Spectroscopy with Diode Lasers

1. Introduction

The use of diode lasers in spectroscopy caused a significant progress in gas and vapor analysis. Main reasons for this are the low costs and the easy handing of diode lasers. With the development of diode lasers, the concepts for diode laser spectroscopy became more sophisticated and effective. Diode laser spectroscopy started with the use of Fabry Perot laser diodes. Due to the lack of single mode emission and tunability , DFB laser diodes as well as external cavity diode laser concepts have been developed. This technical documentation introduces the different concepts of tunable diode lasers and gives a foundation for choosing the correct decision before using such spectroscopic solutions.

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2. Fabry Perot Diodes (FP Diodes)

Fabry Perot laser diodes which are manufactured basing on the material system GaAlAs/GaAs operate longitudinally single mode as long as the chip length is not too long. Laser diodes with a chip length below 500 µm are often single mode operating, laser diodes with a longer chip length usually operate longitudinally multimode. Fig. 1 shows the a typical optical spectrum of a Fabry Perot laser diode measured by a Optical Spectrum Analyzer and a Fabry Perot interferometer.

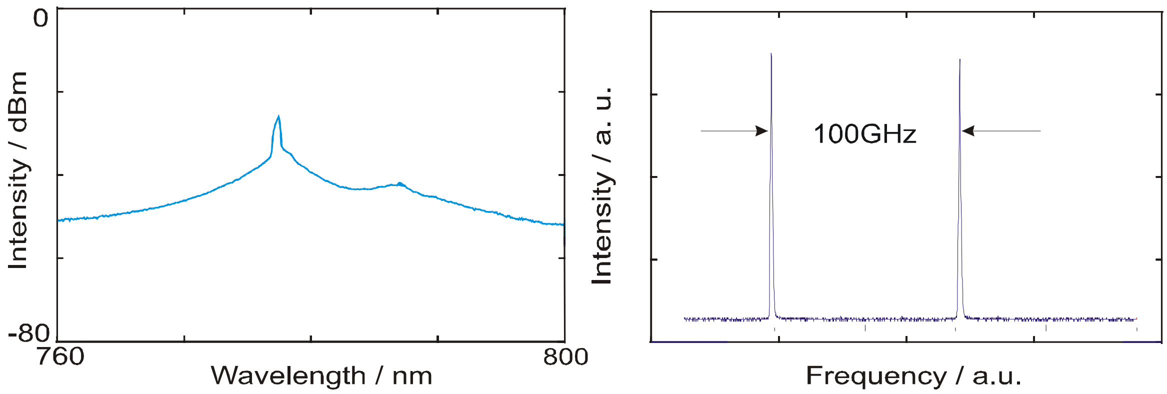

Figure 1: Optical Spectra of a free running Fabry Perot laser diode. The left hand side shows the spectrum measured with an Optical Spectrum Analyzer. The right hand side shows a typical Fabry Perot spectrum. The free spectral range is 100GHz.

Tuning of the emission wavelength of Fabry Perot laser diodes can be performed by changing the temperature of the laser case or by changing the injection current.

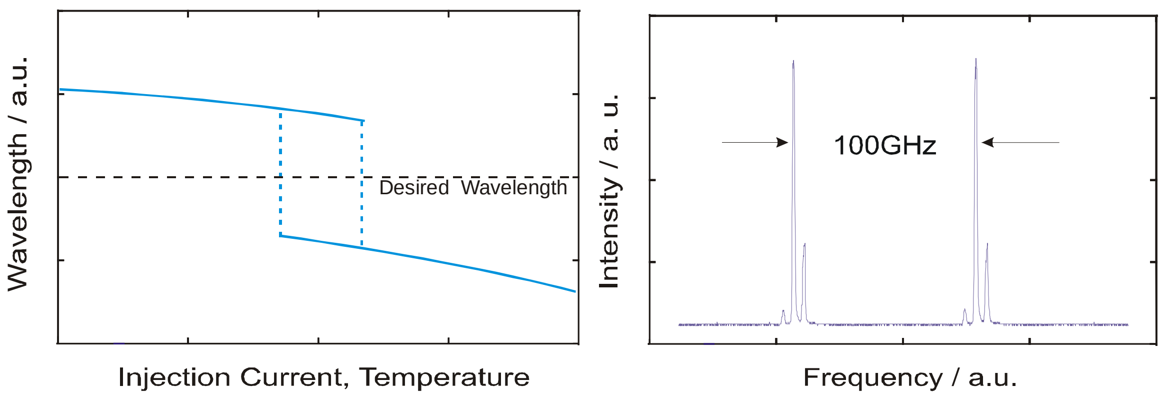

Figure 2: Worst case scenario for using Fabry Perot laser diodes in spectroscopy. The left hand side shows a mode-hop which appears just at the requested wavelength. The right hand side shows a weak multimode spectrum of a free running Fabry Perot laser diode.

<u>Change of Temperature:</u> The change of the laser temperature has two effects on the emission of the laser diode:

1) The refractive index of the laser material is changed. This causes a shift of the lasing modes with the laser temperature. An increase of the laser temperature causes a reduction of the wavelength of the laser modes.

2) The gain of the laser material is shifted to different wavelength. This causes a change of the emission wavelength of the laser diode. An increase of the laser temperature causes an increase of the wavelength of the laser gain.

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Since the change of the wavelength of the lasing modes and the change of the center wavelength of the optical gain are e.g. not synchronous, frequent mode-hops and regions of multimode emission appear. There is even a possibility that a mode hop appears just at the wavelength which is required for the spectroscopy experiment like shown in fig. 2.

Change of Laser Current: The change of the injection current of laser diodes causes a change of the temperature within the active region of laser diode. Due to this, an increase of the injection current shows the same behavior as an increase of the temperature of the laser mount.

Comparison: Changing the temperature of the laser mount is suitable for a larger wavelength tuning. Since the change of the temperature is a slow process, tuning rates are very limited. Changing the laser current results in a faster tuning, however the total tuning range is much smaller than the tuning range by changing the laser temperature.

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3. Distributed Feedback Diodes (DFB Diodes)

DFB laser diodes are designed for overcoming the drawbacks of Fabry Perot laser diodes. For ensuring a safe single mode operation, a Bragg grating is integrated within the laser chip.

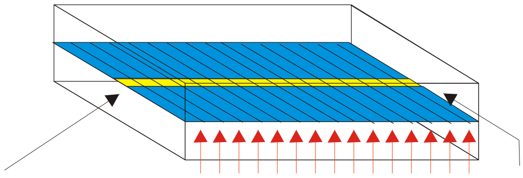

Figure 3: Schematic drawing of a DFB laser diode.

Physical Basis: A DFB laser diode is a laser diode where a Bragg grating is integrated within the laser chip which results in a distributed feedback of the laser light over the entire laser chip. The emission facet is performed with an antireflection coating for suppressing the Fabry Perot modes of the laser chip.

