LASER SYSTEMS

CHAPTER ONE

OPERATION OF PRACTICAL LASERS

1.1 The Laser: background

Lasers: devices that generate and amplify light. The light from a laser is different from ordinary light in several ways:

1. It is extremely parallel: the divergence of the beam for a good laser is between 0.2 and 1 mrad.
2. Its wavelength is very well defined: the spread is around$0.01-0.2$nm.
3. The light is made out of one single wave instead of several independent waves.
4. The pulses of light can be made very short, an order of magnitude of femtosecond$\left(10^{-15}\text{s}\right)$.

Laser can produce coherent light by stimulated emission only if a population inversion is present, and a population inversion can be achieved only through external excitation (pumping) of the atomic (molecular) population.

The basic requirements of any laser are similar. A laser system generally consists of three components (Fig. 1.1):

1. An ACTIVE MEDIUM (Gain medium) with a suitable set of energy levels and can amplify light that passes through it.
2. A source of PUMPING ENERGY in order to create a population inversion in the active medium.
3. An OPTICAL CAVITY to introduce optical feedback and so maintain the gain of the system above all losses.

The specific components of a laser vary depending on the gain medium and whether the laser is operated continuously (CW) or pulsed. Some lasers are equiped with some kinds of accessories such as cooling system, optical devices and tuning elements (such as prisms, gratings, spinning mirrors, modulators, filters and absorbers, may be placed within the optical resonator to produce a variety of effects on the laser output,

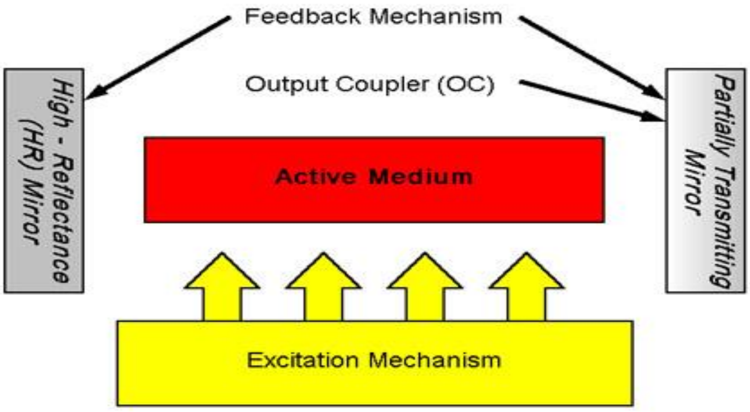

Figure 1.1: Elements of a laser

such as altering the wavelength of operation or the production of pulses of laser light).

One fundamental point is that in order for the light to bounce back and forth in the cavity, it must be in a standing longitudinal wave. Thus a half−integral number of wavelengths of the laser radiation must fit exactly in the cavity ($L=n\lambda/2$). This restriction helps contribute to the monochromaticity property of typical laser light.

Laser will occur in the cavity when the gain due to stimulated emission rises above some threshold value determined by the loss mechanisms active in the cavity (stimulated absorption, scattering from defects in the laser medium, and loss due to transmission).

Lasers have covered radiation at wavelengths ranging from IR range to UV and even soft x−ray range.

1.2 The Active Medium

The material used as the active medium determines:

1. Laser Wavelength.
2. Preferred pumping method.
3. Order of magnitude of the laser output.
4. The efficiency of the laser system.

We saw that the two basic requirements for laser action are:

1. Population Inversion between the upper and lower laser energy levels.
2. The active medium must be transparent to the output wavelength.

There are hundreds if not thousands of different gain media in which laser operation has been achieved. Examples of different gain media include:

- Liquids, such as dye lasers. These are usually organic chemical solvents, such as methanol, ethanol or ethylene glycol, to which are added chemical dyes such as coumarin, rhodamine and fluorescein.
- Gases, such as carbon dioxide, argon, krypton and mixtures such as helium−neon.
- Solids, such as crystals and glasses. The solid host materials are usually doped with an impurity such as chromium, neodymium, erbium or titanium ions. Typical hosts include YAG (yttrium aluminium garnet), YLF (yttrium lithium fluoride), sapphire (aluminium oxide) and various glasses. Examples of solid-state laser media include Nd:YAG, Ti:sapphire, Cr:sapphire (usually known as ruby), Cr:LiSAF (chromium-doped lithium strontium aluminium fluoride),etc.
- Semiconductors, a type of solid, in which the movement of electrons between materials with differing dopant levels can cause laser action.

