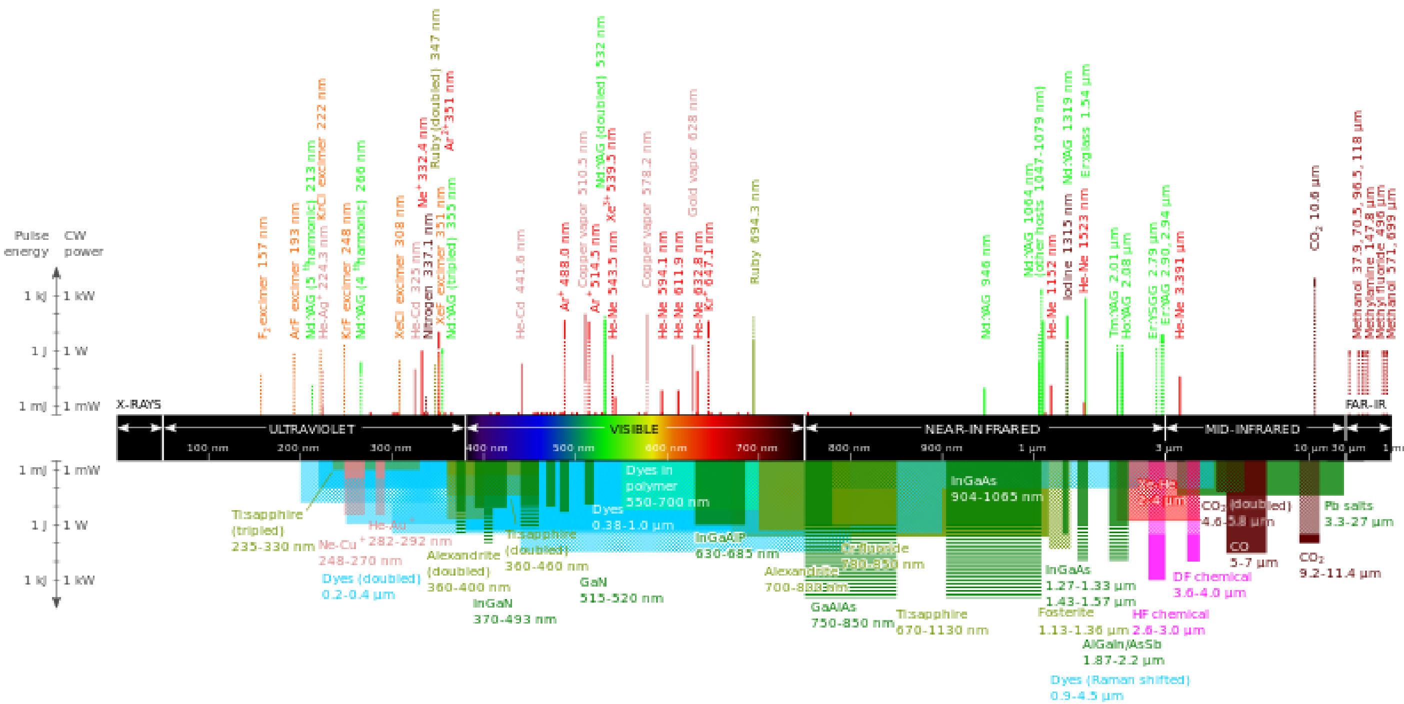
CHEM 524 - Course Outline (Sect. 3-a-Vap/mol) – 2013 rev

For Html Version of This Set of Notes from 2005, with Linked FIGURES CLICK HERE

II.D. Laser light sources (Sect. a - general principles, vapor phase and molecular lasers)