Wavelength Tuning: The emission wavelength of DFB can be tuned by changing the injection current of the laser and/or the temperature of the laser mount. The optical spectrum is well defined by the DFB mode which results in a proper single mode emission and a well defined side mode suppression rate (Fig. 4).

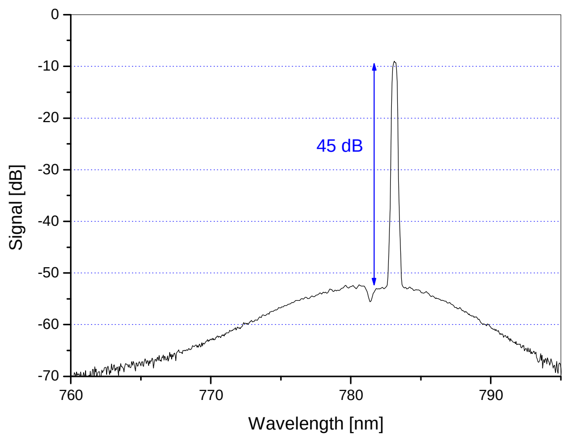

Figure 4: Side mode suppression of a DFB laser diode.

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There are two different methods for tuning the wavelength of DFB laser diode.

1) Temperature Tuning: The thermal tuning method bases on the idea that the optical length of diode lasers varies with the temperature of the laser chip. For applying this method, the temperature of the complete DBR laser chip is changed.

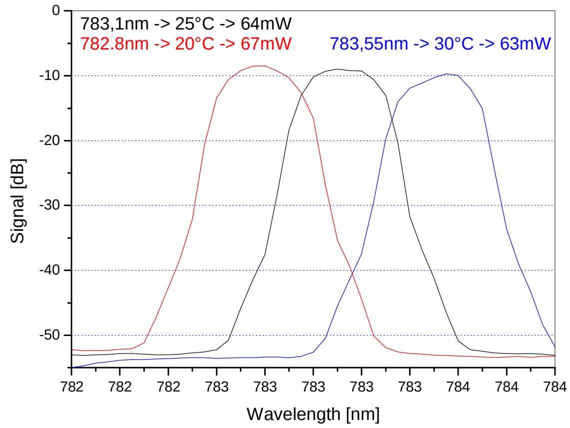

Figure 5: The graphic shows the total tuning range of the 785nm DFB laser with a temperature change from 20°C (red curve) to 30°C (blue curve). The complete temperature tuning range is mode-hop free. The tuning rate is 24GHz/°C (120mA). The tuning speed is limited by the thermal capacity of the laser chip. There is a version of the DFB laser with an integrated Peltier cooler within a TO3 can available.

Temperature Tuning Speed of DFB Lasers: The temperature tuning speed of DFB Lasers strongly depends on the type of packaging of the DFB lasers. A package size with a small thermal load enables a relatively fast tuning frequency in the order of 100mHz as seen in Figure 6.

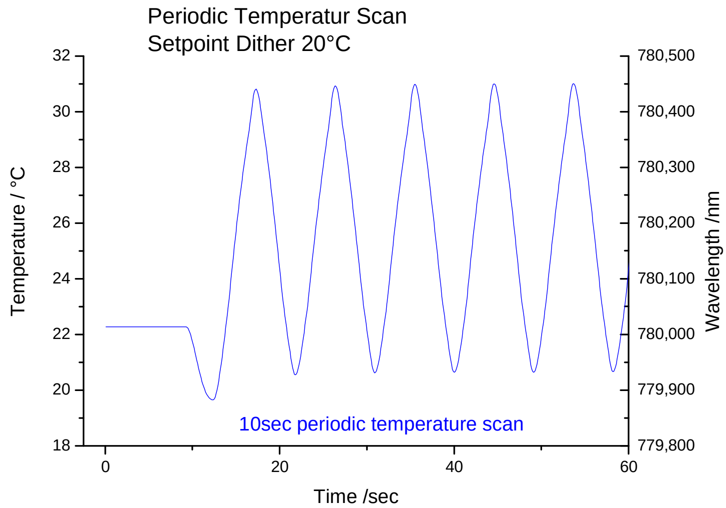

Figure 6: The graphic shows the rapid temperature tuning of a 780nm DFB laser with a low thermal load package. The total temperature change of 10°C results into a wavelength scan of more than 0.4nm. The tuning speed is limited by the thermal capacity of the TO3 or the Butterfly laser package.

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2) Injection Current Tuning: The direct modulation of the injection current of the DFB laser enables significantly higher modulation frequencies. Since the electrical modulation coefficient is about a factor of 100 below the thermal modulation segment, the total wavelength scan is about a factor 100 below the thermal modulation range. The tuning rate is 1.6 GHz/mA (25 °C). The graph of Fig. 7 at the left hand side shows the PI curve of the DFB Laser. The right hand side graph shows the achieved wavelength tuning. There is only one mode-hop of typically 30GHz right above the laser threshold. Beside this mode-hop, the total Injection Current Tuning is mode-hop-free.

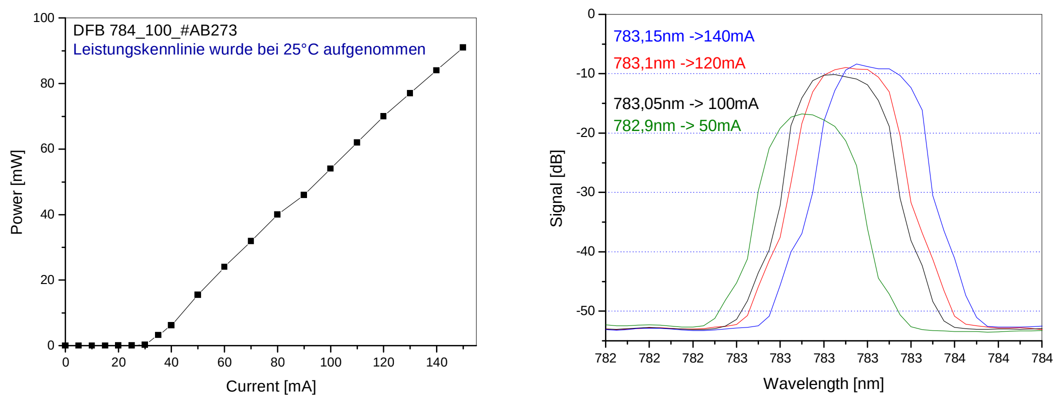

Figure 7:The graph at the left hand side shows the PI curve of the DFB laser. The right hand side graph shows the achieved wavelength tuning. There is only one mode-hop of typically 30GHz right above the laser threshold. Beside this mode-hop, the total injection current tuning is mode-hop-free.

Injection Current Modulation Speed of DFB laser diodes: A relative fast modulation of DFB laser diodes can be performed by modulating the injection current. We investigated the modulation of a DFB laser via the modulation input of our Pilot P500 laser driver as well as via the integrated bias tee BT7 of the TEC-030 Cheetah Laser Head. A modulation current of approximately 10 mA pp with a triangular waveform was applied to the DFB diode laser. The modulation response is shown in Fig. 8.

