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Diode Laser spectroscopy

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Contents

1 Aims of the Experiment

In this experiment, a diode laser operating in the infrared spectrum is explored. The laser is then used to perform absorption spectroscopy to measure the energy splitting of rubidium atoms. To achieve this, an optical grating is used.

2 Theory

This section aims to summarize the basic principles that underpin the operation of diode lasers.

2.1 The Diode Laser

The term 'laser' stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A laser is a unique source of electromagnetic radiation, characterized by properties such as an extensive coherence length, monochromaticity, and concentrated intensity paired with minimal divergence. Owing to these distinctive features, lasers are versatile and find applications in various areas. Within this experiment, we employ a diode laser as a tool for spectroscopic analysis.
The operation of a laser amplifies radiation by the mechanism of stimulated emission. For a laser to function effectively, stimulated emission must dominate over both absorption and spontaneous emission within the laser medium. This is achieved through establishing population inversion. Additionally, an optical resonator is used to enhance the emitted radiation further.

The laser device used in this experiment has at its core a semiconducting diode. It consists of at least three layers: the active layer, the n-doped layer and the p-doped layer. In the n- and p-doped layer, free charge carriers in the form of electrons and electron holes respectively, are present. The active layer of the laser diode forms a cavity. A injection current is run through the diode, causing the electrons and electron holes to recombinate in the active layer between the n- and p-doted layers. Therefore, the wavelength of the emitted photons corresponds to the width of the band gap of the semiconductors material. This process can also be caused by another photon; this process is called stimulated emission. If the injection current is high enough, the amplification through stimulated emission exceeds the optical losses in the diode and population inversion can be achieved. In this case, the diode emits a coherent beam. The emitted radiation is confined by refraction to a channel inside the diode (the active layer), with facets at the ends of the channel that serve as cavity mirrors and output couplers. The diode used in this experiment emits most radiation through the front facet, as the back facet is for the most part reflective. A schematic display of such a laser diode chip is given in Figure 1.

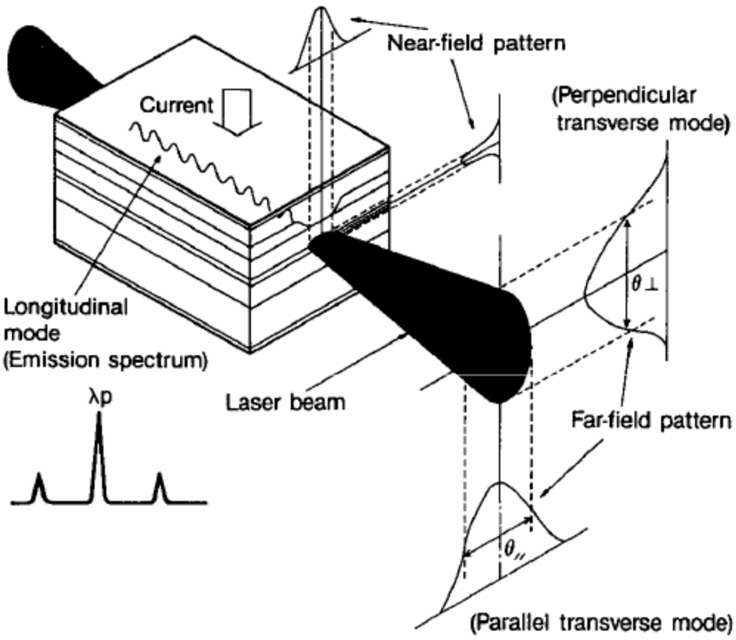


Figure 1: Schematic display of a laser diode (LD) chip [3].

However, the light emitted by the raw laser diode chip has certain limitations; the beam is strongly diverging, the frequency stability is very sensitive to optical feedback and the radiation has a linewidth of 10 times the linewidth of atomic transitions. To overcome these problems, a configuration like the one displayed in Figure 2 can be employed. Here, a collimating lens is used to prevent the divergence of the laser beam. To improve