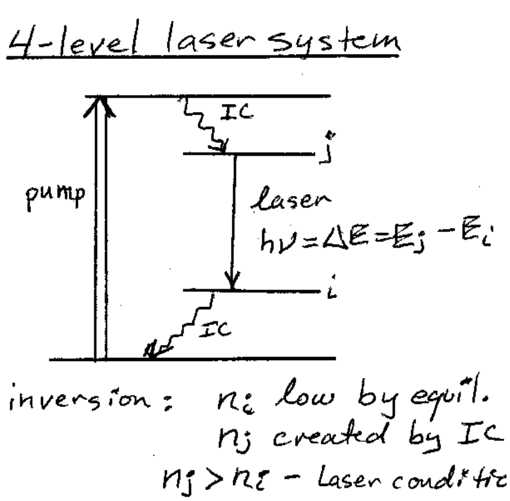
1. General aspects

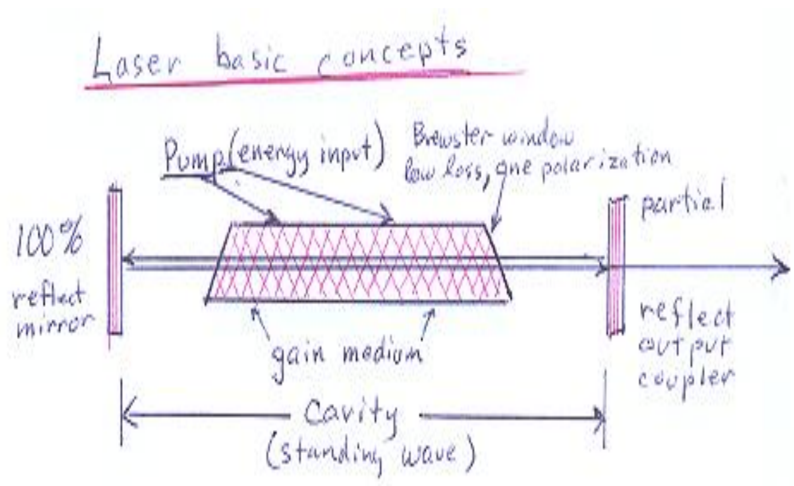
a. Unique Properties: coherence (phase), directionality (pointing), spectral purity (frequency)

b. Stimulated emission — mechanism allows amplification of output of one transition

i. Temperature inverted levels–non-equilibrium population distribution -- $n_i>n_j$, $E_i>E_j$

--4-level system works best since lower state is continuously emptied *(discuss),*





ii. Cavity construction creates standing wave–cycle light wave between mirrors,

--this wave stimulates emission at the same frequency and with the same phase from the gain medium, tends to be directed out in a narrow beam by the cavity design

--i.e. integral number of wavelengths between the (back-reflect & output) mirrors

--gain medium needs to be excited—light or electrical discharge typical

Results: Narrow frequency distribution, defined direction and polarization

—power through amplification of oscillator

1. Can make oscillator have gain if excite enough medium
2. can have separate amplifier – gain medium, no cavity

Every oscillator has 4 main parts (as seen in figure 3.1):

1. Amplifier.
2. Positive resonance feedback.
3. Output coupler.
4. Power source.

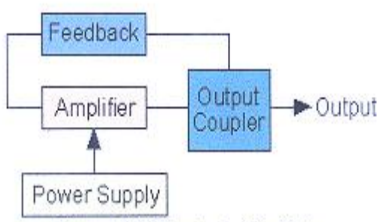


Figure 3.1: Electronic Oscillator

n analogy to the electronic amplifier, the laser can be described as composed of four stru igure 3.2):

1. Active medium, which serves as an optical amplifier.
2. Excitation mechanism.
3. Optical feedback.
4. Output coupler, to allow electromagnetic radiation out of the laser device.

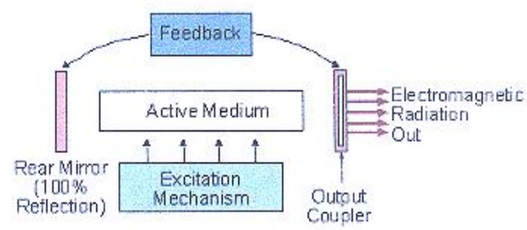


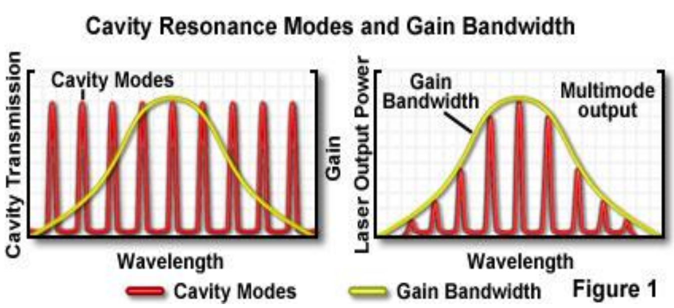
Figure 3.2: The Basic Laser System

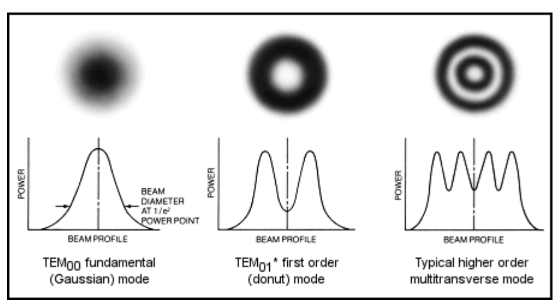
c. Characteristics —categorize ***types*** of laser sources

- *timing*: cw — continuous wave (on all the time, DC) vs. Pulsed — down to fs (10^{-15} s)
- *tune*: single or multiple lines vs. broad band (tune over 100's - 1000's cm^{-1})
- *modes*: --transverse beam (cross-section intensity distribution), TM_{00}–ideal Gaussian

  --longitudinal (standing wave - each mirror at a node) – along propagation

  -- source of ultimate resolution, gain profile selects modes (by media, optics)





