Diodenlaser

Versuch 60

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Abgabe: 12. November 2021

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Inhaltsverzeichnis

Goal

The goal of this lab course was to get to know and learn how to set up Diode Lasers. With the installed diode laser the fluorescence of Rubidium got analysed.

1 Theory

The theoretical background for Lasers and especially diode lasers needs to be understood to properly work with the setup. In this chapter everything important for the lab course is explained.

1.1 Lasers

Laser (Light Amplification by Stimulated Emission of Radiation) is a form of Light emission which is frequently used in the industry and for research. Light emitted from a Laser is coherent in time (all photons have the same phase) and space (the photons travel parallel in the same direction). The Laser-light consists of photons with the same wavelength (monochromatic) and therefore the same energy, the photons also have the same linear polarization. To produce the light a Laser consists out of three major parts: The active medium, the energy pump and the Resonator.
The active medium determines the wavelength of the photons because they are generated by the electrons relaxing over the band gap of the material. To create laser light a population inversion has to be created with the different energy levels in the active medium. If we assume three energy levels in the active medium with the first level E_1 having the lowest energy and the third level having the highest energy. To create population inversion in the medium, the second level E_2 has to have more electrons than the first (lowest) level. The relaxation from the third to the second level E_2 has to be a faster transition than the transition from the second energy level to the first level E_1 (ground state). To provide enough electrons in the higher level a energy pump has to be used to excite electrons from the ground state E_1 to the third energy level.
To relax from the second level E_2 to the ground state E_1 the electrons can either spontaneously relax and emit the corresponding photon or can be stimulated by an incoming photon to relax and therefore emit a second photon with the same properties (Orientation, Frequency, Phase and Polarization). This stimulated emission is the main source for the photons of the laser. The simulated emission and the spontaneous emission are shown in figure 1.
When lasers travel onto rough materials they show a typical speckle pattern which is not seen for normal light [9]. The speckle pattern occurs, because different parts of the laser interfere with each other on the rough surface. By hitting the surface, each illuminated point acts as a source for a new spherical wave and these waves can interfere and create the speckle pattern, if the surface is rough enough to create phase changes greater than 2π.

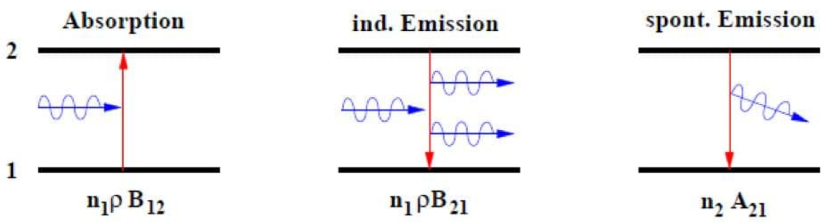
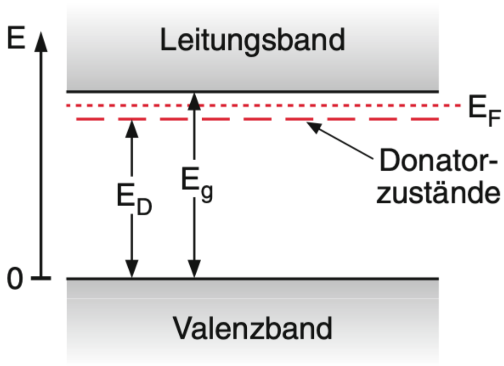


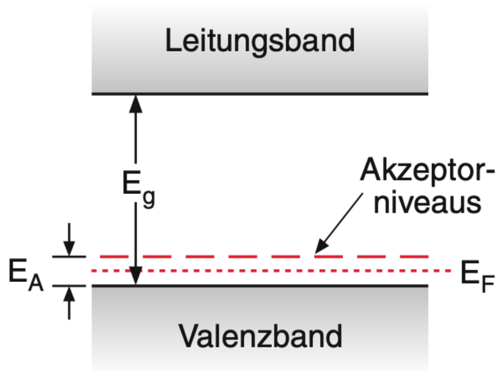
Abbildung 1: The absorption and emission processes in the active medium are shown for a two state system. [2]

1.2 Doted semiconductors

To change the electrical properties of semiconductors the doting of the semiconductor is a widely used method. Doting is the process of introducing atoms of another material with more (n-doted) or less (p-doted) valence electrons than the atoms of the semiconductor. In p-doted semiconductors holes are the majority of the charge carriers and in n-doted semiconductors electrons are the majority of the charge carriers. By doting the semiconductor the Fermi-energy inside the material is changed 2 and another energy level is introduced.



