An Introduction to Laser Safety
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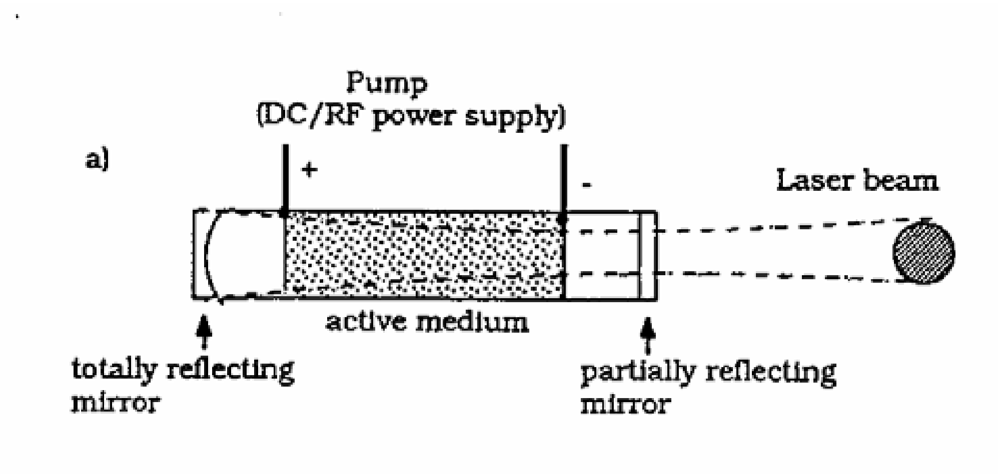
What are Lasers?

"Now you know the difference between a moon beam and a laser beam!"

What are Lasers?

- Light Amplification by Stimulated Emission of Radiation LASER
- Light emitted at very narrow wavelength bands (monochromatic)
- Light emitted in a directed beam
- Light is coherenent (in phase)
- Light often Polarized

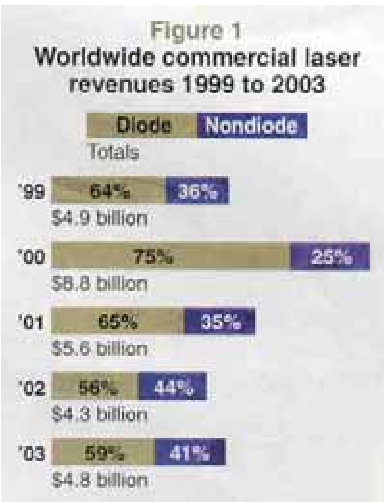


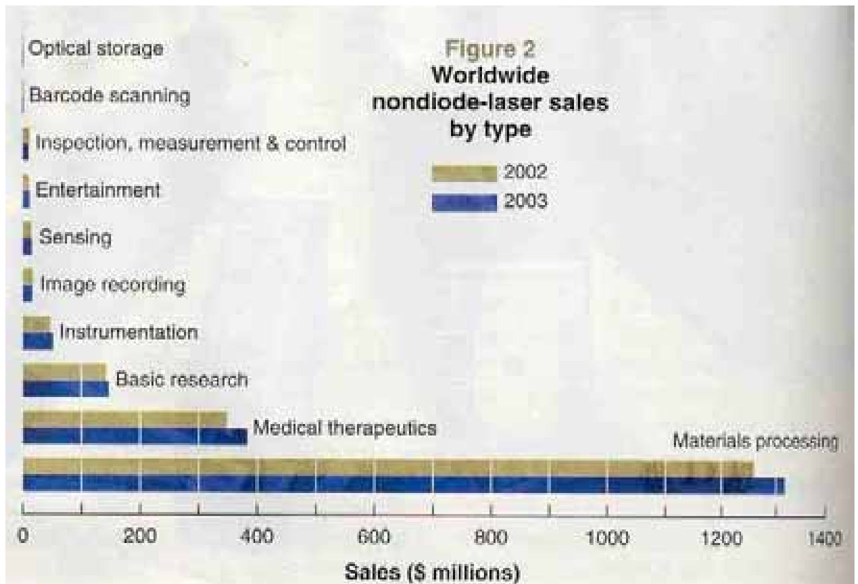
Why Study Lasers: Laser Applications

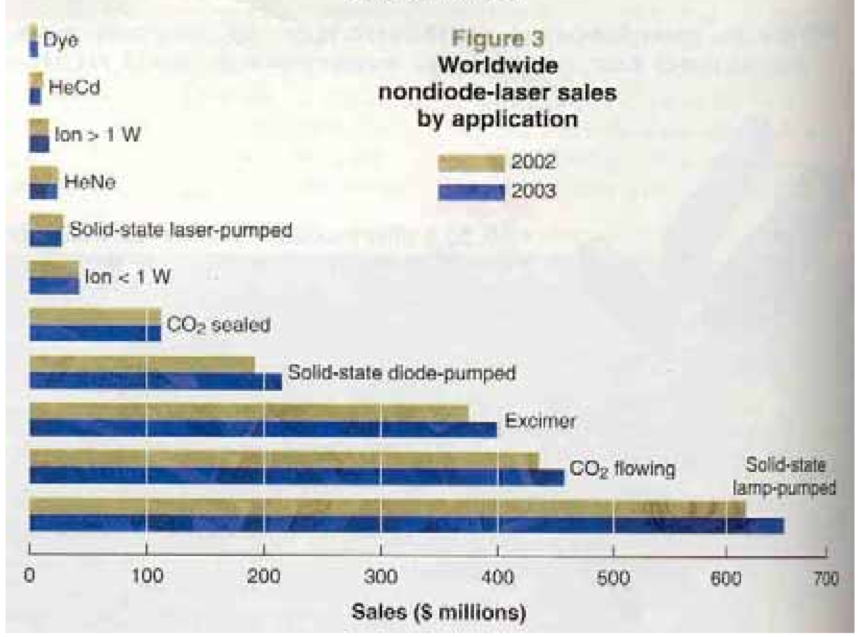
- Market $4.3 billion (2002) (just lasers)

Major areas:

- Market Divided in laser Diodes (56%) & Non diode lasers (44%)
- Materials Processing (28%)
- Medicine (10%)
- Entertainment/CD/DVD/Printers (~50%)
- Communications







History of the Laser

- 1917: Einstein's paper showing "**Stimulated Emission**"
- 1957: MASER discovered: Townes & Schawlow
- 1960: First laser using Ruby rods: Maiman
  first solid state laser
- 1961: gas laser
- 1962: GaAs semiconductor laser
- 1964: CO_2 laser
- 1972: Fiber optics really take off
- 1983: Laser CD introduced
- 1997: DVD laser video disks

