Laser Design for Wide Scan Atom and Molecule Spectroscopy

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A thesis submitted for the degree of

Bachelor of Science (B.S.)

2008 December
Abstract

As the field of atomic physics grows there is a constant need for new diode laser designs that can be used through a wide range of frequencies for use in absorption spectroscopy. This thesis describes the new hybrid design for a long scanning range, hop free, single mode diode laser that can be built at a fraction of the cost of a commercial unit and used with any frequency laser diode with very little modification or turn around time. This Custom Diode Laser (CDL) has been successfully implemented with four separate laser diodes operating at 405nm, 410nm, 780nm and an anti-reflection coated laser diode that can operate in a wide range from 750nm to 790nm. These four diodes were used in the absorption spectroscopy of Gallium, Indium, Rubidium and Oxygen respectively. The CDL has achieved scan ranges of 15-30GHz depending on the frequency of diode and limited only by the piezo electric swing. Calculations indicate that this diode laser should be able to continuously scan well over 100GHz with the proper alignment.
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Introduction

The development of lasers and laser technology has played a very important role in the advancement of Atomic and Molecular Physics. Within the last 50 years since, the creation of the first solid state laser by Theodore Maiman, laser technology has rapidly progressed and lasers are now available all across the light spectrum. With the need for tunable light sources came the invention of the laser diode in 1962. These new sources of light have allowed scientists to probe deep into the fundamental behavior of atoms.

As the use of lasers in atomic spectroscopy continuous to grow, scientists are constantly searching for advanced, effective and inexpensive laser designs. Many of the new diode laser designs concentrate on the ability for single mode long frequency-scanning (5 6 7), while others focus on effective designs to reduce cost (8 9 10). These designs can be seen in detail in references (5 6 8 9). This thesis will discuss a design and implementation of a new diode laser based on these and other criteria, the CDL.

The CDL design is a hybrid of basic designs by A. S. Arnold et. al, and A. Andalkar et. al along with Patrick McNicholl and Harold J. Mertcalf’s theoretical predictions about Littrow scan theory (4 8 9). By combining these ideas, it was possible to create a diode laser that can achieve long range, hop free, single mode scanning. Moreover, this laser is cost effective when compared to commercial models, and can be used interchangeably with all laser diodes across the spectral range with minimal effort and turn around time (1 day).
1. INTRODUCTION
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Laser Diode Theory

The development and implementation of laser technology has created new opportunities to probe into the world of atomic physics. The use of lasers in atomic and molecular spectroscopy has allowed many properties of atom-atom, atom-molecule, and molecule-molecule interaction to be measured to very high accuracy. Such measurements would not have been possible prior to 1958 (the publication date for the laser from Bell Labs) when the lack of high power, high flux, single mode light sources were unavailable.

2.1 Lasing Fundamentals

A laser diode itself is constructed of many layers of varying semiconductors (Fig 2.1), in which a current is passed from the top layer of the diode to the bottom. This current produces electron-hole pairs in the active layer which recombine and emit photons. The frequency of the light emitted from the electron-hole re-combination is dictated by the band gap of the lasing medium. This emitted light is then confined to the active layer by total internal reflection since the active layer has a higher index of refraction than the two surrounding layers. The reflective end facets of the diode form a Fabry-Perot etalon that allows for a finite number of longitudinal modes of resonating light. These modes are then separated by the free spectral range of the cavity given by:

\[ \nu_{FSR} = \frac{c}{2nL} \]  

(2.1)
where $c$ is the speed of light, $n$ is the index of refraction in the semiconductor and $L$ is the cavity length. Because the facets of the diode are not perfectly reflective (the front facet much less reflective than the rear) at low input currents the optical loss of the cavity is higher than the gain and the condition for laser action cannot be achieved\(^{13}\). The current where gain becomes greater then the optical loss is referred to as the threshold current. At this current the diode will begin to emit a coherent beam, whose power scales linearly with input current as shown in Figure 2.2.

It is possible to make laser diodes with an anti-reflection (AR) coating on the front facet of the diode which eliminates the effects of the internal etalon. With this AR coating it is impossible to create a condition where the stimulated emission exceeds the loss in the semiconductor because of an optical loss close to 100\%. In this case it is necessary to create an external feedback cavity to promote lasing in the diode. This is usually achieved with the use of a diffraction grating.
2.1 Lasing Fundamentals

Figure 2.2: Current vs beam power for an anti-reflection coated laser diode showing the laser behavior before and after the condition for laser action has been achieved. This particular laser has a threshold current of 30mA.
2. LASER DIODE THEORY
Gratings and External Feedback

The main use of a diffraction grating is frequency selection from a bare laser diode which effectively decreases the lasing linewidth. This is very useful because in most instances bare laser diodes have very large linewidths of \( \approx 100 \) MHz. These linewidths are large compared to the linewidths of atomic transition (on the order of MHz) and a diffraction grating helps filter out the unwanted frequencies. Also, diffraction gratings are used as frequency selected feedback devices where they use the 1\(^{st}\) order reflection to feedback laser power into the diode’s lasing medium increasing the gain for a specific cavity mode. This also has the effect of shrinking the laser’s linewidth as well as making it possible to promote lasing in an anti-reflection coated laser diode by producing an external cavity.

