Diode Laser Physics

I. BACKGROUND

Beginning in the mid 1960's, before the development of semiconductor diode lasers, physicists mostly used tunable "dye" lasers in pioneering atomic physics experiments needing tunable laser light. Dye lasers use a chemical dye as the active medium, *i.e.* the material which produces the laser emission. A population inversion in the dye is created, typically, with a fixed-frequency "pump" laser. An individual dye will lase over a limited wavelength range, and different dyes are available to make tunable lasers at essentially all visible and near-infrared wavelengths. Unfortunately dye lasers are large, cumbersome instruments that are both very expensive to purchase (~$100,000.00) and expensive to operate and maintain. Some of the solid-state lasers used as dye laser replacements, such as the popular Ti:sapphire crystal (titanium-doped sapphire), work better than dyes, and other techniques using non-linear crystals exist to generate tunable laser light (Yariv 1991). However, while these may be less difficult to use than dye lasers they are still very expensive options.

The recent development of tunable, narrow-bandwidth, semiconductor diode lasers dramatically changed this picture. These lasers are inexpensive, easy to operate, and produce high-power, tunable, narrow-bandwidth radiation ($\Delta\nu < 1$ MHz, $\Delta\lambda < 1.5\times10^{-6}$ nm). For these reasons, tunable diode lasers have rapidly become commonplace in modern research laboratories.

Interior Diagram of TOLD9200 Series

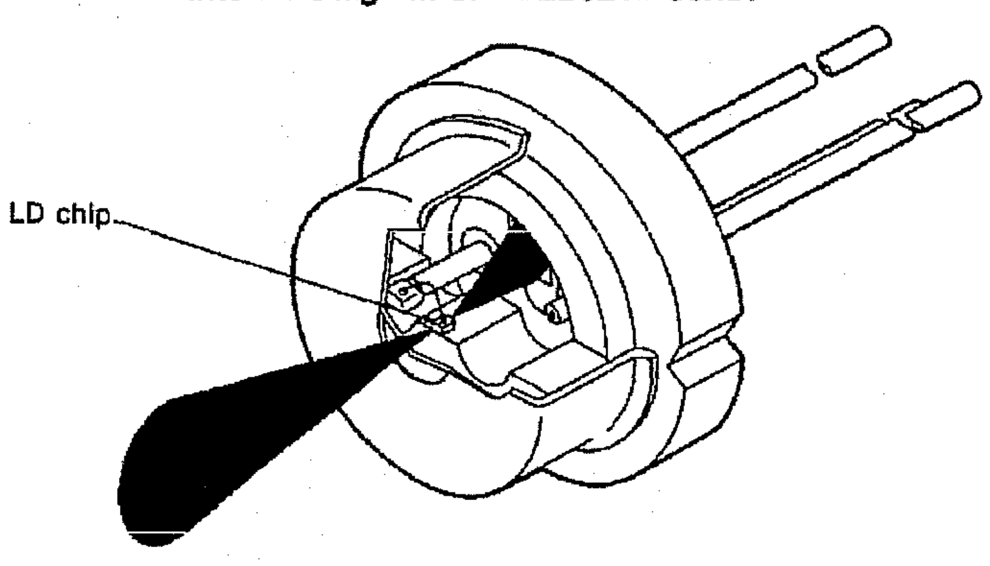


Figure 1: Cut-away view of a typical laser diode can, like those used in the TeachSpin laser

The basic physics of diode lasers is presented in several review articles and books, such as Wieman and Hollberg (1991) and Camparo (1985). Figure 1 shows a cut-away view of a typical diode laser, similar to the ones used in this experiment. The actual semiconductor device is a small chip (LD chip in Figure 1), bonded to a heat-sink. Tiny wires connect the chip to the outside world. Most of the light emitted by the laser comes out the front facet, and a small amount also comes out the back facet. (The two facets are constructed to have different reflectivities). Often, a photodiode is placed at the back of the can, to monitor the laser output power. The main laser beam, which is elliptical and strongly diverging, comes out a window in the front of the laser diode can.

Figure 2 shows a more detailed view of a typical laser diode chip. Current is driven from the top to the bottom of the chip (see arrow in Figure 2), creating electron-hole pairs that recombine in the active layer, emitting light in the process. The light is confined to a narrow channel in the chip, ~2 microns high, ~10 microns wide, and about 400 microns long (wavy line in Figure 2). The facets of the chip, at the ends of the channel, act as partially reflecting mirrors enclosing the laser cavity.