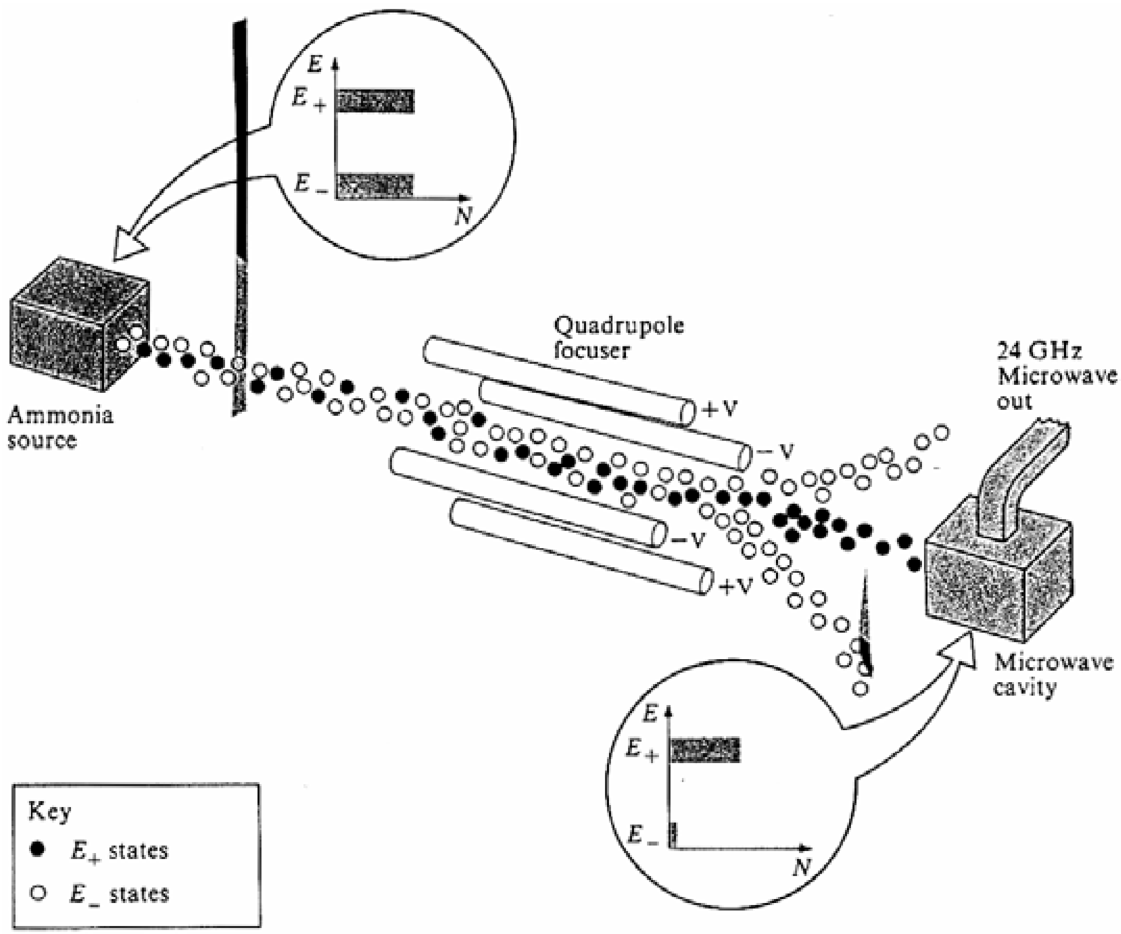
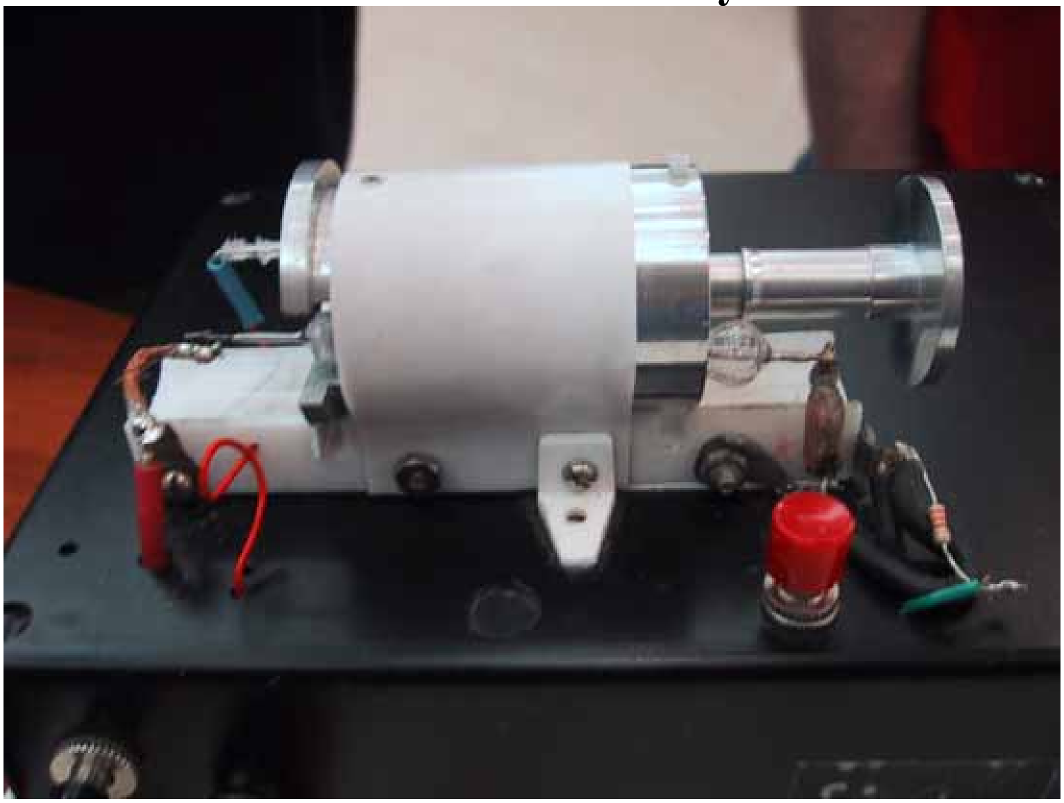
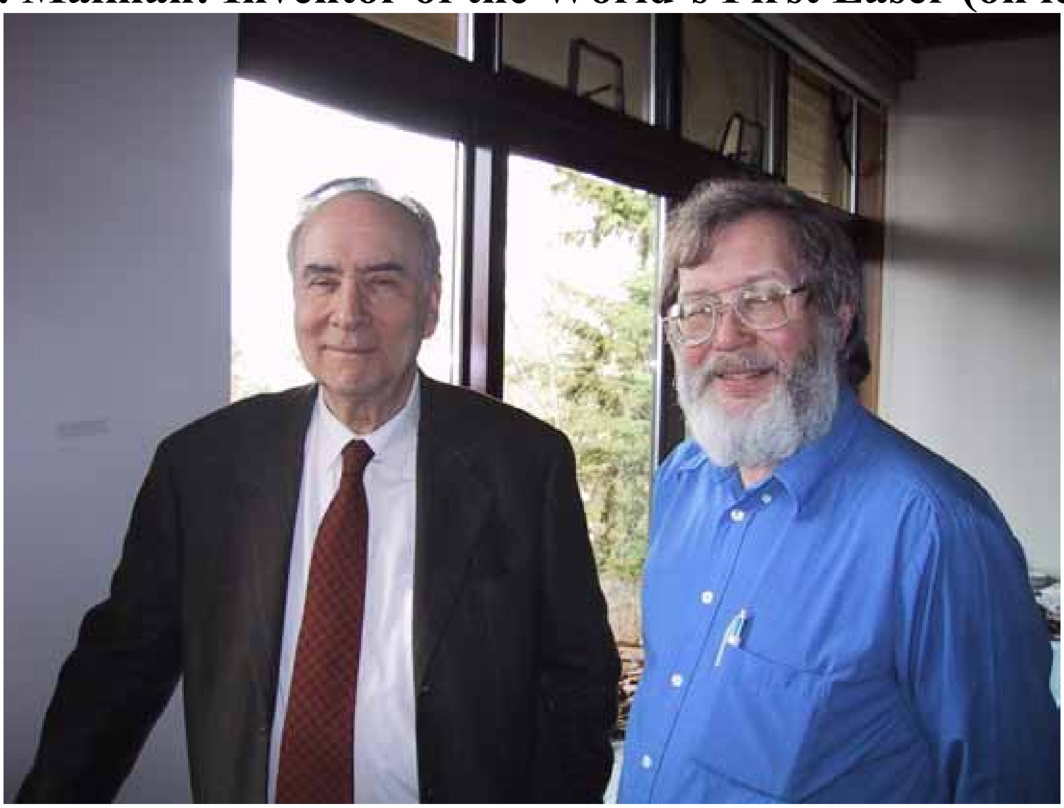