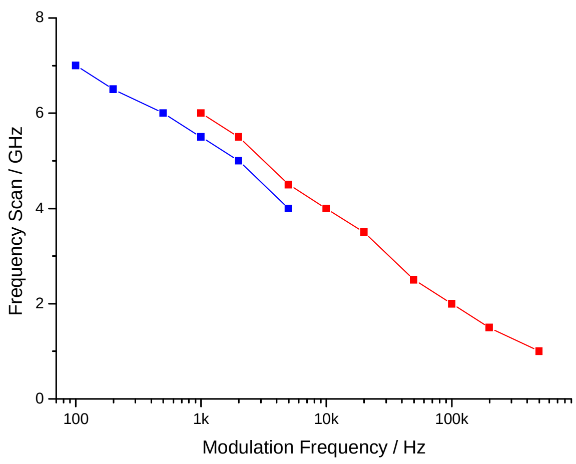

Figure 8: The blue trace shows the modulation response via the P500 modulation input. The red trace shows the modulation response via the BT7 bias tee.

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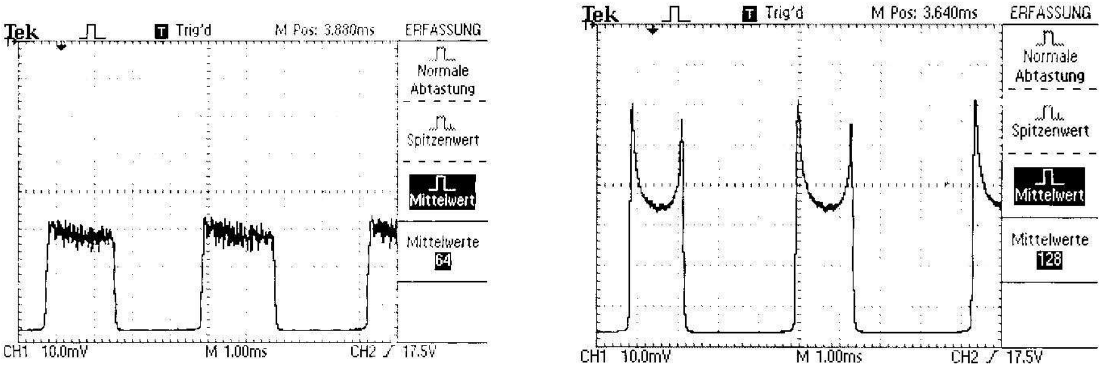

Figure 9. The Fabry Perot spectrum at left hand side shows a modulation response below 10 kHz. The Fabry Perot spectrum at the right hand side shows a modulation response above 100 kHz.

Beyond a frequency of 10 kHz the current modulation of the DFB diode laser changes from triangular to sinusoidal due to the limited modulation response of the DFB laser. This can be identified by a change of the frequency distribution measured via a Fabry Perot interferometer. The Fabry Perot spectra while modulating are shown in Fig. 9.

In order to check the linearity of the modulation response at 50 kHz, we measured the frequency scan of the DFB laser as a function of the modulation amplitude. The result is shown in Fig. 10.

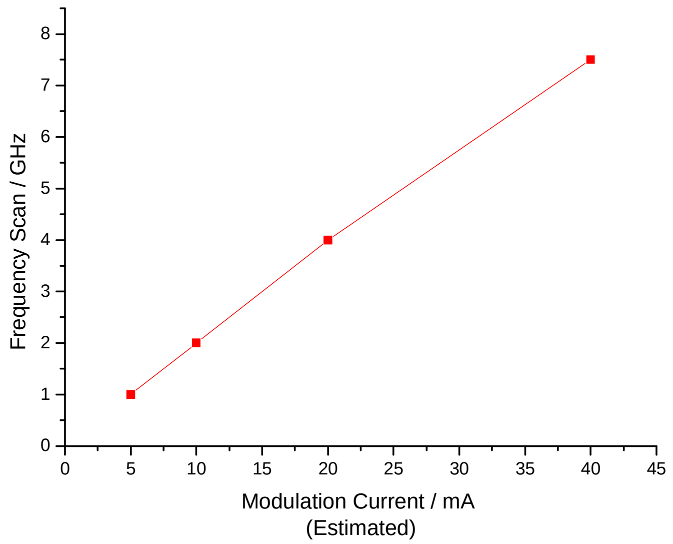

Figure 10. The curve shows an almost linear change of the frequency scan as a function of the modulation amplitude. The tested values range from 5 mA pp to 40 mA pp.

In summary, a DFB laser diode is a well suited instrument for high frequency wavelength scans for moderate frequency scans. Drawbacks of DFB lasers are the relatively high costs and the limited availability of wavelength.

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4. High Frequency Tuning of 1063nm and 1083nm DBR Diode Lasers

DBR lasers are tunable single mode diode laser devices. Their microscopic structure consists of three different chip segments.

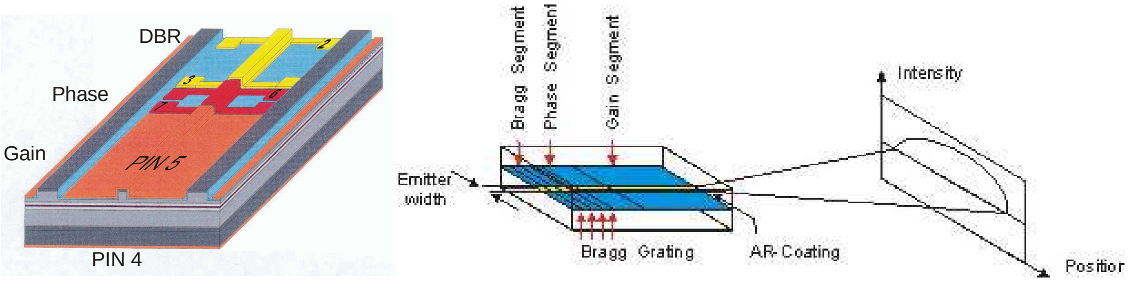

Figure 11. Schematic drawings of the microscopic structure of DBR laser. The left hand side shows the different segments of the DBR laser. The right hand side shows a schematic drawing under a more functional point of view.

The DBR segment is microscopic structured with a first order Bragg grating for providing the wavelength selection. The Gain segment provides the major optical gain of the laser device. The Phase segment is used for ensuring the phase matching between the DBR mode and the cavity modes of the laser chip. There are two different tuning methods for DBR lasers.

Thermal Tuning: The thermal tuning method bases on the idea that the optical length of diode lasers varies with the temperature of the laser chip. For applying this method, the DBR and the Phase segment offer two electrical contacts which enable the user to apply a heat current to the segment. A synchronous modulation of the Phase and the DBR segment with a current ratio of 1:2 allows a mode-hop free tuning of 200GHz.

