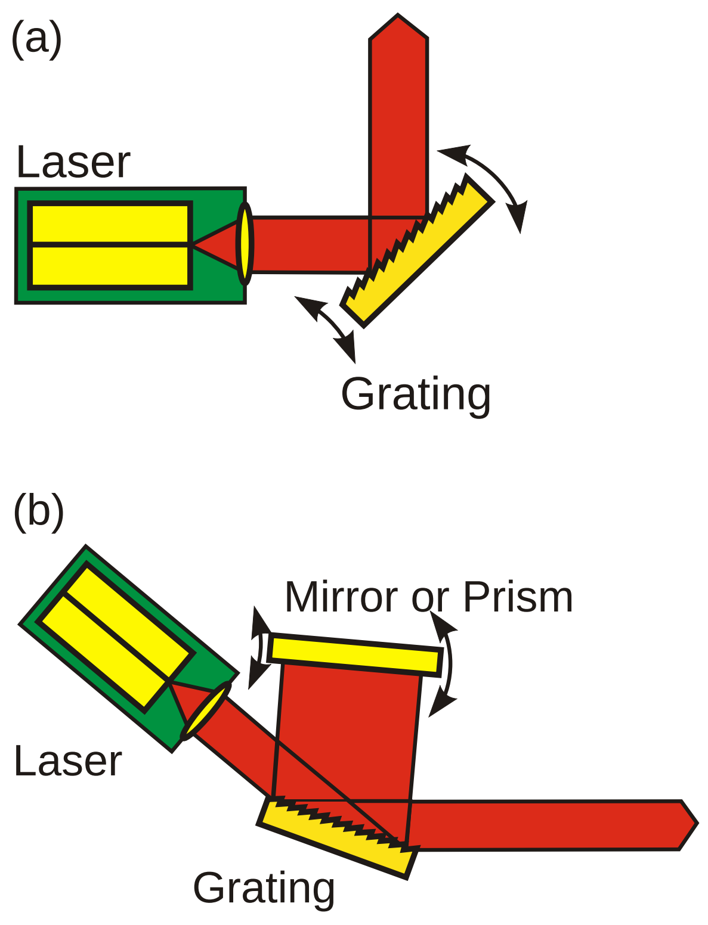
Robust external cavity diode laser (ECDL) and their application in water vapor and saturated-absorption rubidium spectroscopy

F. Schael
Inst. f. Physikalische und Theoretische Chemie
Universität Erlangen-Nürnberg
Egerlandstraße 3, 91058 Erlangen, Germany

L. Hildebrandt, J. Sacher, R. Knispel
Sacher Lasertechnik
Hannah Arendt Straße 3-7
35037 Marburg, Germany

1 Introduction

Compared to traditional lasers, diode lasers are generally small, compact, reliable, easy to operate, amenable to electronic high frequency modulation and temperature tuning. However, tuning characteristics of many commercially available standard diode lasers are far from ideal. ECDL, in which Fabry-Perot (FP) standard laser diodes are employed, can provide an attractive alternative. The objective of this work is to optimize the optical design of ECDL in Littman and Littrow configuration (Scheme 1) for robust sensor applications. The performance of the ECDL is demonstrated by water vapor and rubidium saturated absorption spectroscopy.



Scheme 1: ECDL in Littrow (a) and Littman (b) configuration.

