

# **V60 - Diodenlaser**

Michael Gutnikov  
michael.gutnikov@udo.edu  
Lasse Sternemann  
lasse.sternemann@udo.edu

Durchgeführt am 24.01.2022

# Inhaltsverzeichnis

<b>1</b>	<b>Theoretical Foundations</b>	<b>3</b>
1.1	Aim . . . . .	3
1.2	Working principle of general Lasers . . . . .	3
1.3	Diode Lasers . . . . .	4
1.3.1	Working Principle . . . . .	4
1.3.2	Gain Curves . . . . .	7
1.4	Rubidium . . . . .	8

# 1 Theoretical Foundations

## 1.1 Aim

Within this experiment the working principle of a diode laser should be studied. In order to also get practical experience a diode laser is to be tuned to a wavelength of roughly 780 nm to observe absorption of the laser light within a  $^{85}\text{Rb}$ -,  $^{87}\text{Rb}$ -vapor by doing a frequency scan.

## 1.2 Working principle of general Lasers

The acronym Laser stands for *light amplification by stimulated emission of radiation* and describes a light source, that emits light of a fixed wavelength, which stays coherent over a long distances and is particularly suited for experiments due to its tunability. To achieve these properties a certain optical transition is stimulated and multiplied within an active medium.

To start off an external **pump** excites electrons within an **active medium** from a lower energy state to a higher unoccupied energy state, from which these electrons will relax and the spontaneous emission of a photon will take place. During spontaneous emission photons are emitted isotropically into all directions but with the same energy, which corresponds to the energy difference between the higher and lower energy state  $\Delta E = E_3 - E_2 = \frac{hc}{\lambda}$ . The active medium is located in a **resonator**, which reflects the photons travelling along a certain axis and makes them pass through the active medium multiple times. While doing this they can interact with the active medium in two more ways pictured in figure 1. They can be absorbed and excite an electron to a higher energy state or induce the stimulated emission of a second coherent photon in connection to an electron relaxing in the same way, as the electron, that spontaneously emitted a photon by relaxing. Due to the boundary conditions within the resonator modes will develop and increase their intensity, as the photons of the mode will induce stimulated emission of coherent photons, who will then also contribute to the mode. In order to always have the possibility of stimulated emission a population inversion has to be created. This means that the electron density in the higher energy state is higher than in the lower energy state. To enable the possibility of inversion population one needs a system of at least three energy states. Given a system of four energy states the pump then excites electron from the ground state  $E_1$  into the highest energy state  $E_4$ . These excited electrons then relax into the second highest energy state  $E_3$  by a high probability  $P_{43}$ . From there they relax into the second longest energy state  $E_2$  by stimulated emission and afterwards into the ground state. To keep population inversion the transitions  $4 \rightarrow 3$  and  $2 \rightarrow 1$  have to be fast in comparison to the optical transition  $3 \rightarrow 2$ . This means the transition probabilities  $P_{43}$  and  $P_{21}$  have to be higher than  $P_{32}$ . Additionally the pump of electrons from  $E_1$  to  $E_4$  needs to compensate for the amount of relaxing electrons.

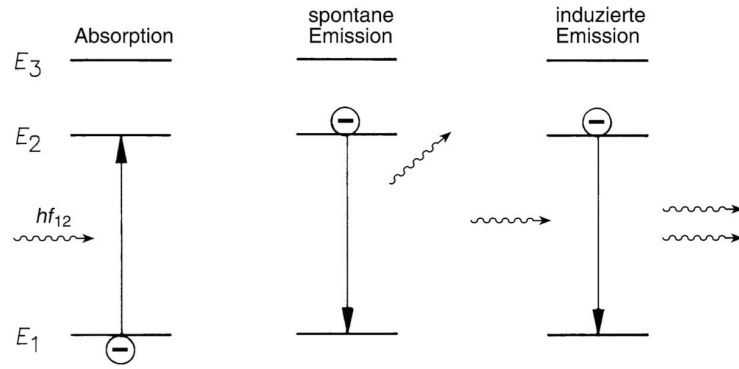


Abbildung 1: Schemes of the possible light-matter-interactions of absorption, spontaneous and stimulated (induzierte) emission.  $E_{1,2,3}$  mark different atomic energy levels,  $h$  the planck constant and  $f_{1,2}$  the photons frequency, which is propotional to  $\Delta E_{12}$ . Taken from [1].

