Exercise FP2-09: Diode Laser With Optical Feedback

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Various properties of a diode laser are improved by the controlled optical feedback that is possible with a grating. Among them, the laser linewidth becomes narrower through the feedback process. While linewidth of free-running laser diodes are typically on the order of several tens of MHz, one can narrow them down to $\sim$ MHz or even below by using the technique of this experiment. In addition, grating-based optical feedback allows the wavelength of the laser to be tuned to a target value, for example, near resonance with an atomic transition wavelength. A narrow laser linewidth and the ability to tune the emitted wavelength in a controlled manner are prerequisites for high-resolution spectroscopy. Such spectroscopy is the basis for many modern quantum optics experiments, and you will see an example of this in another FP exercise (Rb spectroscopy).

GENERAL INFO

The exercise takes place in lab 4/33, Institut für Experimentalphysik, fourth floor in Viktor-Franz-Hess Haus, Technikerstrasse 25.

GOAL

The goal of this exercise is to achieve optical feedback into a diode laser via a grating and to investigate the resulting spectral changes.

RESPECT THE FOLLOWING LASER SAFETY GUIDELINES:

1. Never look directly into a laser!
2. Do not wear watches, jewelry etc. on your wrists and fingers to avoid reflections from them into your eyes.
3. Static electricity can damage the diode. Ground yourself by keeping one hand on the surface of the optical table, which is grounded, when touching the laser.

KEY CONCEPTS THAT NEED TO BE UNDERSTOOD FOR THIS EXERCISE

- Laser diodes and the principle of lasing [1–4], Schawlow-Townes linewidth [5], wavelength shifts with temperature and current and the basic principle of optical feedback (Littman and Littrow configuration) [6, 7]
- Optical resonators [8, 9]: free spectral range, finesse, linewidth, optical modes,...
- Diffraction gratings in the case of normal and grazing incidence [10]
- Photodiodes: basic principle of operation

EXPERIMENTAL SETUP AND TASKS

A diode laser is available with collimated emission in the red spectral range. The diode is temperature-stabilized by means of a temperature sensor and a feedback loop that sends current to a Peltier element. The input current that is sent to the laser diode is regulated by a current driver (Thorlabs), from which the input value can be directly read off. There is an internal photodiode in the laser diode housing that is used for measuring the optical laser power. Up to this point, the components are identical to that of the previous "Diode laser" exercise. You should also recognize the short planar-planar Fabry-Perot interferometer (FPI) from that exercise. The exercise consists of five steps:

(1) Characterized the diode laser without optical feedback. First, determine the approximate lasing threshold by eye: observe the laser emission on a piece of paper as you adjust the input current and find the point at which it becomes suddenly bright. Next, record the optical laser power, measured at the internal photodiode, as a function of the input current "Characteristic curve"). Do that carefully (and at small step size) in the threshold region!

(2) Achieve feedback in the Littrow configuration. The collimated light from the diode is sent to a grating (blaze: 1200/mm). Adjust the grating to roughly realize the Littrow configuration (Fig. 1). Set the diode input current just below the threshold value determined in the previous execrcise. Observe the 0th reflection order on a piece of paper. When the grating alignment is optimized, the 0th reflection order will "flash". Optimize the alignment by repeating the previous steps and then retake the characteristic curve. Measure the geometry and determine the wavelength of the laser (with error bars!) from the grating equation $m\lambda = d(sin\alpha + sin\beta)$.

(3) Achieve feedback in the Littman configuration. Rearrange the optics such that they realize the Littman configuration (Fig. 2). Keep the path short (about 3 cm between diode and grating, and another 3 cm between the grating and the mirror). Determine the threshold with and

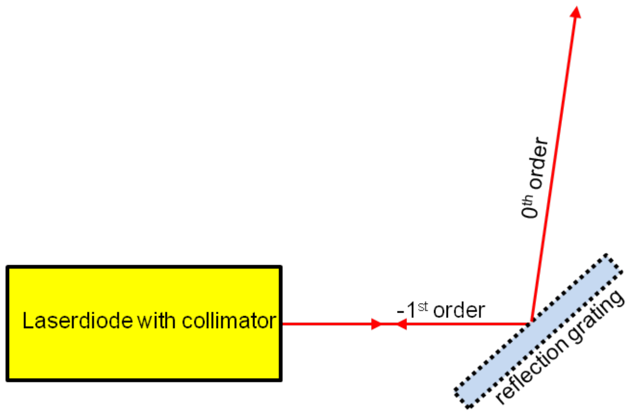

FIG. 1: Scheme of a laser in the Littrow configuration. The red lines/arrows indicate the paths/directions of the laser beams.