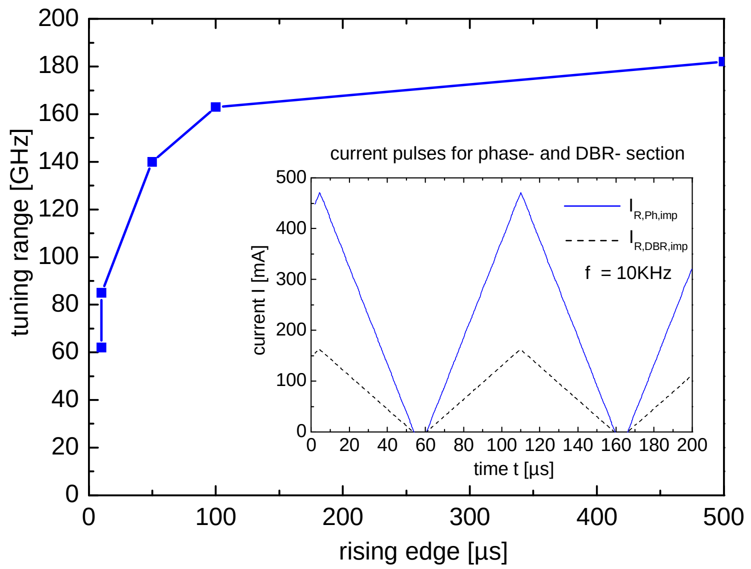

Figure 12. Modulation performance of a DBR laser. The main curve shows the tuning range with different modulation frequencies. The inset describes the ration of DBR and Phase current.

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The graphic shows the response function of the DBR laser for a triangular current modulation. With a modulation frequency of 1kHz, the mode-hop free tuning range is found to be 180GHz. With a modulation frequency of 5kHz, this values shrinks to 160GHz. Increasing the modulation frequency to 50kHz results in a reduction of the tuning range to 60GHz. This is approximately the limitation of the thermal modulation.
Electrical Modulation: The direct modulation of the injection current of the DBR segment enable significantly higher modulation frequencies. Since the electrical modulation coefficient is about a factor of 100 below the thermal modulation segment, the total wavelength scan is typically in the order of 2GHz .. 10GHz. The modulation speed is only limited by the impedance of the laser chip and the laser housing. Typical limitation values are in the order of 10MHz .. 500MHz, depending on the details of the setup.

Cheetah Laser System: The Sacher Lasertechnik Cheetah laser system offers both modulation methods for DBR diode lasers. The Pilot P500 laser driver is an ultra low noise laser driver which allows temperature control as well as laser current control. The Cheetah laser head offers three electrical modulation ports.

1. Gain Modulation:
   The Gain segment is modulated via an internal bias tee up to 10MHz modulation frequency.
2. Phase Modulation;
   The heating current of the Phase segment can be directly accessed via one SMA input connector. With internal connectors at the printed circuit board, the user may exchange from thermal modulation to a fast direct current modulation up to 10MHz.
3. DBR modulation:
   The heating current of the DBR segment can be directly accessed via one SMA input connector. With internal connectors at the printed circuit board, the user may exchange from thermal modulation to a fast direct current modulation up to 10MHz.

In summary, the Cheetah laser system is a very flexible tool for operating DBR diodes in an easy and safe way.

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5. Mode-hop Free Wavelength Tuning with Extended / External Cavity Systems

Mode-hop free wavelength tuning of extended and external cavity diode laser systems requires two conditions which need to be fulfilled simultaneously.

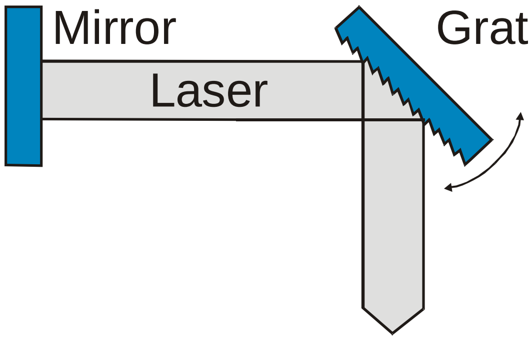

Figure 13: Schematic setup of a tunable laser system with grating feedback.

A typical tunable laser system consists of a laser cavity and a wavelength selective element, e.g. a diffraction grating, like shown in Fig. 13. The emission wavelength can be tuned by a variation of the angle of the cavity grating. For a mode-hop free wavelength tuning, two conditions need to be fulfilled:

1) The first wavelength determining condition is defined by the cavity grating.
2) The second wavelength determining condition is the length of the cavity which defines the cavity modes. Mode-hop free wavelength tuning can be performed by a simultaneous tuning of both conditions. The angle of the diffraction grating and the length of the cavity need to be changed synchronously like shown in Fig. 14.

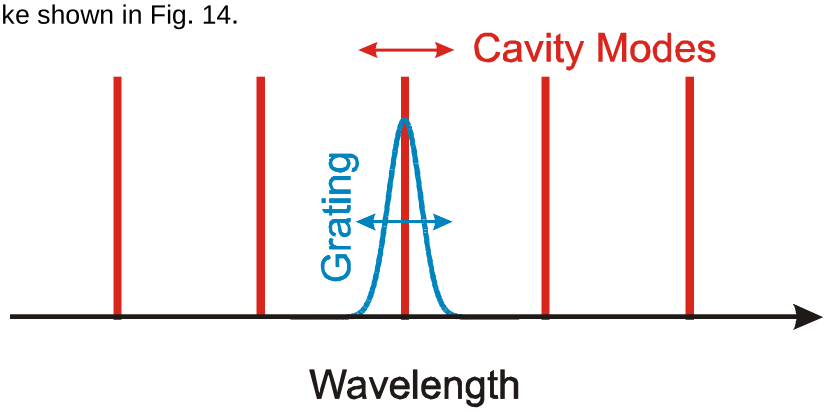

Figure 14: The angle of the diffraction grating and the length of the cavity are changed synchronously to achieve a mode-hop free wavelength tuning.

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6. Extended Cavity Diode Lasers in Littrow Configuration

A more flexible approach for overcoming the drawbacks of Fabry Perot laser diodes for spectroscopy are extended cavity diode laser systems.

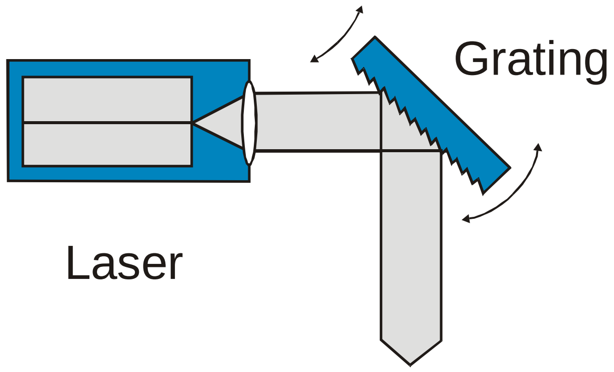

Figure 15: Schematic drawing of an extended cavity diode laser system in Littrow configuration.