Eichler, Laser, Springer Kap. 10.1

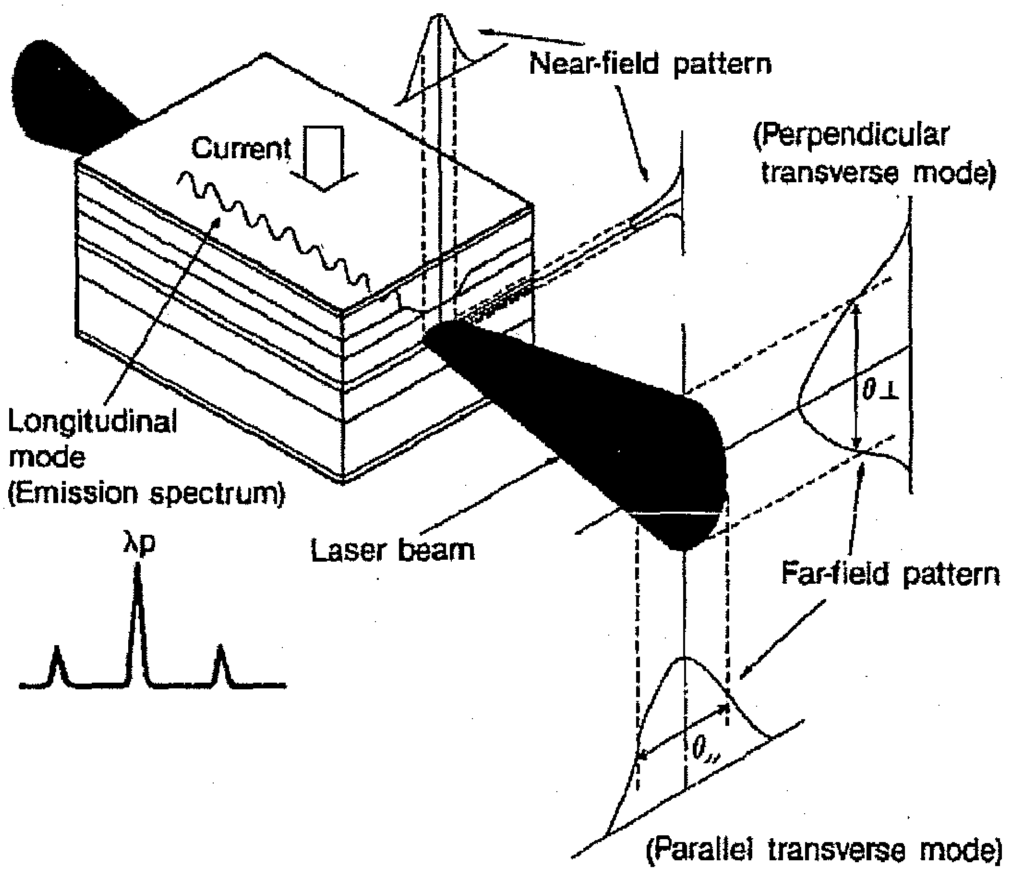


Figure 2: Schematic view of a laser diode chip

Figure 3 shows a schematic picture of the actual semiconductor layer structure in a diode laser. How all this *really* works, the nitty-gritty semiconductor technology, is not something we will concern ourselves with in this discussion. Since light generation in a diode laser results from the recombination of electron-hole pairs injected into an active layer at the diode's n-p junction, the wavelength of the emitted light is approximately that of the band gap of the material. The electron-hole population inversion is restricted to a narrow strip in the active layer, so the laser's optical gain is spatially localized. Gain is the amount that an optical wave is amplified by stimulated emission as it passes through the laser cavity. The diode heterostructure also serves as an optical waveguide; the active layer has a higher index of refraction than its surroundings, so light is confined to the channel by total internal refection. The cleaved facets at the end of the chip serve as the cavity mirrors and output couplers. These can be coated to increase or decrease the facet reflectivity.

