V60 Diode Laser spectroscopy

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1 Objective

Considered a precursor to lasers, light-emitting diodes (LEDs) differ significantly from lasers in their capacity to emit light of equal wavelength, phase, and polarization at very high intensity. Consequently, lasers play an important role in a manifold of physical experiments. In the following experiment, the characteristics of an aluminium gallium arsen (AlGaAs) based diode laser will be measured. Furthermore, the hyperfine splitting of ^{85}Rb and ^{87}Rb will be measured using absorption spectroscopy.

2 Theory

Like any Laser a Diode Laser ("Light Amplification by Stimulated Emission of Radiation") needs three basic components to work an active medium, a resonator and an optical pump. In the case of a diode laser the active medium consists of two doped semiconductors, one p-doped and one n-doped. A reflective coating on the interfaces of the semiconductor layers form the internal resonator. The pump is implemented in the form of a current which generates additional electron-hole pairs in the active medium.

Additionally to the components mentioned above a condition called population in-

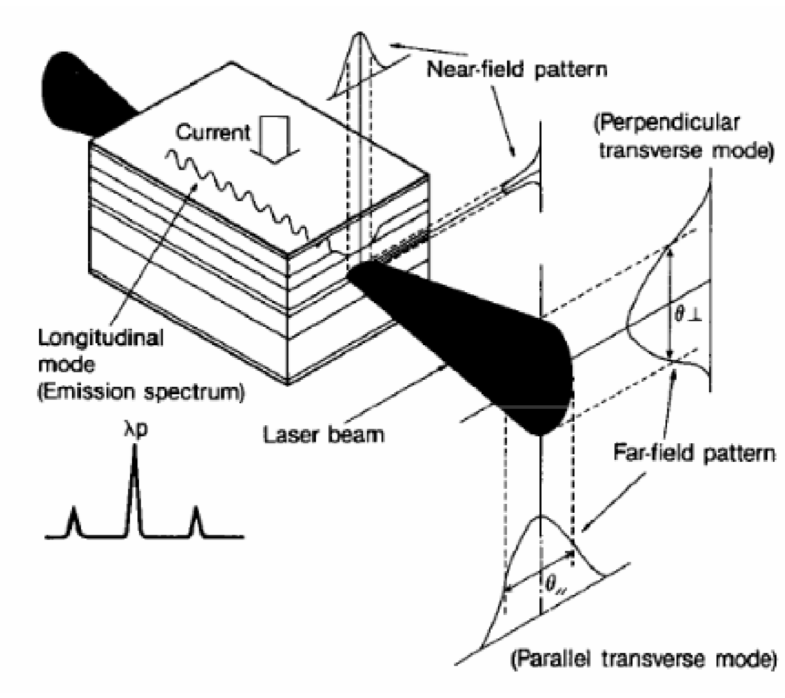


Figure 1: Scheme of the composition of the basic components of a diode laser, consisting of an active medium, reflective coatings and a current causing stimulated emission of light [1].

version has to be met as it is a prerequisit for the dominance of stimulated emission over spontaneous. And as such for the light amplification, which is spoken of as lasing. The proportion of a single passing photon to the number of photons it produces via stimulated emission is called gain. The population inversion condition, however, is not instantlly met but only if a threshold current is reached before which the diode laser behaves just like a common LED. From the process of stimulated emission some of the unique properties of a laser are predicted. The emitted photon has the same wavelength, direction and polarization as the exciting photon. Hence the highly coherent nature of the light emitted from a laser.

To achieve emission one of the sides of the diode is not coated with a highly reflective layer but one which is almost transparent and reflects only 15%. The resulting beam is strongly divergent due to the shape of the diode. To further restrict the bandwidth