1.2.1 Lasing thresholds

In any medium there will be losses due to scattering, absorption by impurities, and losses caused by the cavity and tube walls itself. In a practical laser such as HeNe we might extract 1% of the light in the cavity as a beam. That really means a loss of 1%. Obviously we must have enough gain inside the laser medium to allow us to overcome all losses in the laser as well as allow us to extract our output beam and still allow laser action to continue. Given all losses we can calculate a minimum gain which still allows laser action. This is the threshold gain of the laser medium.

We can control the amount of power we extract through the output coupler (the partially reflecting mirror at the front of the laser). It should be evident that there is a limit on how low the reflectivity of the two cavity mirrors can be for a given laser medium. The regular aluminum mirrors have a reflectivity of only about 85%, and many lasers such as the HeNe lack the gain needed to allow such huge losses. This explains why dielectric or dichroic mirrors are used for many lasers. Of course we can't forget about the length of the laser medium. The longer the tube, the higher the amplification and hence higher losses may be tolerated. Short argon lasers (30 cm) absolutely require dielectric cavity mirrors but longer lasers (1 meter or more) lasing with inexpensive aluminum mirrors, especially on the strongest transitions (514 nm and 488 nm).

Some lasers have HUGE gains–so high that light is amplified to a useable level in a single pass down the tube. Such lasers are termed super-radiant and will operate without feedback (i.e. no cavity mirrors). Nitrogen lasers are usually super radiant. Other lasers such as copper–vapor lasers require very little feedback to lase. An uncoated microscope slide, reflects 8% of the incident light, makes a good output coupler for such a laser.

There is also a threshold on the pumping rate that must be reached for lasing action to occur. This is easily seen with diode lasers (Fig.1.2) in which a certain minimum current must be reached before any laser output is seen. After that point any increase in drive current leads to an increase in laser output up to a point where saturation or overheating is occurred.

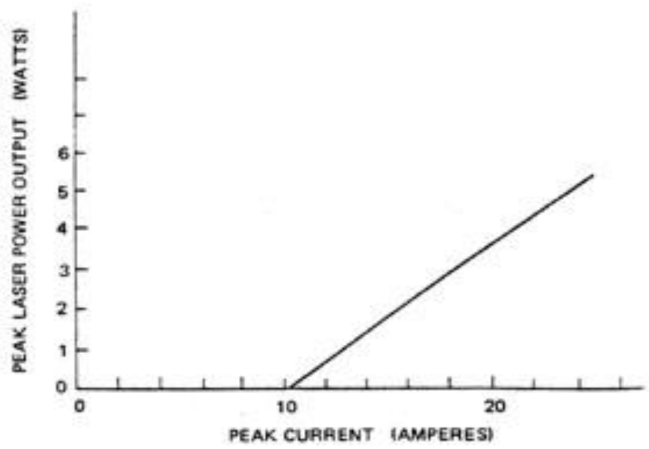

Figure 1.2: Peak power output of laser diode as a function of peak input current.

1.2.2 Types of energy levels in lasers

We take gas lasers as an example. Gas lasers may operate due to energy transitions between excited states in neutral atoms (HeNe), ions (argon), or molecules (CO_2). The transitions are:

i. Electronic transitions, which involve only electrons of the species. Precise and well defined states characterize these transitions are responsible for most visible gas laser transitions. Energy transitions involved in neutral atoms and ion lasers are electronic transitions while these transitions are of lesser importance in molecular lasers.

ii. Vibrational levels, brought on in molecules by various supported modes of vibrations.

iii. Rotational levels, involve the rotation of molecules. Energies for these transitions are low and hence correspond to the far–infrared region (e.g. CO_2 lasers). Unlike vibrational levels, rotational energy levels are not as equally spaced. The energy difference between two adjacent rotational levels becomes larger as higher rotational energy levels are reached as shown in Fig.1.3.b.

