CO_2 gas, helium, nitrogen, hydrogen

- $\lambda = 9.4\ \mu m$ & $10.6\ \mu m$.
- Highest power CW Laser
- Welding, Cutting, heat treating of elements

(4) Argon Ion Laser
Argon Ion as gain Medium.
Many wavelengths : 488 & 514.5 nm are most common.

(5) Nd: YAG Laser (Neodymium Yttrium aluminum Garnet)
($Nd + Y_3Al_5O_{12}$).

- Four level
- pulsed Mode is most Common
- 1064 nm ⟶ freq Doubling — 532 nm & 266 nm.
- Medical Industry
- Manufacturing Industry - drill hols, engraving

(6) Excimer Laser - UV Chemical Laser
- Combination of Inert gas & reactive gas psedo-molecule is created - dimer
- ArF - 193 nm.
- KrF - 248 nm.
- Medical - enough energy to break molecular bonds of Surface tissue. LASIK for eye correction.

(7) Dye Laser - Liquid Laser - organic dye as Lasing Medium.
- tunable to large Wavelengths

(8) FEL: Free electron Laser - relativistic electron beam as Lasing medium.
- Beam is passed through periodic transverse magnetic Field - accelerating electrons release photons. — Widest frequency range - Highly tunable.