![Diagram showing the diffraction by a reflection grating.](image)

**Figure 3.1:** Diagram showing the diffraction by a reflection grating. (Adapted from reference (2))
3. GRATINGS AND EXTERNAL FEEDBACK

3.1 Grating Fundamentals

For the laser design presented in this thesis, a reflective grating was used and details of these types of gratings will be discussed in this section. A diffraction grating is made of a reflective or transparent material that has many equally spaced parallel grooves cut into the surface (Fig 3.1). The reflection of an incident light beam will be diffracted in many discrete directions according to the grating equation:

\[ m \lambda = d \sin(a) + \sin(b) \] (3.1)

where \( m \) is the diffraction order, \( d \) is the spacing between grooves, \( a \) and \( b \) are the incident and diffracted angles, respectively, and \( \lambda \) is the wavelength of the diffracted light. In many instances the diffraction grating is used to produce frequency selected feedback into the laser diode. In this case, it is required that the incident beam and the 1st order diffracted beam are at the same angle. Therefore \( a \) and \( b \) are equal in equation (3.1) and this is known as the Littrow configuration. In the Littrow configuration the grating equation becomes:

\[ \lambda = 2d \sin(a) \] (3.2)

3.2 External Cavity Diode Lasers

An External Cavity Diode laser or ECDL is achieved when the constraints for equation (3.2) are held and there is sufficient power in the feedback light to force lasing in a specific mode, dictated by the grating angle. This feedback from the external cavity allows for specific frequency tuning of the laser over large ranges. The tunable frequency range is greater than that possible using only temperature or current tuning. Another advantage of the ECDL is that it reduces the output linewidth significantly compared to the bare diode. The tuning of output wavelength with the use of a diffraction grating has made the external cavity diode lasers or ECDL’s an irreplaceable tool for atomic spectroscopy.
3.2 External Cavity Diode Lasers

3.2.1 Littrow Configuration

The Littrow laser configuration is a type of ECDL that allows for continuous tuning of output wavelength and is limited by the phase change associated with changing grating angle. The relation between phase and grating angle will be discussed later and can be seen in equation 5.5. The phase change of diffracted light will eventually lead to a mode hop in the lasing frequency. The relation between the external cavity and the wavelength is shown in equation 3.3 and the phase grating angle relation is shown in equation 5.1. The phase accumulation equation 5.1 is due to the competing modes the external cavity, equation 3.3 and the grating modes, equation 3.2. The basic setup is shown in Figure 3.2 where a diffraction grating is placed in front of the output of a laser diode at the Littrow angle and the grating pivot point is in the plane of the diode. This allows for the 1st order diffraction to be coupled back into the internal cavity of the laser diode while the 0th order is reflected and used as the ECDL’s output beam. In equation 3.3, \( \lambda \) is the wavelength of emitted light, \( L \) is the external cavity length and \( n \) is an integer multiple of \( \lambda \) (\( n=1,2,3... \)).

\[
n\lambda = 2L \tag{3.3}
\]

The tuning is then achieved by adjusting the grating angle, which in turn changes the feedback frequency (see equation 3.2) and forces the laser to lase at that frequency. A minor disadvantage in this setup is that the angle of the output beam changes as the grating angle is adjusted. A simple and effective fix is to send the output beam, reflected off the grating onto a mirror at the opposite angle that translates the beam down the table. This fix was utilized in this work, and a schematic diagram of the tuning optics is given in Figure 8.4.
3. GRATINGS AND EXTERNAL FEEDBACK

Figure 3.2: Basic setup for a Littrow configuration diode laser. (Adapted from reference [3])
Absorption Spectroscopy

The use of absorption and fluorescence spectroscopy has been implemented for many years to discover the chemical makeup of astronomical bodies. With the invention of the laser diode, it has become increasingly easier to create lab experiments that use atomic absorption and emission to investigate properties of gas phase atoms and molecules. The experiments in which the CDL was involved relied on atomic absorption for data acquisition. Therefore, I will focus on the fundamentals of absorption spectroscopy before presenting experimental results.

4.1 Atomic Spectra

All atoms have unique atomic spectra associated with their atomic structure. An atomic absorption spectrum is shown in Figure 4.1, where the peaks are related to specific frequencies, or energy levels, at which the atom can absorb a photon. The energy required to drive these transitions from a low level energy state \(E_g\) to a higher level energy state \(E_e\) is given by equation (4.1),

\[
h\nu = (E_e - E_g)
\]

where \(\nu\) is the frequency of the absorbed photon.

