Rubust external cavity diode laser (ECDL) with implemented antireflection coated blue laserdiodes and their performance in atom absorption spectroscopy

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Robust external cavity diode lasers with implemented antireflection coated "blue" laser diodes and their performance in atom absorption spectroscopy

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Introduction

Compared to traditional lasers, diode lasers are generally small, reliable and easy to operate. However, tuning characteristics of many commercially available standard diode lasers are often far from ideal.

External **C**avity **D**iode **L**asers (**ECDL**), in which **antireflection** (**AR**) coated Fabry Perot laser diodes can be utilized, provide an attractive alternative with wavelength tuning ranges of up to **100 nm**, linewidths of several hundred kHz and cw-power of up to **200 mW**. They are small-sized and suitable for electronic high frequency modulation which makes these light sources desirable for sensor application. [1]

Recent improvements of room temperature diode laser technology for data storage applications have given rise to enhanced availability of semiconductor lasers with wavelengths in the **blue** spectral region, which have suitable beamprofiles and reasonable lifetimes (>5000 h). Sacher Lasertechnik has developed **AR-coatings** for these diodes in order to optimise the performance of our **TEC 100-Littrow** and **TEC 500-Littman** lasersystems.

Results and Discussion

1 ECDL Design

Typical (singlemode) standard laser diodes have a linewidth of ten to several hundred MHz. The emission wavelength of such semiconductor lasers can be tuned by injection current and temperature changes in the order of MHz/mK and MHz/μA. [1] For the use of singlemode laser diodes within an external cavity, the front facet needs to be **antireflection coated**. This suppresses the modes of the laser diode. The facets of the laser diodes have a typical reflectivity of about 30% to 40%, due to the difference in the refractive index between air and semiconductor material. Several dielectric layers will result in a residual reflectivity of typically **R<0.02%**.

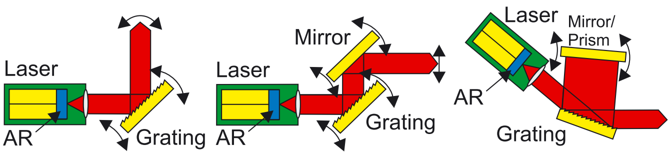

Fig. 1: ECDL in Littrow configuration without (left) and with (middle) beam correction mirror and in Littman configuration (right).

Fig. 1 schematically shows an ECDL in Littrow configuration. [2,3] The collimated light out of the antireflection coated front facet hits a holographic grating. The light diffracted in the first order is reflected back into the laser diode, while the light diffracted in the zeroth order is coupled out and can be used for the experiments. The wavelength change is achieved by tilting of the grating. This also results in an angle change of the laser beam, or a parallel shift when implementing a beam correction mirror. A second concept is the external cavity in Littman configuration. [4] Again, the output beam of the laser diode is directed onto the grating. The first diffraction order of the grating hits a reflection element (mirror or prism) rectangular and is reflected back onto the grating and from here back into the diode in order to build the resonator of the laser. The **size** of the optical and mechanical components in Littrow and Littman ECDL were systematically **reduced** to enhance **thermal** and also **mechanical** stability of the laser cavities. [5] Fig. 2 shows a picture of our Littrow ECDL with geometrical dimensions.

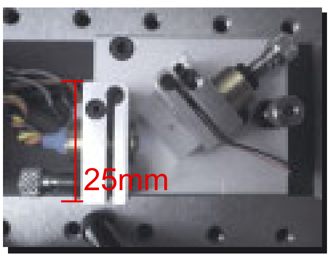

Fig. 2: Picture of our size reduced Littrow ECDL with dimensions.

2 ECDL Characteristics

Littrow and Littman ECDL have different characteristics which make them suitable for different types of applications. The Littrow ECDL is very **easy to align**, cost effective and has a larger output power than Littman ECDL. The main drawback is a moving beam when tuning the wavelength. The main application is **Raman** spectroscopy and optical pumping or cooling of atoms or molecules, where a small linewidth, exact positioning of the wavelength and high cw-power is needed, but a larger de-tuning of the once fixed wavelength is not routinely done. [6] For example more than **130 mW** of cw-power at around **785 nm** and **>150 mW** at **830 nm** have been achieved recently. If wavelength tuning is required for more than a few GHz and the beam has to be stable in position (for example because the experiment requires a long optical path or the laserlight has to be coupled into a fibre), the Littman resonator is preferable, because de-tuning is received with turning the reflection optic and not the grating. [7] Both configurations contain a piezoelectrical element which tunes the wavelength quickly for about 1 nm. At around 633 nm, 780 nm and 1380 nm to 1650 nm a **modehop free** tuning of more than 1 nm can be achieved this way, limited at this point only by the usage of a piezo for wavelength tuning. With a DC-motor, the whole tuning range of >100 nm can be modehop free tuned at 1550 nm for example. A summary of the accessible cw-power is given in Tab. 1. Wave-length that are currently covered are limited at this point by the availability of suitable laser diodes.

wavelength	Littrow cw-power	Littman cw-power
400 – 420 nm	15 – 25 mW	3 – 8 mW
625 – 700 nm	8 – 15 mW	2 – 5 mW
730 – 1100 nm	50 – 200 mW	10 – 40 mW
1230 – 1660 nm	5 – 15 mW	2 – 5 mW

Tab. 1: Accessible cw-power of our ECDL.

