V60

Diode Laser Spectroscopy

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Contents

1 Goals of this Experiment

This experiment should be seen as an introduction to diode laser physics.

A spectroscopy of rubidium will be performed with a diode laser operating in the infrared region using an optical grating.

2 Theory

2.1 Basics of Lasers

A laser is a source of electromagnetic radiation such as visible light that has properties conventional light sources such as a light bulb cannot fulfill simultanously. The most important of these properties of the emitted radiation are:

- high intensity
- low divergence, i.e. highly focused
- narrow bandwidth, i.e. monochromatic
- high coherence length

Because of those properties lasers are widely used nowadays. Use cases can be laser-pointers, lightshows, distance measurements, lasercutters, data storage via optical drives, laserprinters, fiber-optics and many more. One of those use cases is spectroscopy and this is what we will do in this experiment.

Laser is the abbreviation for "light amplification by stimulated emission of radiation". Therefore a laser operates in such a way that energy is pumped into a medium so that the atoms can be excited. If enough atoms are excited (i.e. population inversion) a single photon can stimulate an atom such that it emits another photon. The so produced radiation is reflected back and forth in some kind of resonator where it can stimulate more emissions. A certain ratio of photons can escape the resonator and those photons now have the previously mentioned properties.

The classical technology for lasers are dye lasers, but those lasers are expensive and difficult to use. The use of semiconductor laser diodes have changed this drastically.

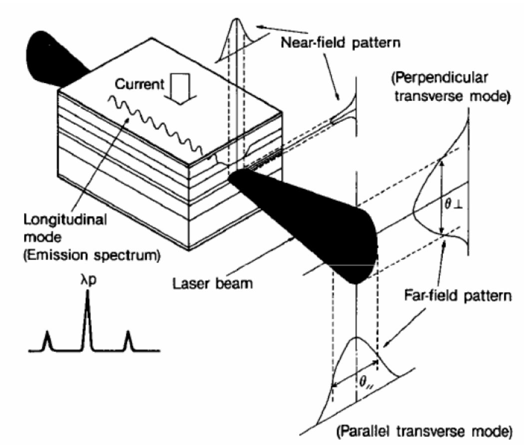

Figure 1: Schematic view of a laser diode chip [1]

2.2 Basics of Diode Lasers

A diode laser is constructed of a minimum of three layers, the n-layer, the active layer and the p-layer. A basic scheme of a diode laser can be seen in Figure 1. The n- and p-layers are doped so that they are charged negative (electrons) or positive (electron holes).

When injection current is run through the diode the active layer is injected with both the electrons and electron holes. The process of recombination emits a photon. Another photon can cause this emission to be stimulated. The amount of amplification by stimulated emission is called the optical gain. The surfaces of the n- and p-layers are made highly reflective so that the active layer is an inner cavity for the photons and inside is a standing wave.

The emitted radiation can escape the inner cavity at the front facet or the back facet. Although the laser diode used in this experiment has a coated back facet so that most of the radiation is reflected back.

A laser diode only starts to lase above a certain threshold current. Below this threshold it operates more like a LED. Above the threshold the radiation is coherent and the intensity increases linearly with the injection current. It should be noted that the emitted radiation is highly divergent and has a large bandwidth compared to the bandwidth of atomic transitions.

A configuration like shown in Figure 2 is used to solve multiple problems a bare laser diode has. The lense collimates the highly diverging radiation into a beam. The optical grating is used to feed a small portion of the emitted radiation back into the laser diode but prevent external radiation to enter the laser diode. This creates an external cavity and helps with stabilizing and narrowing the frequencies of the emitted radiation. With

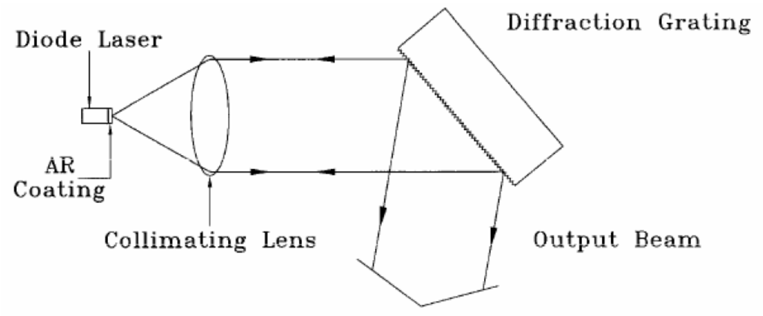

Figure 2: Schmeatic configuration of a laser diode using grating feedback [1]

this a bandwidth can be achieved that is much smaller than the bandwidth of atomic transitions.