Longitudinal modes reflect fit of wavelength to the cavity length, gain profile

Transverse modes represent beam quality can limit focus ability

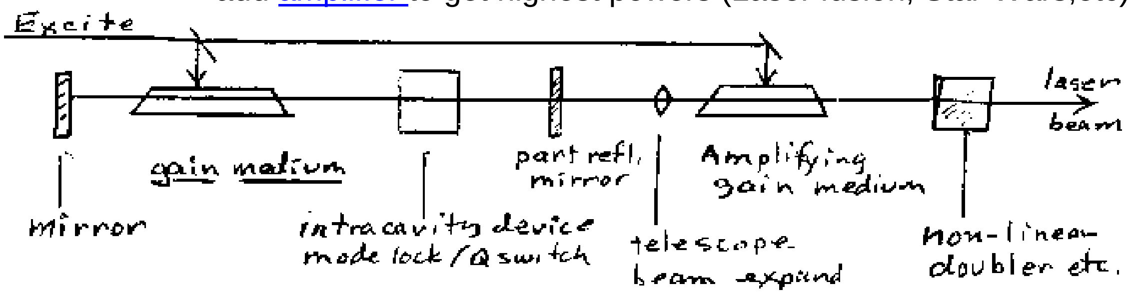
- *power*: -- cw (mW to a few W typical); exception: biggest — CO_2 welders (100s W)

  - also YAG based ones now

  --pulsed -- can be many MW but for short pulse durations,

  high power can saturate oscillator, deplete inversion, terminate pulse

--add amplifier to get highest powers (Laser fusion, Star-Wars,etc)



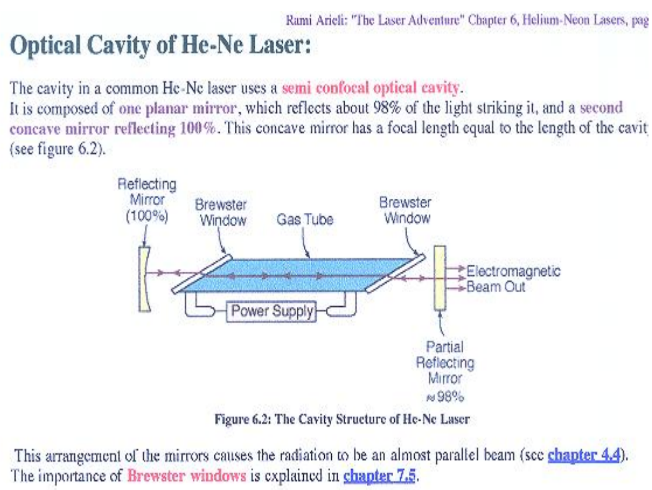
Typical Laser source components (single frequency)

2. Types available

a. Gas ion -- lines or narrow bands, (HeNe —2nd laser invented, but *inefficient*, low power),

efficiency ex.: 130 mW of light require 10A to excite ion pop. At 100V = 1KW (*need cool*)

HeNe typically use red line at 632.8 nm, but *low power*, also has IR lines: 1.15 μ, 3.39 μ

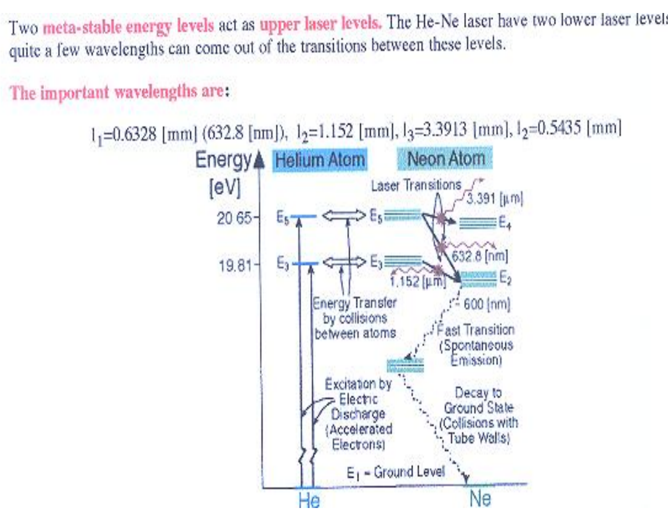

Rami Arieli: "The Laser Adventure" Chapter 6, Helium-Neon Lasers, pag

Optical Cavity of He-Ne Laser:

The cavity in a common He-Ne laser uses a semi confocal optical cavity.
It is composed of one planar mirror, which reflects about 98% of the light striking it, and a second concave mirror reflecting 100%. This concave mirror has a focal length equal to the length of the cavit (see figure 6.2).

Figure 6.2: The Cavity Structure of He-Ne Laser

This arrangement of the mirrors causes the radiation to be an almost parallel beam (see chapter 4.4). The importance of Brewster windows is explained in chapter 7.5.


Two meta-stable energy levels act as upper laser levels. The He-Ne laser have two lower laser levels quite a few wavelengths can come out of the transitions between these levels.