Fig. 3.4 Schematic of the ammonia-beam maser. Because the energy separation of the two states (● and ○) is small compared to the thermal energy of the system ($E_+ - E_- \ll kT$), the energy levels are nearly equally populated (top insert). By passing the atoms through an electric field gradient (quadrupole focuser), the higher-energy-state atoms (●) are directed into a microwave cavity resonant at $\nu = (E_+ - E_-)/h$. This physical separation creates a population inversion in this two-level system (bottom insert).

World's First Laser: Ruby Laser



Dr. Maiman: Inventor of the World's First Laser (on left)



Electromagnetic Spectrum

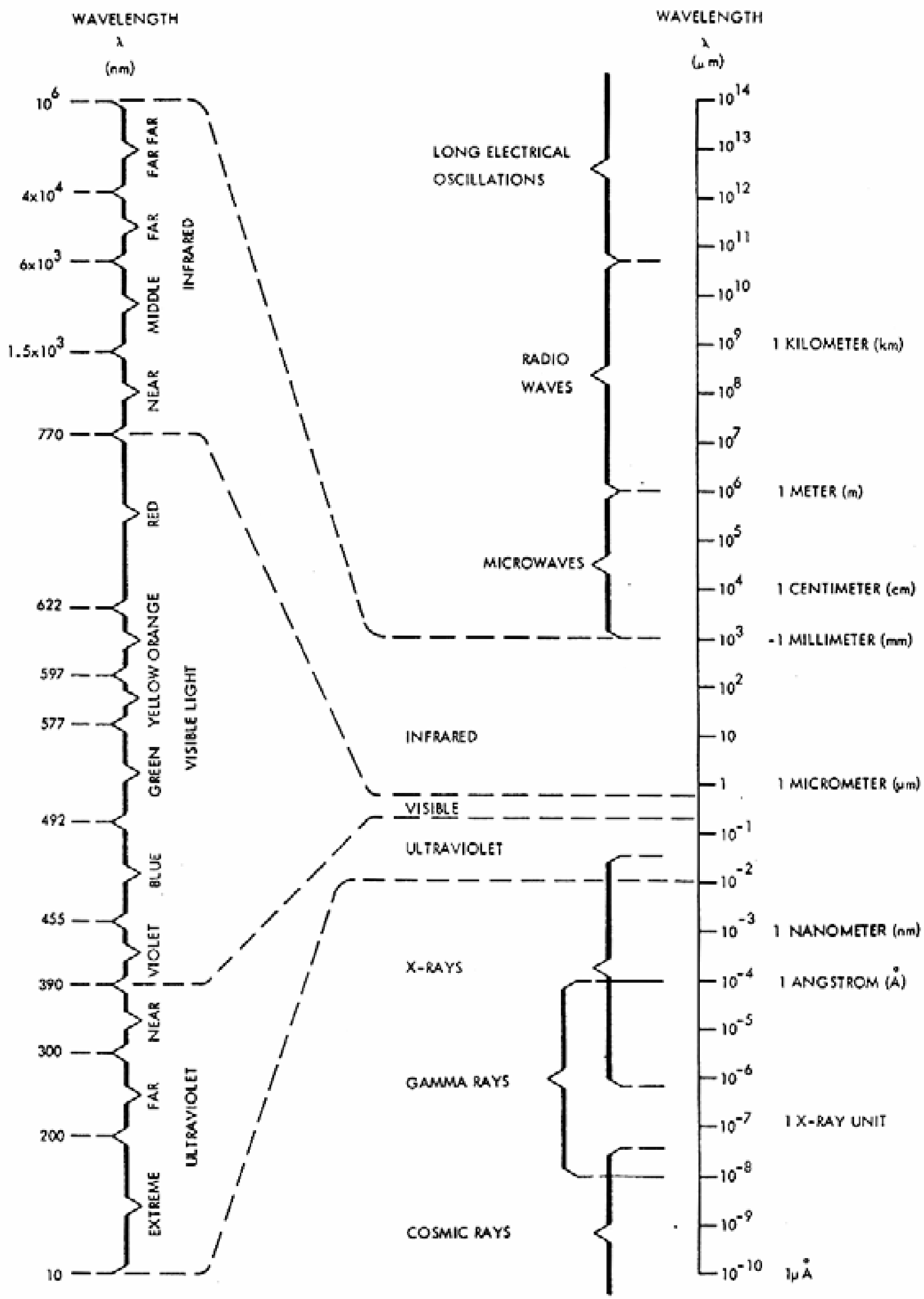


Fig. 1-6 Electromagnetic spectrum.

Spontaneous and Stimulated Emission

- Consider 2 energy levels E_0 (ground state) and E_1 (excited state)
- Photon can cause **Stimulated Absorption** E_0 to E_1
- Excited state has some finite lifetime, τ_{10}
  (average time to change from state 1 to state 0)
- **Spontaneous Emission** of photon when transition occurs
- Randomly emitted photons when change back to level 0
- Passing photon of same λ can cause **"Stimulated Emission"**
- Stimulated photon is emitted in phase with causal photon
- Stimulated emission the foundation of laser operation