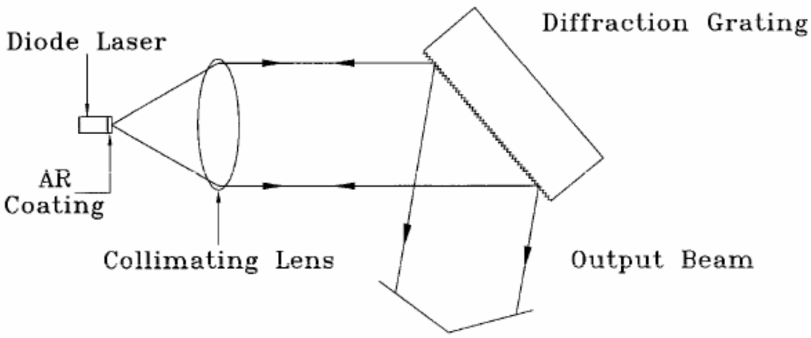


Figure 2: Configuration of a laser system [3].

frequency stability, around 15 % of light is routed back into the diode through the use of a diffraction grating. This grating acts as an external cavity (in addition to the internal cavity inside the laser diode chip). The grating also reduces the linewidth of the laser beam to less than $\nu = 1\,\mathrm{MHz}$, which is smaller than the atomic transitions linewidths.

2.2 Tuning of the Diode Laser

After the lasing process has started, the beam mostly consists of light with the frequency that offers the highest net optical gain. The exact frequency depends on several factors, which are displayed in Figure 3.

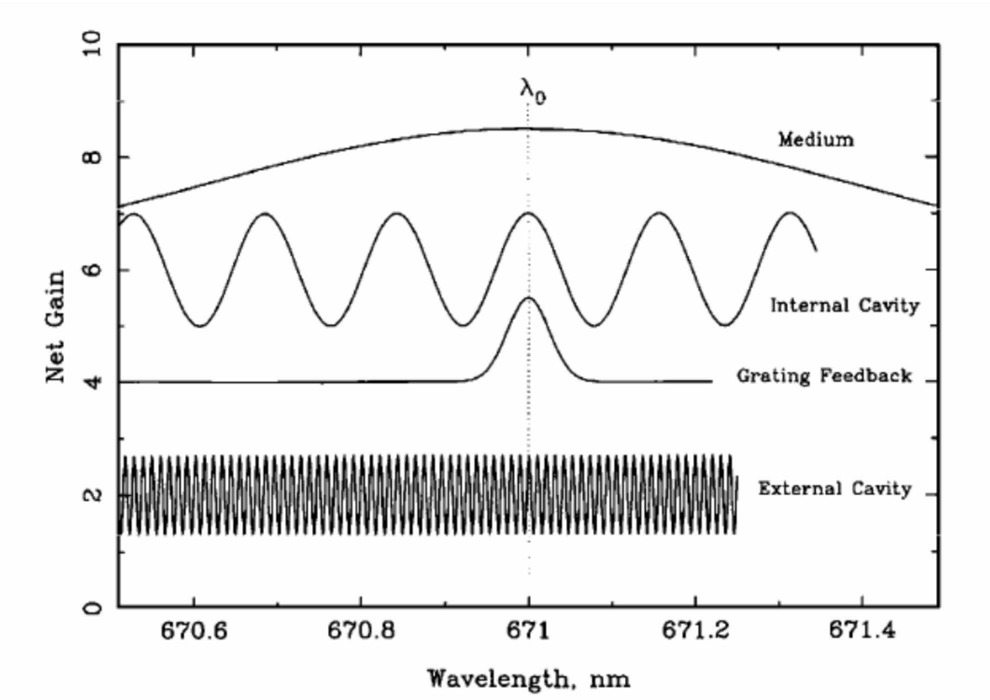


Figure 3: Schematic display of different sources of amplification for different wavelengths [3].

2.2.1 The Medium Gain

The medium gain pictured in Figure 3 is defined by the semiconductors material. It is quite broad and is only influenced by the materials temperature, which can be used to shift the medium gain. It is the least precise tuning parameter of a diode laser and should therefore be tuned at first.

2.2.2 The Internal Cavity Gain

The gain caused by the internal cavity of the laser diode chip depends on the length of the cavity and the injection current. Its periodic frequency is a result of the normal mode structure of the optical cavity; the period length is defined by the length of the cavity, which is influenced by the temperature.

The temperature is then again influenced by the injection current; its strength changes both the cavity length through temperature change as well as influencing the amount of charge carriers in the active layer.