Scheme 1 shows the design of Littman and Littrow ECDL. For the Littrow configuration, a diffraction grating is mounted so that the light diffracted in the first order is reflected back into the laser, while the light diffracted in the zeroth order is coupled out. For the Littman configuration, the light diffracted in the first order is reflected back to the grating by a mirror or prism. In both designs laser diodes with and without antireflection (ar) coating were employed

2 Results and Discussion

2.1 Optical design

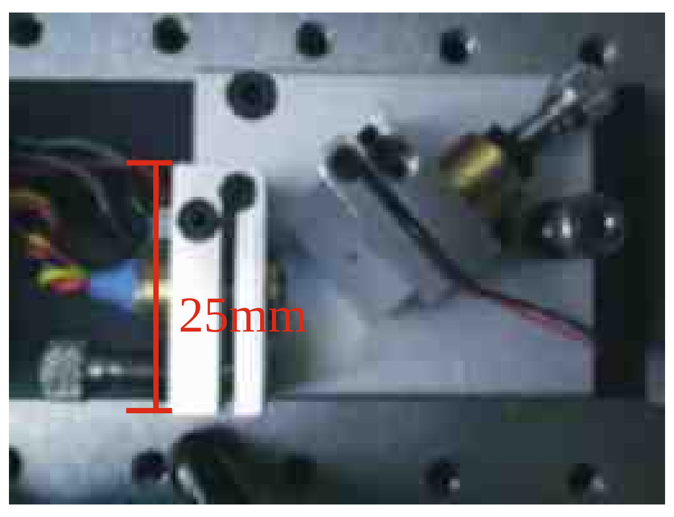


Fig. 1: Size reduced Littrow ECDL.

The size of optical and mechanical components in Littrow and Littman ECDL were systematically reduced to enhance thermal and mechanical stability of the laser cavities. Exemplary, in Fig. 1 the dimensions of a Littrow ECDL are shown.

Various reflecting elements (mirror, prisms) were employed in Littman ECDL. Exemplary, in Fig. 2 the tuning behaviour of a laser using a mirror and a prism, respectively, is compared. A laser diode with 815 nm central wavelength was utilized in this experiment. The laser cavity is not realigned during wavelength tuning.

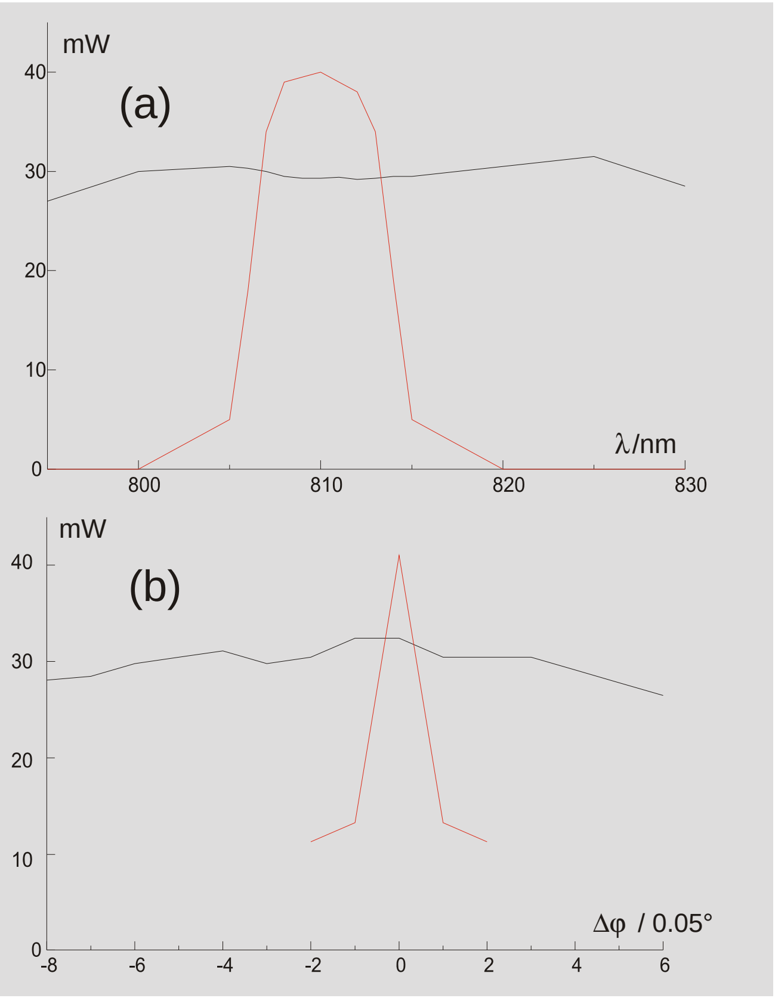


Fig. 2: Comparison of the tuning behaviour of Littman ECDL with a mirror (red lines) and a prism (black lines). (a) Output power vs. wavelength without realignment of the cavity. (b) Output power vs. tilt angle of diffraction grating