2.3 Tuning a Diode Laser

Once the laser is lasing it emits mostly radiation of a single frequency. While this frequency depends on many different factors, it is just the frequency where the net optical gain is the highest.

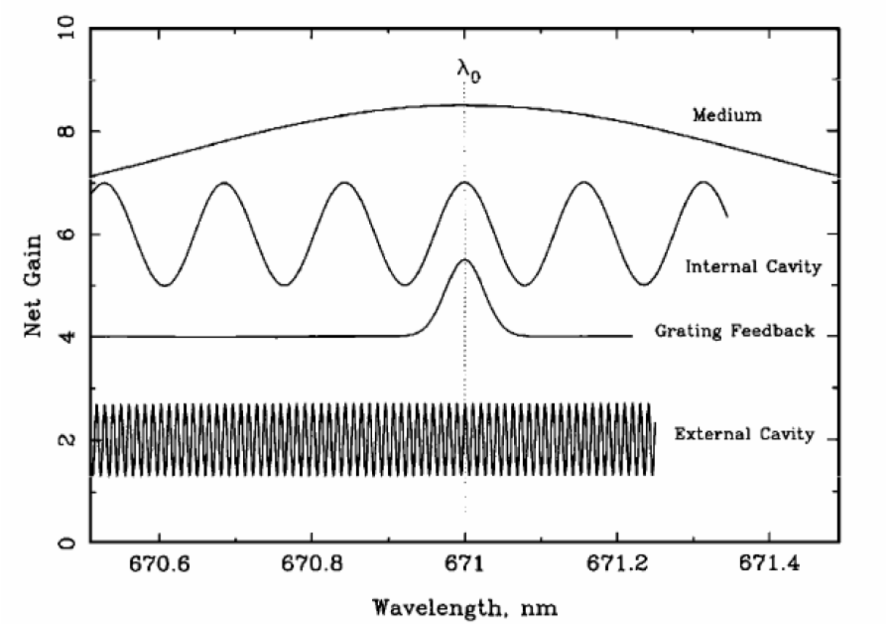

Figure 3: Schematic of the different contributions to the net optical gain of an arbitrary laser as a function of frequency. The curves are displaced relative to one another for clarity. [1]

In Figure 3 you can see the different contributions to the laser frequency. Those contributions will be discussed in the following sections.

2.3.1 medium gain

The material used for the semiconductor defines a maximum gain at some frequency. This peak is broad and is tuned (shifted) only by heating or cooling the laser diode to different temperatures. The medium gain is the most coarse tuning parameter and should be tuned at the beginning of the experiment.

2.3.2 internal cavity gain

The internal cavity gain is dependent on two things, the cavity length and the injection current.

Every optical cavity has a normal mode structure and therefore the net optical gain is periodic in frequency. The period length is changed by the cavity length and the cavity length is changed by the temperature.

The amount of injection current firstly also heats the laser diode and therefore changes the cavity length. Secondly the current changes the concentration of charge carriers in the active layer and by that also affects the net optical gain.

Because the internal cavity gain and the medium gain change with the temperature but at different rates, change in the temperature creates so called "mode hops" between different maxima of the internal cavity gain.

2.3.3 grating feedback gain

The dispersion of the optical grating feeds only a narrow frequency bandwidth back into the laser diode. This can be seen as a single peak in the gain and this peak is shifted by changing the angle of the grating. This angle can be changed either manually, for instance with a screw, or with a piezo crystal which changes its volume corresponding to an applied voltage.

2.3.4 external cavity gain

The external cavity consists of the reflective back facet of the laser diode and the reflection of the optical grating. In contrast to the internal cavity the external cavity is much larger. Therefore the period length of the gain to the frequency is much smaller.

2.3.5 net gain and mode hops

As mentioned earlier the frequency mainly emitted by the laser diode with grating feedback is defined by the frequency with the most net optical gain.

It is desirable to change the frequency of which the laser emits the most radiation continously. This is problematic due to the so called mode hops. Figure 4 should help clarify why mode hops occur.