(a) n-doted



(b) p-doted

Abbildung 2: The Band structures with the fermi energy and the donator and acceptor states sre shown for p- and n-doted materials [**demtroeder**]

1.3 Diode Laser

In this experiment a pn-junction diode is used. A pn-junction diode is a part of a electrical circuit. The diode has a positive and negative direction and only allows the current to pass the diode in the positive direction. A pn-junction consists of two semiconductors (one p doted and another n doted 1.2) which are combined to build the junction at the border. By applying a current to the diode, the holes and the electrons meet in junction region and recombine. During the recombination the laser photons get emitted and due to the internal reflection stimulated emission occurs in the medium. Because the Diode produces a laser which is strongly diverging and has a big frequency width a external optical setup is used (seen in figure 6 and more deeply explained in section 1.4.3). With an lens the diverging laser is transformed in a parallel light and then pointed onto a grid surface. [7]

1.4 Gain Curves

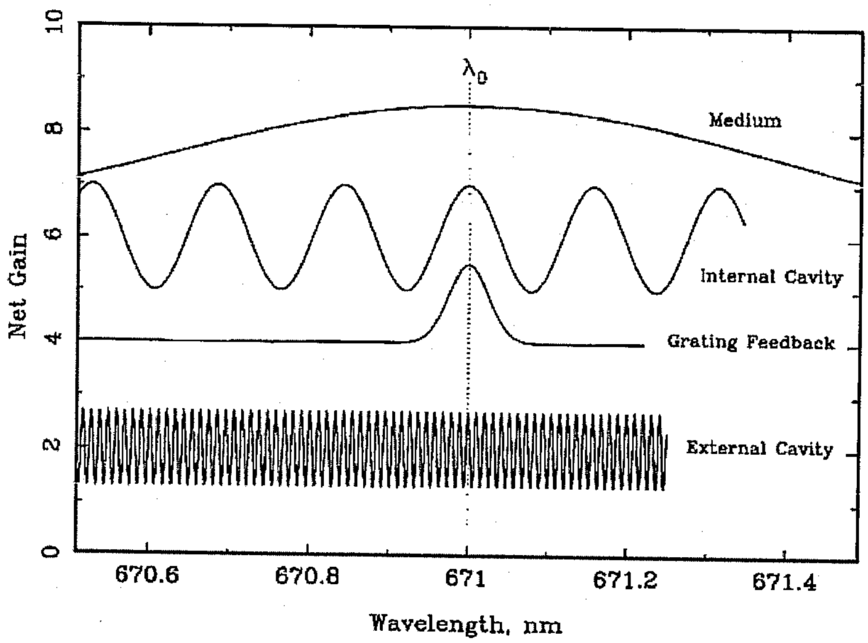


Abbildung 3: The different parts of the Gain Curves of the DIode laser are shown separately. By adjusting the different parts the wanted frequency can be reached [1]

1.4.1 Medium Gain

The medium band gap dictates the energy and therefore the frequency/wavelength of the photons. The medium gain curve is very broad for the temperature region in the experiment (which is chosen for the 780 nm of the rubidium resonance).

1.4.2 Internal Cavity

The internal cavity is the standing wave due to the reflection inside the medium. This kind of laser is called 'Fabry-Perot-Laser-Diode' but for a material like GaAs a additional set of mirrors is not necessary because on the border of the medium to air a reflection of

0,32 is reached. Due to the standing wave the frequency of the laser is dependent on the length of the active medium.

1.4.3 Grating Feedback and external cavity

To determine the frequency emitted by the laser instead of the internal cavity, also a external resonator is used. To get a frequency selection a optical grating is placed in front of the laser with a lens between the diode and the grating. The grating is assembled in a way to reflect the first order of reflection travels back into the diode. The frequency of the laser light is then dependent on the angle of the grating and can be varied by turning the Grating. This assembly of a laser feedback is called a Littrow Laser(Kap 10.5.3 [3]).

1.5 Rubidium

Rubidium has two stable isotopes, ^{85}Rb and ^{87}Rb. In figure 4 the energy states of the isotopes and the relaxation paths are shown. The relaxations (denoted by a and b) can be associated to the different signals of the transmission spectrum of rubidium. [6]