2.2.3 The optical Grating Gain

The optical grating routes a small amount of radiation within a specific portion of the frequency band back into the laser diode chip. The resulting singular peak can be seen in Figure 3. The position of this peak in the spectrum can be ajusted through a change in the angle of the optical grating. Said adjustment can be done manually (e.g. with a screw) or though utilising a Piezo-electric crystal; applying different voltages on such a crystal causes a proportional volume change, which can be converted into a change of angle.

2.2.4 The external Cavity Gain

The external cavity works similarly to the internal cavity gain, except its much larger cavity length: it is confined by the reflective facet of the laser diode chip on one side and by the optical grating on the other. As with the internal cavity gain, the length of the cavity determines the periodicity of the resulting amplification. Because of its larger size, the external cavity gain is much shorter in its period length, as can be seen in Figure 3.

2.2.5 Mode Hops

As mentioned before, after the lasing process has begun, the laser mostly emits radiation with the wavelength that maximises the optical amplification. Adjusting the laser to a frequency where it emits the most radiation continuously is complicated by mode hops, meaning a jump between different maxima in different gains. When the angle of the optical grating is changed and therefore its gain is shifted, the total net gain also depends on the other gain factors, like the internal cavity gain. The emitted frequency will then hop between the maxima of the different gain factors. This can be seen in Figure 4. To prevent mode hops, the gain factors have to be adjusted simultaneously.

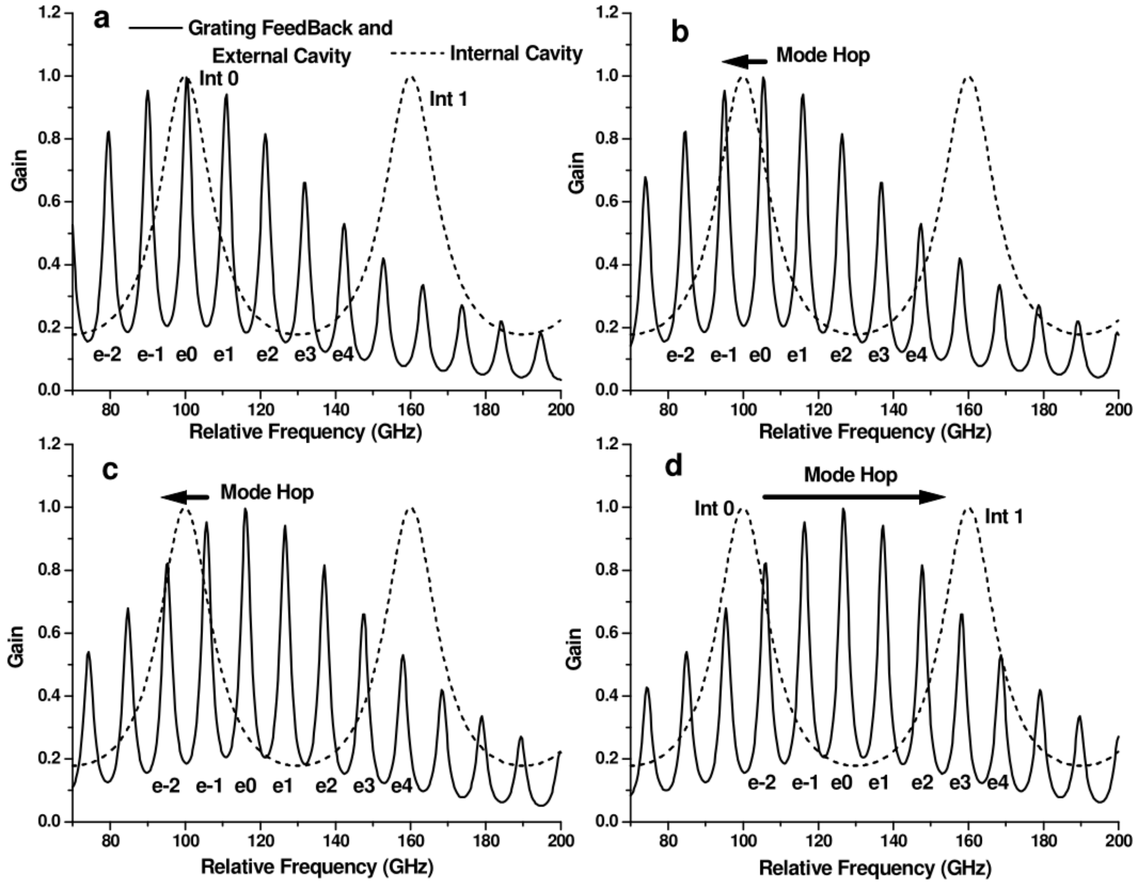


Figure 4: Several plots of the gain by the external cavity and the optical grating for different wavelengths [3].