The important wavelengths are:

l_1=0.6328 [mm] (632.8 [nm]), l_2=1.152 [mm], l_3=3.3913 [mm], l_2=0.5435 [mm]

Simple low power HeNe seal mirror to tube

He provides excitation channel,

Ne is gain medium, acts as 4-level system

i. Atomic ion lasers-- discharge through low pressure gas (plasma):

(collision) --> A^{+*} -- > $\mathbf{A^{+}+h\nu}$ — > ($+e^-$) -- > A

-- low efficiency (<0.1%) – higher power designs are large (> m long) and need water cooling

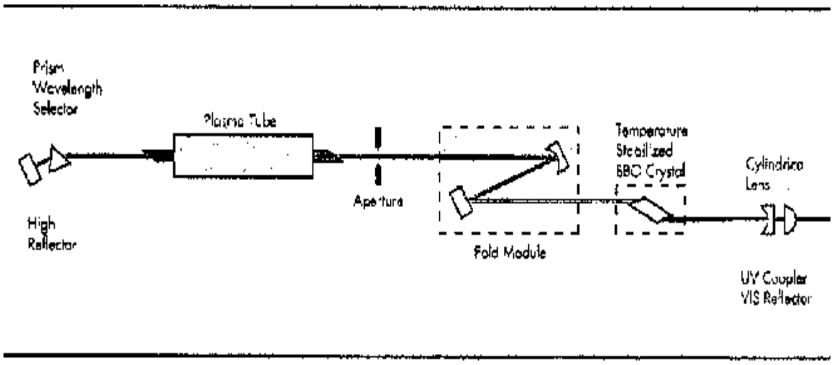
-- cw stable oscillator (depletes ground state), normally rare gas ions, most lines in visible

-- power supply is expensive/ also at multiple KW needs cooling, large power drain (e.g. 220V)

-- sensitive alignment of optics – need very stable resonator design → cost increase

-- can be intracavity doubled (update) if high power (Fred design)—this is pricy (~$50 K+)

but can be useful for spectroscopy (e.g. resonance Raman or fluorescence excitation)



Fred laser design/ BBO double xtal

INNOVA 90C FRED

		SHG[1]		Fundamental[2]	
Output Power Specifications		Wavelength (nm)	Power (W)	Wavelength (nm)	Power (W)
				Multiline Visible	5.00
		264.3	0.02	528.7	0.35
		257.2	0.10	514.5	2.00
		250.8	0.015	501.7	0.40
		248.2	0.06	496.5	0.60
		244.0	0.10	488.0	1.50
		238.2	0.03	476.5	0.60
		229.0	0.01	457.9	0.35
				Multiline UV[3]	0.4
Beam Parameters[4]		**SHG**		**Fundamental (514.5 nm)**	
	Beam Diameter (mm)	0.6-0.9[5]		1.7[5]	
	Beam Divergence[1] (mrad)	0.5-0.85		0.5	
	Output Polarization	100:1 horizontal		100:1 vertical	
	Power Stability[8]	±1.0%		±0.5%	

SHG-second harmonic generation

--main types and transitions commonly seen:

- **Ar** strongest at 514.6, 488.8 nm + weaker blue and uv lines 351.1 and 363.8 nm

The Argon laser was invented in 1964 by **William Bridges** at Hughes.

Argon ion laser contains a tube filled with Argon gas which transforms into **plasma** in an excite
(**Plasma** is a state of matter in which the electrons are separated from the atoms and molecules
means that it contains free electrons and ions).

A schematic diagram of the energy levels of the Argon laser is shown in figure 6.4.

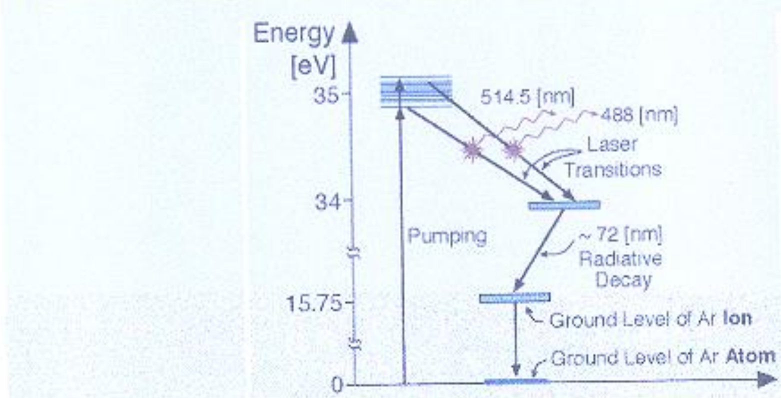
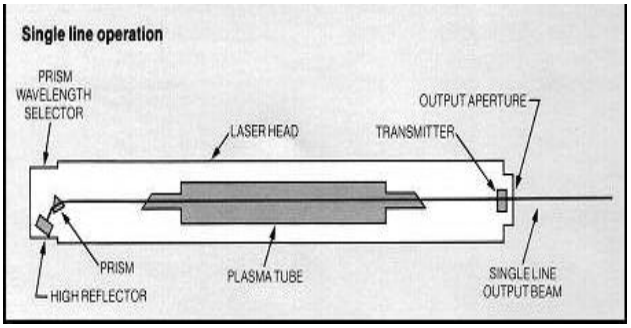