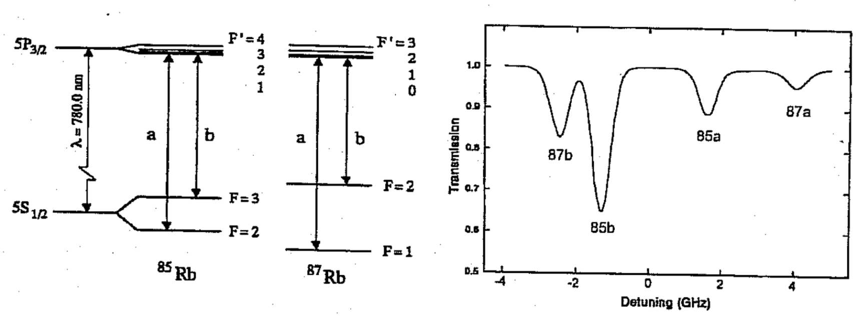


Abbildung 4: On the left side the energy levels of ^{85}Rb and ^{87}Rb are shown. On the right side the corresponding transmission spectrum of rubidium at wavelength near 780 nm is shown. [1]

2 Assembly and Execution

2.1 Assembly

The diode laser and all other instruments are set up on an optical table. To discern where the diode laser is pointing a special card was given to us which turns the non-visible light from the laser into visible light. Further a CCD-camera connected to a screen is used to broadcast a live video of the light spot on the card or the fluorescence in the cell to get a more convenient look at them. The rubidium gas is confined to a cell whose temperature is regulated via a control panel. The diode laser itself can be rotated in the horizontal plan via a side knob. This causes a variation of length for the external cavity as well as the angle between the diode and the grating which in turn causes a change in frequency of the laser.

2.2 Determination of the Threshold Current

At first the threshold current I_{th} at which lasing takes place has to be determined. As seen in Abbildung 5 a card is placed so that it intercepts the laser beam and the camera is focused on the card. Now the current is steadily increased from zero. In the beginning a light spot is visible on the card. This means that the diode laser only acts as an LED. But when a certain threshold current is passed the light spot suddenly gets brighter and a speckle pattern can be observed.

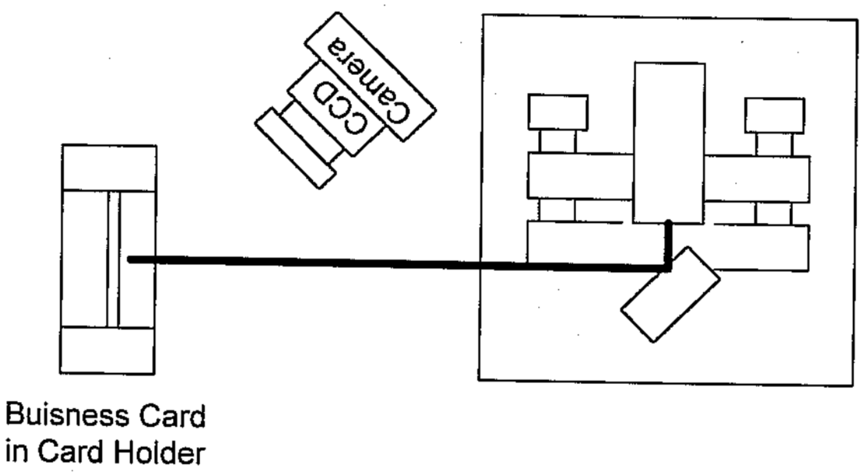


Abbildung 5: Assembly containing the diode laser, the camera and the card to determine the threshold current. [1]

2.3 Rubidium fluorescence

Next, you set up a rubidium cell so that the laser beam passes through it like in Abbildung 6. The camera is now aligned vertically to the direction of propagation as it is focused on the cell. The current is set significantly higher than the threshold current. The side knob is now used to adjust the horizontal position and thus the frequency of the external cavity. A piezoelectric stack scans a comparably small part of the frequency spectrum by moving the optical feedback grating with a certain frequency. By changing these two parameters, the horizontal position and the frequency of the piezo, it is achieved that the rubidium fluorescence is seen at all times.

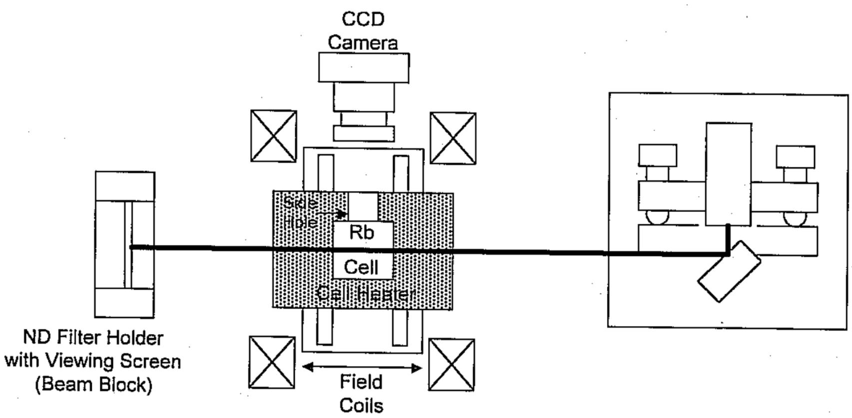


Abbildung 6: Assembly containing the diode laser, the camera, the card and the rubidium cell to observe rubidium fluorescence. [1]