Fig. 15 shows the tunable diode laser setup in Littrow configuration. It consists of a standard laser diode, collimation optics and a diffraction grating. The emission of the laser diode is collimated and coupled to the diffraction grating. The zeroth diffraction order is coupled out as laser beam. The first order diffraction is coupled back into the laser diode chip. Wavelength tuning can be performed by rotation of the tuning mirror. The extended cavity approach was developed within the Hänsch group and published by Ricci et al. [3].

Principle of Operation: It is a very effective approach for using commercial available laser diodes in an extended cavity configuration for spectroscopy. The first order diffraction of the grating is used for providing feedback into the laser chip. As soon as one Fabry Perot mode of the laser diode is matching to the frequency which is feed back by the grating, this Fabry Perot mode is enhanced and all other Fabry Perot modes of the laser diode are suppressed. With tuning the angle of the diffraction grating, a small tuning range in the order of 6-8 GHz may be performed.

Limitations of Operation: The principle of extended cavity diode laser systems shows several drawbacks. These drawbacks limit the range of applications where such a system is suitable for.

1. The extended cavity concept shows multi-stability of emission modes and hysteresis effects. The physical background is as follows. The emission modes of Fabry Perot laser diodes are strongly depending on the provided optical feedback. The modes do not only depend on the frequency of the optical feedback, they also depend on the direction and the angle of the optical feedback. There are various publications on this feature since the late 1980s. Figure 16 describes the physical basis of a diode laser with an extended cavity. The left hand side shows one of the possible beam path within an extended optical cavity. The right hand side shows the light intensity of the laser system as a function of the tilting angle of the external cavity mirror as a contour plot. There are several maxima of the light intensity as a function of the external cavity mirror. In between these maxima, the laser system shows coherence collapse behavior. With a short extended cavity, this type of behavior becomes more pronounced and the number of maxima of the light intensity increases. A complete description of this behavior is given by Sacher et al. [4]. In case of a diffraction grating as extended cavity mirror, the situation becomes more difficult.

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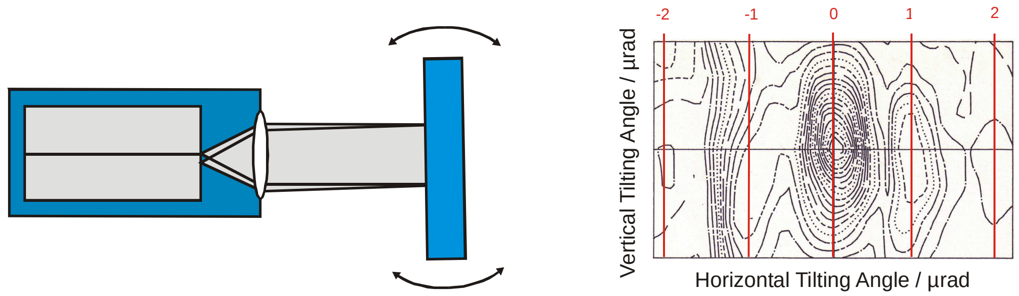

Figure 16: Physical basis of a diode laser with an extended cavity. The left hand side shows one of the possible beam path within an extended optical cavity. The right hand side shows the light intensity of the laser system as a function of the tilting angle of the external cavity mirror as a contour plot. The center of the plot corresponds to the best cavity alignment. The indicated lines show local maxima of the laser intensity for different angles of the external cavity mirror [4].

Fig. 17 shows a possible beam path within the extended cavity where the external cavity mirror is replaced by a diffraction grating. Since each angle of reflection of the diffraction grating represents a different wavelength for the extended cavity, several emission wavelength are possible with one angle of the diffraction grating. Each maximum -2, -1, 0, 1, 2 within the contour plot of fig. 15 represents a possible emission frequency of the laser system. In result, the extended cavity diode laser system is a multi-stable laser system where the lasing wavelength may depend on the initial conditions. With tuning the laser system by changing the grating angle, irregular mode-hops with unpredictable frequency distances occur.

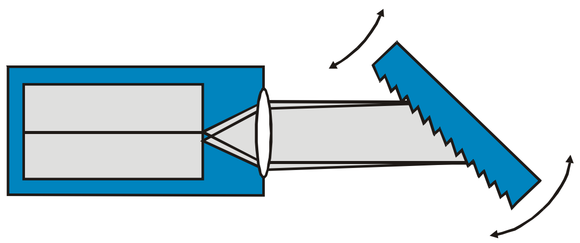

Figure 17: Physical basis of a diode laser with an extended grating cavity. The graph shows one of the possible beam path within the extended optical cavity.

2. The use of commercially available Fabry Perot laser diodes reduces the mode-hop free tuning range to typically 4-6 GHz. Outside of these single mode emission islands, the extended cavity diode laser system shows multimode emission behavior. The physical background of this behavior is related to the coherence collapse of diode lasers with external cavities. A detailed description of this scenario is provided in [5].

3. Since the laser beam is coupled out via the zeroth order of the diffraction grating, a beam steering occurs with a change of the wavelength of the laser system as shown in Fig. 18.

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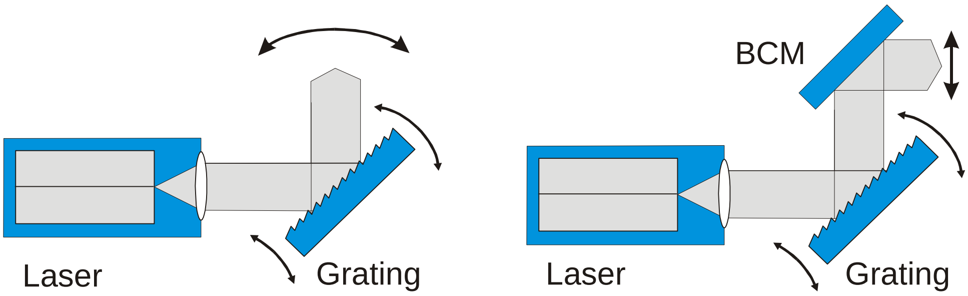

Figure 18: Principle of the beam steering in a Littrow extended cavity diode laser.

The beam steering may be avoided by using a beam-correction-mirror. However, this mirror only translates the angle steering of the laser beam into a parallel translation of the laser beam. This translational moving of up to several microns may cause problems with optical fiber couplers or any other application which requires an excellent beam pointing stability.

The experienced physicist may handle this type of laser with the described behavior. However, these well understood phenomena limit the use of extended cavity diode laser systems for industrial applications where turn-key behavior is required. This type of behavior can be reduced or avoided by using diode lasers with an excellent antireflection coating. The Information that extended cavity diode lasers offer higher power than external cavity diode lasers with antireflection coated diodes is not correct. Since the effect of different classes of antireflection coatings is not too well documented yet, we provide a summary within the next section.