For any given atom, the energy separation of possible excitation transitions is discrete. Owing to the nature of quantum mechanics where energy is quantized instead of displaying the continuous energy distribution of a classical system. There are three types of atomic interactions that create energy splitting that were
investigated with this laser. These phenomena include, fine-structure, hyperfine structure and Zeeman splitting. These splitting come about due to electron interactions: Fine-structure splitting is due to the atoms electron spin-orbit interactions, hyperfine structure splitting is due to the nucleus-electron interaction and Zeeman splitting is a result of placing an atom in a static external magnetic field which, in turn breaks the degeneracy of the individual spectral lines due to the atoms total angular momentum. The fine and hyperfine structure splittings are proportional to,

$$\nu_{fs} \propto s \cdot L \quad (4.2)$$

$$\nu_{hfs} \propto I \cdot (s + L) = I \cdot J \quad (4.3)$$

Laser absorption spectroscopy utilizes these different transitions to investigate atomic properties such as inelastic and elastic collision rates between atoms and atomic collisional cross sections.

**Figure 4.1:** Absorption spectrum of atomic Galium taken with the Custom Diode Laser using the Sanyo $DL − 5146 − 152$ laser diode. In this spectrum the different hyperfine and different isotopes are clearly defined and labeled.
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Custom Diode Laser (CDL)

5.1 Purpose

The motivation behind this new laser design was to make a stable single mode laser that was capable of a long hop free scan, which is easily compatible with many different frequency laser diodes, and could be used in absorption laser spectroscopy of atomic gases. The main atomic and molecular transitions which were of spectroscopic interest for this laser were Rubidium (Rb) at $12816.545 \text{ cm}^{-1}$, Indium (In) at $24372.956 \text{ cm}^{-1}$, Gallium (Ga) at $24788.530 \text{ cm}^{-1}$, and Oxygen ($O_2$) around $13157.00 \text{ cm}^{-1}$. To achieve this, the diode laser is a hybrid based on the general design of A. Andalkar et al’s laser for cesium and P. McNicholl’s calculations for grating angle-laser phase relation(4) (8).

5.2 Design

The specifications of the laser itself can be seen in later in this section as well as in Appendix B. The Diode laser itself consists of three main pieces; the diode mount, compressor, and a tuning arm, all of which are made of aluminum. The basic design of the mount and tuning arm resemble a Thor Labs three axis mirror mount. This simply means that the diode mount and tuning arm are held together by spring tension on three screws. This idea behind this design can be seen in detail in A. Andalkar’s External Cavity Laser System for Cesium D1.(8)
5. CUSTOM DIODE LASER (CDL)

Figure 5.1: Assembled diode laser without box top or front plate.
5.2 Design

5.2.1 Diode Mount

The diode mount shown in Figures 5.2, 5.3, and 5.4 holds a collimation tube that encompasses the laser diode. The compressor bolts onto the diode mount and forms a pressure seal around the collimation tube. To ensure good thermal conductivity, the collimation tube is surrounded by a thermal contact sheet. The diode mount is 1.8” by 1” block with a .5” by 2” tower on the side. The block has half of a .605” dia through hole on center with the top plane. This hole is the resting place for the laser diode collimation tube. The compressor contains the other half of the .605” dia hole. Four holes are drilled in the tower, .345” dia for the top and bottom holes, which hold the manual hex adjust screws, and .313” for the inside holes, which hold two extension springs. .291” under the collimation tube hole in the mount a .813” long by .313” tall hole is drilled; this will hold two more extension springs. To the right of the .813” hole there is a second through hole at .345” dia that will hold the third adjust screw. The third screw is responsible for the grating angle adjustments. This mount supports the tuning arm completely and is bolted to the base plate with a peltier cooler in-between the base plate (heat sink) and the base of the diode mount. The diode mount also holds an AD-590 temperature sensor for monitoring the laser temperature.
5. CUSTOM DIODE LASER (CDL)

5.2.2 Tuning Arm

The tuning arm is one of the most important parts of the diode laser simply because it holds the grating and piezo electric which frequency tune the laser. The tuning arm shown in Figures 5.5, 5.6, and 5.7 consists of a base in the shape of the letter L with three vertical towers on top. Two of the vertical tower reside
5.2 Design

Figure 5.3: Top view of diode mount.