## 1.3 Diode Lasers

### 1.3.1 Working Principle

For diode lasers the same principles of a pump, stimulated emission within an active medium and population inversion can be applied. Additionally some adaptions have to be done to correct for the solid state properties of the active medium, as there are now longer well defined energy states in the form of atomic orbitals. Instead the nergy states now correspond to different energy bands wihtin the solid states band structure. Every solid state body has a valence band, which is the highest occupied band below the Fermi-Energy and a conduction band, which is the lowest unoccupied energy band above the Fermi-Energy. The energy difference between these two bands is called band gap  $\Delta E = E_{CB} - E_{VB} = \frac{hc}{\lambda}$  and roughly defines the energy of a diode lasers light. In this setup a pn-junction-diode is used as the active medium. A pn-junction constists of a highly n-doted layer, which is stacked onto a highly p-doted layer. A highly n-doted layer leads to an increase of the Fermi-Energy and the insertion of electrons into the conduction band. Vice versa a highly p-doted layer leads to a lowered Fermi-Energy and the creation of holes in the valence band. These processes are depicted in figure 2.



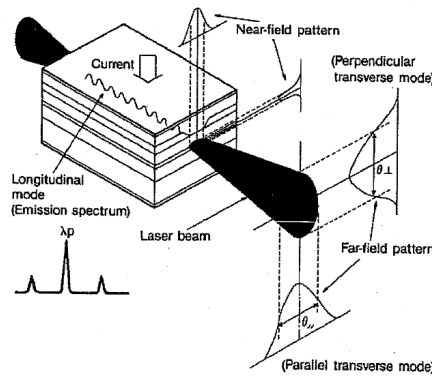


Abbildung 4: The diffusion of electrons and holes into the active layer by application of a current and the emission of photons by recombination of electron-hole-pairs. Taken from [2].

These two deficits are compensated for by the in figure 5 optical setup, that remains the laser in a so called *Littrow*-configuration and creates an additional **external resonator**. The setup consists of lense, which collimates the light exiting the laser diode and a grating, at which the collimated beam is diffracted. This happens in a way, that the zero-order-maximum, i.e. the reflected beam, is guided out of the laser setup as the operating beam, while the first-order-maximum is diffracted back into the laser diode. Thus the new external resonator is formed between the grating and the fully reflective backend of the laser diode. The wavelength of the light diffracted back into the laser diode, has to fulfill the condition for the first-order-maximum at the given angle of the grating. The back-reflected beam helps selecting a certain wavelength in a way, that is further discussed in the section on the gain curves of a diode laser.

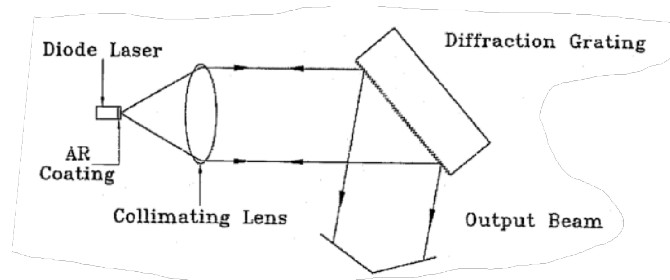


Abbildung 5: The diffusion of electrons and holes into the active layer by application of a current and the emission of photons by recombination of electron-hole-pairs. Taken from [2].

### 1.3.2 Gain Curves

To emit light of a well defined frequency the laser has to lase in fixed combination of a mode of the internal and one of the external resonator. Which modes will be selected, is determined by the gain curves depicted in figure 6. They show the different gains of laser intensity via different contributions against the laser wavelength. The wavelength for which the total amount of gain by all contributing factors, namely **Medium**, **Internal Cavity**, **Grating Feedback** and **External Cavity**, is the highest will be the lasing frequency and the closest internal and external modes will be the lasing modes.