The cavity in which a prism is employed can be tuned from 795 nm to 830 nm with constant output power, while the cavity with a mirror shows stable laser operation in a destinct wavelength region only (Fig. 2a). In Fig. 2b the influence of the tilt angle of the grating on the output power is shown. If a mirror is employed in the Littman configuration, the tilt angle has to be controlled within an accuracy of 0.05°, while for the design utilizing a prism, the tilt angle is not very crucial. It can be concluded, that the prism design leads to significant simplification of alignment procedures, while employment of a mirror results in a higher output power.

2.2 Spectrum

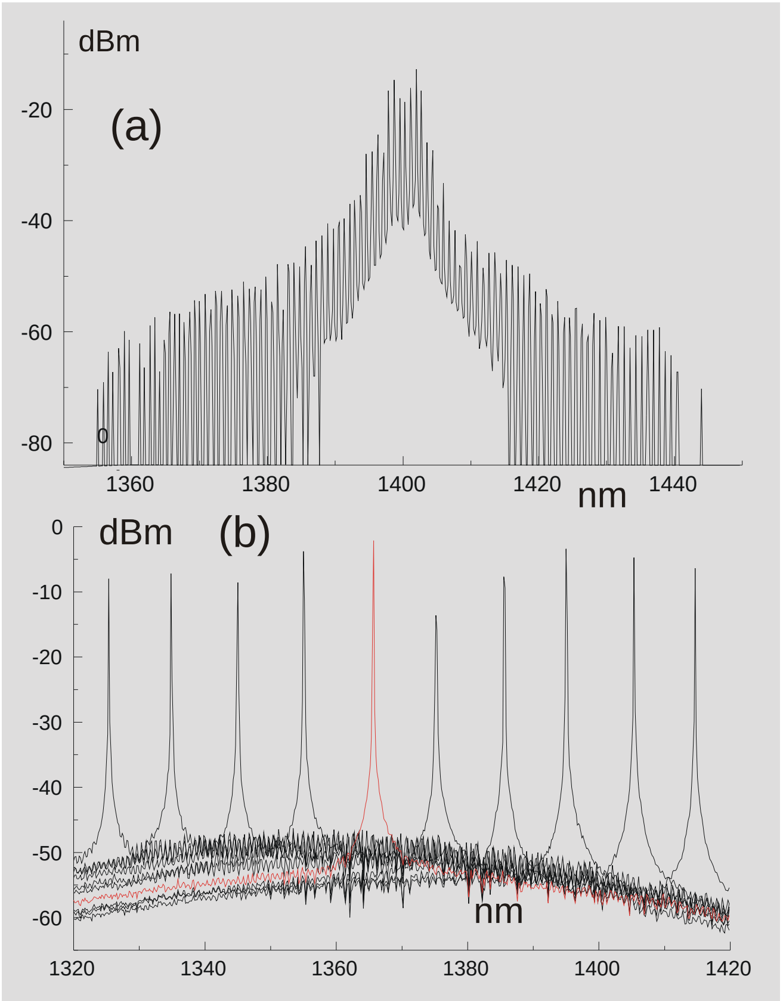


Fig. 3: Exemplary spectrum of a free running FP diode (a) and of the same diode in an ECDL (b).