Figure 5.4: Front view of diode mount without collimation tube.
5. CUSTOM DIODE LASER (CDL)

on the long part of the L and are used as rigid supports for a grating and mirror. The third tower is shaped almost the same as the tower on the diode mount, with the inner holes capturing the other end of the extension springs. The only difference is the top and bottom hole now have diameters of .262” and are used to hold a grooved and coned carbide insert respectively. These inserts allow the screws to adjust the position of the tuning arm with very little resistance. In the position where the third adjust screw would hit the tuning arm there is glued a piezo electric that allows the user to frequency adjust the laser on the range of 15 – 30 GHz depending on the frequency of diode and limited by the piezo swing. A major factor in attaching the tuning arm to the mount with the use of only springs is that it allows for easy removal of the arm if one needs to replace a grating, mirror or piezo.
5.2 Design

5.2.3 Box

The box of the laser is made up of an aluminum (early design) or brass (second generation) base plate that is 6" long, 3.75" wide and 1.25" tall, a front and back plate which are .25" thick aluminum and a cover that is .125" thick aluminum rectangular tube. The front plate has a .5" dia by 1" through hole to allow that laser light to be transmitted. The rear plate has holes drilled for two D-sub
5. CUSTOM DIODE LASER (CDL)

Figure 5.6: Top view of tuning arm, with grating, mirror, piezo and carbide inserts.

Figure 5.7: Front view of tuning arm.
5.3 Alignment

inserts that control laser current, peltier cooler and read the temperature sensor, a female BNC jack that supplies the piezo voltage, and three holes aligned with the adjust screws for manual grating adjustments without removing the case.

Figure 5.8: First generation box.

5.3 Alignment

In the implementation of this laser design, the frequency is scanned by adjusting the grating angle. This adjustment will lead to a change in phase of the diffracted light back into the diode. If this phase change is too large the laser will hop to another longitudinal mode. According to Lars Nilse and Patrick McNicholl in order to achieve the greatest scan range possible it is imperative that the alignment of the grating pivot point with respect to the laser diodes effective spatial lasing point give us the smallest \( \frac{d\phi}{df} \) (\( \phi \) is phase and \( f \) is frequency). For a Littrow designed laser diode the phase of the round trip light, one pass from the grating through the diode and back out, is given by (4):

\[
\phi = 2k(x_o + x_1\cos(\theta)) \quad (5.1)
\]

where \( x_o \) and \( x_1 \) are given as distances away from point \( A \) in Figure 5.9. From the Littrow grating equation (3.2),

\[
2\sin(\theta) = g/k \quad (5.2)
\]
Figure 5.9: Configuration for a Littrow oscillator. A is the axis of rotation or pivot point. From reference [4].
5.3 Alignment

\[ k = \frac{2\pi}{\lambda} \quad (5.3) \]
\[ g = \frac{2\pi}{d} \quad (5.4) \]

where \( \lambda \) is the wavelength of the diffracted light and \( d \) is the grating spacing.

It is seen immediately from (5.1) that the ideal case for infinite scan range is accomplished when \( (x_o + x_1\cos(\theta)) \) is equal to zero. Therefore from this equation we can solve for an ideal solution for any Littrow setup once \( x_1 \) (usually due to machining) is found. This also allows us to find a relation between scan range and \( x_o \) with a given amount of \( d\phi \) allowed to maintain single mode lasing. This is accomplished by substituting and solving these equations for \( d\phi/df \) to get:

\[ d\phi/df = \frac{4\pi}{c} \ast (x_o + x_1/cos(\phi)) \quad (5.5) \]

Once expanded in Taylor series, equation 5.5 becomes:

\[
\begin{align*}
\frac{d\phi}{df} &= \frac{4\pi}{c}(x_o + x_1/cos(\theta_o))/c \\
&+ 4\pi x_1 \sin(\theta_o)(\theta - \theta_o)/(c\cos(\theta_o)^2) \\
&+ 4\pi((1/2)x_1 + x_1\sin(\theta_o)^2/cos(\theta_o)^2)(\theta - \theta_o)^2/(c\cos(\theta_o))
\end{align*}
\]

A graph of \( \phi \) vs \( f \) is shown in Figure 5.11. The second order expansion shows good agreement to the direct calculations of phase in equation 5.1.
5. CUSTOM DIODE LASER (CDL)

Figure 5.10: scan range vs laser phase change: Showing the slope differences as the pivot point is moved away from ideal. These are a result of direct calculation from equation 5.1.
5.4 Protection Circuit

In order to protect the laser diodes from unwanted voltage surges it was necessary to design a protection circuit seen in figures 5.12 and 5.13. The purpose of the protection circuit is to cut out all voltage above the diodes maximum rated voltage. To accomplish this we implemented the use of a RC circuit directed through a Schottky diode and Zener diode in parallel. The RC circuit is in place to filter out high frequencies. The Schottky diode, which has a fast response time, is in place to protect against reverse voltages, and the Zener diode, which has a slower response time, is designed to allow current to pass if above the laser.

