Chapter 6

INSTABILITIES AND BISTABILITY IN LASER DIODES

Even though most state-of-the-art laser diodes exhibit pretty stable light versus current characteristics, it is interesting to note which causes may be responsible if instabilities are observed.

Instabilities often appear in terms of repetitive self-pulsations. These self-pulsations are often related to nonlinearities in the light-output versus current characteristics above threshold, the so-called 'kinks'. With increasing operation time of the laser diodes the tendency towards instabilities increases. Since these instabilities are detrimental for laser operation a lot of material has been published devoted to obtaining a better physical understanding of such phenomena [1—12].

In order to explain the self-pulsations one usually assumes some kind of a Q-switching process, where the term Q-switching denotes a switching of the quality-factor of the laser cavity. If, due to some reason to be discussed later, an increase of optical power yields a decrease of optical loss (or an increase of optical gain) within the laser, the roundtrip gain $G$ may become larger than unity, yielding an exponential increase of optical power, corresponding to the rising edge of a developing pulse. On the other hand an increased power yields an increasing consumption of carriers so that finally the carrier density is too low to maintain a unity roundtrip gain and therefore the optical power collapses. A recovery time is required in order to increase the carrier density again until the next pulse develops. The repetition frequency for these pulses is of the same order as the relaxation resonance frequency and it varies between several hundred megahertz and several gigahertz.

In the preceding chapters we assumed a gain compression (compare eq. (3.44)) rather than a gain enhancement with increasing optical power. Such a gain enhancement is indeed possible, however, for example:

(a) An increased optical power yields a change of the lateral carrier distribution and thus of the lateral refractive index distribution. One
thus obtains a change in the lateral waveguiding which may eventually yield an increased modal gain with increasing optical power. In addition, an emission in multi-transverse modes may be observed, which are guided in so-called ‘filaments’.

(b) A laser diode which is inhomogeneous in an axial direction may consist of amplifying and absorbing sections. An increased optical power yields a decreased carrier density in the amplifying sections and an increased carrier number (due to photoinduced carrier generation) in the absorbing sections. Therefore an increased power simultaneously yields a gain reduction in the amplifying sections and a loss reduction in the absorbing sections. If the loss reduction overcompensates for the gain reduction, the net gain increases with increasing optical power.

The concept (b) has also intentionally been used for generating pulse trains with short pulses or for obtaining bistable laser devices by using laser diodes with segmented contacts [13—20]. In the following sections the above phenomena (a) and (b) are considered more in detail.

6.1 Repetitive Self-Pulsations Due to Lateral Instabilities

Lateral instabilities may occur in laser diodes with stripe widths \( w \geq 5 \mu \text{m} \). In such laser diodes the lateral waveguiding is strongly affected by the lateral carrier distribution. Fig. 6.1 schematically shows the lateral carrier distribution under lasing conditions. Due to stimulated emission most carriers recombine at the lateral position of maximum optical intensity, yielding there a spatial hole in the carrier distribution. This reduction

![Fig. 6.1. Carrier distribution with spatial hole burning yielding a self-focusing waveguide.](image-url)