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7. Classes of Antireflection Coatings

Most state of the art external cavity diode laser systems for atomic spectroscopy base on the publication of Ricci et al [3]. This concept uses commercial diode lasers and stabilizes the laser emission with an extended cavity. The output beam is coupled out via the zeroth order of the cavity grating. This concept requires several compromises which result from the insufficient facet coating of the diode laser chip.

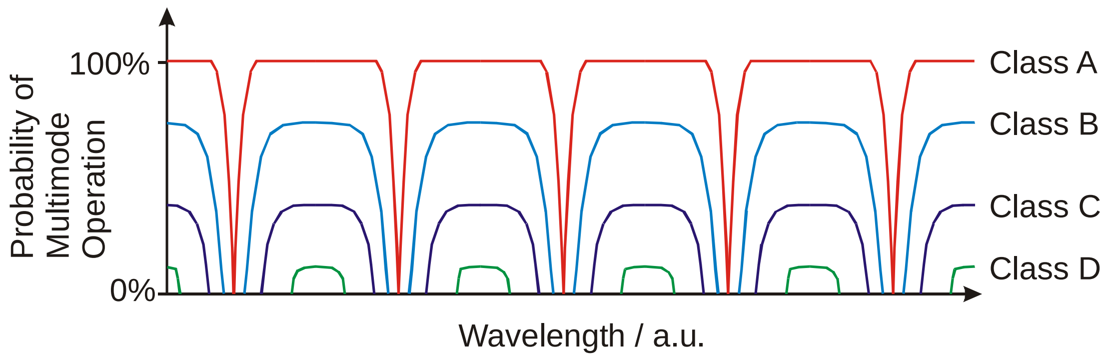

Figure 19: The different classes of antireflection coatings of the laser diode facet.

Fig. 19 shows four different classes of antireflection coatings of the laser facet.
Class A, R = $3{\cdot}10^{-1}$ .. $5{\cdot}10^{-3}$ results in an increased output power of diode lasers. Coupling such laser diodes to an external cavity will result in only a very narrow single mode operation regime if the resonance frequency of the extended cavity matches one of the modes of the laser diode chip. In between the modes of the laser diode chip, multimode emission will occur due to the presence of the coherence collapse [5].
Class B, R = $5{\cdot}10^{-3}$ .. $5{\cdot}10^{-4}$ results in a moderate coupling between the laser diode and the external cavity with an enhanced single mode operation regime.
Class C, R = $5{\cdot}10^{-4}$ .. $5{\cdot}10^{-5}$ results in a reasonable coupling of the laser diode and the external cavity for the Littrow type of external cavities.
Class D, R < $5{\cdot}10^{-5}$ results in a good coupling of the laser diode and the external cavity for the Littman/Metcalf type of external cavities. The feedback requirement for a proper single mode operation of such a laser system results in high external cavity feedback for laser diodes with high facet reflectivity.

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8. Example for non-sufficient antireflection coating

There are suppliers who are offering antireflection coated diode lasers without providing a proof of the quality of the antireflection coating. Such coatings may cause serious problems with the operation of external cavity diode lasers.

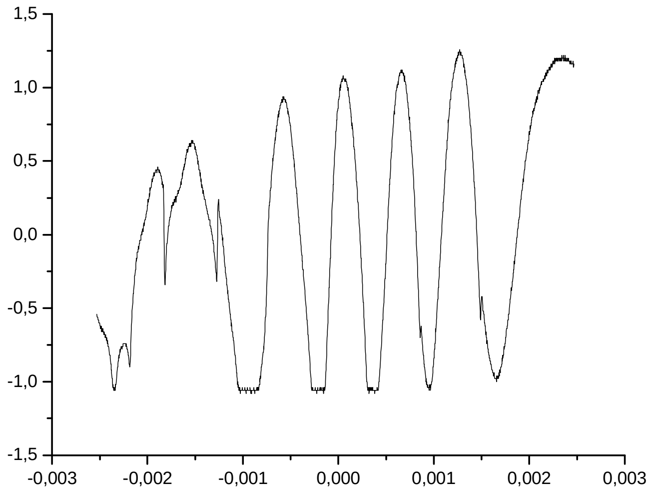

Figure 20: The different classes of antireflection coatings of the laser diode facet.

The graph of Fig. 20 shows an example of the tuning curve of an Antireflection Coated Diode Laser with Class C coating within a Littman/Metcalf cavity. The oscilloscope trace shows the piezo voltage of the wavelength scan versus the optical power. The laser switches completely on and off during the wavelength scan and shows a large number of mode-hops. The regions with high light intensity are present as long as the frequency of the external cavity modes matches the modes of the diode laser. The regions where the laser system shows only minor intensity with spontaneous emission occur when the frequency of the modes of the external cavity and the modes of the diode laser do not match. In summary, there is no reasonable mode-hop free tuning possible.

In summary, antireflection Coated Diode Laser with Class C coatings not suitable for operation in Littman/Metcalf type of cavities. With some restrictions, Class C antireflection coated diode lasers are suitable for Littrow type of cavities.

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9. External Cavity Diode Lasers in Littrow Configuration

The setup of an external cavity diode laser system in Littrow configuration is closely related to the setup of the extended cavity diode laser system described in the previous section.

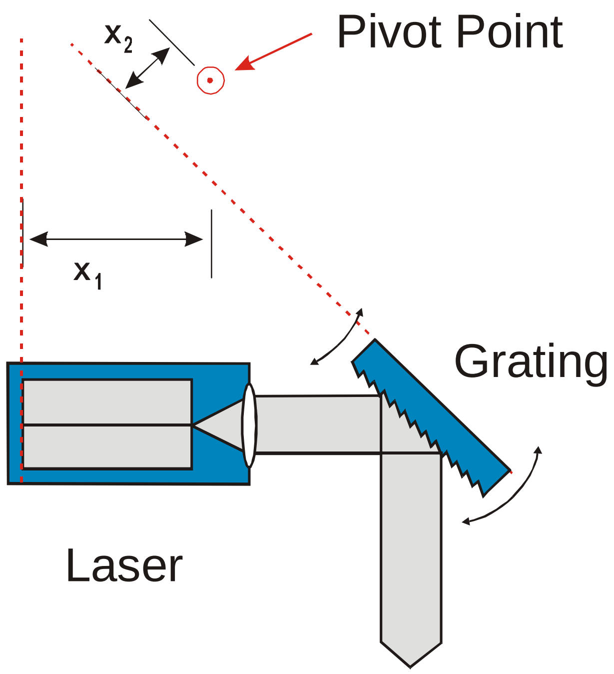

Figure 21: Schematic drawing of an external cavity diode laser system in Littrow configuration.