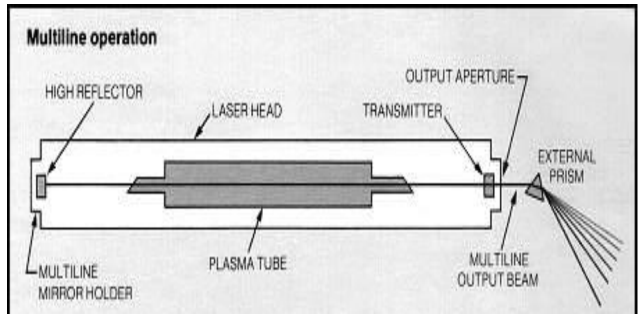
Figure 6.4: Energy Level Diagram of Ion Argon Laser.

- Power demand is high, 5W laser takes ~3KW – 1m long, water cooling

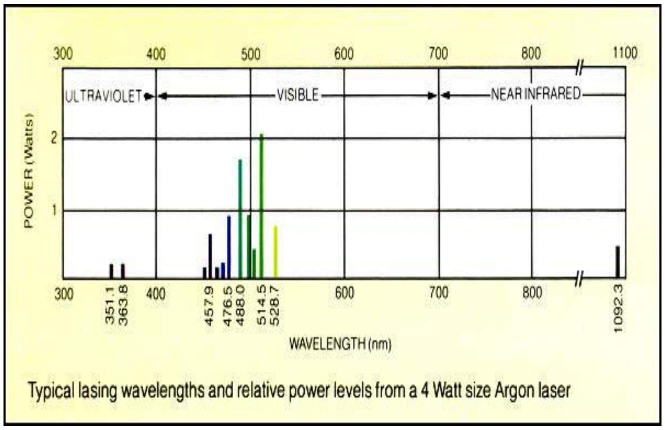
- 4-level system, but multiple states populated, can operate on one or several lines

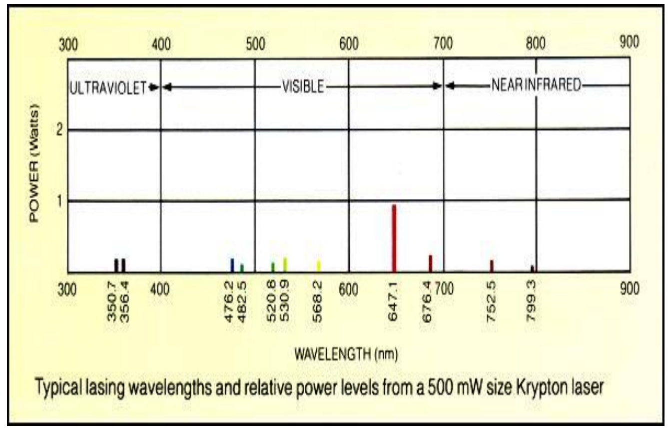
--Summary: 351.1, 363.8 (uv only high power models), 454.6 , 457.9 , 465.8 , 476.5 , 488.0 , 496.5 , 501.7 , 514.5 , 528.7 , 1092.3 nm





Original- quartz tube (due to heat), now ceramic + quartz windows, BeO bore or magnet contain plasma





- **Kr** – same style - red lines strongest 647.1 nm + 568, 531, 521 nm in "yellow and green" and has uv lines at 351, 356 nm, but less efficient than Ar (costly)
  - [vis lines: 406.7, 413.1, 415,4, 468.0, 476.2, 482.5, 520.8, 530.9, 568.2, 647.1, 676.4 nm]
- **HeNe** -- 632.8 nm (Ne), low power efficiency, also near-IR lines. Lots of cheap ones available for alignment (eg. surveying) or FTIR calibration, low power, few mW.

Less common:

- **HeCd** -- 441 nm -- laser between energy levels of **Cd^+ ions**, **gain medium** - ionized vapor.
  1. He excited by collisions with accelerated electrons, then they excite Cd by collisions.
  2. main application is in the optics laboratory, for fabricating holographic gratings.
- **Cu** -- *pulsed* green laser light at 510.6 nm and yellow laser light at 578.2 nm
  1. relatively efficient (up to 1%) for visible laser, high pulse power achieved.
  2. needs high temperature and a buffer gas like Ne
- **Au** - Gold Vapor laser - similar to **Cu** both in structure, and principles of operation. Red: 628 nm
- **Xe and I** lasers also have been built for research, I can be very powerful, laser fusion application

Tuning the Laser Wavelength

An example of such tuning element can be seen in figure 6.17, which show a prism inside the optical cavity.