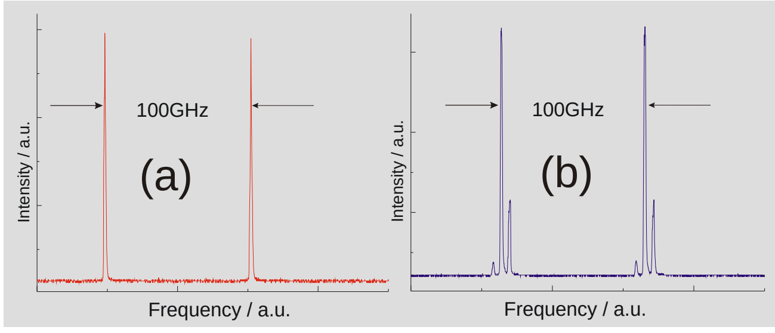


Fig. 4: High resolution emission spectra of a Littrow ECDL using a diode with (a) and without (b) ar coating obtained with a Fabry -Perot spectrometer.

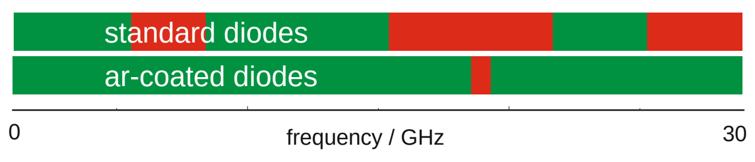


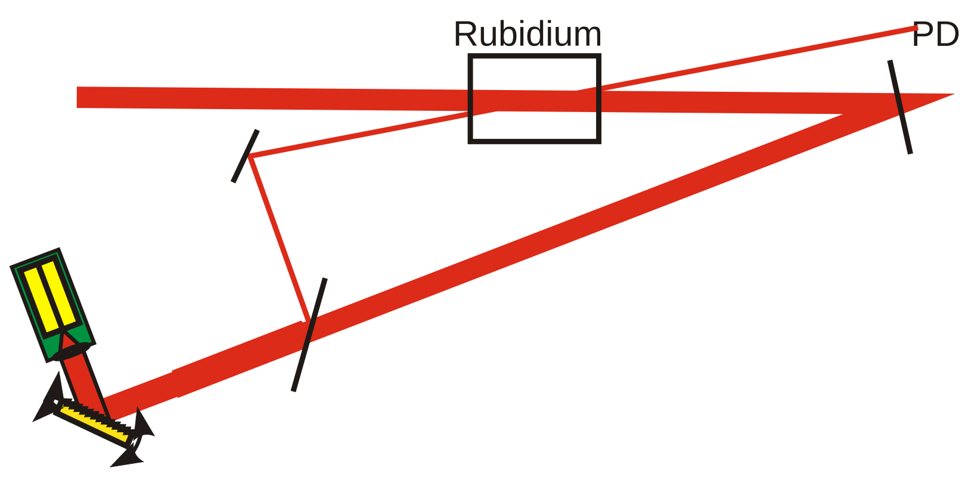
Fig. 5: Exemplary emission ranges with less than 1 % side mode intensity (green) for ECDL with diodes with and without ar-coating at 780nm.

In Fig. 3, the spectrum of a free running FP laser diode (a) and of the laser diode a in an Littman ECDL (b) is shown.The free running FP diode exhibits multi-mode emission, which can be tuned by several nm through temperature and laser current. In an ECDL, single-mode emission with the same ar-coated diode (reflectivity< 2e-4) can be achieved. The wavelength tuning range in this example was 1325 nm to 1415 nm with mode hop-free tuning regions of ca. 100 GHz. Employing FP lasers with central emission wavelengths of 633 nm and at 852 nm, more mode hop- free tuning ranges of ca. 300 GHz and a coarse wavelength tuning of more than 12 nm was achieved. Single-mode emission of the ECDL can significantly be improved by employing ar-coated FP laser diodes (Fig. 4). Exemplary, in Fig. 5 the laser frequency regions, where the intensity of the side modes were less than 1 % of that of the main laser line, are compared for ECDL using diodes with and without ar coating.