3 Experimental Setup and Measurements

3.1 The Laser

The laser system consists of the diode laser a lens used to collimate the beam, an electric heating system and the diffraction grating. These components can be seen in Figure 5.

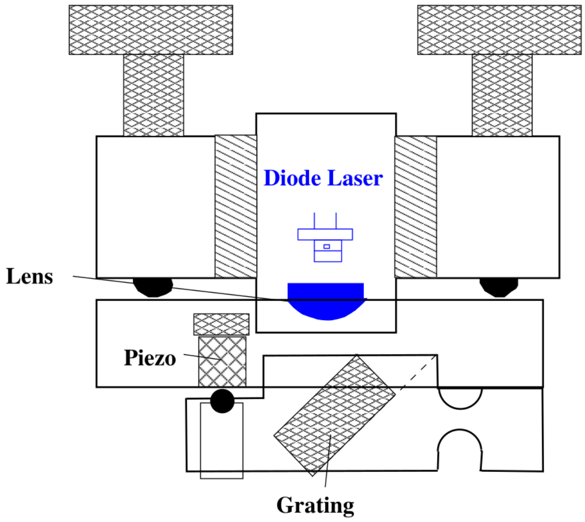


Figure 5: Display of the laser assembly [2].

The diode laser uses a p-n semiconductor made from aluminium gallium arsenide (AlGaAs), with facets on both ends of the chip with 100 % and 15 % reflectivity respectively. The external cavity is realised through the diffraction grating in Littrow configuration. To adjust the laser, using an indication card, a photodiode or a CCD camera is required because the laser wavelength is in the near infrared region of the spectrum and can therefore not be seen by the human eye. To adjust the external cavity, the angular orientation of the optical grating is modified until the first and second order diffraction overlap on the monitor of the CCD camera. If this is the case, the second order of diffraction is routed back into the laser diode. The maximise the output power, the CCD camera is replaced by a photodiode and a connected voltmeter. Then, the lens is adjusted until the maximum power is reached.

3.2 Measurements

3.2.1 The lasing Threshold and Characteristics

To study the characteristics of the diode laser, the current threshold for the lasing process is measured. For this, a piece of paper is placed in the laser beam in front of the laser. The light reflected by the paper is observed with the CCD camera. The injection current is increased; at the threshold, the brightness of the reflected beam suddenly increases and a speckle pattern is visible. Mode hopping is observed and documented using an oscilloscope. Additionally, the external cavity length is varied and the resulting effect measured.

3.2.2 The Hyperfine Splitting of Rubidium

For the measurement of the hyperfine splitting of rubidium, a cell containing 72 % ^{85}Rb and 28 % ^{87}Rb, a heating device, a cooling finger as well as a pair of Helmholtz coils is placed in the laser beam. The Helmholtz coils have a radius of $r = 87.4\,\mathrm{mm}$ and 320 turns. They are made of copper. Here, two photodiodes are used to suppress noise. The full structure can be seen schematically in Figure 6.

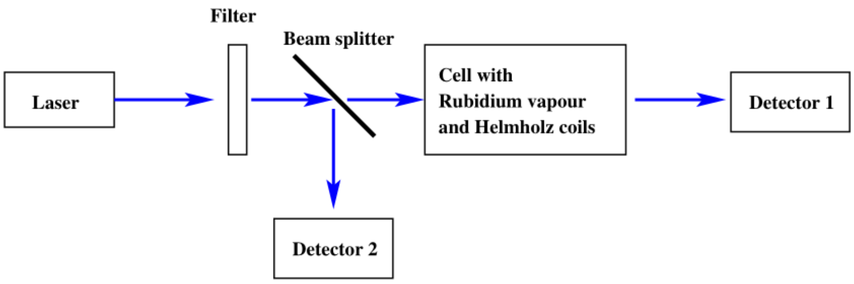


Figure 6: The experimental setup for measuring the hyperfine splitting of rubidium [2].

