10.3.1.6 Lasers

In this section the *laser* will be considered as a *thermal source* and not as a primary source of highly monochromatic *coherent radiation*.

Radiation from a *laser source* is emitted with a very small *angle of divergence*. Its *radiant intensity*, i.e., its *radiant power per solid angle* can be very high. By focusing laser radiation with a *focusing lens* or a *focusing mirror* of *focal length* f on to a *target*, i.e., the surface of a sample, a high irradiance in a small *focal spot* is obtained. This is sufficient to cause vaporization and atomization of materials, irrespective of their physical properties. The vapour cloud that is produced may contain enough neutral atoms in the ground state for atomic absorption analysis. If the laser-produced vapour cloud is sufficiently hot to radiate in the optical spectral region, it can be used directly as an excitation source for optical emission spectroscopy. Additional forms of excitation may be used to increase the spectral radiance of the vapour or to improve the analytical line-to-background intensity ratios.

10.3.1.6.1 Characterization of lasers

Basically, a laser consists of an *active medium* in which, by *optical pumping* or *electrical excitation* (whichever is applicable), *population inversion* of energy levels and hence *stimulated emission* of radiation may be obtained. *Laser action* may either be continuous, i.e., *continuous wave* (cw-operated) or discontinuous in the form of a *laser pulse* or sequence of laser pulses.

In order to obtain sufficient optical amplification to cause oscillation in the direction of its axis, the active medium is placed in the *laser resonator*. This is essentially an interferometer consisting of the two *laser mirrors* (or similar optical devices) of high *reflectivity* and low loss (absorption). Of the various *mirror configurations*, the *parallel-parallel* is most generally used. A *semi-transparent mirror* permits the laser radiation to leave the resonator in the form of a *laser beam*.

Sources which lase continuously may be characterized by the *pumping* or *excitation energy* (or current strength), the *laser output power*, the wavelength and the angle of divergence.

Pulsed laser sources may, in addition, be characterized by the duration of the *pumping period* and the *laser output energy*. The individual pulses are characterized by the *pulse power*, the *pulse energy* and the *pulse duration*. The laser resonator can also be considered as a resonant cavity with, theoretically, an infinite number of possible *eigen-frequencies*, which are commonly described by their *modes*, i.e., *transversal* as well as *longitudinal*. By suppression of transversal modes with a *mode selector*, the laser beam angle of divergence can be decreased. Longitudinal mode selection is not effective in this kind of application.

10.3.1.6.2 Solid state lasers

The active medium is usually a rod 5 to 15 cm in length and 5 to 15 mm in diameter, consisting of a *host material* which is doped with a *laser-active substance*. Examples are *Nd-glass*, i.e., glass doped with neodymium; *Nd: YAG*, i.e., yttrium aluminium garnet doped with neodymium, or ruby, i.e., aluminium oxide doped with chromium. The active medium is placed in the *pumping cavity* where it is illuminated by the *pumping lamp*. The wavelength of the emitted radiation is either in the visible or near infrared spectral region.

10.3.1.6.3 Continuous wave operation (CW-Operation)

Continuous wave operation is only feasible if the *pump power* required to exceed the *lasing threshold* is low. This may be accomplished by optically pumping a Nd: YAG rod by means of a *tungsten-halogen lamp*. Power output is usually of the order of a few watts.

10.3.1.6.4 Free-running operation

Under *free-running operation*, the laser output is characterized by the emission of a large number of irregular and incoherent radiation pulses called *laser spikes* of short duration, i.e., lasting less than a microsecond. Typical *spike power* is of the order of some kilowatts, and the total duration of the laser action is of the order of some tenths of a millisecond.

10.3.1.6.5 Q-switched Operation

A shutter called a *Q-switch* is inserted in the laser resonator to obstruct or impede the path of light during part of the pumping period. It may allow more energy to be stored in the active medium by population inversion. When the shutter opens sufficiently fast, the Q of the resonator and hence the *internal oscillation amplitude* rises rapidly, resulting in the emission of a short *single pulse*, also called *giant pulse*, of high power (typically of the order of several MW). Shutters, which do not open fast enough, may cause the emission of several spikes of *medium power* (100 kW). This action is called *semi-Q-switched*. *Q-switched operation* may be initiated several times during a pumping period. Many types of Q-switches are used, e.g., *saturable dye-switch* consisting of a *bleachable substance* which may be transparent or opaque to the laser radiation, depending on the degree of irradiance, *electro-optical shutters*, which make use of the *quadratic electro-optical effect* (*Kerr cell*) or of the *linear electro-optical effect* (*Pockels cell*), mechanical shutters such as a *rotating disc*, a *rotating mirror*, a *rotating prism* or *magneto-optical shutters* which temporarily cause diffraction or refraction in the laser resonator. The latter type of Q-switch is capable of producing an equidistant series of spikes of medium power.

10.3.1.6.6 Other lasers

Liquid lasers having suitable host solutions doped with neodymium or dyes as the active medium, can give performance similar to solid state lasers. With *dye lasers*, a wide variety of wavelengths is available.

Electrically excited (i.e., low pressure electrical discharge) *gas lasers* can be operated in the various modes described previously. With some, a very high *laser output* can be obtained, e.g., the CO_2 laser at a wavelength of 10.6 μm.

10.3.1.6.7 Vaporization and atomization

A *crater* is formed that is characterized by the *crater diameter*, the *crater depth* and the *crater shape*. The crater diameter should not be confused with the focal spot diameter, which may be larger or smaller than the crater diameter, depending mainly on the energy of laser output. The diameter of the focal spot also influences the crater diameter. The theoretical *ultimate focal spot diameter* is diffraction limited and because of imperfections of the active medium, usually cannot be achieved.

The vaporized material leaves the target in a vapour stream or jet forming the *laser plume,* which may consist partly of free atoms. To prevent unwanted chemical reactions (e.g., oxidation) of the plume with the surrounding air, a sample chamber filled or flushed with a suitable inert gas is often used.