10.2/3

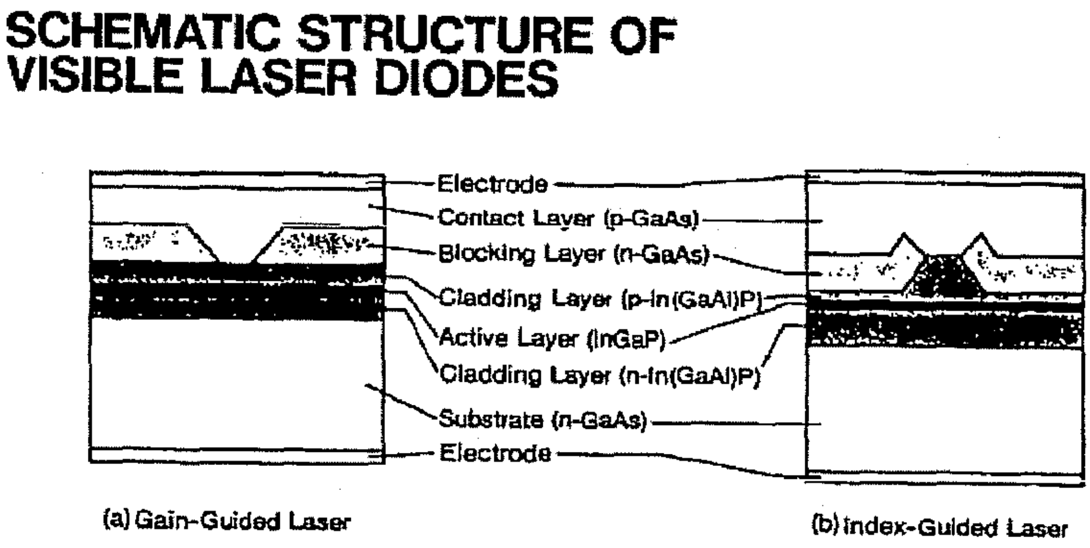


Figure 3: Schematic picture of the internal semiconductor structure of some typical laser diodes This view is looking into one facet of the laser cavity.

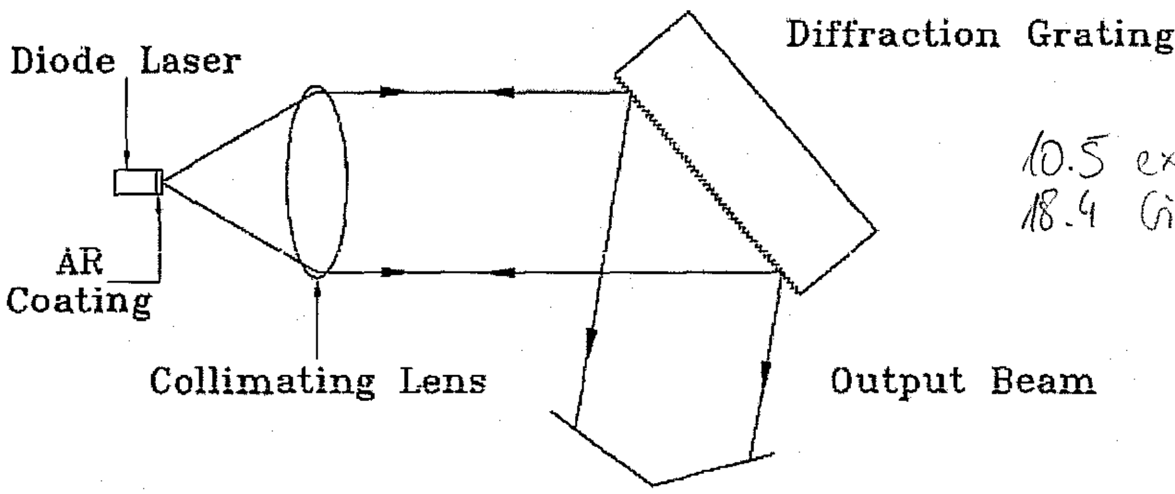
By careful construction of the diode cavity, the laser can be made to emit in a single longitudinal cavity mode (*i.e.* a standing wave inside the cavity, with a fixed number of nodes along the cavity axis and no nodes in the transverse direction). A "bare" diode laser has a linewidth of typically $\Delta\nu \sim 50$ MHz. The spatial mode of the laser, and thus the shape of the output beam, is defined by the narrow channel that confines the light. Since the channel is rectangular, and not much larger than the light wavelength, the output beam is elliptical and strongly diverging (see Wieman and Hollberg 1991).