2.4 Applications

Rubidium saturated-absorption spectroscopy

An ECDL in Littrow configuration (output power 40 mW, laser linewidth < 30 MHz) was employed for Doppler-free spectroscopy of rubidium vapor at around 780 nm. In scheme 2 the experimental set-up is shown.



Scheme 2: Experimental setup

A beamsplitter devides the laser beam in a strong pump and a weak probe beam, which pass the cell approximately collinear in opposite propagation directions. While scanning the laser wavelength through an atomic absorption band, all transitions of atoms belonging to velocity classes with velocity components in the laser propagation direction are excited and contribute to the observed absorption linewidth. Pump and probe beam are propagating in opposite directions, and the only velocity class of atoms which is detectable with pump and probe beam at the same time are with a zero velocity component in the propagation direction of the laser beams. These transitions are saturated by the pump beam and appear in the spectrum recorded with the probe beam as Lamb-dips. The linewidth of the ECDL enabled observation of several separated dips in line 2, which can be assigned to cross over transitions (see Fig. 7).

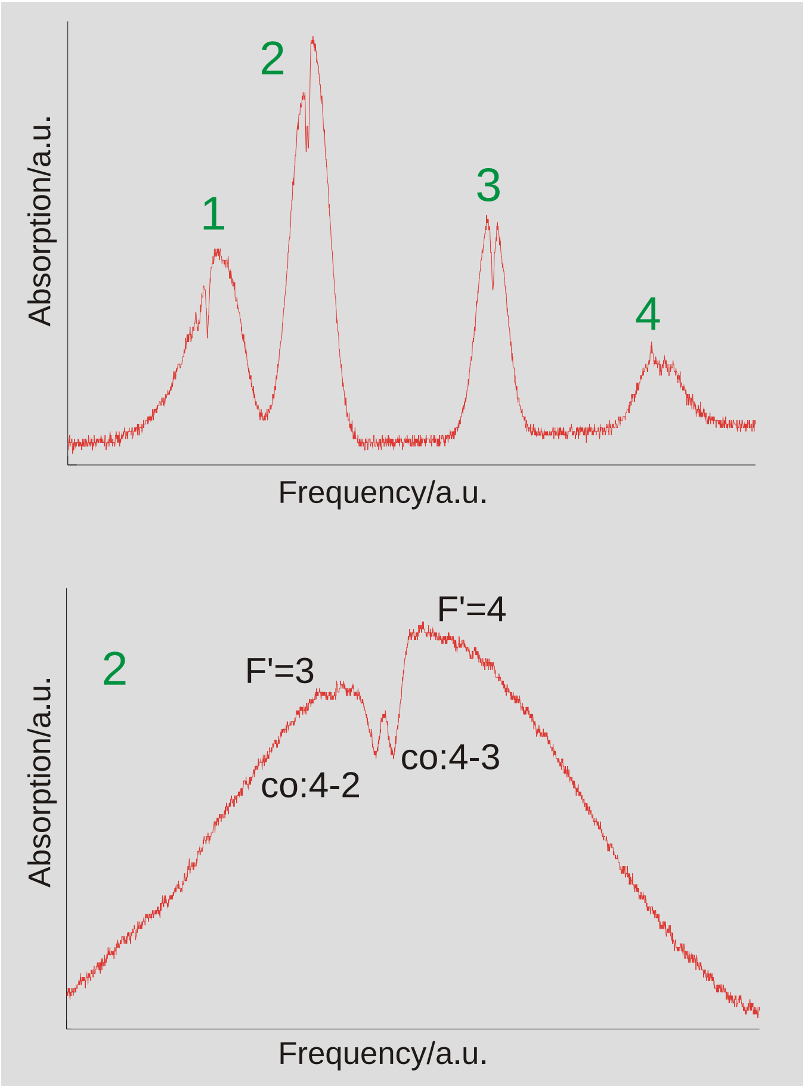


Fig. 6: Absorption spectrum of rubidium vapor around 780 nm (cf. Fig. 7 for assignments).

