LASER SYSTEMS

CHAPTER ONE

OPERATION OF PRACTICAL LASERS

1.1 The Laser: background

Lasers: devices that generate and amplify light, just as transistors: generate and amplify electronic signals at audio, radio or microwave frequencies.

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. If the beam is treated in a beam expander, the divergence can be brought down to 0.01 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 (10^{-15}s).

1.2 The Active Medium

The gain medium is the major determining factor of the wavelength of operation, and other properties, of the laser.

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. The exact chemical configuration of the dye molecules determines the operation wavelength of the dye laser.

- Gases, such as carbon dioxide, argon, krypton and mixtures such as helium−neon. These lasers are often pumped by electrical discharge.
- 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), Er:YLF, Nd:glass, and Er:glass. Solid−state lasers are usually pumped by flashlamps or light from another laser.
- Semiconductors, a type of solid, in which the movement of electrons between materials with differing dopant levels can cause laser action. Semiconductor lasers are typically very small, and can be pumped with a simple electric current, enabling them to be used in consumer devices such as compact disc players. See laser diode.

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.

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.
There is also a threshold on the pumping rate that must be reached for lasing action to occur.

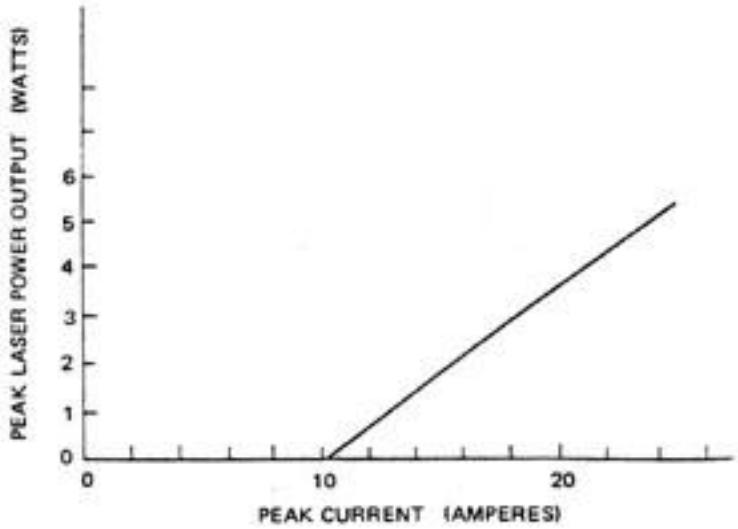


Fig. 2 Peak power output of laser diode as a function of peak input current.

1.2.1 Types of energy levels in lasers

i.Electronic transitions

ii.Vibrational levels

iii.Rotational levels

1.2.2 Level Lifetime

One problem that might be encountered along the way is the lifetime of lasing levels. Some levels have very long lifetimes (metastable).

1.3 The Pump Source

The pump source is the part that provides energy to the laser system. Examples of pump sources include electrical discharges, flashlamps, arc lamps, light from another laser, chemical reactions and even explosive devices. The type of pump source used principally depends on the gain medium, and this also determines how the energy is transmitted to the medium.

1.4 The Optical Cavity

In commercial lasers the rear mirror (totally reflecting) is almost always a dielectric mirror designed to reflect as much light as possible back into the gain medium. Such a mirror may have twenty or more alternating thin dielectric films (such as magnesium fluoride, cerium oxide, or similar dielectric material).

The output coupler must also be selected with respect to the ratio of how much light is reflected to how much is transmitted. High transmission ratios represent a high loss to the laser. Many gas lasers use output couplers with transmissions between 1% and 5% (and bear in mind that this is a lot lower than the loss from even the best aluminum mirrors).

1.6 Modes of Operation

Lasers may operate in continuous mode (Known as continuous wave or CW) or in a pulsed mode.

1.6.1 Continuous wave lasers (CW lasers)

With CW lasers, energy is continuously applied, or pumped into a lasing medium, producing a continuous laser output. Because gain medium is constantly being excited, the power of CW lasers is limited since the gain medium can overheat.

1.6.2 Pulsed lasers

With pulsed lasers, the pump energy is applied in pulses, usually with a flashlamp in the case of solid state lasers, or pulsed radiofrequency energy in the case of gas laser. Laser light is emitted very briefly, 10 ms to 10 fs. Laser pulses can appear as a single pulse or repetitive pulses, and the rate of pulses can be as high as thousands of millions per second.