Figure 5.11: Distance from ideal pivot vs scan range assuming 0.1 radians of phase change before mode hop. The dots are points obtained from equation 5.1 and the line is obtained from the second order expansion of equation 5.3.
5. CUSTOM DIODE LASER (CDL)

diodes maximum operating voltage, thereby avoiding damage to the laser diode. The behavior of this protection circuit is shown in Figure 8.6.

![Figure 5.12: Board for protection circuit.](image)

![Figure 5.13: Protection circuit flow diagram.](image)
6

Performance

This unique diode laser design has been successfully implemented in absorption spectroscopy with four separate laser diodes operating in the ultra-violet across the visible and into the IR. The four laser diodes used with this diode laser have been a Thor Labs L780P010 at 780nm for Rb (Rubidium) spectroscopy, two Sanyo DL-5146-152’s at 410nm for In (Indium) spectroscopy and 403nm for Ga (Gallium) spectroscopy, and an AR (anti-reflection) coated Eagleyard Photonics EYP-RWE-0790-04000-0750-SOT01-0000 from 750 to 790nm for $O_2$ (Oxygen) spectroscopy. Due to the internal modes of the Rb, In and Ga diodes to achieve single mode scanning it was necessary to implement a current feed-forward circuit in order to match internal and external modes as the grating was being scanned.

Typical linewidths for commercial diode lasers are on the order of MHz, this diode laser has shown a linewidth of 20 MHz. Although this linewidth is an order of magnitude larger than the typical commercial diode lasers, such as the Toptica DL100 rated at 1MHz and lab measured at 12 MHz, the resolution of the CDL is good enough to observe Doppler free spectral lines. The rather large linewidth may be attributed to the instability of the tuning arm and poor vibrational damping in the base. Further vibrational damping may be accomplished in a second-generation design by adding a brace between the mirror and grating mounts to damp out tuning fork affects and by machining the base out of brass instead of aluminum and adding extra thickness.
6. PERFORMANCE

6.1 Diode Properties

6.1.1 Rb

Transition $5s^2 s_{1/2}$ to $5p^2 p_{3/2}$, $12816.545 \text{ cm}^{-1}$ (16)

The first laser diode to be used with the CDL was a Thor Labs L780P010 with a Newport 10HG1800 – 300 – 1 plane holographic reflection grating, with a measured 17% of the initial beam power being used for feedback, for the external cavity. This setup of the laser diode was used mainly to observe the stability of the laser, which has been described previously, and using saturation spectroscopy of rubidium was used in finding the stability of a lab made Fabry-Perot cavity.

6.1.2 In

Transition $5p^2 p_{1/2}$ to $6s^2 s_{1/2}$, $24372.956 \text{ cm}^{-1}$ (16)

The laser diode used for In spectroscopy was a frequency selected Sanyo DL – 5146 – 152 at 409.9nm with a Newport 10HG3600 – 300 – 1 plane holographic reflection grating for the external cavity. The purpose of using the diode laser for In spectroscopy was to observe elastic and inelastic collision properties between In and He. Due to the internal cavity of this diode, it was necessary to investigate how frequency ($f$) relates to current and temperature since they can both change the effective length of the internal cavity. Adjusting the current changes the index of refraction of the lasing medium and adjusting the temperature changes the physical length of the lasing medium through thermal expansion. The properties of this diode can be seen in Figures 6.1, 6.2, 6.3, and 6.4.

Note: We removed the window on the diode because it was believed that the window was creating unwanted feedback, causing the laser to hop modes. After the window was removed, it was noticed that the output power of the laser was decreasing significantly on a day to day basis, about .1mw per hour of operation. After contacting the manufacture they believed that the decrease in performance was do to oxidation on the diode itself.
6.1 Diode Properties

![Graph showing temperature vs beam power, with a decrease in beam power as temperature increases.]

**Figure 6.1:** Temperature vs beam power, the decrease in beam power as temperature increases was not an expected result but is consistent with all laser diodes tested.

6.1.3 Ga

Transition $4s^2 \ 4p \ ^2p_{1/2}$ to $4s^2 \ 5s \ ^2s_{1/2}$, $24788.530 \text{ cm}^{-1}$ ([10])

The laser diode used for Ga spectroscopy was a frequency selected Sanyo $DL - 5146 - 152$ at 405.8nm with a Newport $10HG3600 - 300 - 1$ plane holographic reflection grating for the external cavity. The purpose of using the diode laser for Ga spectroscopy was to observe elastic and inelastic collision properties between Ga and He. The Properties of this diode in use with the CDL design are very
Figure 6.2: Showing the lasing threshold with and without feedback for laser diode Sanyo DL – 5146 – 152. By producing feedback into the diode it is creating more stimulated emission at a given frequency, this results in a drop of the threshold current from just the bare diode.
Figure 6.3: Current vs frequency relation showing the effect of the diodes internal cavity. As the current input to the diode is changed it effectively changes the index of refraction of the lasing medium making the diode emit in different longitudinal modes (see equation 3.3).
Figure 6.4: Temperature vs wavenumber relation showing the thermal effect of the diodes internal cavity and showing the maximum and minimum obtainable frequencies. Adjusting the temperature of the diode changes the physical length of the lasing medium creating a different distance between end facets causing the diode to lase in different modes (see equation 3.3).
similar to that of the diode used for In spectroscopy and can be seen in Figures 6.1, 6.2, 6.3, and 6.4.