Schematic Setup: Fig. 21 shows the tunable diode laser setup in Littrow configuration. It consists of an antireflection coated laser diode, collimation optics and a diffraction grating. The emission of the diode laser is collimated and coupled to the diffraction grating. The zeroth diffraction order is coupled out as laser beam. The first order diffraction is coupled back into the laser diode chip. Wavelength tuning can be performed by rotation of the grating. Mode-hop free wavelength tuning can be performed by a proper choice of the pivot point.

Main difference between the *external* and the *extended* cavity diode laser system is the use of Class C or better antireflection coated laser diodes. By this way, most of the drawbacks of the multiple beam path within the extended cavity will be overcome. The Information that extended cavity diode lasers offer higher power than external cavity diode lasers with antireflection coated diodes is not correct.

Since main applications require high output power, it is required to use a grating with low efficiency for the first order diffraction. The situation is as follows: The feedback requirement for a proper single mode operation of such a laser system results in the requirement on high external cavity feedback for laser diodes with high facet reflectivity. On the other hand, high output power of the laser system requires low feedback from the external cavity and causes multi-stability as discussed in section 5. This results in a compromise for external cavity lasers between output power and single mode emission. We developed a concept where we overcome this compromise which will be described within the next section.

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10. External Cavity Diode Lasers in Littrow Configuration by Sacher

Sacher Lasertechnik modified the standard Littrow external cavity concept for overcoming the problems described in the previous section (3 patent applications pending).

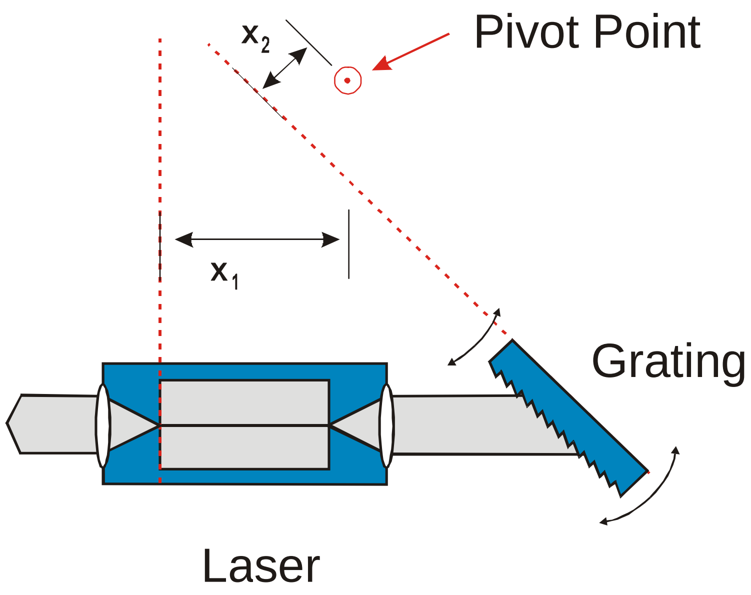

Figure 22: Schematic drawing of an external cavity diode laser system in Littrow configuration according to Sacher Lasertechnik.

Schematic Setup: Fig. 22 shows the tunable diode laser setup in Littrow configuration. It consists of an antireflection coated diode laser, collimation optics and a diffraction grating. The emission of the diode laser is collimated and coupled to the diffraction grating. The first order diffraction is coupled back into the diode laser chip. The rear facet emission of the laser chip is collimated and coupled out as laser beam. Wavelength tuning can be performed by rotation of the grating. Mode-hop free wavelength tuning can be performed by a proper choice of the pivot point.

The new Sacher design was developed for a significant improvement of conventional Littrow laser design as it was published by Ricci et al. [3]. We use the back facet of the diode laser chip for coupling the laser light out of the system. By this approach, we are able to design a high quality external cavity. There are no longer compromises required.

1. The strong coupling of the diode to the external cavity results in an excellent repeatability of the laser system, no longer spending half an hour in the morning to get the system back to work.
2. The side mode suppression of the laser system has drastically improved. Typical values go up to 55dB.
3. The output power was increased.
4. The total tuning range as well as the mode-hop free tuning range are drastically improved.
5. There is no longer a beam walk when changing the wavelength with adjusting the grating angle.

In summary, the new Sacher design provides a major improvement in the state of the art of designing tunable external cavity diode lasers.

The new Sacher design is currently available for the wavelength higher than 760 nm. Please ask us for your desired wavelength.

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11. External Cavity Diode Lasers in Littman/Metcalf Configuration

A second common concept for external cavity diode lasers is the Littman/Metcalf configuration. The Littman/Metcalf concept offers several advantages in comparison to the Littrow configuration which will be pointed out in this section.

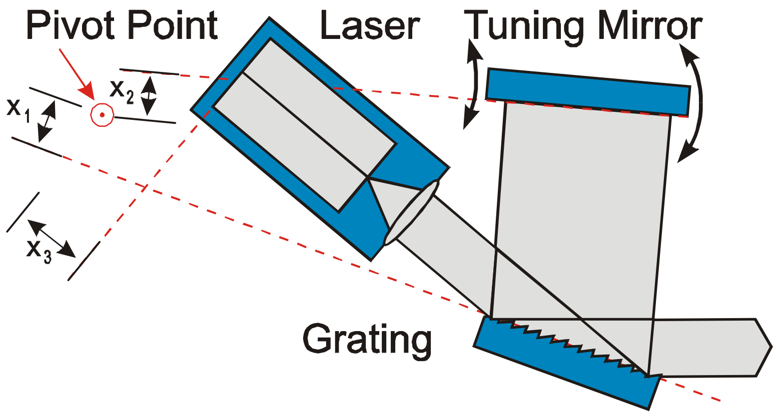

Figure 23: Schematic drawing of an external cavity diode laser system in Littman/Metcalf configuration.

Schematic Setup: Fig. 23 shows the tunable diode laser setup in Littman/Metcalf configuration. It consists of an antireflection coated diode laser, collimation optics, a diffraction grating and a cavity mirror. The emission of the diode laser is collimated and coupled to the diffraction grating. The zeroth diffraction order is coupled out as laser beam. The first order diffraction is directed to the cavity tuning mirror, reflected back to the diffraction grating and coupled back into the diode laser chip. Wavelength tuning can be performed by rotation of the tuning mirror. Mode-hop free wavelength tuning can be achieved by a proper choice of the pivot point according to our US-Patent 5,867,512.