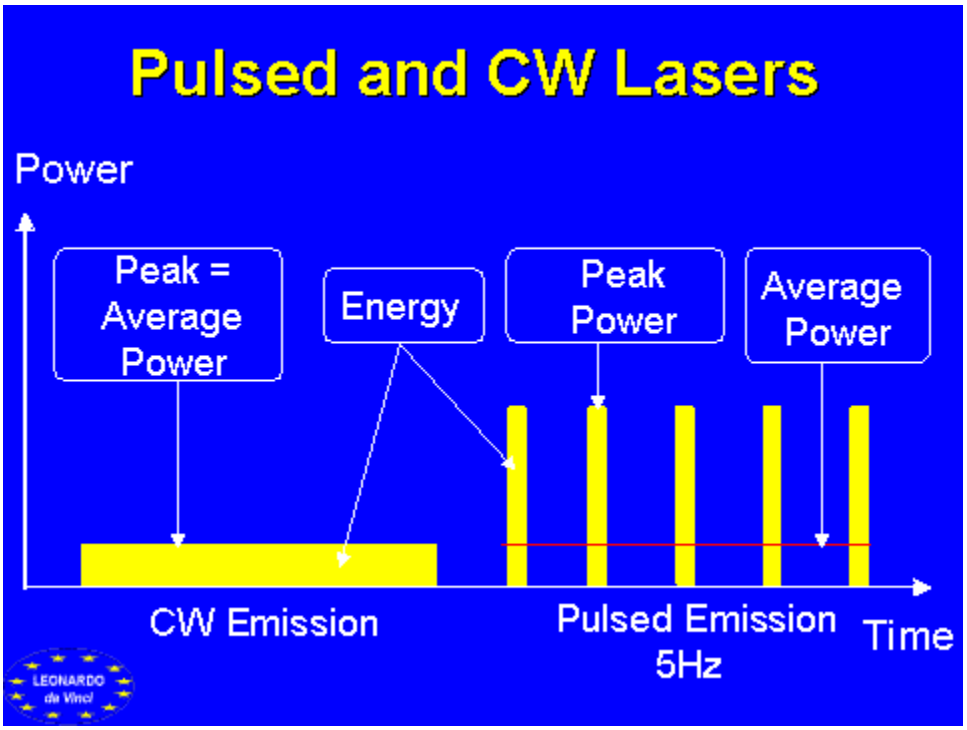
1.7 Output Parameters

1.7.1 Laser power and laser energy

The power (p) is expressed in Watts (W), and the energy (Q) in Jouls (J). These parameters are related by the expression: $Q=p\times t$, where t is the time in seconds.

The output of CW lasers, like that of a light bulb or electric heater, is measured as power in Watts, referring to the rate at which work is performed, or the energy applied per unit time. Because of the spiking output of pulsed lasers, the

precise output power of a given laser pulse may be difficult to determine although the energy and pulse duration usually remain constant. For this reason, the output of pulsed lasers is more conveniently expressed as energy in joules.



- Average power (P_{av}): is defined as the power of a continuous laser that would transmit the same amount of energy per second as the pulsed laser (this definition because output power of pulsed laser is not continuous), i.e., it is a measure of the rate at which the energy is emitted from the laser during one complete period

$$\mathbf{P_{av} = E_p.f = E_p/T}$$

Average power (P_{av}) describes the amount of energy transmitted by the laser beam in a second.

- Peak power (P_{max}), is the maximum emitted power and may be approximated by dividing the energy of the output pulse by pulse duration

$$\mathbf{P_{max} = E_p/\Delta t_{1/2}}$$

Hence, the definition of the duty cycle becomes:

$$\mathbf{D.C= \frac{\Delta t_{1/2}}{T} = \frac{E_p/p_{max}}{E_p/P_{av}} = \frac{P_{av}}{P_{max}}}$$

- Energy of a single pulse $\mathbf{(E)= \Delta t_{1/2} \times P_{max}}$

1.7.2 Laser efficiency

The overall efficiency of a laser is a measure of how much input (electrical, optical, …) energy it requires to produce its laser output.

$$\mathbf{Laser\ efficiency= \frac{Output\ power}{Input\ power} \times 100\%}$$

$$\eta = \frac{\mathbf{P_{out}}}{\mathbf{P_{in}}} \times \mathbf{100\%}$$

1.7.3 Operating wavelength

Lasers must be able to operate on wavelengths appropriate to the system being designed. The operating wavelength of a laser depends on the materials used for lasing and on the geometry of the laser cavity. Lasers have covered radiation at wavelength ranging from IR range to UV and even soft x−ray range.

1.8 Classification of lasers

The laser world is really rich and interesting that laser research has produced a variety of improved and specialized laser types, optimized for different performance goals, including:

- New wavelength bands.
- Maximum average output power.
- Maximum peak output power.

Lasers can be divided into groups according to different criteria:

1. The state of matters of the active medium: solid, liquid, gas, or plasma.
2. The spectral range of the laser wavelength: visible, infrared (IR), ultraviolet (UV), x−ray spectrum.
3. The characteristics of the radiation emitted from the laser (i.e., by operating mode: continuous wave (CW) or pulsed).
4. The excitation (pumping) method of the active medium: Optical pumping, electrical pumping, etc.
5. The number of energy levels which participate in the lasing process.