Technical Note – No. 1

Principles of Diode Lasers

Diode lasers are compact, efficient, reliable, low cost sources of coherent light for almost any desired kind of application. Additional to well established applications like optical data storage or telecommunications, diode lasers have arisen to a well suited tool for spectroscopy and metrology.

The following section gives a short summary of fundamental characteristics of diode lasers and antireflection coated diode lasers.

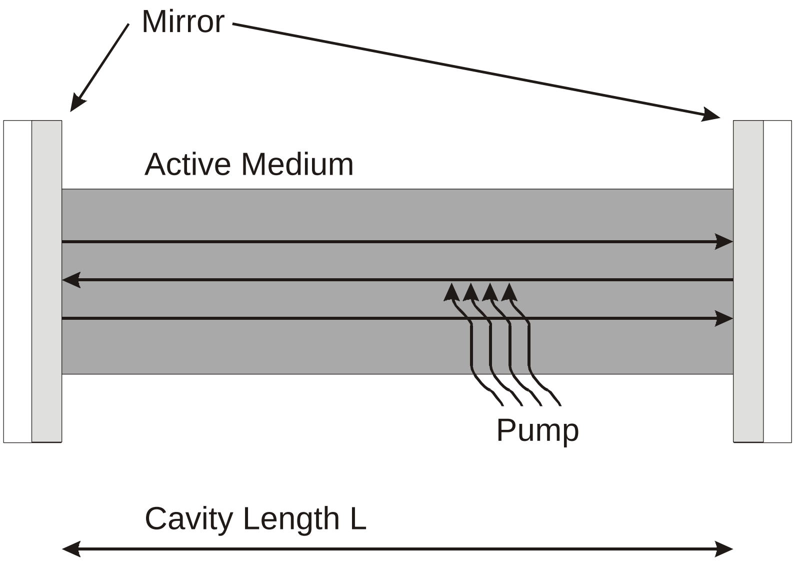

Figure 1: Basic elements of a laser

Laser Condition

A laser (laser: **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation) consists of a light amplifying medium (active medium) where significant amount of stimulated emission occurs and of a resonator cavity. These requirements are depicted schematically in Figure 1.

Lasing occurs, when stimulated emission, e.g. between an excited state and a ground state of an atomic system overcomes the stimulated absorption and other loss mechanisms within the cavity. In consequence, the population of the excited state has to be higher than that of the ground state. This condition is realized only when the system is operated in a non - equilibrium state called *inversion*. In order to maintain this inversion, energy has to be supplied to the system. This process is called *pumping*. Pumping can be achieved by injecting light of sufficient energy (optical pumping) or, in the case of a diode laser, simply by injecting charge carriers into the p-n junction of a semiconductor diode.

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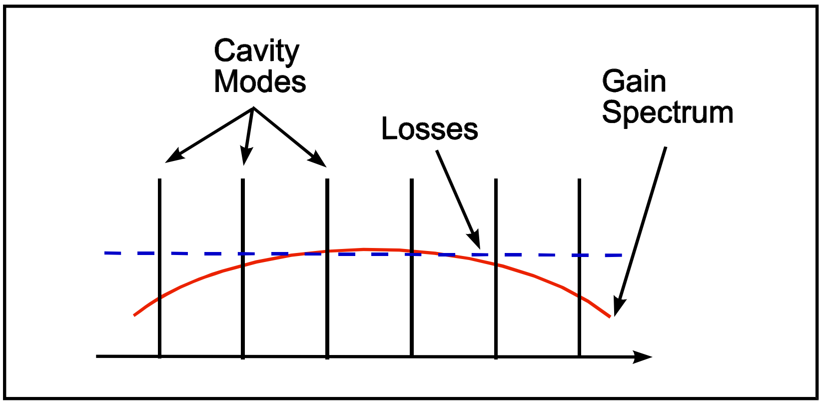

Figure 2: Schematic view of the mode spectrum of the laser cavity and of the gain spectrum of the active medium.

The second condition to obtain a laser is optical feedback. Accordingly, the active medium has to be placed within an optical resonator cavity. The simplest resonator is a pair of high-reflecting parallel mirrors. This configuration is referred to as *Fabry - Perot cavity*. Such cavities support particular optical wavelengths which fit into the cavity as standing light waves. These standing light waves are called *resonator modes*. As soon as the amplification compensates all loss mechanisms (e.g. re-absorption, mirror losses), the mode which receives the highest value of amplification by the active medium starts to oscillate. This is shown schematically in Figure 2 where the mode spectrum of the cavity and the gain spectrum of the active medium are depicted.

Lasing starts above a characteristic level of the pumping called *laser threshold*. At low pumping rates no lasing occurs, the laser is operated below threshold and emits weak, incoherent and spectrally broad luminescence. Above threshold, intense, coherent and spectrally sharp emission is observed. The spectral purity of the laser emission, i.e. the laser linewidth, is a very important characteristic of the laser, in particular for applications in spectroscopy.

Microscopic structure of Diode Lasers

Semiconductor diode lasers are extremely small and highly efficient solid state lasers. In contrast to gas laser systems where optical transitions take place between discrete energy levels, in a semiconductor the optical transitions appear between continuous energy bands. The band corresponding to the ground state is called valence band while the band corresponding to the excited state is called conduction band. Valence band and conduction band are energetically separated by a regime called band-gap. The band-gap energy determines the spectral regime of the laser emission.