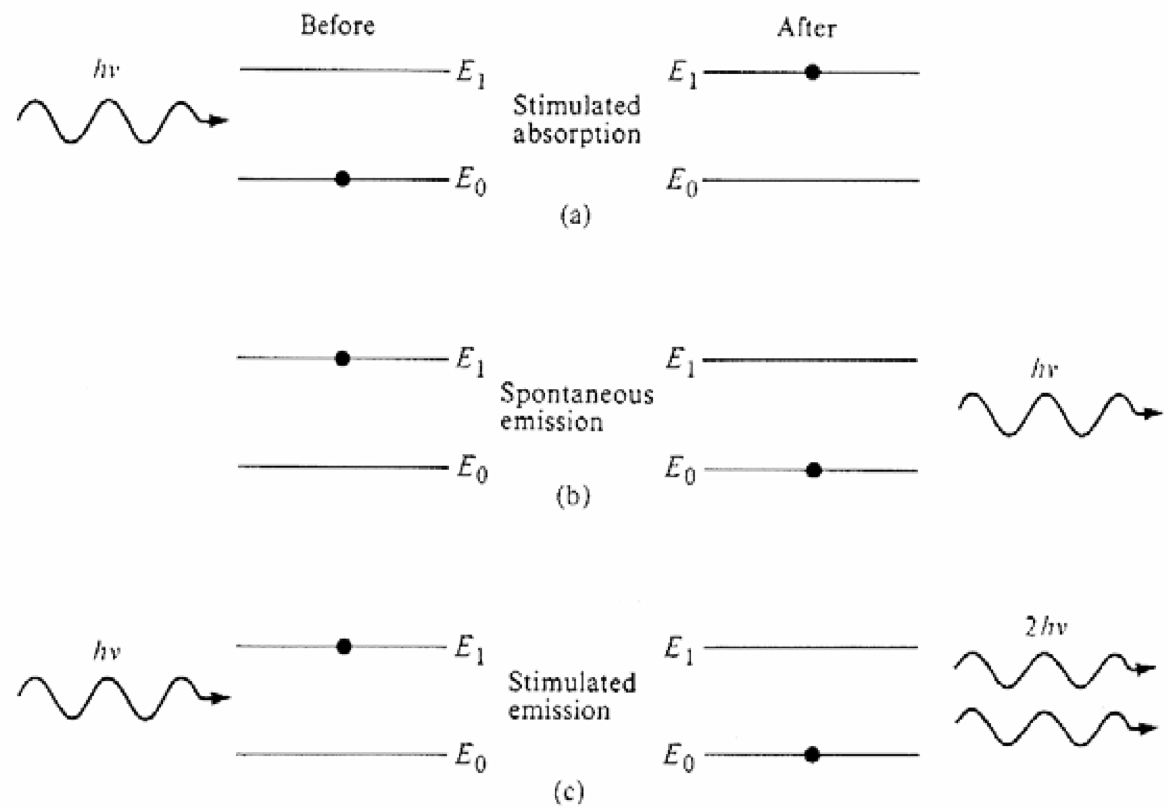


Fig. 3.1 Energy-state-transition diagram differentiating between stimulated absorption, spontaneous emission, and stimulated emission. A black dot indicates the state of the atom before and after the transition takes place. In the stimulated emission process, energy is added to the stimulating wave during the transition; in the absorption process, energy is extracted from the wave.

Main Requirements of the Laser

- Optical Resonator Cavity
- Laser Gain Medium in the Cavity
- Sufficient means of Excitation (called pumping)
  eg. light, current, chemical reaction
- Population Inversion in the Gain Medium due to pumping

Laser Types

- Two main types depending on time operation
- Continuous Wave (CW)
- Power measured in Watts
- Pulsed operation
- Power measured in Jules/pulse
- Repeatition rate important for pulsed systems
- Ranges from ~ sub Hz to ~10 kHz
- Pulsed is easier, CW more useful

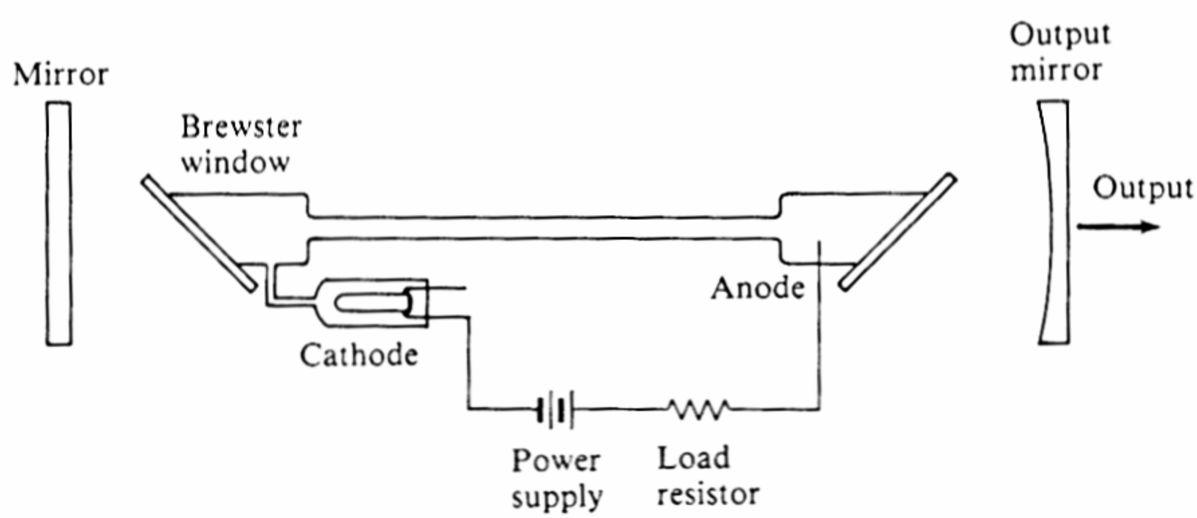


Fig. 2.25 Schematic construction of a low-power gas laser such as the helium–neon laser. The load resistor serves to limit the current once the discharge has been initiated.

Laser Threshold

- With good Gain Medium in optical cavity can get lasing but only if gain medium is excited enough
- Low pumping levels: mostly spontaneous emission
- At some pumping get population inversion in gain medium
- Beyond inversion get **Threshold** pumping for lasing set by the losses in cavity
- Very sensitive to laser cavity condition eg slight misalignment of mirrors threshold rises significantly
- At threshold gain in one pass = losses in cavity

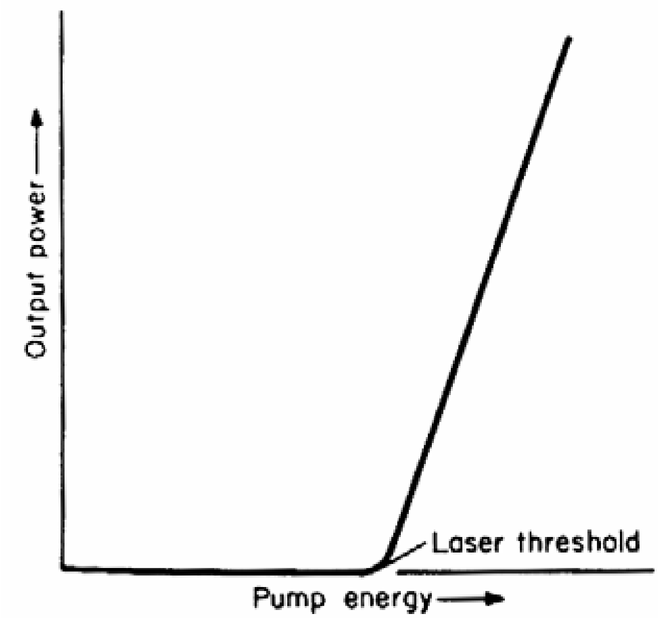


Figure 3.5 Laser threshold phenomenon—a laser does not generate significant optical output until the pump energy passes a threshold. At higher pump energies, the output power increases rapidly. In practice, each laser has limits on output, and eventually the output-input curve bends over.