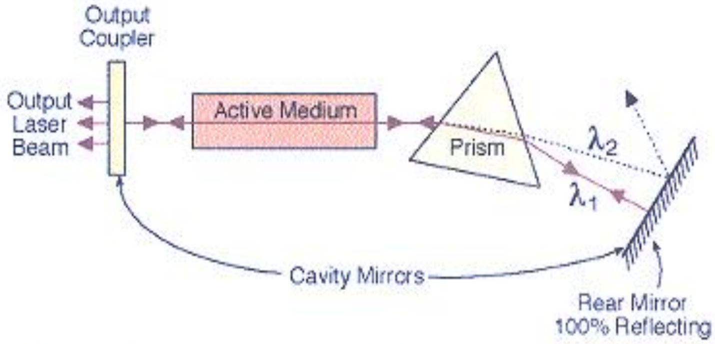


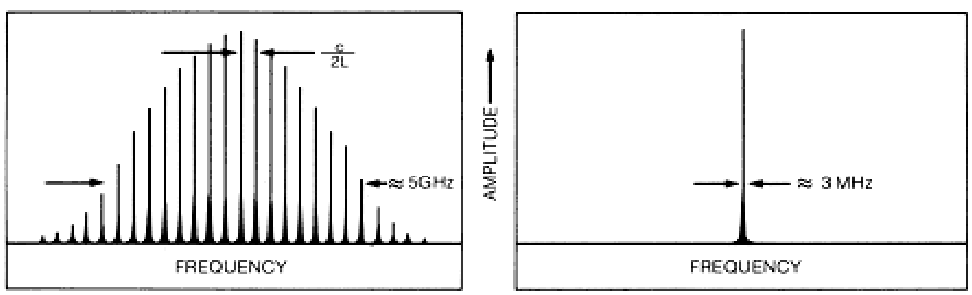
Figure 6.17: Choosing a single wavelength in a tunable laser with a prism.

The dispersion of the prism cause each wavelength to bend at different angle, and only one wavelength will continue to move back and forth within the optical cavity.
Moving the prism enable selecting the desired wavelength.

The pump bands are:

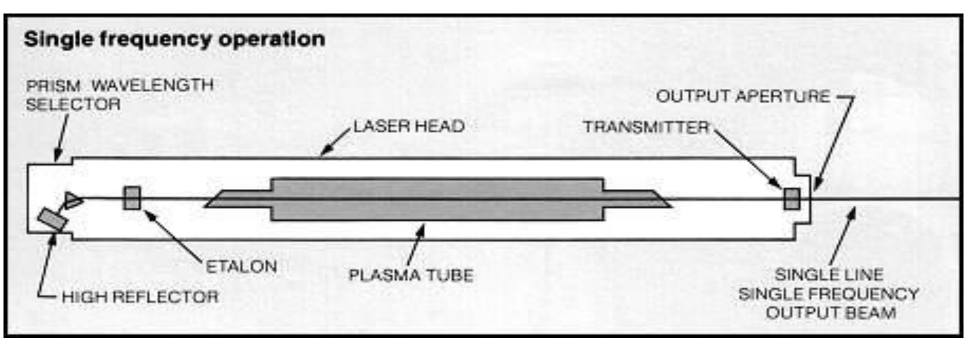
- **[nm] spectrum range which is suitable for flash-lamps.**
- **[nm] which is suitable for diode laser pumping.**

Longitudinal modes – group selected by gain profile, pick single one by etalon (interference)



Normal multilongitudinal mode distribution of typical ion laser

Single longitudinal mode (or single frequency) output of ion laser using an etalon

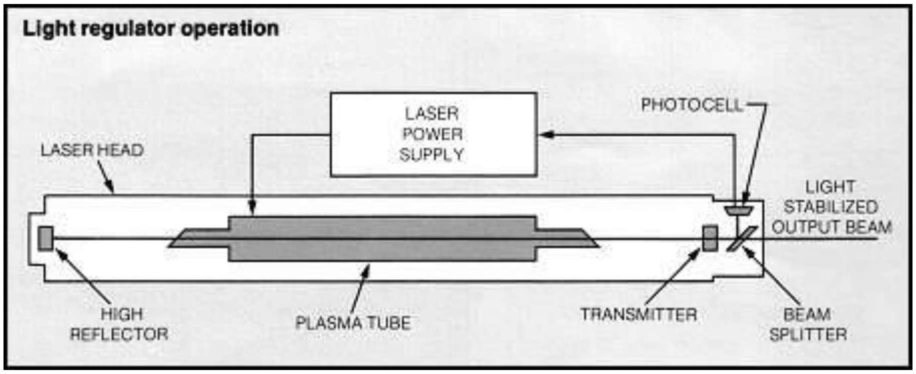


Polarization will be in vertical plane due to Brewster angle windows, for ion lasers