To measure the hyperfine splitting, the transmitted light is measured as a function of the laser frequency.

4 Results

4.1 Laser Threshold Current

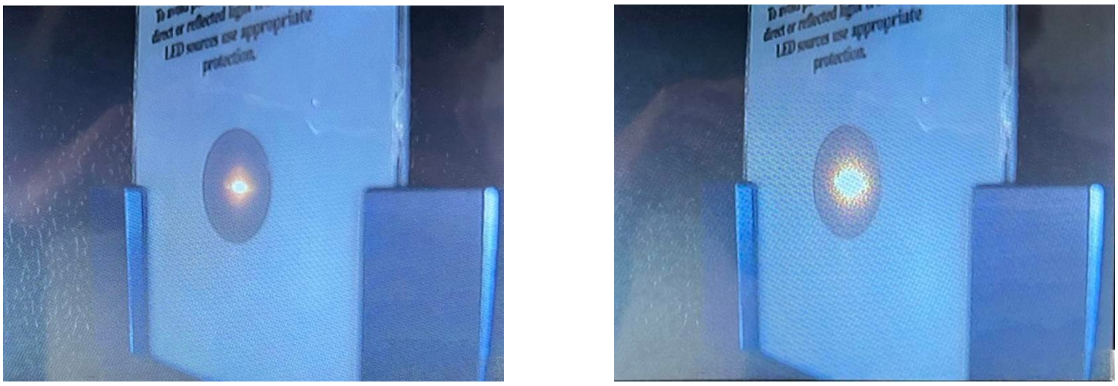
The current at which the diode transitions from emitting LED to laser light is determined as

$$I_{\text{threshold}} = 35.3\,\mathrm{mA}.$$

Figure 7 illustrates the radiation emitted by the diode at two current values: $I = 35.0\,\mathrm{mA}$ (see 7a) and $I = 35.3\,\mathrm{mA}$ (see 7b). The sharp increase in intensity corresponds to the onset of laser operation.

4.2 Rubidium Fluorescence

Figure 8 displays the fluorescence light emitted by rubidium.



(a) Diodelaser below the threshold. The diode operates as an LED.

(b) Diodelaser above the threshold. The diode operates as Laser.

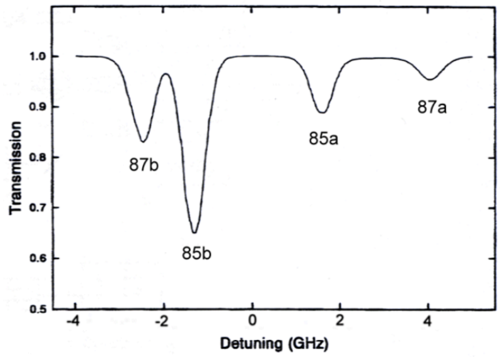
Figure 7: Comparison of diode operation below and above the threshold.

Figure 8: Picture of the yellow fluorescence beam within the rubidium vapour.

4.3 Rubidium Absorption Spectrum

The measured absorption spectrum is depicted in Figure 9a, while the theoretical expectation is presented in Figure 9b.

(a) Absorption spectrum of ^{85}Rb and ^{87}Rb (yellow) and triangular voltage of the generator (blue) as a function of time.



(b) Theoretical prediction of the absorption spectrum of ^{85}Rb and ^{87}Rb. The frequency of the minima corresponds to the energy transitions in the rubidium atoms [1].

Figure 9: Rubidium absorption spectrum measurements and theoretical predictions.

5 Conclusion

The measurements align closely with the theoretical predictions. The threshold current exhibited clear discreteness, initiating visible laser operation.
The absorption spectrum meets expectations, with all four minima clearly visible. This indicates successful avoidance of mode hopping. The triangular background from the generator was effectively removed by balancing the signal from both detectors, as described in Section 3.2.2. This resulted in the flat line observed between the minima in Figure 9a. One challenge encountered during the measurements was the sensitivity of the laser's alignment to minor mechanical disturbances. Any imprecise adjustment led to disruptions in the measurements.

References

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