At low levels of injection current, the optical losses exceed the gain and a population inversion is not achieved. The light output is then broad-band, spontaneous emission, similar to that of an LED. But, above a "threshold" current, the laser emits a coherent beam, which increases in intensity linearly with injection current. The output power in coherent radiation can be as high as 50 percent of the input electrical power, which is very efficient compared with other methods of producing laser light.

Diode lasers have many uses; primary among these are retrieving data stored on optical disks (for instance all compact disk players use diode lasers) and sending light pulses down optical fibers for telecommunications. At present, one can purchase diode lasers that operate at wavelengths from the blue to the infrared; there is a big push in industrial labs to produce shorter wavelength lasers, in order to increase the density of optical disk storage. Power levels for single-mode diode lasers are typically a few mW, but can be as high as 1 Watt.

The TeachSpin diode lasers (Sanyo DL-7140-201S) emit up to 70 mW of output power near 785 nm. The back surface of the tiny semiconductor laser cavity is highly reflecting, while the front surface is often coated with a thin antireflection layer to enhance its transmission. (Only the manufacturer knows exactly how the facets are prepared; such details are often carefully guarded industrial trade secrets.)*

Bare diode lasers have two undesirable properties: 1) their linewidths ($\Delta\nu$~50 MHz) are large compared to the linewidths of atomic transitions (in our case Γ~5 MHz); and 2) they are extremely sensitive to optical feedback – as little as 10^{-6} of the output light scattered back into the laser may affect its frequency stability. As shown in Figure 4, we overcome both these problems by using a diode laser with a small amount of controlled feedback from a diffraction grating.



10.5 ext cavity
18.4 Gitter

Figure 4: Basic configuration of the diode laser system

A lens in front of the laser collimates the output into a nearly nondiverging elliptical beam. After the lens, the beam strikes a diffraction grating, which is a holographic (no blaze) grating with 1800 lines/mm. Most of the light is directly reflected by the grating (m=0 grating order), but roughly 15 percent is reflected back into the laser (m=1 order). The grating forms an "external cavity" (*i.e.* external to the laser's own internal semiconductor cavity), which serves to frequency-stabilize and line-narrow the laser output (see Wieman and Hollberg 1991, and references therein, to understand how this happens). With the simple addition of the diffraction grating, the laser is much less sensitive to stray light feedback, and its linewidth will be reduced to $\Delta\nu < 1$ MHz, much smaller than the atomic transition linewidths we will be observing.

* It is possible to get an approximate measure of the reflection coefficient, R = 16.5% ± 5%. (See section A4-2 for details.)