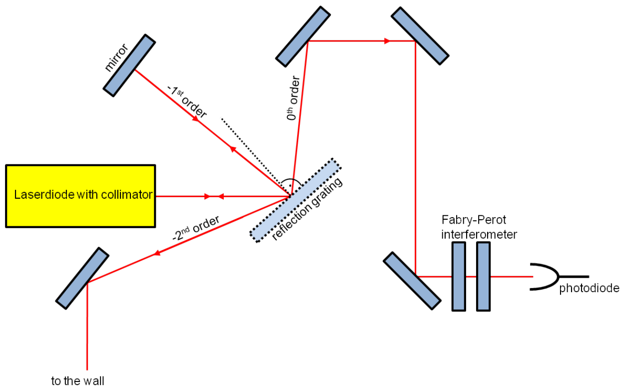

FIG. 2: Scheme of a laser in the Littman configuration. The red lines/arrows indicate the paths/directions of the laser beams.

without feedback. In the second case, simply block the mirror with paper. Determine the wavelength of the laser, and compare its value to that obtained in the Littrow exercise.

(4) Quantitative characterization of the wavelength tunability in the Littman configuration and (5) Determination of the free spectral range of the FPI. In the Littman configuration, you should measure how the wavelength can be tuned (mode selection) by adjusting the mirror. This measurement is carried out in two ways: a. by determining the beam geometry through the deflection angle of the 2nd diffraction order, and
b. by spectroscopy, with the help of a short Fabry-Perot interferometer (FPI).
The steps can be carried out in parallel. The grating should be adjusted so that the -2nd diffraction order passes narrowly by the laser (see Fig. 2). The positions of individual laser modes can then be traced out on the wall. In addition, the 0th order beam should be coupled via two mirrors into the FPI (Fig. 2, also FP 1). The length of the FPI is clearly less than 1 mm, and the free spectral range (FSR) will be between 500 and 1000 GHz, depending on the alignment. You should determine the exact value of the FSR in the course of this exercise. A cylindrical piezoelectric crystal, driven by a function generator, is used to vary the distance between the mirrors of the FPI. Observe the voltage ramp sent to the piezo and the transmission signal of the FPI on the oscilloscope, measured on a photodiode. For rough adjustment, the laser beam can be observed after the FPI on a piece of paper. For fine adjustment, optimize the photodiode signal on the oscilloscope. Now tune the horizontal (left-right) adjustment of the mirror that reflects back to the grating. You will see on the FPI signal how different laser modes swing past, that is, how the wavelength of the laser can be adjusted by varying the grating angle. Typically, you should be able to scan through a few FSRs on the FPI. Determine the approximate range over which you can tune the laser wavelength.

REPORT

After a brief introduction, the report contains a short section with the relevant theory discussion. This is followed by a section on the experimental procedure and data taking. The results are discussed in the next section. The report concludes with a brief summary and critical appraisal. Do not forget to discuss limitations and suggestions of how the data could be improved.

[1] `http://www.thorlabs.de/tutorials.cfm?tabID=24960`
[2] `http://www.rp-photonics.com/external_cavity_diode_lasers.html`
[3] W. Demtröder, *Laser spectroscopy* (Springer, 2002) , p. 221ff.
[4] W. Demtröder, *Laserspektroskopie* (Springer, 2007) , p. 149ff.
[5] P. Milonni and H. Eberly, *Laser Phyics* (Wiley, 1988) , p. 348ff.
[6] W. Demtröder, *Laser spectroscopy* (Springer, 2002) , p. 112ff and p. 312ff.
[7] W. Demtröder, *Laserspektroskopie* (Springer, 2007) , p. 76ff and p. 218ff.
[8] W. Demtröder, *Laser spectroscopy* (Springer, 2002) , p. 226ff.
[9] W. Demtröder, *Laserspektroskopie* (Springer, 2007) , p. 154ff.
[10] e.g. H. Hecht, *Optics* (Oldenbourg, 2001) , p.476ff.