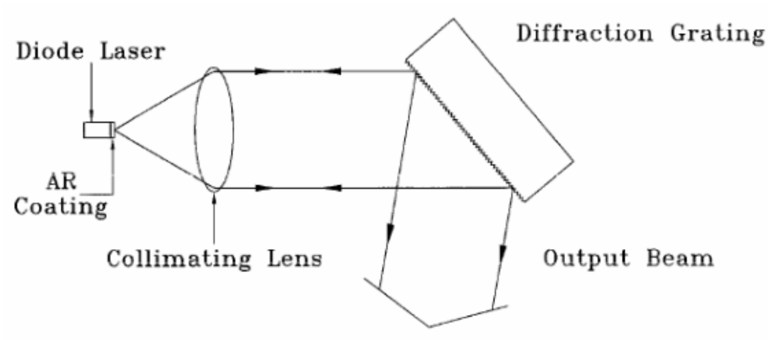


Figure 2: External cavity of a diode laser with an optical grating [1].

and stabilize the laser a diffraction grating is placed behind the diode. The first order reflection is reflected back into the laser, while the other parts are refracted. The reflected part again provides stimulated emission, whereby the spectrum of the resulting wavelengths is limited by the small part of the reflection. The grating forms an external cavity together with the diode. The resulting gain is contingent on the distinct cavities within the laser, as depicted in Figure 3. It distinguishes between the gain of the active medium, the gain of the internal cavity, the gain of the external cavity, and the grating feedback. The position of the maximum gain in the active medium aligns with the band gap, yielding a continuous spectrum due to the charge carriers' unrestricted mobility within the bands. The gain in the internal cavity exhibits a standing wave pattern, arising from the reflected light within the resonator. The period of this standing wave, known as the "free spectral range," can be calculated using the equation

$$\Delta\nu_{FSR} = \frac{c}{2Ln}, \tag{1}$$

where L represents the cavity's length and n signifies the refractive index. Concerning grating feedback, a solitary, narrow peak corresponds to the wavelengths of the light reflected back into the laser. The gain within the external cavity exhibits similar

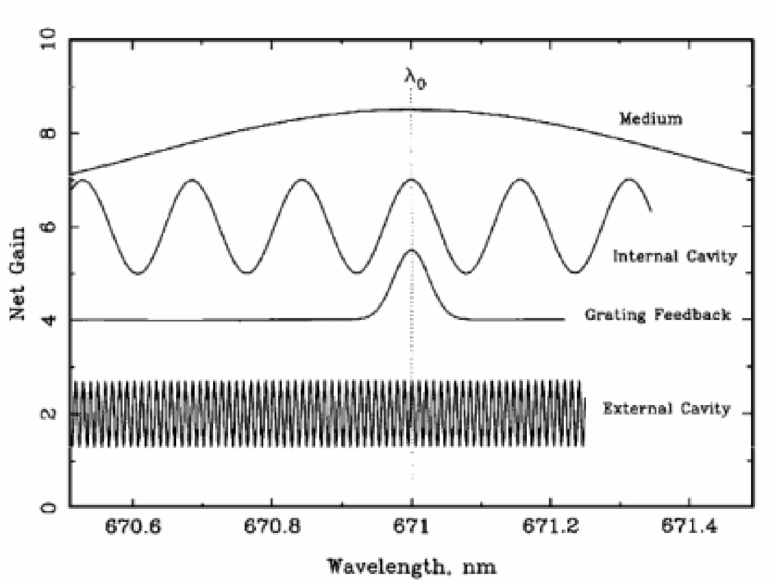


Figure 3: The gain function varies based on the different laser cavities. In both the internal and external cavities, a standing wave is produced, while the medium's gain and the feedback from the grating exhibit a single peak all contributing to the final gain function determining the lasers emission spectrum [1].

characteristics to that of the internal cavity, mainly due to the reciprocal reflection of light between the optical grating and the laser diode. In this case, the period can be precisely described as $\Delta\nu_{FSR} = c/2L$. The laser's ultimate wavelength can be determined using the equation $\lambda = d\sin(\theta)$, where d represents the line number of the grating, and θ corresponds to the grating angle. Both the gain within the active medium and the internal cavity are contingent upon the current applied and, by extension, the temperature of the diode. This is due to the diode's propensity to heat up as current increases, consequently altering the concentration of charge carriers within the active medium. As a result, the wavelength of the emitted radiation exhibits a linear correlation with current intensity and temperature. However, it's important to note that different components exhibit distinct wavelength changes in response to variations in current, leading to what is commonly referred to as "mode hopping." These mode hops are exemplified in Figure 4, where, in this instance, changes in the grating angle were introduced.