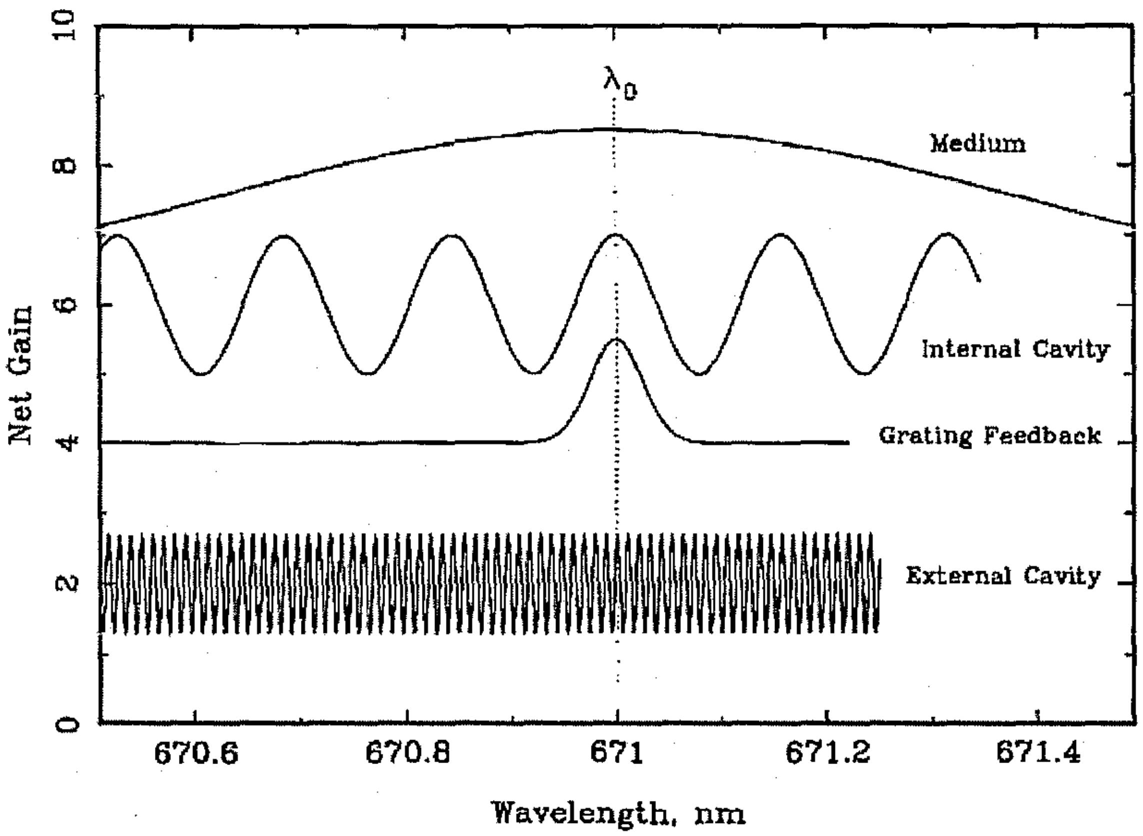


Figure 5: Schematic of the different contributions to the net optical gain of an arbitrary laser as a function of frequency. The curves are displaced relative to one another for clarity.

Laser Tuning: With grating feedback, the frequency of the laser output depends on a number of factors. In order for you to effectively tune the laser to an atomic transition, it is helpful to understand how these factors determine the laser output frequency. The laser will tend to lase at the mode frequency with the greatest net gain (*i.e.* stimulated emission minus optical losses) (see Yariv 1991). Once the laser begins to lase in this mode, stimulated emission limits the number of electron-hole pairs which are available for lasing in other modes, and the result is a laser with a single-mode (*i.e.* single frequency) output beam. (Note: This does not always happen. Our lasers will sometimes lase in two or more modes at the same time, and sometimes the output frequency will vary rapidly and chaotically over a broad frequency range. While these behavior patterns are interesting, and the subject of some amount of research, we will mainly try to find a place in parameter space where the laser operates in a single mode.) To determine the laser operating frequency (assuming single-mode operation), we need to find the frequency with the highest net gain. Figure 5 shows, schematically, the different contributions to the net gain. These contributions are best explored individually.

1. The medium gain

This depends on the properties of the semiconductor material from which the laser is made, in particular the band gap. The medium gain shows a broad peak in frequency space, whose position depends mainly on laser temperature. Since we are aiming for the rubidium atomic transition, we must set the laser temperature, using the temperature controller, so that it operates near 780 nm, the wavelength of the rubidium resonance lines. This temperature is recorded on the antistatic bag in which each diode is shipped. The temperature for the diode that was shipped in your laser is listed on the data sheet included in your manual. A plot of Wavelength versus Temperature for a typical laser is shown in Figure 6. The overall slope of this data is about 0.23 nm $°C^{-1}$, which should be about equal for all the Sanyo diodes. From this slope and the temperature set point for 780 nm, you can determine an appropriate temperature for any desired wavelength for that specific diode. Once this is done, the medium gain curve is so broad that it is unimportant for determining the precise wavelength of the laser.