2.4 Absorption spectrum of Rubidium

As seen in Abbildung 7 the beam passing through the cell is intercepted by a photodiode which turns the intensity of the laser beam to a proportional voltage. This voltage is displayed on the screen of a connected oscilloscope. Since the photodiode is very sensible to ambient light the room is darkened. On the oscilloscope can now be seen various peaks and mode hops. The second photodiode is aimed at with a 50/50-beam-splitter positioned in between the diode laser and the rubidium cell which lets through half of the laser light and reflect the other half. To eliminate external influences the signals of both photodiodes are subtracted from one another. Lastly the absorption spectrum on the oscilloscope is chosen by varying the current, the piezo and the side knob (and the oscilloscope settings) so that no mode hops and all four, maximally visible absorption peaks can be observed.

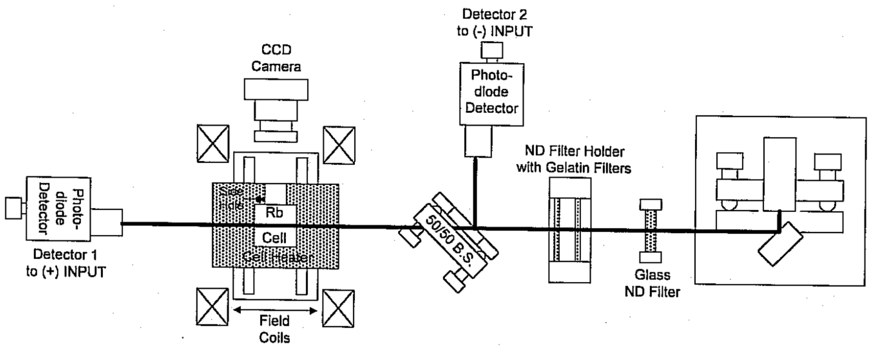
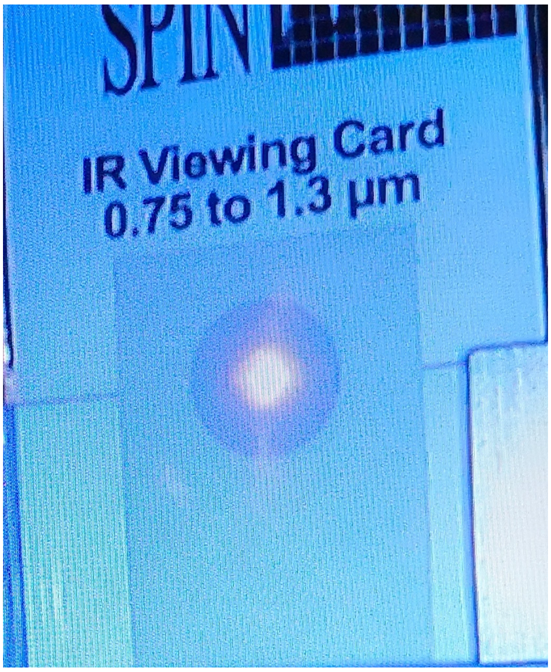


Abbildung 7: Assembly containing the diode laser, two photodiodes, the 50/50-beam-splitter and the oscilloscope to get the absorption spectrum of rubidium. [1]

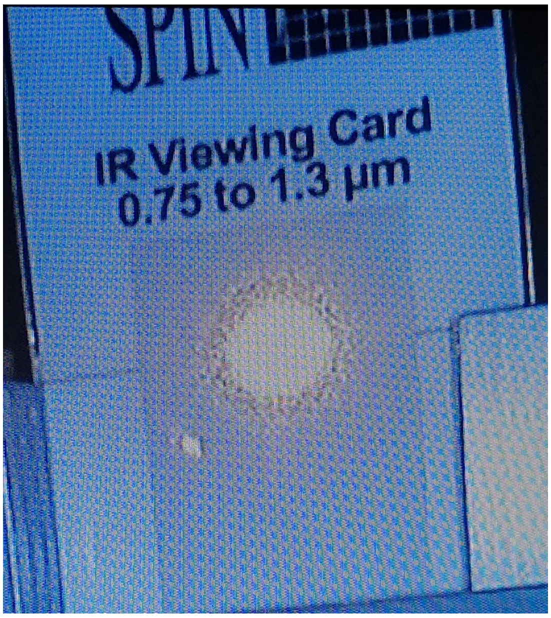
3 Evaluation

3.1 Determination of the Threshold Current

As stated in 2.2 the current is slowly raised. Abbildung 8a shows the photo of the light spot before the current exceeds the threshold current. Abbildung 8b shows the record of the laser light at the threshold current $I_{\mathrm{th}} = 37,0\,\mathrm{mA}$.