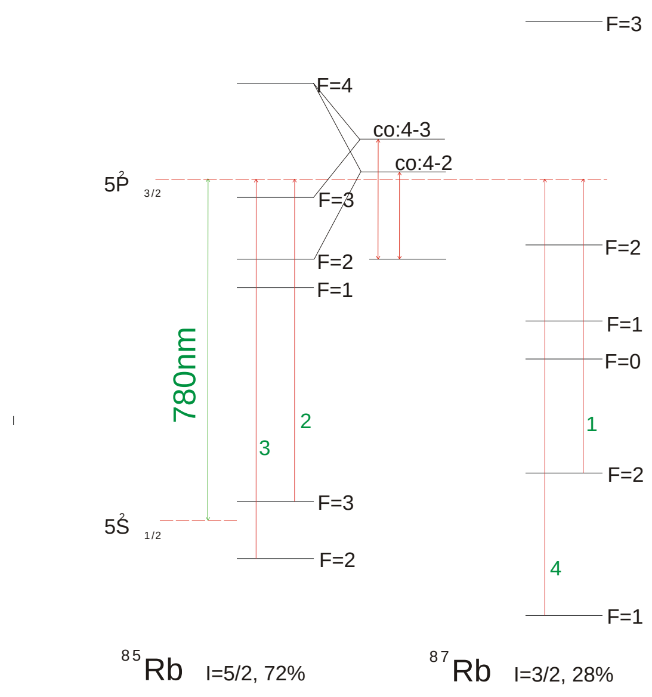


Fig. 7: Energy level diagram of natural rubidium for the transitions around 780 nm [2].

Water vapor absorption spectroscopy

Absorption lines of atmospheric water were detected around 1388 and 1368 nm utilizing an Littman ECDL (5 mW Output power, 1390 nm central emission wavelength). A wavelength region of approximately 1 nm can be covered by electro-mechanical fine tuning (Fig. 8). In a simple experiment, the partial pressure of water vapor, which was equilibrated with liquid water in a 10 cm absorption cell, was varied through variation of the cell temperature. In Fig. 9 the detected optical density at the absorption maximum (1367.86 nm) is plotted versus the absorption coefficient calculated according to the Hitran96 database [3].