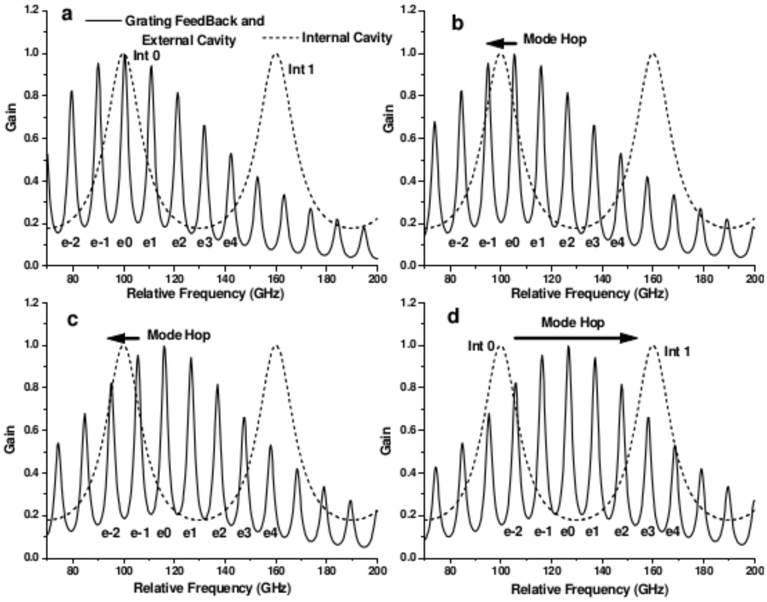


Figure 4: Gain functions showing the phenomenon of mode hopping caused by varying internal cavity gain functions due to temperature and or current change. [1].

3 Measurement

3.1 Materials

The provided materials include an AlGaAs diode laser with its external cavity following the Littrow configuration, allowing for adjustment of the diffraction grating. Both the grating and the collimator lens are pre-installed in the laser. The laser is mounted on a breadbord. Additionally, there is a CCD camera and a IR indicator card to render the infrared light, invisible to the human eye, visible. The rubidium contained within a rubidium cell, two photodiodes, filters, and a 50/50 beam splitter are further materials. Throughout the entire measurement, the laser is maintained at a temperature of 50°C to match the wavelength relevant for rubidium. The laser is connected to a power supply unit with corresponding controls for temperature regulation, current adjustment, and control of the other components. An oscilloscope can also be employed as needed.

3.2 Speckle

The first step involves determining the laser's threshold current using the phenomenon of laser speckle, also known as laser granulation. Laser granulation occurs when highly monochromatic, coherent light strikes a surface with irregularities on the order of the wavelength. According to Huygen's principle, these irregularities act as small scattering centers generating spherical waves. Due to the surface's unevenness, a random interference pattern forms, resulting in a grainy light spot on the indicator card. If the laser were still in the LED range, laser granulation would not occur because the generated light is not sufficiently coherent, and thus, such an interference pattern cannot be produced. To determine this minimal required current, known as the threshold current. The angle of the grating must be adjusted so that light is emitted and becomes visible on the indicator card. The current is gradually increased until laser granulation becomes visible.

3.3 Absorption spectrum of Rubidium

In the next step, the laser is to be adjusted to make an emission line in the rubidium cell visible. To achieve this, the setup shown in Fig. 5 is implemented.

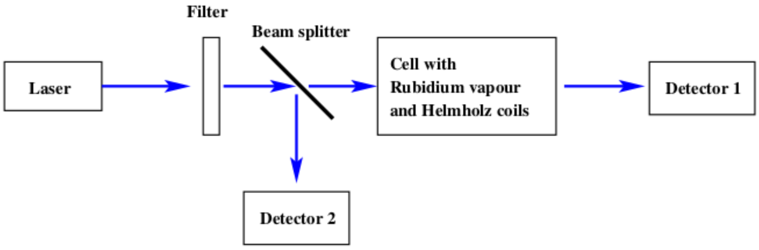


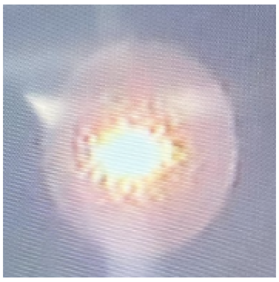
Figure 5: Schematic overview of the experimental setup used for measuring Rubidiums absorption spectrum [1]