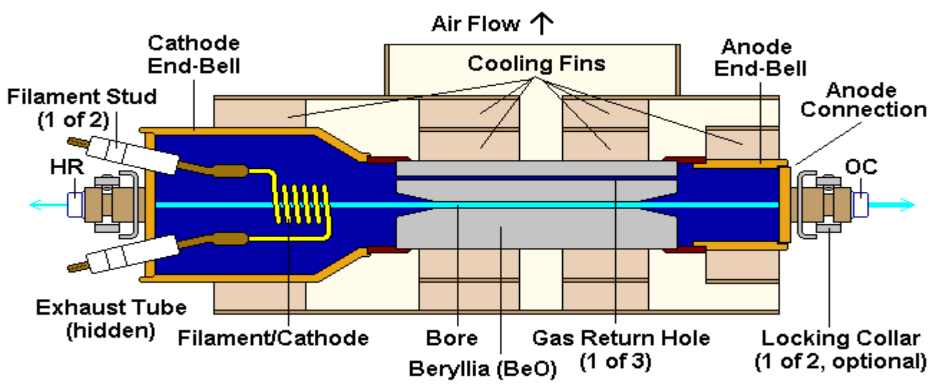
- relatively pure, to change it best to use a rotator (Faraday effect)

Stabilize power with a feedback system, can be very important for spectroscopy

Current control is basic, but if beam wanders the gain and output power will change



Sealed system – windows must adjust on tube (see HeNe demo in class)



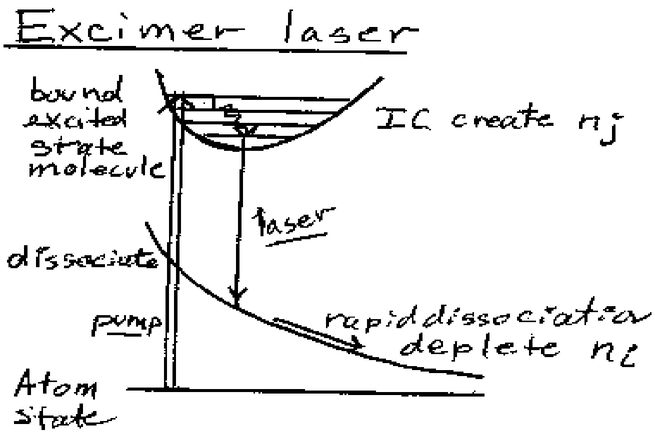
Structure of Typical Cynonics/Uniphase Argon Ion Laser Tube

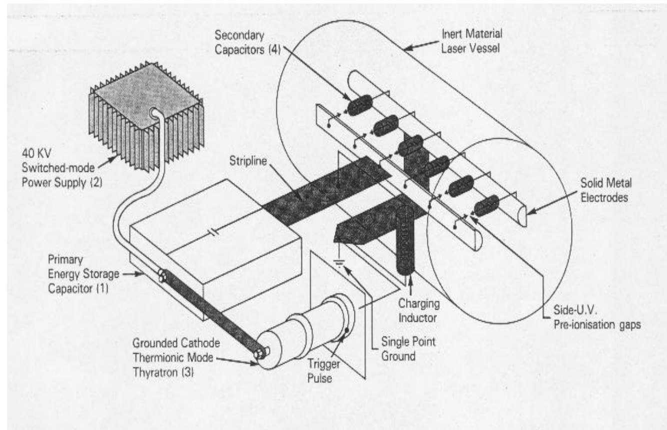
Metal-vapor lasers - comparative listing

Laser gain medium and type	Operation wavelength(s)	Pump source	Applications and notes
Helium-cadmium (HeCd) metal-vapor	441.563 nm, 325 nm	Electrical discharge in metal vapor mixed with helium buffer gas	Printing and typesetting applications, fluorescence excitation examination, scientific research.
Helium-mercury (HeHg) metal-vapor	567 nm, 615 nm		Rare, scientific research, amateur laser construction.
Helium-selenium (HeSe) metal-vapor	up to 24 wavelengths between red and UV		Rare, scientific research, amateur laser construction.
Helium-silver (HeAg) metal-vapor laser[1]	224.3		Scientific research
Neon-copper (NeCu) metal-vapor laser[1]	248.6	Electrical discharge in metal vapor mixed with neon buffer gas.	Scientific research
Copper vapor laser	510.6 nm, 578.2 nm	Electrical discharge	Dermatological uses, high speed photography, pump for dye lasers.
Gold vapor laser	627 nm		Rare, dermatological and photodynamic therapy

ii. Molecular --higher power, pulsed — 100-500 mJ/pulse – electronic transitions – vis, uv

Excimer --rare gas and halogen (exciplex), excited state dimer has no bound ground state,





Transverse Discharge capacitor through high pressure perpendicular to lasing direction

-- pulsed: moderate repetition rate and high power, fast deplete n_j

-- Beam quality poor-- transverse dye pumping OK-- can be improved (like for YAG) w/ optics

-- tunable over a short range (XeF, XeCl) by insertion of prism

Examples: - note specialized configurations used for *eye and other surgery*- control focus and ablation