While change in the angle will shift the maximum gain of the grating feedback, the maximum net gain also depends on the internal cavity gain. So the emitted frequency will hop from one maximum of the external cavity gain to another maximum. (e.g. e0 to e1 in Figure 4) Eventually the emitted frequency will also hop to another maximum of the internal cavity. (e.g. Int 0 to Int 1 in Figure 4)

To prevent these mode hops and allow a continuous sweep through different frequencies, the internal cavity has to be modulated via change in the injection current simultanously to the change in the grating angle via the piezo crystal.

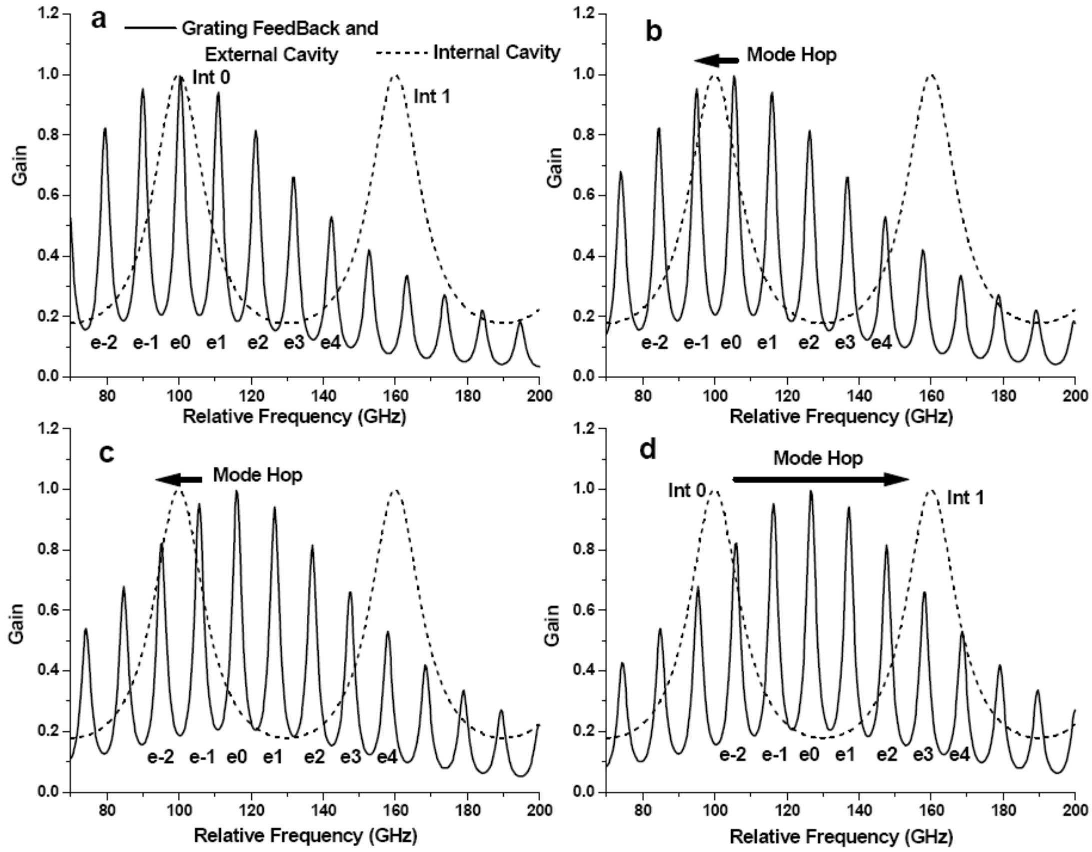

Figure 4: Series of graphs showing showing how the external and grating feed back mode shifts as the grating angle is changed. [1]

3 Procedure

The description of the procedure will be split up in different segments, so that we can focus on the steps necessary to get the absorption spectrum of rubidium. During the entire experiment everyone in the room needs to wear safety goggles!

3.1 Setting up the laser

Assuming the laser has already heated up and has reached its optimum temperature we need to align the laser first. For that you need to put the diode laser on an optical breadboard. In its direction of emission we put the rubidium absorption cell and behind it a photodiode detector to register the laserbeam.

Now we need to align the laser, so that its beam travels directly through the cell. Because the laser is not visible for the human eye we need an IR Card to see its position. The orange circle area of the card emits visible light if hit with the laserbeam. With this method you can locate the laser, although it is invisible. Put the TV camera in front of the card, so that you can observe the emitted light clearly. Your setup should look like the setup in Figure 5.