(a) The light spot on the card before lasing happens at a current below I_{th}. [2]



(b) The light spot on the card at the threshold current I_{th}. The laser granulation is seen on the card. [2]

Abbildung 8: The light spot caused by the diode laser before and after lasing.

3.2 Rubidium fluorescence

The picture in Abbildung 9 was taken of the rubidium cell as the fluorescence could be seen at all times albeit it was a bit dim.

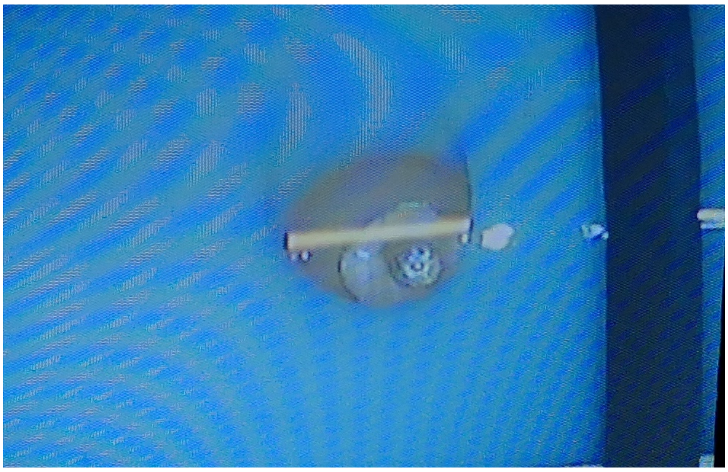


Abbildung 9: The rubidium fluorescence which is seen when the diode laser reaches the necessary energy to excite the rubidium gas. [2]

3.3 Absorption spectrum of Rubidium

In Abbildung 10 the absorption spectrum of rubidium is shown after the fine adjustment mentioned in 2.2 which involves varying the current, the piezo voltage and the side knob in turn. From left to right the absorption peaks belong to the transitions 87b, 85b, 85a and 87a. The blue graph in Abbildung 10 signifies a sweep of the piezo.

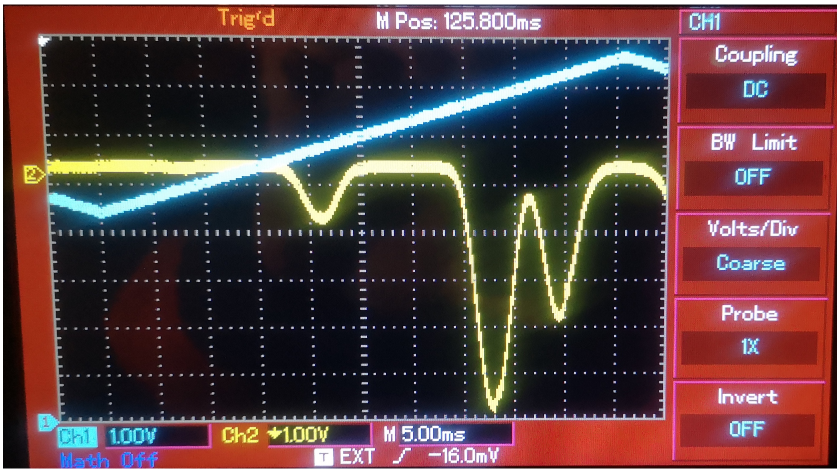


Abbildung 10: The absorption spectrum of rubidium containing the peaks belonging to 85a, 85b, 87a and 87b after the adjustment of the laser parameters. [2]

4 Conclusion and discussion

The three major results of this experiment coincide with the expected theoretical values. The first part confirms the existence of a threshold current at which the diode laser starts to lase. The rubidium fluorescence could also be observed by adjusting the laser to the matching frequency. We had some problems with the demonstration of the four absorption peaks on the oscilloscope, namely the fourth peak 87a was not visible for the most part of the experiment. Only the fine tuning we did in the end showed a slight peak. The reason for the trouble at finding the last peak may be that the intensity of the laser was not strong enough to cause sufficient 87a transitions so that the peak did not stand out to much from the baseline intensity.

Literatur

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[9] *Wikipedia speckle pattern*. URL: `https://en.wikipedia.org/wiki/Speckle_pattern`.