Fig. 3a shows the emission spectrum of a Fabry Perot laser diode with a centre wavelength of about 1400 nm. The multimode behaviour of this laser is evident. This spectrum can be wavelength tuned by a few nm with changes in temperature and current. Fig. 3b shows the tuning behaviour (10 different wavelengths shown in the picture) of the same laser diode in a Littman cavity after it is AR-coated. With a **sidemode suppression** of about **40 dB**, the wavelength of this lasersystem can be **tuned** from **1325 nm to 1415 nm** with modehop free regions of 1 nm. High resolution measurements with a scanning Fabry Perot interferometer show the singlemode behaviour of the lasersystem (Fig. 3c). The **linewidth** of such a laser is below **1 MHz**.

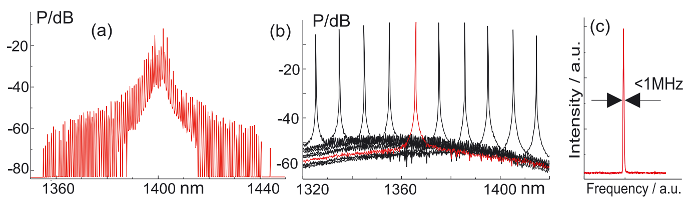

Fig. 3: (a) Emission spectrum of a Fabry Perot laser diode; (b) Tuning characteristics of an AR-coated laser diode in external cavity; (c) High resolution measurement with a Fabry Perot interferometer.

3 Antireflection Coated "blue" Laser Diodes

The facets of the laser diodes have a typical reflectivity of about 30% to 40%, due to the difference in the refractive index between air and semiconductor material. Even with a good feedback from the grating there will be three cavities which disturb the singlemode behaviour of the whole laser. [8] Fig. 4 shows these three resonators of such a diode laser in an extended cavity. The resonators are built by: 1) The reflecting element and the rear facet of the laser diode. 2) Both facets. 3) The front facet and the reflecting element.

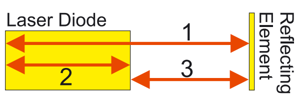

Fig. 4: The three resonators of an uncoated laser diode in an extended cavity.

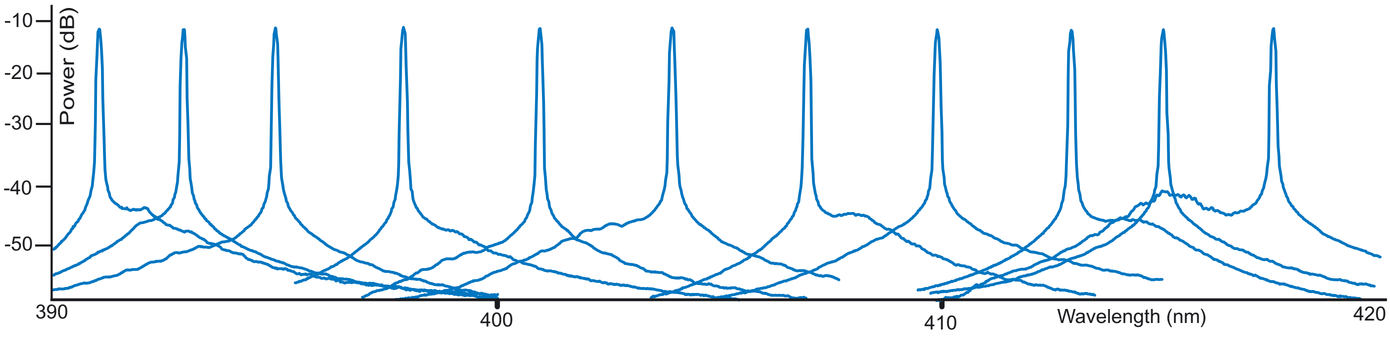

Fig. 6: Compilation of typical output spectra with various AR-coated "blue" laser diodes in ECDL archived so far.

We did perform an **antireflection** coating for such a "**blue**" diode with several dielectric layers which results in a residual reflectivity of below **R<0.5%**. This way both disturbing resonators (2 and 3 in Fig. 4) vanish and the laser will only run if the grating is properly aligned. The success of this process is shown in Fig. 5. In the P-I curve, the uncoated diode shows a threshold of 40 mA and a thermal saturation at above 52 mA which results in a maximum accessible power of below 15 mW. After coating, the same laser diode shows a threshold of above 60 mA and a thermal saturation starting at 85 mA. This AR-coated laser diode implemented in our Littrow cavity will result in a threshold of 42 mA and more than 20 mW at above 70 mA. Since this laser shows no thermal saturation at currents lower than 70 mA, one can achieve up to **30 mW** at around 80 mA. However, this might result in lowering the lifetime of the diode according to the exp (E_A/kT) law.