General Laser Types

- Solid State Laser (solid rods): eg ruby
- Gas laser: eg He-Ne
- Dye Lasers
- Semiconductor Laser: GaAs laser diode
- Chemical Lasers
- Free Electron Lasers

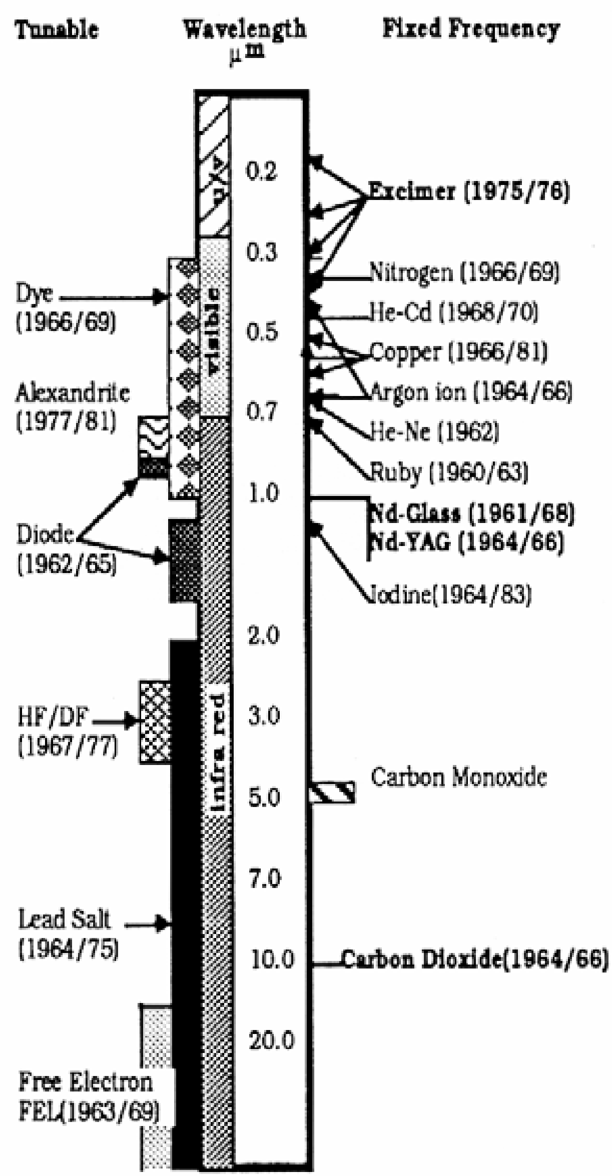


Fig. 2. Range of wavelengths for current commercial lasers. First date is date of discovery, the second is of commercialisation (4).

Gas Lasers

- Gas sealed within a tube with brewster windows
- electric arc in tube causes glowing of gas
- glow indication of pumping
- Commonest type He-Ne

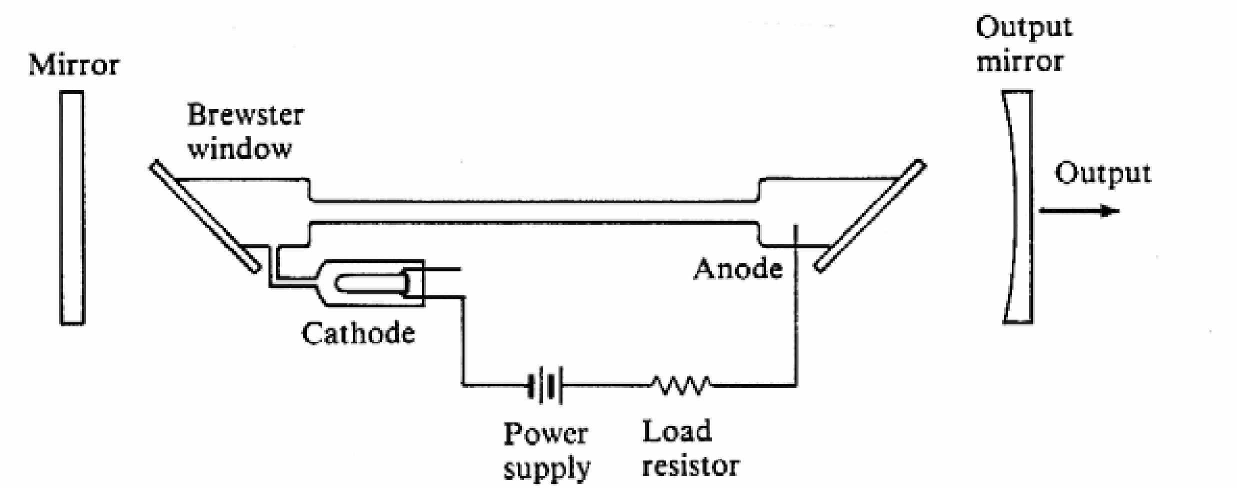


Fig. 2.25 Schematic construction of a low-power gas laser such as the helium–neon laser. The load resistor serves to limit the current once the discharge has been initiated.

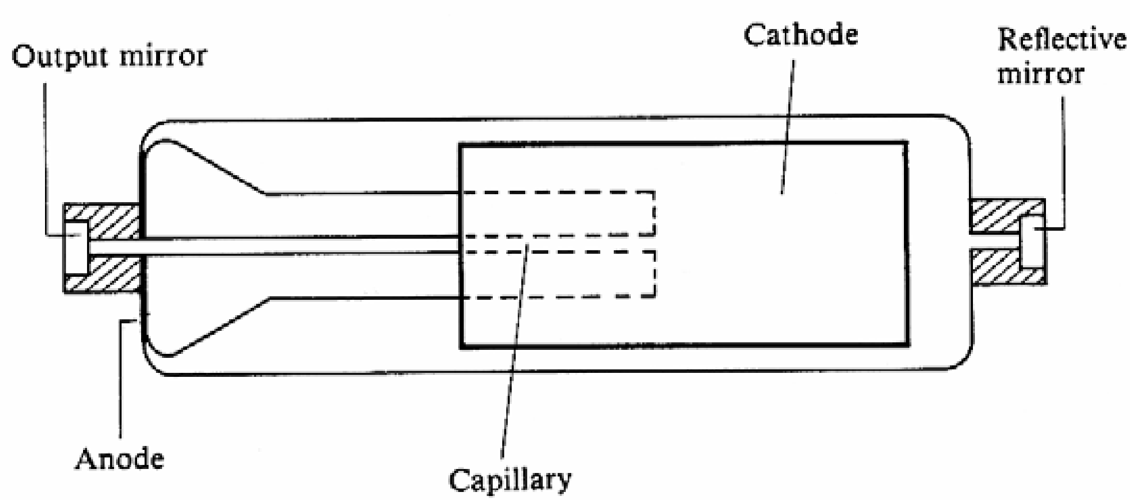


Fig. 2.27 Typical structure of a sealed mirror HeNe laser.