Data-Sheet: 775-800
up to 60

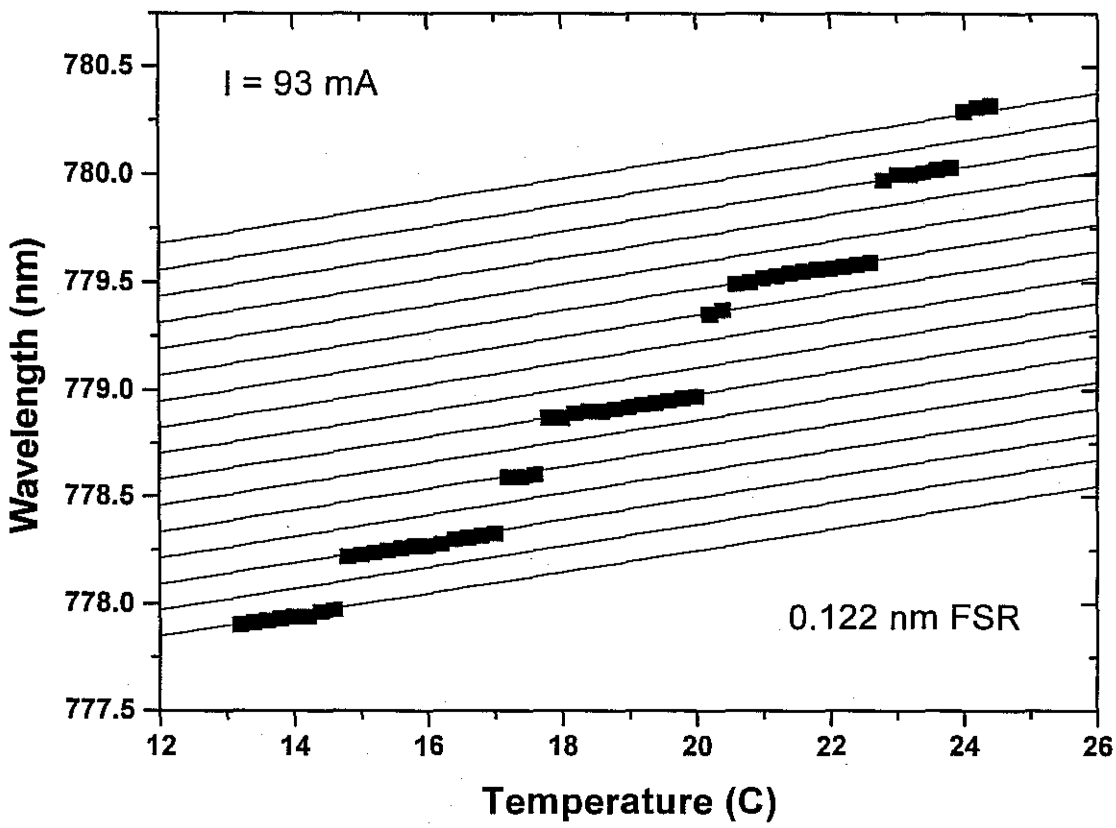


Figure 6: Output wavelength of a free-running (*i.e.* no external optical feedback) Sanyo DL-7140-200S diode laser as a function of diode temperature. (The behavior of other diode lasers is similar.)

2. The internal cavity

The diode junction forms a small Fabry-Perot etalon, or optical cavity, and like all optical cavities, it has a normal mode structure. This translates to an effective frequency-dependent net gain function which is periodic in frequency, as shown in Figure 5 (see Yariv 1991 or Möller 1988 for a discussion of optical cavities). The period is called the "free spectral range", and is given by $\Delta\nu_{FSR} = c/2Ln$, where c is the speed of light, n is the index of refraction ($n \approx 3.6$ in the semiconductor), and L is the cavity length. For this particular laser we have $\Delta\nu_{FSR} \approx 60$ GHz

$\Delta\lambda = \frac{\lambda^2}{c} \cdot \Delta f = \frac{c}{f^2} \cdot \Delta$

($\Delta\lambda \approx 0.122$ nm). The internal cavity gain function will shift in frequency with changes in the diode temperature at roughly 0.05 nm $°C^{-1}$ this is measured from the small scale slope the individual steps in Figure 6. Unfortunately, the temperature of the laser head can not be changed very quickly. The thermal time constant of the laser head can be estimated to be on the order of 10 seconds.* The internal cavity modes will also change with the diode current. (See Figure 7.)