The most simple diode laser is a small GaAs semiconductor chip of some hundred micron length, which contains a p-n-junction. When it is biased in forward direction the injected electrons and holes create a laser - active region in the surrounding of the p-n junction. In a p-n-junction, the size of this active region is determined by diffusion. These so-called homojunction laser diodes are quite inefficient. Modern devices are realized as heterostructure laser diodes. They consist of semiconductor materials with slightly different band-gap energies. The active region is un-doped and sandwiched between p-doped and n-

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doped regions of another semiconductor with a slightly larger band-gap energy. This design leads to an efficient confinement of the charge carriers in the active region and, in addition to a confinement of the optical field to the active region. Typical dimensions of the active region are length of 300 µm, a thickness of about 1µm and a width of about 3 µm. Due to this small size of the active region diffraction leads to a considerable divergence of the emitted light. Additionally, due to the different dimensions of the active region in the lateral and vertical direction the light output is astigmatic. This astigmatism has to be corrected by using appropriate optics.

Light Intensity -- Injection Current -- Characteristic

Semiconductor diode lasers are electrically pumped by the injection current. It can be operated with a small battery and emits coherent light of a few tens of mW optical power. High power devices are available up to several tenth or hundred watts.

At small injection currents, the device emits incoherent light, comparable to a LED. The emitted spectrum is very broad and determined by the gain spectrum of the laser material. Above a certain injection current which is called 'threshold current', the diode laser starts to emit coherent light. In this operation regime, the emitted light intensity is almost proportional to the difference between applied current and injection current. Regarding a single mode diode laser, the linewidth is in the order of some tenth of MHz up to some hundred MHz.

Tuning of the emission wavelength

The emission wavelength of a semiconductor diode laser can be tuned by changing the temperature of the laser chip. Figure 3 is an example for the temperature tuning behavior. Due to the temperature change, the maximum of the gain (broken line) shifts towards lower energies, which relates to higher wavelength. The modes of the optical resonator cavity also shift to lower energies and higher wavelength. The mode closest to the gain maximum will attend to lase. However, there are wavelength regimes between the cavity modes, which are not available by this tuning method. This may cause problems in the application of diode lasers for spectroscopy.

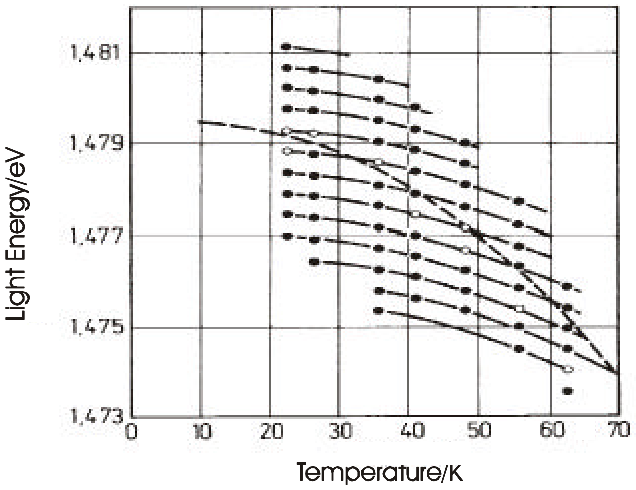

Figure 3: Dependence of the gain maximum (broken line) and the cavity modes of the case temperature.

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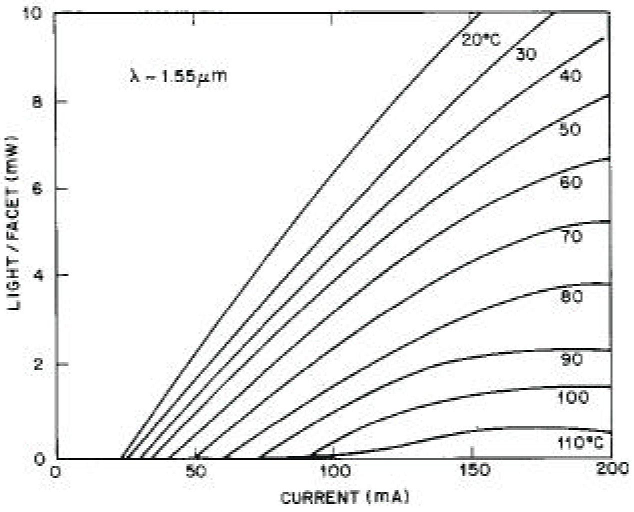

Figure 4: Light versus current characteristics of a 1.55µm laser diode for different temperatures.

Another drawback of the temperature tuning is the influence on the Light Intensity -- Injection Current -- Characteristic. This is illustrated by Figure 4 where characteristics are plotted for different temperatures for a laser diode emitting at 1.55 µm. It is obvious that the performance of diode lasers is strongly temperature dependent. For increasing temperature, the threshold current increases and the emitted light power decreases.

To obtain a well behaved wavelength tunability of the emission wavelength and narrow linewidth, external cavity geometries are more favorable. However, in order to achieve the best coupling to the external cavity and to avoid chaotic behavior, the laser diode mirror facing the external cavity should to be antireflection coated. If only narrow linewidth is required, a simple high reflecting mirror is sufficient. If wavelength control is required, diffraction gratings are employed as external cavity mirror. In this case, rotation of the grating allows spectral tuning of the emission wavelength of the diode laser. Narrow linewidth emission can be obtained for any spectral position within the gain spectrum of the diode laser.

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