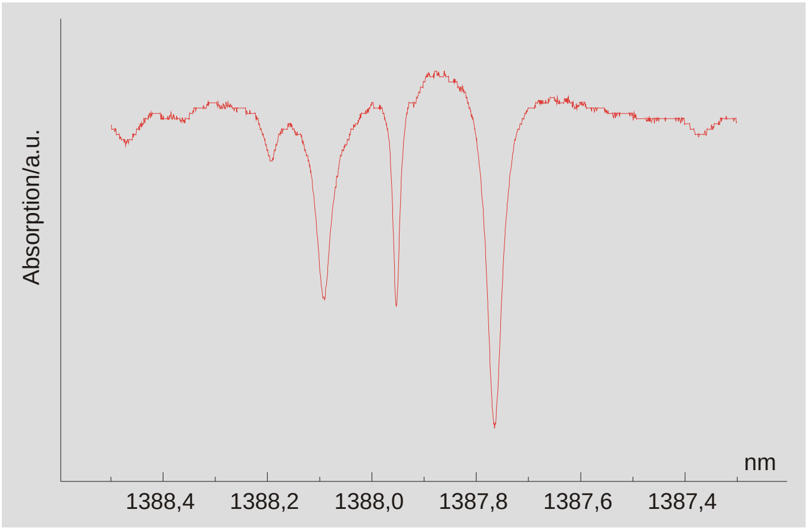


Fig. 8: Absorption spectrum of water vapor around 1388 . nm

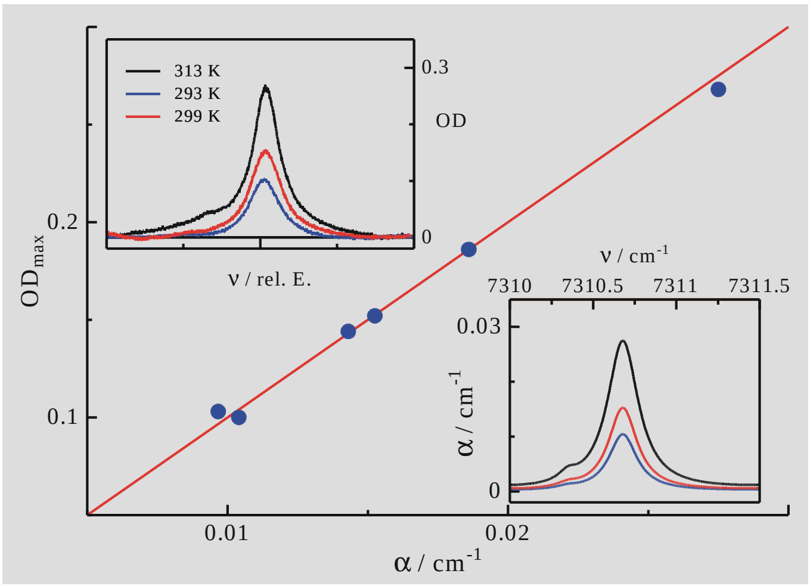


Fig. 9:Experimental (top inset) and calculated absorption profiles (bottom inset) of water at 1367.86 nm and plot of maximum optical density vs. absorption coefficient according to the Hitran96 database (see text).

Sensitive absorption measurements can be performed by applying wavelength modulation techniques. The laser wavelen can be modulated by changing the laser-di current or by changing the voltage of the piezoelectric actuator. In this experiment, wavelength modulation spectroscopy was accomplished by mixing a low (typ 1-100 Hz) and a high frequency voltage (up to 3 kHz) for driving of the piezoelectric actuator. The low frequency tunes the laser wavelength over the absorption band, while the high frequency modulates the wavelen sinusoidally by about the FWHM of the absor The 2f absorption spectra recorded with an Lock-in amplifier under the same conditions as direct absorption measurements (see abo are shown in Fig. 10. While this experiment demonstrates the ability of ECDL for simple electronic modulation techniques, further work is neccessary to improve long-term stability of piezo driven mechanical components, e. g. of the mirror and prism holder, respectively.

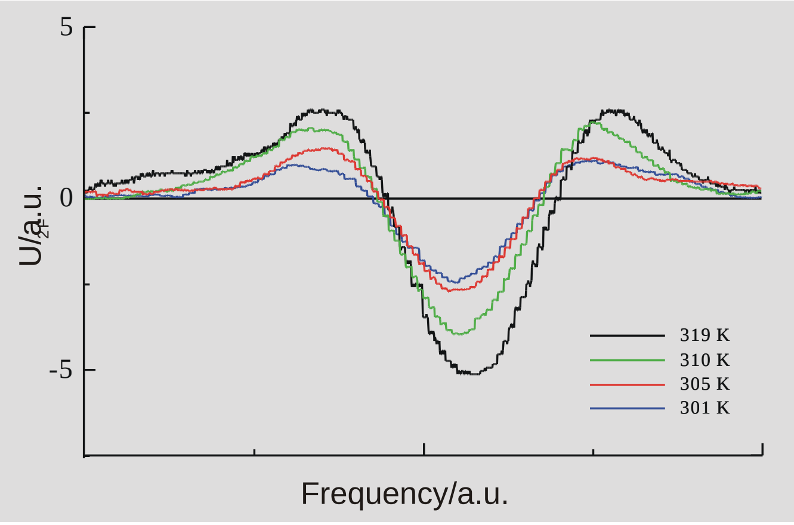


Fig. 10: 2f absorption spectra of water vapor 1367.86 nm (same conditions as measurements in Fig. 9).