Gas Lasers

- Gas sealed within a tube with brewster windows
- electric arc in tube causes glowing of gas
- glow indication of pumping

Most Common Types

- Atomic (atoms not ionized) eg He-Ne 632 nm (deep Red)
- Power ~1-40 mW
- Nobel Gas Ion Lasers eg. Argon 514/488 nm (Green) to UV
- Power 10mW – 100 W
- Molecular Lasers: CO_2 10.6 micorns (Far IR)
- pulsed 50 nsec >100J/pulse
- Excimer Lasers (UV range XeF 350 nm to F2 (157 nm)

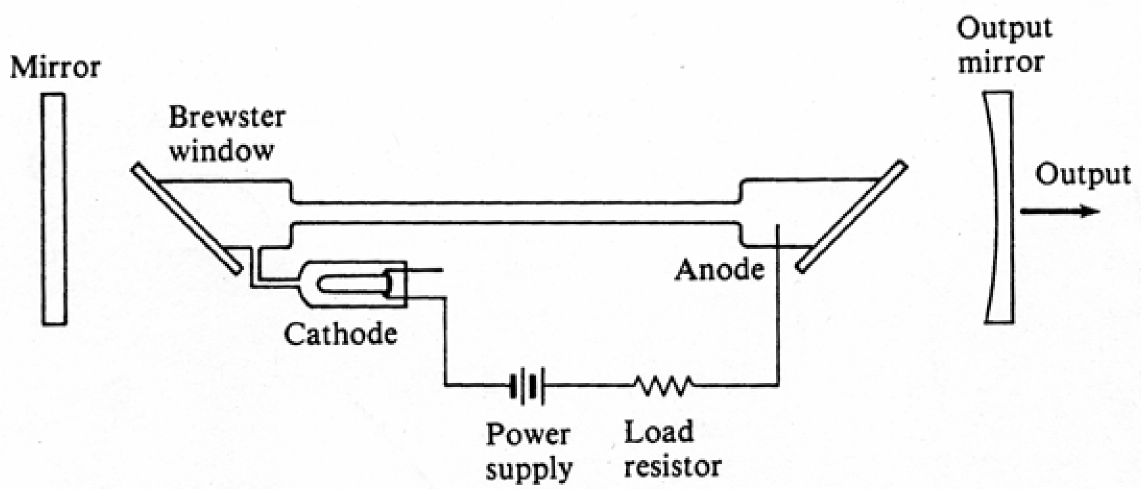
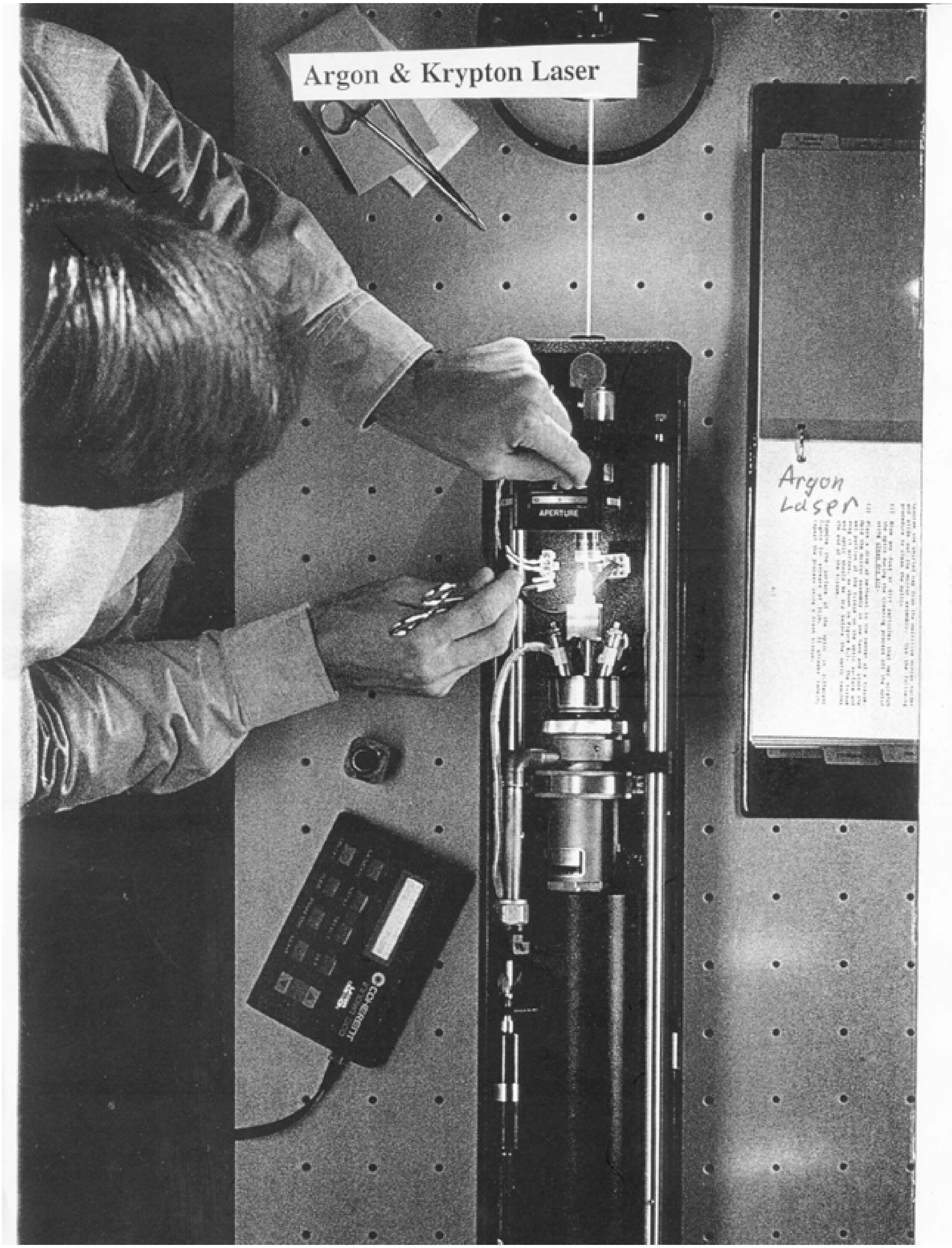


Fig. 2.25 Schematic construction of a low-power gas laser such as the helium–neon laser. The load resistor serves to limit the current once the discharge has been initiated.

Argon & Krypton Laser



Solid State Lasers

- Was first type of laser (Ruby 1960)
- Uses a solid matrix or crystal carrier
- eg Glass or Sapphire
- Doped with transition metal or rear earth ions
- eg Chromium (Cr) or Neodynmium (Nd)
- Mirrors at cavity ends
- Typically pumped with light
- Most common a Flash lamp
- Light adsorbed by doped ion, emitted as laser light
- Mostly operates in pulsed mode