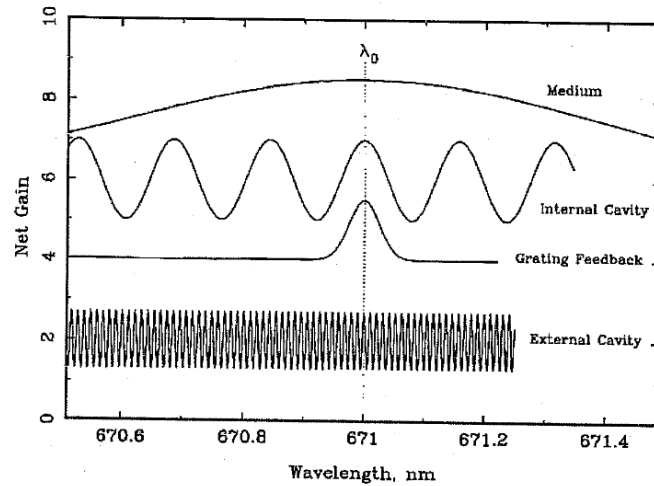


Abbildung 6: The contributing gain curves for the diode laser used in the setup. Taken from [2].

The **Medium-Gain** has a widespread peak with its maximum at the wavelength corresponding to the energy gap of the active medium. Thus the choice of the medium is the main factor governing the lasers wavelength. The position of the peak has a small dependence on the laser diodes temperatur, which is neglectible for the given experiment.

The gain of the **Internal Cavity** oscillates and has it peaks at the wavelengths of the longitudinal modes, which develop in the internal cavity. The distance between the different peaks is inversely propotional to the length of the resonator, i.e. the length of the diode, and thus rather large.

The gain of the **Grating Feedback** has a sole peak at the frequency of the first-order refracted light, that is reflected back into the diode and can thus be changed by varying the angle of the grating.

The gain of the **External Cavity** oscillates equivalently to the gain of the internal cavity but has a way smaller distance between the mode peaks, as the external resonator is way longer in comparison to the internal resonator. The position of the modes can be varied by changing the position of the grating and consequently the length of the external cavity.

## 1.4 Rubidium

The  $5S_{1/2}$ -electrons of the Rubidium isotopes  $^{85}\text{Rb}$  and  $^{87}\text{Rb}$  can be excited into the  $5P_{3/2}$ -orbitals with photons of a wavelength of roughly 780 nm. A closer look at the in figure 7 depicted fine-structure of the two isotopes shows two characteristic transitions per isotope. If you transmit a beam through Rubidium-vapor and slightly vary the beam wavelength around 780 nm, one will detect four dips in the transmitted intensity. Each dip is located at the wavelength equivalent to the excitation energy of the particular transition.

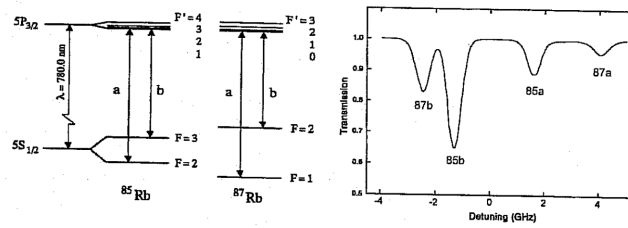


Abbildung 7: The four possible transitions from the  $5S_{1/2}$ -orbital to the  $5P_{3/2}$ -orbital for the two Rubidium isotopes and the corresponding dips in a transmission measurement. Taken from [2].



## Literatur

- [1] Hans-Joachim Eichler und Jürgen Eichler. *Laser: Bauformen, Strahlführung, Anwendungen*. 8., aktualisierte und überarbeitete Auflage. Lehrbuch. Berlin Heidelberg: Springer Vieweg, 2015. 491 S. DOI: 10.1007/978-3-642-41438-1.
- [2] TU Dortmund. *Versuchsanleitung V60 - Diodenlaser*. 2022.