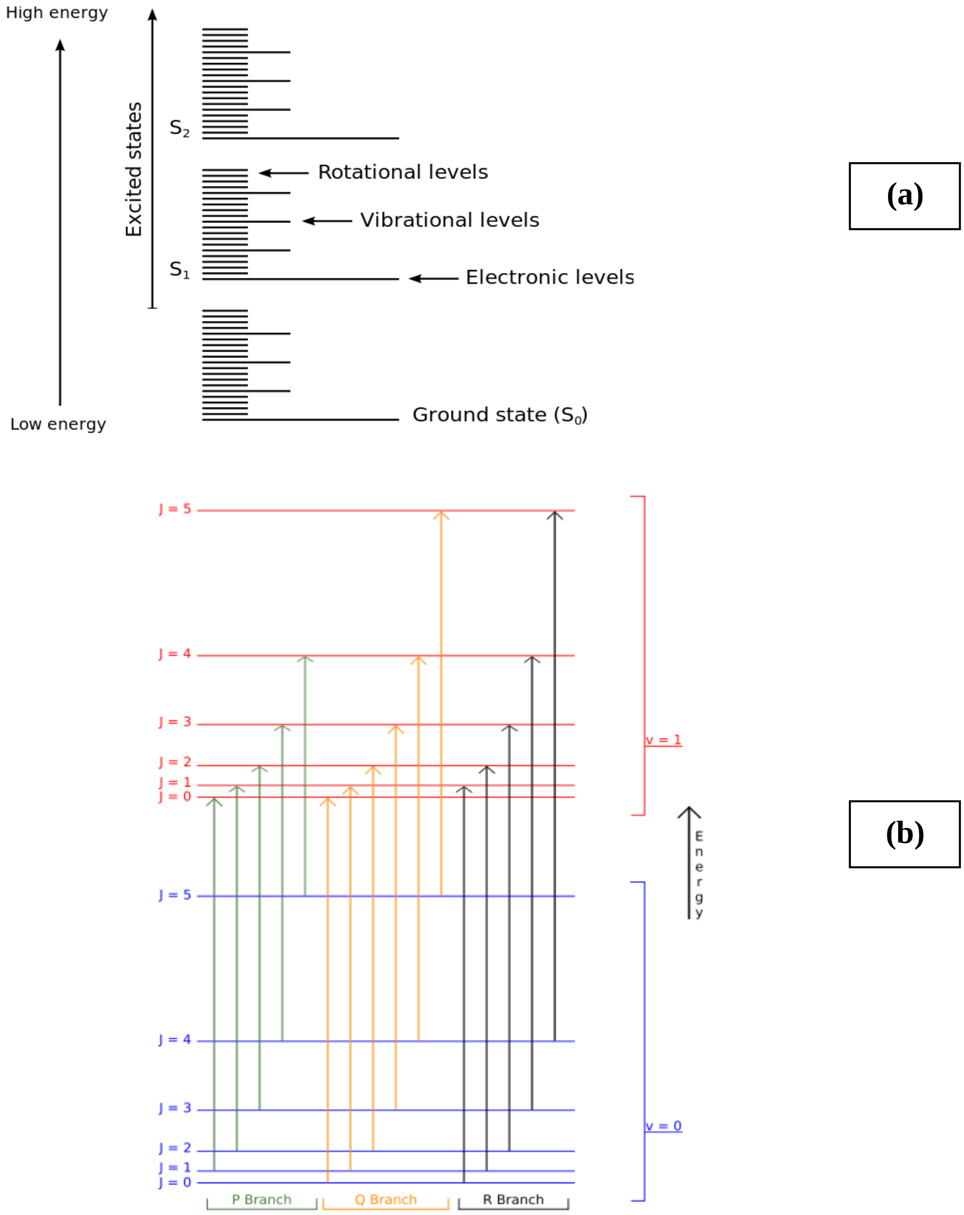

Figure 1.3: Energy Levels Diagram.