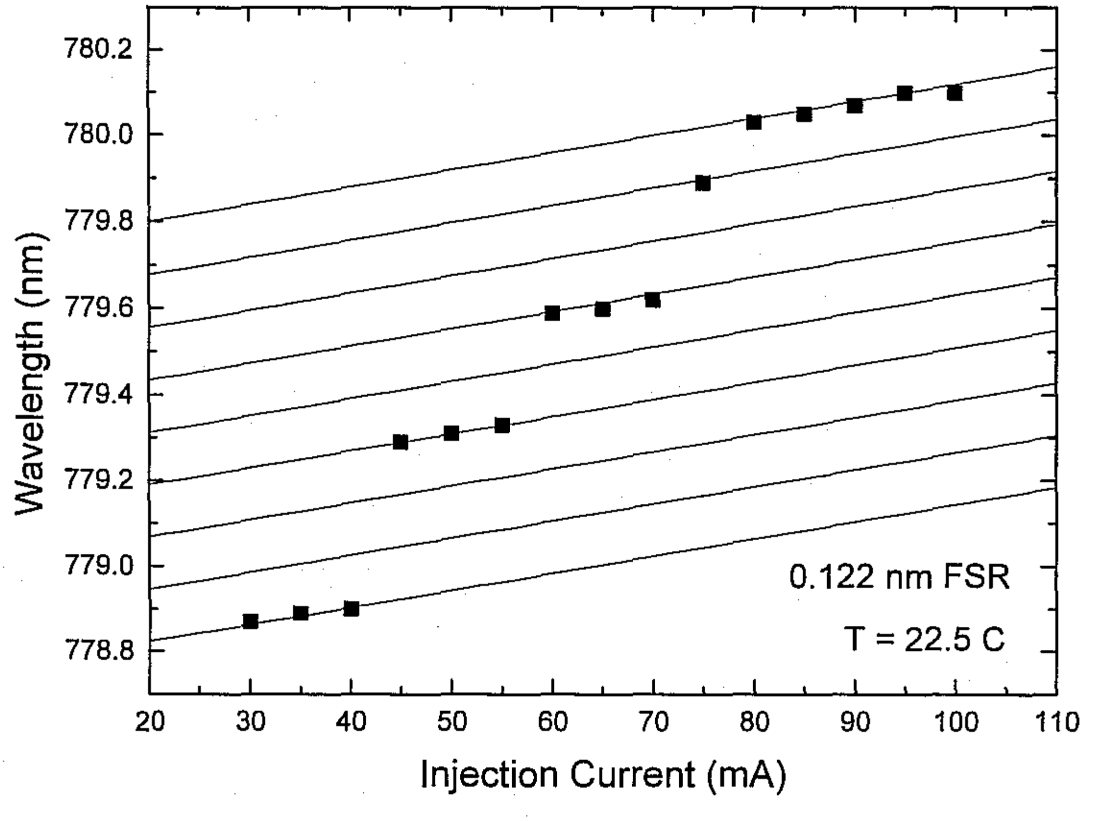


Figure 7: Free-running laser Wavelength versus Injection Current at a fixed temperature

The current affects a diode in two ways. First, increasing the current causes simple heating, which changes the temperature of the diode and thus the wavelength in much the same way as heating the laser head directly. As far as wavelength is concerned, modulating the current can be thought of as a means of rapidly changing the diode temperature. This effect predominates for time scales longer than 1 μs and tunes at roughly 2 GHz/mA as shown in Figure 7. The second means by which the current changes the free-running laser wavelength is by changing the carrier concentration in the active region. This modulates the optical path length of the diode, with a tuning rate of about 200 MHz/mA, up to a maximum frequency that is set by the relaxation oscillation frequency of the diode, typically several GHz.

Taken together, Figures 5 - 7 demonstrate the interaction of several influences. Figure 6

* Estimated from the mass (≈170grams), heat capacity and thermal conductivity, assuimng the laser head is a solid cube of aluminum with the TEC on one face and the diode and temperature sensor at the center .

shows a plot of the wavelength of a free-running laser as a function of temperature. As the temperature is increased, the maximum gain of both the medium and the internal cavity modes shown in Figure 5 will shift to longer wavelengths. They do not, however, shift at the same rate. This creates laser "mode hops" to different peaks of the cavity gain function. In practice, we would like to set the temperature and injection current so that the laser operates at the rubidium resonance frequency. But, as can be seen from Figure 6, this is not always possible with a free-running laser. With the addition of an external grating, the laser can be made to operate at any wavelength within a reasonably broad range.