### 6.1.4 $O_2$

Transition (NA)
The laser diode used for $O_2$ spectroscopy was an Eagleyard Photonics EYP-RWE-0790-04000-0750-SOT01-0000 that has an anti-reflection coating and can range from 750 to 790nm with a Newport 10HG1800-300-1 plane holographic reflection grating for the external cavity. This laser was used to look at spectral $O_2$ lines in the atmosphere and in the future will be used to look at $O_2$ in Ti (Titanium) +$O_2$ to TiO + O reaction collisions. Due to the anti-reflection coating of this diode there are essentially no inertial cavity modes that lead to high dependence between current, temperature and wavenumber. This also allows for hop free, single mode scanning without any external current feed-forward to stabilize the internal modes as the grating is rotated. Therefore, the only dependence on lasing frequency will result from the external cavity which is controlled by the grating angle. The properties measured for the $O_2$ laser are shown in Figures 6.5, 6.6, and 6.7.
Figure 6.5: Current, frequency relation showing very limited frequency dependence from the internal cavity due to the diodes anti-reflection coating. With the anti-reflection coating the diode has no internal cavity and therefore should have no significant frequency dependence with increasing current because there is no internal cavity for it to perturb.
Figure 6.6: The dependence on beam power as temperature is changed has a trend consistent with all other diodes tested (as $T$ increases $\rightarrow P$ decreases). With the anti-reflection coating the diode has no internal cavity and therefore should have not display significant frequency dependence on temperature because there is no internal cavity for it to perturb.
Figure 6.7: Graph showing the 40nm potential scan range of the anti-reflection coated diode. This data was taken by scanning the grating angle in steps by hand and observing the frequency on a spectrometer.
Appendix A: Parts List
Material

1 x Grooved Carbide insert (Newport Corp.)
1 x Coned Carbide insert (Newport Corp.)
1 x Piezo Electric (Noliac)
5 mil Kapton
2 x Fine Adjust Screw (New Focus Inc.)
1 x Fine Adjust Screw (New Focus Inc.)
1 x Valumax Mirror (Newport Corp)
1x Diffraction Grating (Newport Corp)
Peltier Cooler (Thorlabs Inc.)
2 x Extension Spring (MSC)
2 x Extension Spring (MSC)
4x Dowel Pin (McMaster Carr)
Collimation Tube (Thorlabs Inc.)
Thermal Contact Sheet (Bergquist Comp.)
Laser Diode
3 x 8-32 x 1 ” Bolt
4 x 8-32 x ” Bolt
3 x straight male Molex connector (Waldom Elec.)
1 x right angle male Molex connector (Waldom Elec.)
Temperature Sensor (Allied Electronics)
Resistor 1 ohm (Digi-Key)
Capacitor 1 mF (Digi-Key)
Schottky Diode 30 volt (Digi-Key)
Zener Diode(Digi-Key)
IC Socket (Allied)

Part #

part # 39625-02
part # 39625-03
part # CMAP5
part # 9313-K
part # 9318-K
(Laser Dependent)
(Laser Dependent)
part # TEC3-6
part # 91664185
part # 91666677
part # 90145A418
(Laser Dependent)
10 mil Sil-Pad2000
part # 22-03-2021-P
part # 22-05-2021-P
part # AD590KF
part # RP20T1.0CT-ND
part # PCC1882CT-ND
part # BAT42WS-FDICTND
(Laser Dependent)
part # 905-3158
Appendix B

8.1 Assembly Instructions

8.1.1 Cleaning

1. Clean diode mount, diode compressor, tuning arm, carbide inserts, springs, spring rods, and bolts in the ultra sonic with soap and water. Do NOT clean the fine adjust screws.
2. Rise and clean same pieces with deionized water. Dry thoroughly with kimwipes. Let stand in air for 15 to 20 min to make sure all surfaces are free of water.