- XeCl -- 308 nm, good for dye pump, does not photolyze dye so fast as KrCl, KrF or ArF
- XeF -- 351 nm – nuisance of handling F (passivate tube) makes less useful
- ArF -- 193 nm, good for photochem + VUV source (for photo lithography, chip design)
- F_2 -- 157 nm, good VUV (photochem, photo lithography)
- KrCl -- 222 nm and KrF -- 249 nm less commonly used
- N_2 -- "un-laser" -- super radiance 337.1 nm, 3-5 ns pulses, self terminates

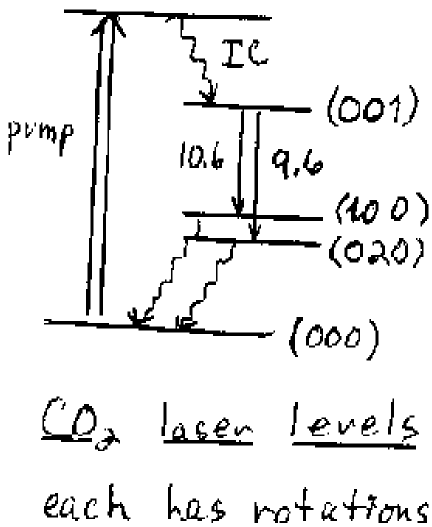
  -- can be pump for (short pulse) dye lasers, low power fluorescence lifetime

Excimer	**Wavelength**	**Rel. Power**	**Excimer**	**Wavelength**	**Rel. Power**
Ar_2*	126 nm		XeCl	308 nm	50
Kr_2*	146 nm		XeF	351 nm	45
F_2	157 nm	10	CaF_2	193 nm	
Xe_2*	172 & 175 nm		KrCl	222 nm	25
ArF	193 nm	60	Cl_2	259 nm	
KrF	248 nm	100	N_2	337 nm	5
XeBr	282 nm				

Excimer lasers are usually operated with a pulse rate of around 100 Hz and a pulse duration of ~10 ns, although some operate as high as 8 kHz and 200 ns.

iii. Molecular—vibration-rotation (IR region)

• CO_2 --4-level system, very efficient: asymmetric stretch to bend (overtone) or sym. stretch, lower level relaxes very fast to ground state



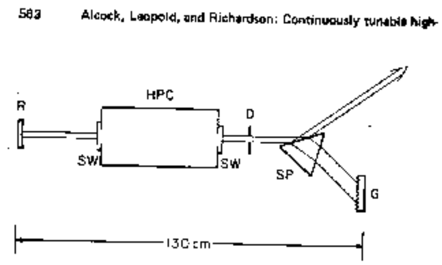


FIG. 2. Resonator configuration employed for continuously tunable laser. R—5-m gold mirror; SW—NaCl window; HPC—high-pressure chamber; D—diaphragm; SP—NaCl prism; G—grating.

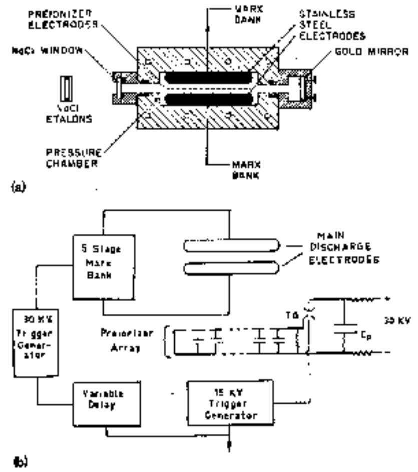


FIG. 1. (a) Cross section of high-pressure CO_2 laser showing location of main discharge electrodes immediately above the preionizer array. (b) Schematic diagram of preionizer and main discharge circuits.

--**molecular *vib - rot* transition (9.6-10.6 μ; --centers of bands, many lines, ~ 2 cm^{-1} apart)**

--multiple lines (coarse tune – line hop – like comb), high pressure-continuous discharge and collision excite, get ~ continuum (intensity between lines), but lots of intensity variation

-high power, can operate cw or pulsed

Many variants — CO (~5-6 μ), NO_2 (similar to CO_2), HCl (3.5-4 μ), DCl (5-5.6 μ), HBr, HF (2.5-3.3 μ), DF (3.5-4 μ),

Especially in far-IR: H_2O, CF_4 (15-17 μ), CH_3OH (37-700 μ), CH_3F (100-1200 μ)

Homework for Notes 3 (laser sources)

3. Laser light sources:

Text reading this section covers: Chapter 4-3 – pretty inadequate, out of date

Also review Kansas State web pages provided in links,

http://www.phys.ksu.edu/perg/vqm/laserweb/Preface/Toc.htm

Problems in the book

For discussion Ch. 4-18

To hand in eventually: Ch. 4 - # 2,14

More in Section 3b

Links:

Sam's laser FAQ – general place to look up info

http://www.repairfaq.org/sam/lasersam.htm

http://www.repairfaq.org/sam/laserfaq.htm

http://www.repairfaq.org/sam/laserhen.htm#hentoc

http://www.repairfaq.org/sam/laserarg.htm#argtoc