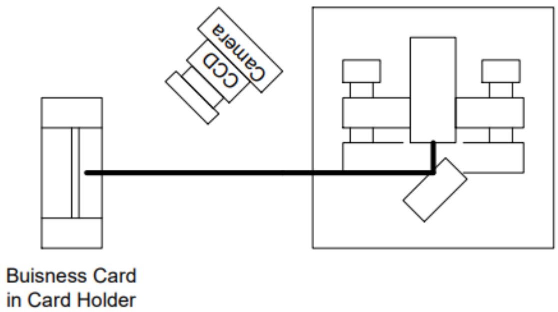

Figure 5: Setup for lining up the laser [1]

Now we increase the current of the laser, until speckles are visible on the card. The speckles and the increased intensity indicate that the current is above the laser threshold. Take a picture of the monitor where the laser is lasing and one where it is not lasing.

Our pictures are shown in Figure 6.

(a) diode in LED mode (b) diode in laser mode

Figure 6: Photos of the laser dot on the IR card

3.2 Calibration of the absorption wavelength

First we take the IR Card away and let the laser go into the rubidium cell. Then you rearrange the camera, so it looks directly in the side hole of the cell. For optimum results you should also dim the lights, so that no other light source may influence the photodiode. The intensity of the laser needs to be reduced otherwise the photodiode will be saturated. You need to put neutral-density filters infront of the laser.

Now you need to set up the oscilloscope for the calibration. For that you need to recreate the setup in Figure 7.

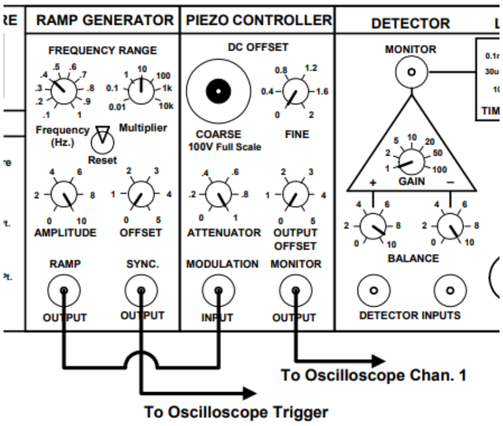

Figure 7: Setup of the oscilloscope for the calibration [1]

After that your experiment should look like in Figure 8.

Set the ramp generator frequency to 10 Hz and calibrate the settings so that the ramp generator produces a large-amplitude triangle wave.

Then you can start adjusting the laser current of the diode laser. When the rubidium cell starts emitting light in a consistant strength you found the right frequency. Take a photo of the camera monitor.

The one we took is presented in Figure 9.

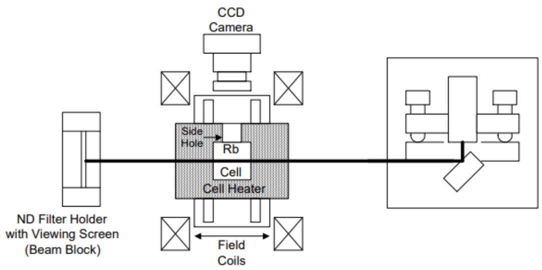

Figure 8: Experiment when calibrating the absorption wavelength [1]

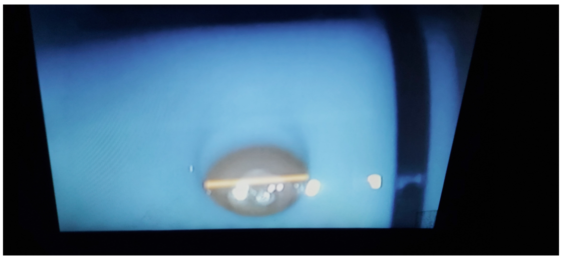

Figure 9: Photo of the fluorescence in the rubidium cell

On the oscilloscope you should now see mode hops. In the next part we will try to eliminate them through simultaneous modulation of the injection current and the piezo voltage.

3.3 The absorption spectrum

To get rid of the mode hops and to see a good picture of the absorption spectrum we change the setup of the experiment.

First of we rearrange the cables on the oscilloscope to what is shown in Figure 10.