This design which is commonly known from publications has several drawbacks which we overcome with our redesign:

1. In order to achieve high output power, there is the need for operating the grating in low efficiency mode.
2. The weak coupling results in a reduced repeatability on the laser system. Therefore, it is not suitable for OEM customers.
3. Application which require a good side mode suppression suffer by a poor side mode suppression in the order of 40 dB of this design.
4. There is a significant loss of optical power due to the Littman/Metcalf loss beam. This beam is explained as follows:

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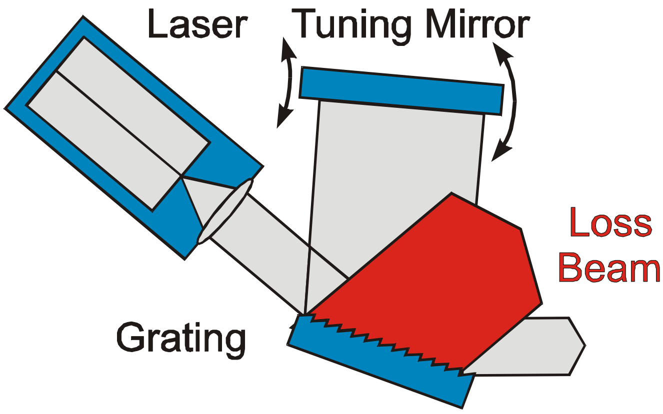

Figure 24: Explaination of the loss beam of the common Littman/Metcalf configuration.

The laser beam is emitted by the laser diode chip, is collimated and then reaches the grating. The grating acts as a beam splitter. The zeroth order beam is coupled out of the laser whereas the first order beam is coupled to the tuning mirror of the laser. There, it is coupled back to the grating. Then, the grating acts *again* as a beam splitter. The first order beam is coupled back into the laser. However, there appears again a zeroth order beam, which is coupled out of the laser, which is indicated as loss beam as shown in fig. 24.

This is the reason for the lower output power of the Littman/Metcalf laser systems in comparison to conventional Littrow laser systems and the new Sacher Littman/Metcalf laser system. Due to our experience, conventional Littman/Metcalf Laser Systems offer about 30% of the available output power of a Sacher Lasertechnik Littman/Metcalf Laser System.

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12. External Cavity Diode Lasers in Littman/Metcalf Configuration by Sacher

Sacher Lasertechnik modified the Littman/Metcalf configuration for overcoming the drawbacks of the traditional setup.

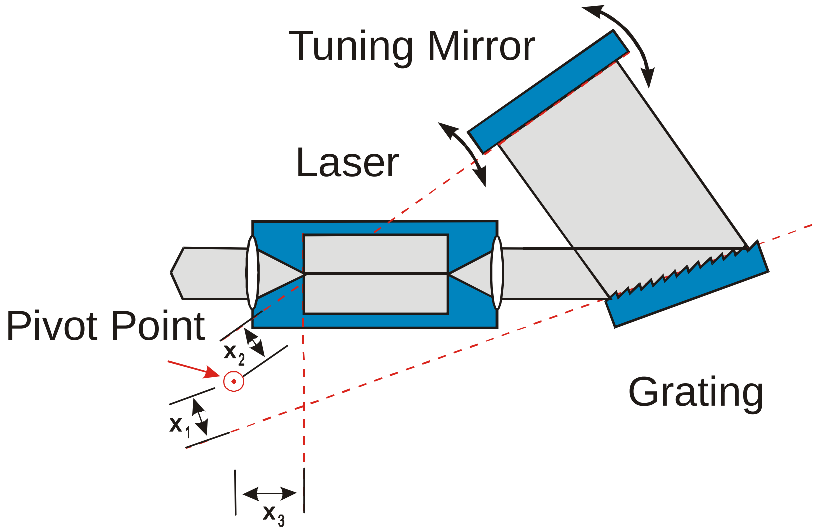

Figure 25: Schematic drawing of an external cavity diode laser system in Littman/Metcalf configuration according to Sacher Lasertechnik.

Schematic Setup: Fig. 25 shows the tunable diode laser setup in Littman/Metcalf configuration according to Sacher Lasertechnik. It consists of an antireflection coated diode laser, collimation optics, a diffraction grating and a cavity mirror. The emission of the laser diode is collimated and coupled to the diffraction grating. The first order diffraction is directed to the cavity tuning mirror, reflected back to the diffraction grating and coupled back into the laser diode chip. The rear facet emission of the laser chip is collimated and coupled out as laser beam. Wavelength tuning can be performed by rotation of the tuning mirror. Mode-hop free wavelength tuning can be achieved by a proper choice of the pivot point according to our US-Patent 5,867,512.

The new Sacher design was developed for a significant improvement of conventional Littman/Metcalf laser design. We use the back facet of the diode laser chip for coupling the laser light out of the system. By this approach, we are able to design a high quality external cavity. There are no longer compromises required.

1. The strong coupling of the diode to the external cavity results in an excellent repeatability of the laser system.
2. The side mode suppression of the laser system has drastically improved. Typical values go up more than 55 dB.
3. The output power is increased by a factor of 3.
4. The output power variation during the wavelength scan is significantly reduced.
5. The total tuning range as well as the mode-hop free tuning range are drastically improved [11].
6. There is no Littman/Metcalf loss beam with this design as discussed within the previous section.

In summary, the new Sacher design provides a major improvement in the state of the art of designing tunable external cavity diode lasers.

The new Sacher design is currently available for the wavelength higher than 760 nm. Please ask us for your desired wavelength or check the availability of your desired wavelength at http://www.sacher-laser.com/LmnData.php.

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13. Summary and conclusions

A brief summary of different diode laser concepts for spectroscopy was presented. The suitability of Fabry Perot diode lasers, distributed feedback lasers, and external cavity diode lasers in Littrow and Littman/Metcalf configuration was compared.

Fabry Perot Diode Lasers:
This concept shows a major drawback for application. Since the mode dynamics of Fabry Perot diode lasers is difficult to control, no predictable wavelength tuning is possible.

Distributed Feedback Lasers:
This type of laser is excellent suited for spectroscopy applications. However, each wavelength requires a different type of distributed feedback laser which may be highly expensive for some applications.

Extended Cavity Diode Lasers:
The development of extended cavity diode lasers defines a starting point of the application of diode laser systems in atomic spectroscopy. Major drawback is the multistability of the system and the irregular type of modehops which are caused by the multistability. This type of laser system is well suited for scientific applications.

External Cavity Diode Lasers in Littrow Configuration:
The use of antireflection coated diode lasers improved the suitability of extended cavity laser system drastically. However, the required compromises in terms of the quality of the cavity set limits for industrial applications.

External Cavity Diode Lasers in Littrow Configuration by Sacher: Lasertechnik
This concept overcomes the problems of the convential external cavity diode laser system in Littrow configuration. The high quality of the external cavity results in a true turn key system for industrial applications.

External Cavity Diode Lasers in Littman/Metcalf Configuration:
The Littman/Metcalf cavity concept offer the advantage of a double grating pass within the external cavity. This results in a higher selectivity of the external cavity and in better wavelength tuning behavior. However, this output power of this design is quite moderate due to losses at the grating.

External Cavity Diode Lasers in Littman/Metcalf Configuration by Sacher Lasertechnik:
The modification of the Littman/Metcalf configuration by Sacher Lasertechnik overcomes the problems of the conventional Littman/Metcalf design. This results in a very high output power which is comparable with the Littrow type of external cavity. It unifies the high power of the Sacher Littman external cavity design with excellent tunablility of the Littman/Metcalf external cavity design.

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