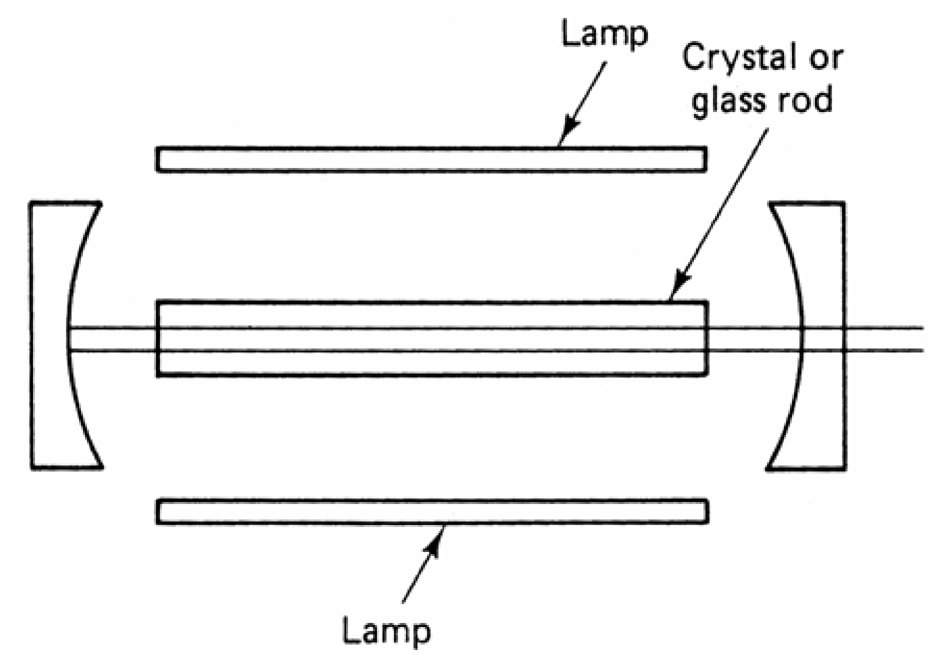


Figure 8–4 Schematic of solid laser—for example, ruby

Most Commn Nd: YAG Lasers

- Dope Neodynmium (Nd) into material most common
- Most common Yttrium Aluminum Garnet - YAG:
  $Y_3Al_5O_{12}$
- Hard brittle but good heat flow for cooling
- Next common is Yttrium Lithium Fluoride: YLF
  $YLiF_4$
- Stores more energy, good thermal characteristics
- Nd in Glass stores less energy but easy to make
- Generally pulsed lasers: pulses from 2 nsec – 10's msec
- Powers from microJ/pulse to > 10^4 J/pulse
- Can be run in CW mode also (less efficient)
- Power from mW to ~10W
- Can change to different wavelengths with non-linear crystals
- Get 2nd Harmonic (533 nm) (green common)
- 3rd Harmonic (544 nm), 4th harmonic (266 nm) and 5th(213 nm)

TABLE 22.1 Optical Characteristics of Major Nd Hosts for 1-µm Line

Material	Wavelength, nm	Cross section, $\times 10^{-20}$ cm	Linewidth, nm	Lifetime, µs
YLF*	1047	37	—	480
	1053	26		
Phosphate glass	1054	4.0–4.2	28	290–330
GSGG	1061	11	—	222
Silicate glass	1061–1062	2.7–2.9	19–22	340
YAG	1064	34	0.45	244

*YLF is a birefringent material with different refractive indexes for light of different linear polarizations; wavelength depends on the polarization.

Semiconductor Lasers

- Semiconductors were pumped by lasers or e-beams
- First diode types developed in 1962:
- Modified form of Light Emitting Diodes
- Must use Direct Bandgap Materials:
  eg III-V or II-VI compounds
- Most common are GaAs, AlAs, InP, InAs combinations
- Si is an indirect bandgap material (except spongy Si)
- Indirect materials must emit an acoustic package
  (phonon) during transition
- Very inefficient
- Direct band: highly efficient

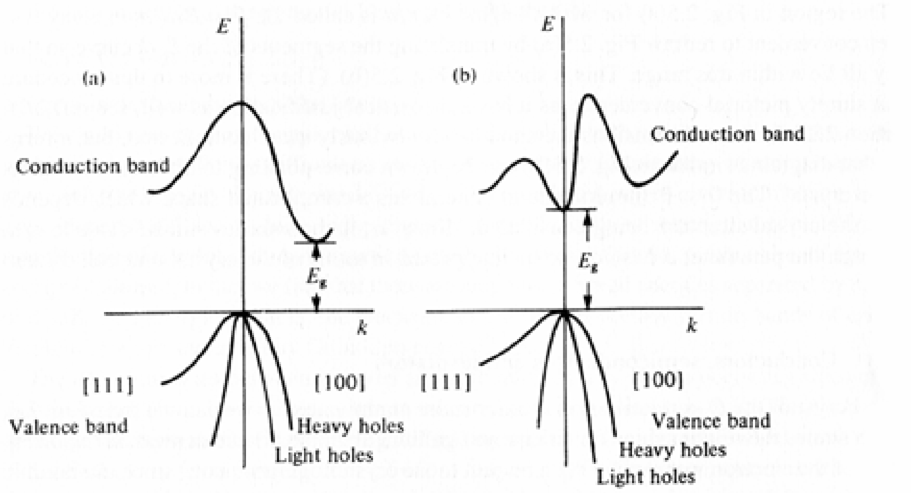


FIG. 2.6 Relationship of E–k for real solids: (a) silicon (which has an indirect bandgap) and (b) gallium arsenide (which has a direct bandgap). The figure shows the conduction and valence bands and the energy gap E_g between them. Note that (i) k is specified in different crystallographic directions to the left and right, and (ii) there are holes present with different effective masses (sections 2.2.1 and 2.3).

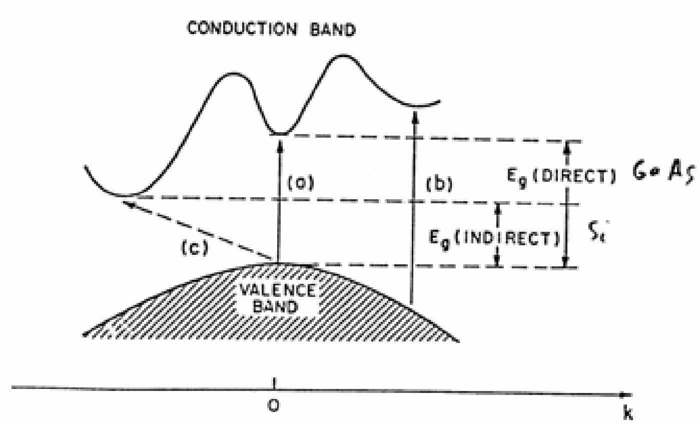


Fig. 26 Optical transitions: (a) and (b) direct transitions; (c) indirect transition involving phonons.

Simple Diode Laser

- Abrupt junction of P doped and N doped regions
- Emission confined to junction area
- Mirrors created by cleaving rods
- Uses crystal planes to create smooth mirrors (change in n mirrors)
- Highly Ellipitical emission: 1x50 microns
- Homojunction where first type of laser diodes
- Homojunction: materials the same on both sides of the Junction
- Hetrojunction better: P and N materials different
- Typical powers 1mW-40 mW
- Typical wavelengths 830 nm (GaAs), 670 nm (Red)
- Many now in Green and into Violet/UV