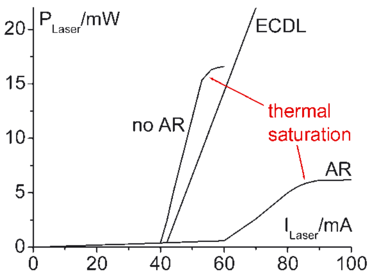

Fig. 5: P-I curve of the same laser diode uncoated, AR-coated and in TEC 100 Littrow-ECDL.

4 Performance of AR-Coated "blue" Laser Diodes in ECDL

We have tested the same diodes before and after AR-coating in Littrow and in Littman ECDL. For Littrow we found a small improvement of the modehop free tuning of >25 GHz instead of about 20 GHz without coating. The main improvement was the behaviour of the laser in general. With the uncoated diode we found it was very hard to align the cavity and even if it was aligned, there were large regions where multimode behaviour occurred. We have seen this behaviour before with uncoated diodes at 780 nm. [5] With the use of **AR-coated** diodes the laser barely had any multimode regions. The achieved power was increased from 15 mW to above 20 mW and the coarse tuning range was increased to lower wavelengths: for example 395.5 nm to 399 nm instead of 397 nm to 398.5 nm without AR-coating. With a little cooling or heating this tuning range can be increased for another ±1 nm. The sidemode suppression in ECDL is >30 dB. An example at **410 nm** is shown in Fig. 7. The uncoated laser diodes did not run in Littman ECDL at all. With AR-coating we found >5 mW and again >25 GHz modehop free tuning. The coarse tuning was comparable for **Littrow** and **Littman**. Since the laser chips are very long (1 mm), we did not expect to get a larger modehop free tuning in Littman than in Littrow. A very important aspect is, that the Littman can easily be fibre coupled into a 6 µm singlemode fibre and tuned without a drawback in coupling efficiency. Fig. 6 shows a summary of the wavelengths we can get from our lasersystems. As it can be seen from Fig. 8, the beamprofile of the **blue laserlight** is elliptical and almost gaussian in both directions.

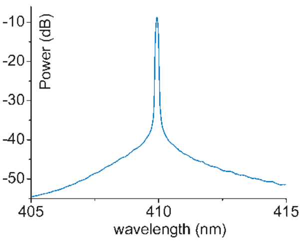

Fig. 7: AR-coated laser diode in ECDL.

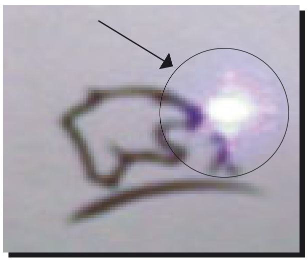

Fig. 8: Picture of the beamprofile of the blue laserlight.

5 Application example: Indium-atom absorption and fluorescence

Important applications for such a lasersystem are atom absorption spectroscopy (AAS), fluorescence spectroscopy or atom lithography where cost-effective lasers are needed in the blue spectral region. One of the first spectroscopic results with an uncoated laser diode in ECDL were presented by H. Leinen et al. [9] But although their spectroscopic results were excellent, their system showed a very poor beamprofile and also the tuning characteristics and specifications were unsatisfying at this stage

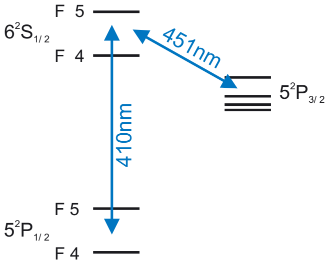

Fig. 9: Excerpt from the Indium level scheme at 410 nm.

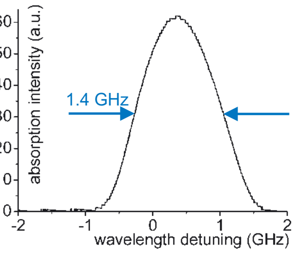

Fig. 10: Absorption profile of Indium at 410 nm.

Fig. 11: Indium cell with blue fluorescence.

In a very **simple set-up** we have detected fluorescence and also absorption of light. The laserlight from our **TEC 100-Littrow** lasersystem at 410 nm is directed through the absorption vacuum-cell – which is filled with **Indium** metal – and hits the Si-detector. The cell is heated to >1300 K for getting much of the element in vapour condition. Fig. 9 shows an excerpt from the Indium level scheme. The $6^2S_{1/2}$ exited state of Indium vapour was reached from the $5^2S_{1/2}$ ground state by **absorption** of **410 nm** laser light. Fig. 10 shows the absorption profile with a linewidth of about 1.4 GHz (FWHM). The exited stage can decay into either the $5^2P_{3/2}$ or back into the $5^2S_{1/2}$ state, while emitting 451 nm or 410 nm light in the process. Fig. 11 shows the heated Indium cell with this **blue fluorescence**.

Conclusion

We have successfully antireflection coated "**blue**" Nichia diodes and employed them to our Littrow and Littman ECDL. We demonstrated the performance of the lasersystems for spectroscopy. In general we are proud to provide a turn-key "**blue**" ECDL-system which is suitable for industrial applications.

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