8.1.2 Carbide Inserts

Use loctite 609 as adhesive for the carbide inserts

1. Lay tuning arm on back so the surface of the mounting holes are horizontal to the table.
2. When gluing it is easier to glue the grooved carbide insert first for alignment purposes.
3. Coat the inside front edge of the insert holes and the back edge of the grooved insert and the cone insert with a thin layer of loctite 609.
4. Place the carbide inserts into the holes using a twisting motion to assure spreading of adhesive.
5. Use a ruler to align the grooved insert to a vertical position with respects to the arm.
6. Wipe away any excess adhesive using a kimwipe.
7. Allow 1 hour to dry before handling the tuning arm. Full curing time 24 hours.

8.1.3 Mounting Fine Adjust Screws

Use loctite 609 as adhesive for the fine adjust screws.

1. With gloves on remove fine adjust screws from their screw sleeves and place on a clean kimwipe.
2. Coat the inside front edge of the sleeve holes and the back outside edge screw sleeves with a thin layer of loctite 609.
3. Place the sleeves into the holes using a twisting motion to assure spreading of adhesive.
4. Wipe away any excess adhesive using a kimwipe.
5. Allow 1 hour to dry before handling the tuning arm. Full curing time 24 hours.
6. After adhesive has dried, using a new pair of gloves, screw the fine adjust screws back into their sleeves. 9313-K’s on the vertical tower, and 9318-K in arm tuning position.

**8.1.4 Piezo**

1. Solder a male Molex connector to the piezo wires. Do this before gluing to tuning arm.
2. Mark piezo location on tuning arm.
3. The Piezo should NOT be glued directly to the aluminum. To avoid this, cut out a .35” square of 5 mil Kapton that will be glued in-between the piezo and the tuning arm.
4. Clean the Kapton with a kimwipe and acetone.
5. Using as little adhesive as possible glue the Kapton to the back of the piezo.
8. APPENDIX B

Wait to dry, 1 min.
6. Now apply glue the piezo and set in the desired position on the tuning arm, Kapton side down. Wait to dry, 1 min.

8.1.5 Mirror and Grating

Use loctite minute-bond adhesive 312 on the mirror and grating.

1. Location of mirror and grating:
2. Before gluing double check that the mirror and grating you have selected are correct for the wavelength laser diode you will be using.
3. Open mirror box prepare mirror to be lifted out of its’ holder.
4. With gloves on spray Primer NF onto one of your fingers and rub onto the back of the mirror and the aluminum-mating surface. Allow 5 min to dry.
5. Change gloves.
6. Apply a small amount of loctite SpeedBonder 312 directly to the back of mirror and to mating aluminum surface. If any gets on your gloves change gloves again.
7. Pick up mirror by the sides, being careful not to touch the surface, and press firmly, in desired position, to mating surface in for 1 min.
8. Wipe excess adhesive away with a kimwipe.
9. Before securing the grating make sure to check the orientation of the grooves. You can do this by looking at the grating at a 45 degree angle to seeing if colored

Figure 8.4: Top view of tuning arm for grating and mirror postions.
light is refracted back at your eyes.
9. Repeat steps 2 through 8 for the diffraction grating.
10. Wait 30 min to an hour before any further work.

8.1.6 Mounting the Diode Mount to the Base Plate

1. Solder a male Molex connector to the peltier wires. Do this before placing on base plate.
2. The Diode mount is not mounted directly to the base plate, instead it sits on top of a peltier cooler for temperature stabilization. For best thermal contact it is necessary to place a .8” x 1” sheet of 10mil sil-pad 2000 (or similar material) on both sides of the peltier.
3. Align the peltier in the center of the bolt pattern on the base plate and place the diode mount on top.
4. Using 3 8-32 x 1 1/2” screws secure the diode mount. Do NOT use much force as it could damage the peltier.

![Figure 8.5: Side view of laser showing peltier position.](image)

8.1.7 Connecting the Tuning Arm to the Diode Mount

1. After all Adhesives have had sufficient time to dry, 1 hour, it is time to connect the tuning arm to the diode mount.
2. To do this you need a piece of aircraft wire with a hook in one end and a pair
of needle nose pliers.
3. The springs 91666677 (short) will go on the vertical tower and springs 91664185 (long) will go on the horizontal.
4. Put one end of one of the short springs in position on the back of the diode mount. Using the aircraft wire slide the wire through the correct spring hole in the tuning arm and hook the spring.
5. Pull the spring out the other side of the tuning arm and insert the spring rod.
6. Repeat for all springs.
7. Align the tuning arm such the adjust screws are set in the carbide inserts.