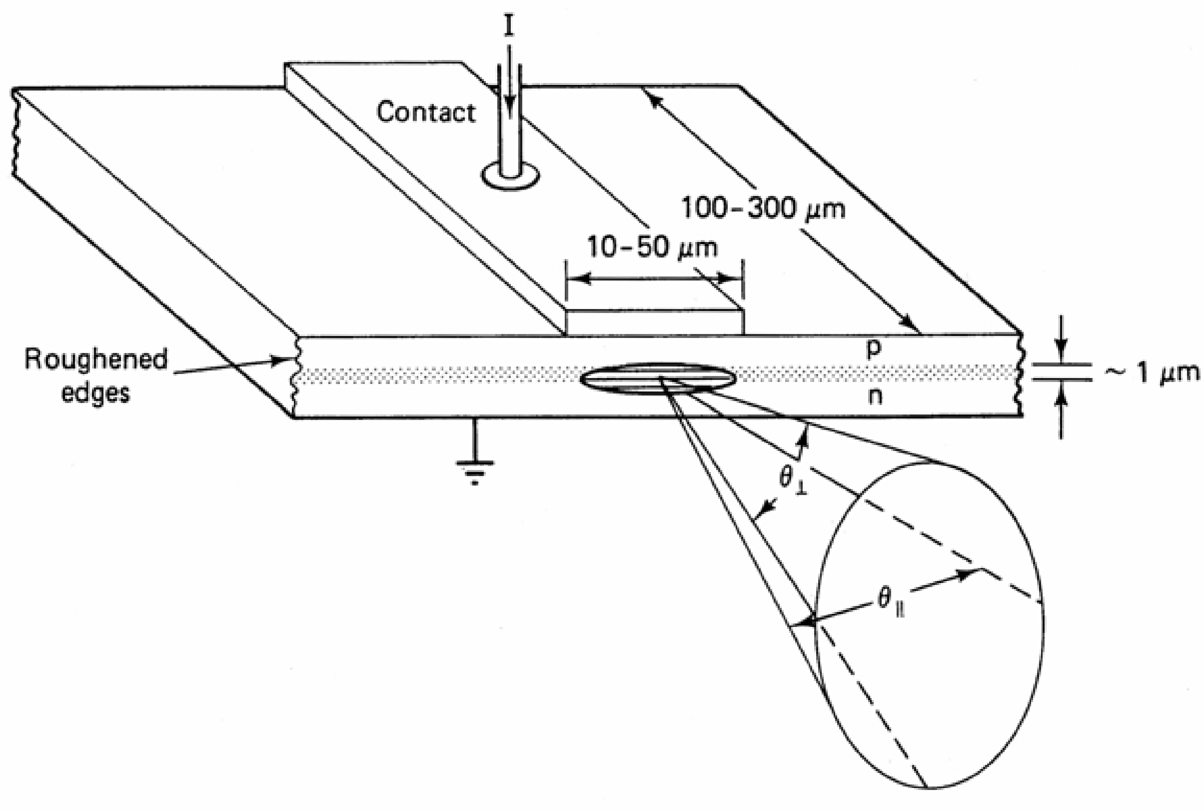


Figure 11.11 The radiation field of a semiconductor laser.

Monolithic Array Lasers

- Single strip lasers limited to 200 mW
- Many Laser strips edge emitters
- Bars with up to 200 strips produced
- 50 W power achieved
- 20: 10 micron wide strips on 200 micron centers

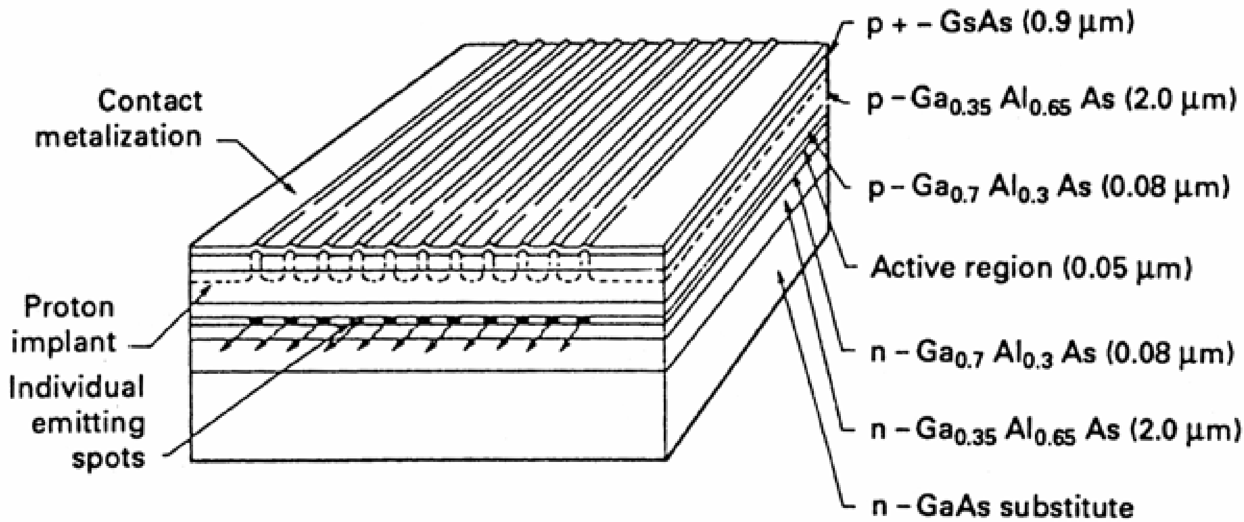


Figure 18.9 Monolithic array of diode laser stripes. (*Courtesy of Spectra Diode Laboratories.*)

Human Eye

- Human eye is a simple single lens system
- Crystalline lens provide focus
- Cornea: outer surface protection
- Iris: control light
- Retina: where image is focused
- Note images are inverted

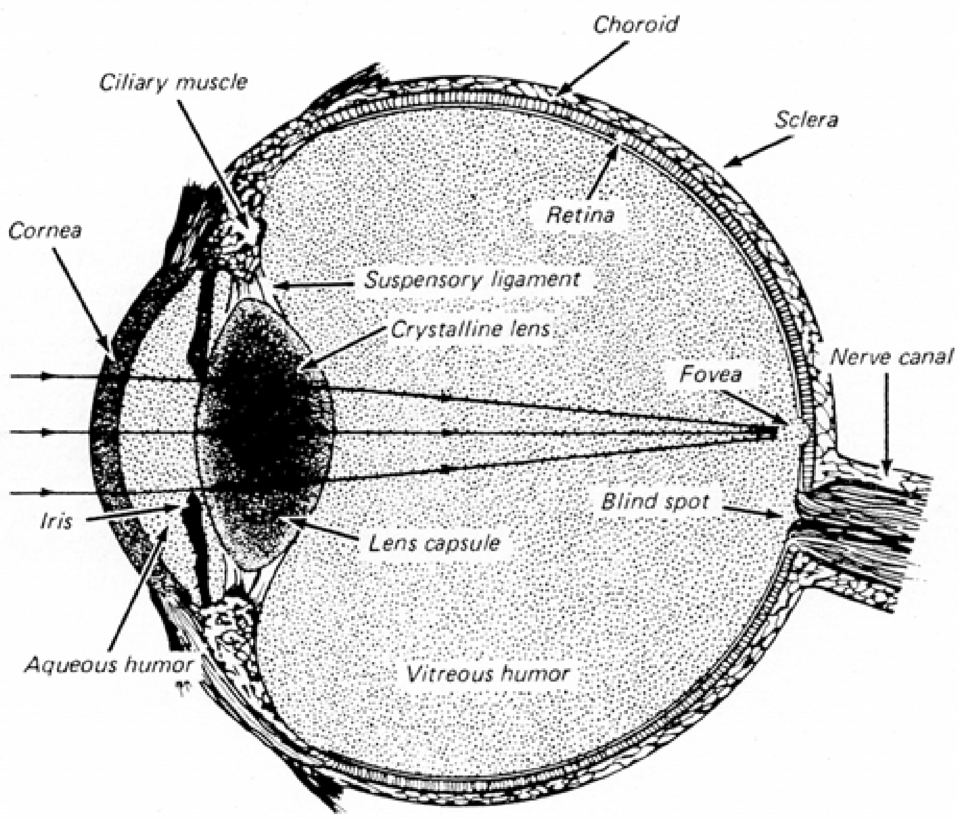


FIGURE 10A
A cross-sectional diagram of a human eye, showing the principal optical components and the retina.