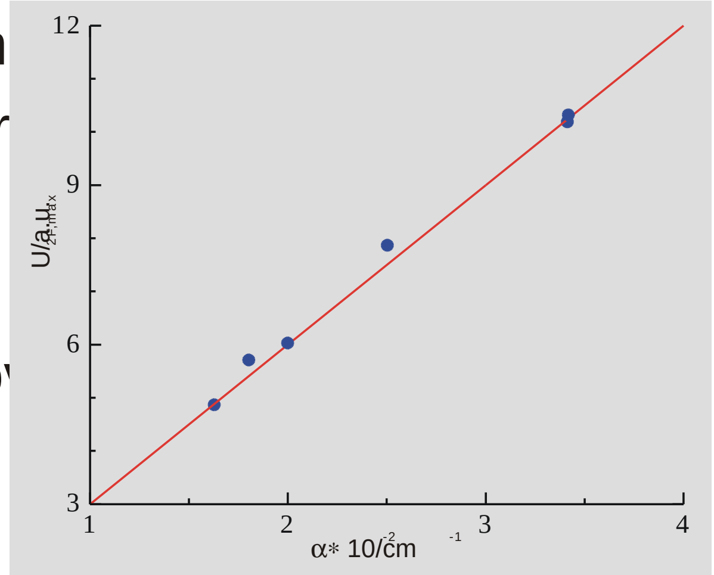


Fig. 10: 2f absorption intensities at 1367.86 nm vs. absorption coefficient according to the Hitran96 database.

3 Summary

External cavity diode laser (ECDL) in Littrow and Littman configuration were optimized. The optical design obtained in this work leads to significantly improved mode stability, alignment procedure and wavelength coverage. Wavelength that are currently covered with various laser diodes include the regions 625 - 700, 730-1090, and 1250-1660 nm, limited at this point by the availability of laser diodes. Diodes emitting at shorter wavelengths have not been employed yet because of their relatively short lifetimes. Most diodes emitting at longer wavelength currently require operation temeratures below room temperature. Linewidths achieved were typically 10 MHz. The mode-hop free tuning range was at least 50 GHz and 4 GHz for the Littman and the Littrow configuration, respectively. Simple application examples demonstrate the performance of ECDL. Further work is in progress to improve mirror and prism holder for wavelengt modulation techniques using the piezoelectric actuator.
The current study underlines the promising potential of ECDL as cost effective laser sources for monitoring systems and sensor applications.

References

[1] C.E. Wieman, L.Hollberg, " Using diode lasers for atomic physics" ; Rev. Sci. Instrum. 62 (1) 1991

[2] G.N. Rao, M.N. Reddy, E. Hecht " Atomic hyperfine structure studies using temperature/current tuning of diode lasers: An undergraduate experiment ", Am. J. Phys. 66, 702-712 (1998).

[3] cf. L.S. Rothman, R.R. Gamache, R.H. Tipping, C.P. Rinsland, M.A.H. Smith, D.C. Benner, V.M. Devi, J.-M. Brown, R.A. Toth, " The Hitran molecular database: editions of 1991 and 1992 ", J. Quant. Spectrosc. Radiat. Transfer 48, 469-507 (1992).

Acknowledgement

Financial support by the Bundesministerium für Bildung, Forschung und Technologie is gratefully acknowledged (Förderprogramm Laser 2000, Forschungsverbund “Grundlegende Untersuchungen zur Gasanalyse mit Diodenlasern“; FKZ 13N7164, 13N7157).

SACHER LASERTECHNIK

SIGILLUM ACADEMIAE FRIDERICO ALEXANDRINAE