8.1.8 Diode Protection Circuit

1. The Purpose of the protection circuit is to protect the laser diode from power surges and static discharge.
2. It may make assembly easier to use tweezers or needle nose pliers to hold components in place while soldering.
3. Solder a right angle male Molex connector to the V+, V- holes at the top of circuit.
4. Solder resistor (1ohm) to position marked R1. Check for connectivity.
5. Solder capacitor (1 mF) to position C1. Check for connectivity.
6. Solder Schottky diode (30 Volt) to position D1. Line on diode should solder to V+ side.
7. Chose a Zener diode with the appropriate turn on voltage for your laser diode’s maximum voltage.
8. Solder Zener diode (Laser Diode Dependent) to position D2. Line on diode should solder to V+ side.
9. Solder IC socket (905-3158) on to circuit board as appropriate on pads at end of board.
10. The Circuit is not complete until you solder wires from the marked V+ and V- to the pads. Before doing this it is necessary to know which pins on the laser diode are the anode and cathode.
11. The anode of the laser diode should be connected to V+ and the cathode of the laser diode should be connected to V-.
12. Once the circuit is soldered, short the V+ and V- on the IC socket and connect the Molex connector to a varying voltage supply.
13. To make sure the protection circuit will work correctly you need to measure the voltage across the 1 ohm resistor as a function of the voltage across the capacitor (input voltage) as you vary the input voltage. The voltage across the resistor can be converted into current \( I=V/R \). The current should remain zero until the voltage across the capacitor reaches the voltage rating for the Zener diode. Your current Vs voltage curve should look similar to Figure 8.6. If this works the protection circuit has been assembled correctly and is ready to plug into the laser diode.

8.1.9 Inserting the Laser Diode

1. Laser diodes’ are very sensitive to static shock so always wear a ground strap while you are working with one.
2. Double check that your collimation tube optic is the correct optic for your wavelength laser diode.
3. Prepare the collimation tube for the laser diode, by removing all components except the optic.
Figure 8.6: Behavior of a protection circuit with a 1ohm resistor, 1mF capacitor, 30 Volt Schottky diode, and a 6.8 Volt Zener diode. This particular protection circuit was designed for the Eagleyard Photonics EYP-RWE-0790-04000-0750-SOT01-0000 laser diode.
5. Remove the laser diode from its’ packaging and place in the aluminum 5.6 mm laser diode clamp holder.
6. Place laser diode and clamp holder into the back of the collimation tube.
7. Screw in the 5.6mm holder in the back of the collimation tube until snug.
9. Wrap the collimation tube in the sil-pad sheet.
10. Place the collimation tube on the diode mount with the front of the collimation tube even with the front of the diode mount.
11. Place the compressor on top of the collimation tube and secure using four 8-32 x” bolts.

8.1.10 Mounting the Temperature Sensor

1. Sand the ends of the AD590 leads and solder a pair of wires to those leads. Make sure to write down which wire is ground. The positive lead of the AD590 has a bump on the side of the lead.
2. Solder a male Molex connector to the end of the wires.
3. Cut out a small piece of 10 mil sil-pad 2000 just big enough to cover the back surface of the AD590.
4. The proper temperature sensor position is on the back of the diode mount just above the horizontal adjust screw.
5. Mount the AD590, larger surface side down with the piece of sil-pad in-between the AD590 and the diode mount, with a 6-32 bolt and washer. Be careful not to apply much force as you may damage the sensor.

8.1.11 Achieving Laser Action

Non AR Coated Diode:
1. Make sure both temperature and current settings on the control box are within the specific operating limits for your diode.
2. Once all leads have been connected to the control boxes. Turn on temperature
control and wait for diode to come to stable temperature.
3. Turn on current control.
4. Place a power meter in the beam path.
5. Without any feedback, grating tuned far beyond 45 degrees, step the input current form low to high and write down the power output at all steps. From this data it should be obvious when the laser power slope changes. This is the bare diodes threshold current.
6. Move the grating to the proper angle to achieve feedback. Step the input current form low to high and write down the power output at all steps. From this data it should be obvious when the laser power slope changes. Continue this process adjusting the grating angle slightly each time until the threshold current is below that of the bare diode. This can be seen in Figure 6.2.
7. Optimize the feedback by repeating step 6 until the threshold current is at a minimum.
8. You have achieved optimum laser action for your external cavity diode laser.

AR Coated Diode:
1. Make sure both temperature and current settings on the control box are within the specific operating limits for your diode.
2. Once all leads have been connected to the control boxes. Turn on temperature control and wait for diode to come to stable temperature.
3. Turn on current control.
4. Place a power meter in the beam path.
5. Without any feedback, grating tuned far beyond 45 degrees, step the input current form low to high and write down the power output at all steps. This should be a flat line, meaning laser action has not been achieved.
6. Move the grating to the proper angle to achieve feedback. Step the input current from low to high and write down the power output at all steps. When there is an obvious change in line slope during the steps from low to high you have achieved laser action and your threshold current is the current where the slope changes. This can be seen in Figure 2.2.
7. Optimize the feedback by repeating step 6 until the threshold current is at a minimum.
8. You have achieved optimum laser action for your external cavity diode laser.
References