To ensure that the laser is sufficiently strong, the current is regulated well above the threshold current. Another adjustment possibility is provided by the piezoelectric crystal, which changes its volume depending on the voltage applied to it. This fine-tuning can be more precise than adjusting the grating. These adjustments are made until the rubidium fluorescence becomes visible on the CCD camera, and a photograph is taken. To capture the rubidium transmission spectrum, a 50/50 beam splitter is placed in front of the rubidium cell. One half of the beam is directed through the cell, and the other is reflected directly to a photodiode. The transmitted beam is captured by a photodiode behind the cell. The beam splitting is crucial to filter out the background. Both photodiodes are connected to a differential amplifier, which subtracts the input signals from each other, allowing only the changes caused by the rubidium absorption lines to become visible.

4 Results

Firstly the minimal lasing current was determined by looking at the emitted light on the IR viewing card. The results are shown in Figure 6. In the left Subfigure 6a the diode is operating below the minimal lasing threshhold $I_{\mathrm{LED}} = 32\,\mathrm{mA}$ which results in a picture similar to that of an LED, since no population inversion is obtained. On the right Figure 6b the same is shown but above the threshhold with a current of $I_{\mathrm{LASER}} = 35\,\mathrm{mA}$. The intensity rises drastically and the speckles on the viewing card indicate constructive interference, meaning that the light is now monochromatic. The diode is now functioning as a Laser. We then adjusted the setup to wavelengths that can resolve the hyperfine structure of Rubidium. The resulting luminescent light behind the Rubidium probe is

(a)



(b)

Figure 6: On the left (a) the emitted light of the diode is shown slightly below the minimal lasing threshhold ($I_{\mathrm{LED}} = 32\,\mathrm{mA}$). The right figure (b) shows the light marginally above lasing threshhold ($I_{\mathrm{LASER}} = 35\,\mathrm{mA}$).

shown in Figure 7. Lastly, the absorption spectrum of Rubidium is displayed in Figure 8.

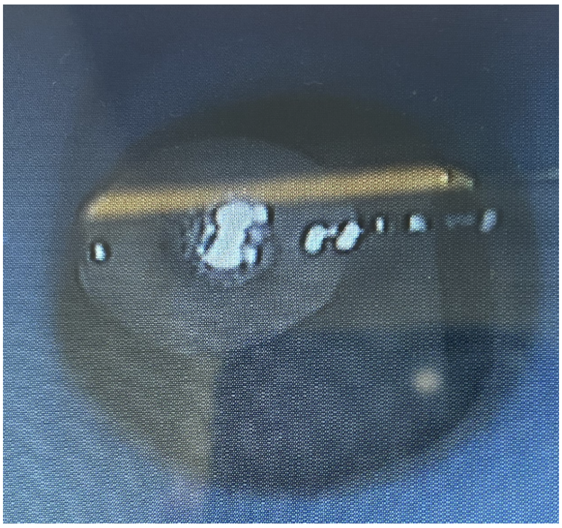


Figure 7: Luminescent light coming from the Rubidium probe.

The blue line shows the ramp generator signal and the yellow line depicts the in total four hyperfine levels of ^{85}Rb and ^{87}Rb.

Figure 8: .

5 Discussion

In general, the experiment yielded success, with the laser being appropriately tuned to encompass the required spectrum and stability. However there are a few things to notice. It was necessesary to adjust the grating angle with an allen wrench on the side knob of the diode mount. This was rather tedious and shows the sensitivity of the setup, especially regarding small shocks. Additional tuning was necessesary to get rid of visible mode hops. The main background of the Rubidium absorption was accounted for by using the 50/50 beam splitter and a double photo-diode setup. Other possible light background such as room-light did not affect the qualitative results shown in Figure 8. In conclusion, the Rubidium hyperfine structure using the diode laser could be determined to a good precision.

References

[1] *V60 Diode laser absorption spectroscopy.* Fakultät Physik, TU Dortmund. 2023.