6. Lasers

The LASER light source, whose name is based on “Light Amplification by Stimulated Emission of Radiation”, is the most important device in almost all photonic applications. First built in 1960 [6.1–6.5] it allows the generation of light with properties not available from natural light sources. Modern commercially available laser systems allow output powers of up to $10^{20}$ W for short times with good beam quality and of several kW in continuous operation, usually with less good beam quality. Very short pulses with durations smaller than $5 \cdot 10^{-15}$ s, wavelengths from a few nm in the XUV to the far IR with several 10 µm, pulse energies of up to $10^4$ J and frequency stability’s and resolutions of better $10^{-13}$ can be generated. The laser prices range from $1$ to many millions of dollars and their size from less than a cubic mm to the dimensions of large buildings.

The good coherence and beam quality of laser light in combination with high powers and short pulses are the basis for many nonlinear interactions, but the laser is a highly nonlinear optical device itself, using nonlinear properties of materials as described in the previous chapters. Therefore, the fundamental laws treated in Chap. 2 for the description of light as well as the description of linear and nonlinear interactions of light with matter in Chaps. 3, 4 and 5 are the basis for the analysis of laser operation and its light properties.

Therefore, the theoretical description of laser devices represents an application of these laws and can be presented in this chapter in a compact form. For details the related sections of the previous chapters should be consulted. The different lasers and their constructions, as well as the resulting relevant light and operation parameters, are described and the consequences for photonic applications are discussed. Finally, possible classifications are given and safety aspects are mentioned. For further reading see [M6, M16, M17, M23–M25, M27, M28, M30, M33, M43, M44, M49, M50, M58–M65].

6.1 Principle

Lasers are based on the stimulated emission of light in an active material which has been pre-excited by a pump mechanism. The stimulated emission can be carried out in laser oscillators which are always the primary source of laser light. In addition this light can be amplified via stimulated emission
Lasers pump energy laser oscillator coherent light laser amplifier 1 pump energy laser amplifier 2

**Fig. 6.1.** Laser setup consisting of a laser oscillator (master oscillator) and two amplifiers (MOPA scheme)

In light amplifiers as shown in Fig. 6.1 where a master oscillator is combined with, e.g., two amplifiers in a MOPA (Master Oscillator Power Amplifier) setup. In combination with these amplifier and/or other nonlinear converter systems the light can be modified regarding almost all parameters such as, e.g., for shorter or longer pulses, different wavelengths, polarization or geometry.

In any case the coherent laser light has to be originally generated in a laser oscillator. This laser oscillator as nothing else but a special light source consists of *three basic parts* as shown in Fig. 6.2.

![Fig. 6.2. The three basic parts of a laser oscillator: pump source ①, active material ② and resonator ③](image)

The fundamental function of these three components is described in Table 6.1 (p. 361).

The laser operates in the following way:

- The pump mechanism provides enough energy in the active material and produces an *inversion* of the population density resulting in the higher