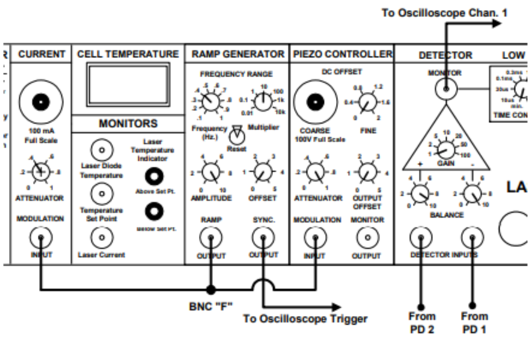

Figure 10: Setup of the oscilloscope for the absorption spectrum [1]

Now we want do produce a better picture of the spectrum. You turn the ramp generator amplitude up to maximum and follow that up with turning up the current attenuator knob. You should be able to use all the knobs and calibrations to make a picture like in Figure 11, but here it is inverted.

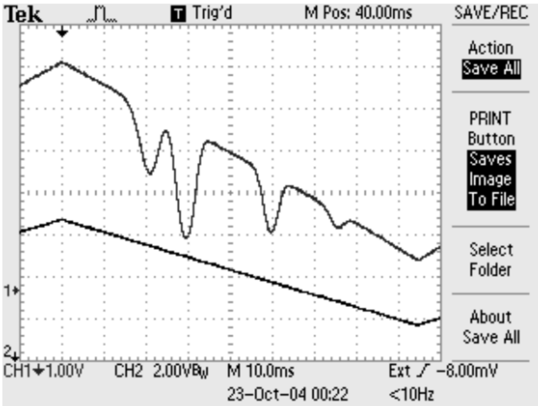

Figure 11: Picture of the absorption lines without mode hops [1]

Cleary this is not the optimal figure. The scan of the laser intensity and the laser frequency are scanned together here, but we can correct that. We add a second photodiode on the optical breadboard. Put a 50/50 Beam splitter in front of the rubidium cell and place the second photodiode in its path, like shown in Figure 12.

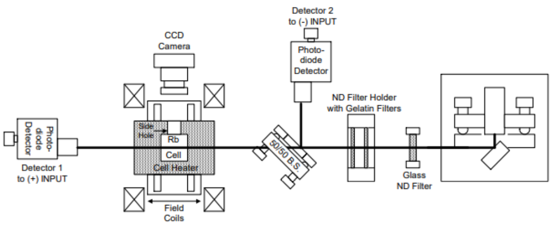

Figure 12: Final setup of the optical breadboard [1]

After final adjustments the final figure on the oscilloscope should be the spectrum shown in Figure 13.

If we compare our picture in Figure 14 with the theoretical one, its fair to say, that the recording of the absorption spectrum was successful.

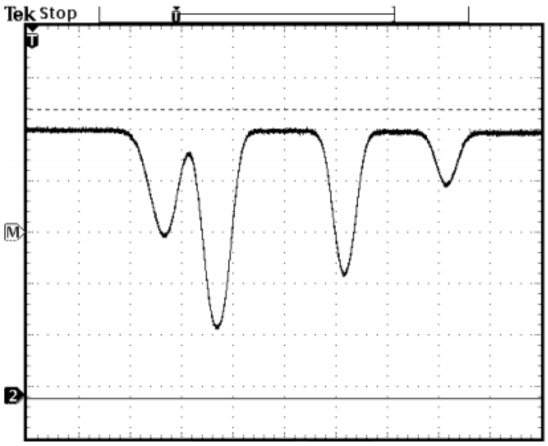

Figure 13: Inverted absorption spectrum of rubidium [1]

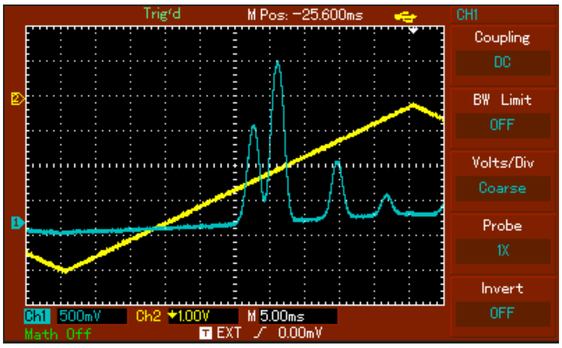

Figure 14: Our not inverted absorption spectrum of rubidium

References

[1] TU Dortmund. *Experiment Instructions. V60 Diode Laser Spectroscopy*. 2021.