3. The grating feedback

Since a grating disperses light, only light from a narrow wavelength band will be fed back into the laser for a fixed grating left/right (L/R) angle. (The grating up/down (U/D) angle should be set so that the light from the grating reflects back into the laser.) In this apparatus, the grating is used in a Littrow configuration where the first order diffraction is sent back into the diode. In this configuration, the wavelength can be found from $\lambda = 2\, d \sin\theta$, where d is the line spacing of the grating and θ is the grating angle (measured from the normal). Assuming an ideal grating, where the resolving power is limited only by diffraction, the spectral width of the first order diffraction, $\Delta\nu$, will be given approximately by $\nu/\Delta\nu = N$, where ν is frequency and N is the number of grating lines subtended by the laser beam (see Möller 1988 or any general optics book, for a discussion of grating properties). For example, with a 0.3 cm laser beam width, we will find $N = 5400$ and $\Delta\nu \approx 70$ GHz. The position of this peak is determined by the grating L/R angle.

4. The external cavity

This is similar to (2) above, but with the external cavity, one end of which is the grating, and the other is the highly reflective back facet of the diode. Since the external cavity is much larger we have $\Delta\nu_{FSR} = c/2L \approx 10$ GHz. for a 15 mm external cavity length. (See Section A.4 and Figure A.4.1 for the relevant dimensions.) This curve shifts by moving the grating position, which we do either with the L/R knob on the laser head or with the piezo-electric transducer (PZT) in the grating mount.

In order to force the laser into single-mode laser operation at a predetermined wavelength λ_0 (e.g. an atomic resonance line), the gain from each of the components should peak at λ_0 as shown in Figures 5.

To get a more complete understanding of how these contributions interact, how the laser tunes as the grating angle is changed, we have tried to construct an accurate "best guess" picture of the shape of the various cavity modes in the laser. This picture is shown in Figure 8. Referring back to Figure 5, the grating feedback and external cavity gains have been merged into the single solid line of Figure 8. The broad medium gain has been left out of the plot. Figure 8 is a picture of the various cavity modes with all the gains having a maximum at the same frequency.

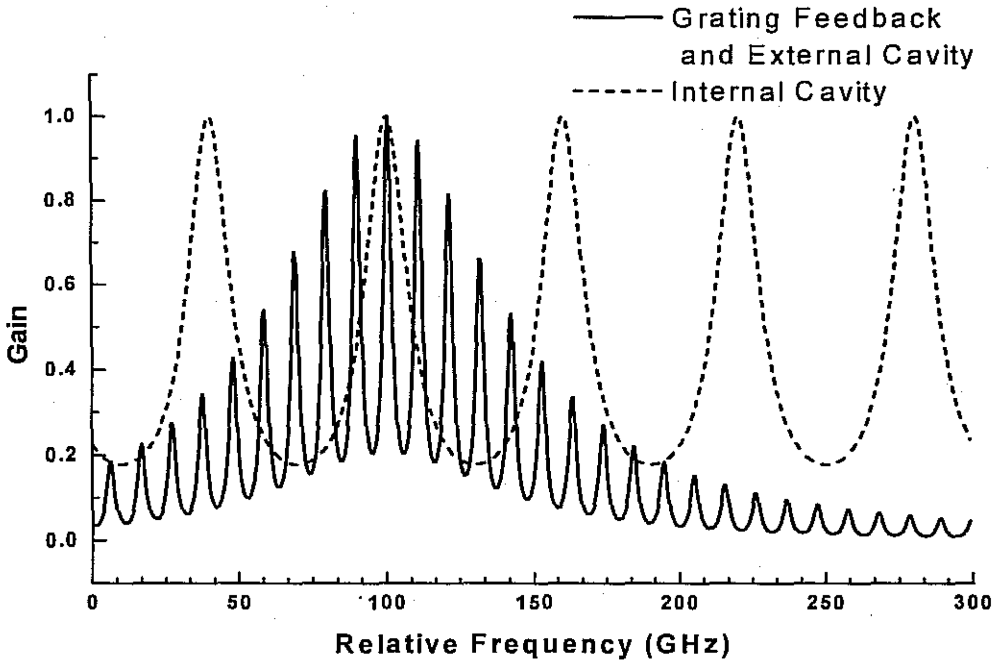


Figure 8: "Best guess" picture internal cavity, grating feed back and external cavity modes in the laser

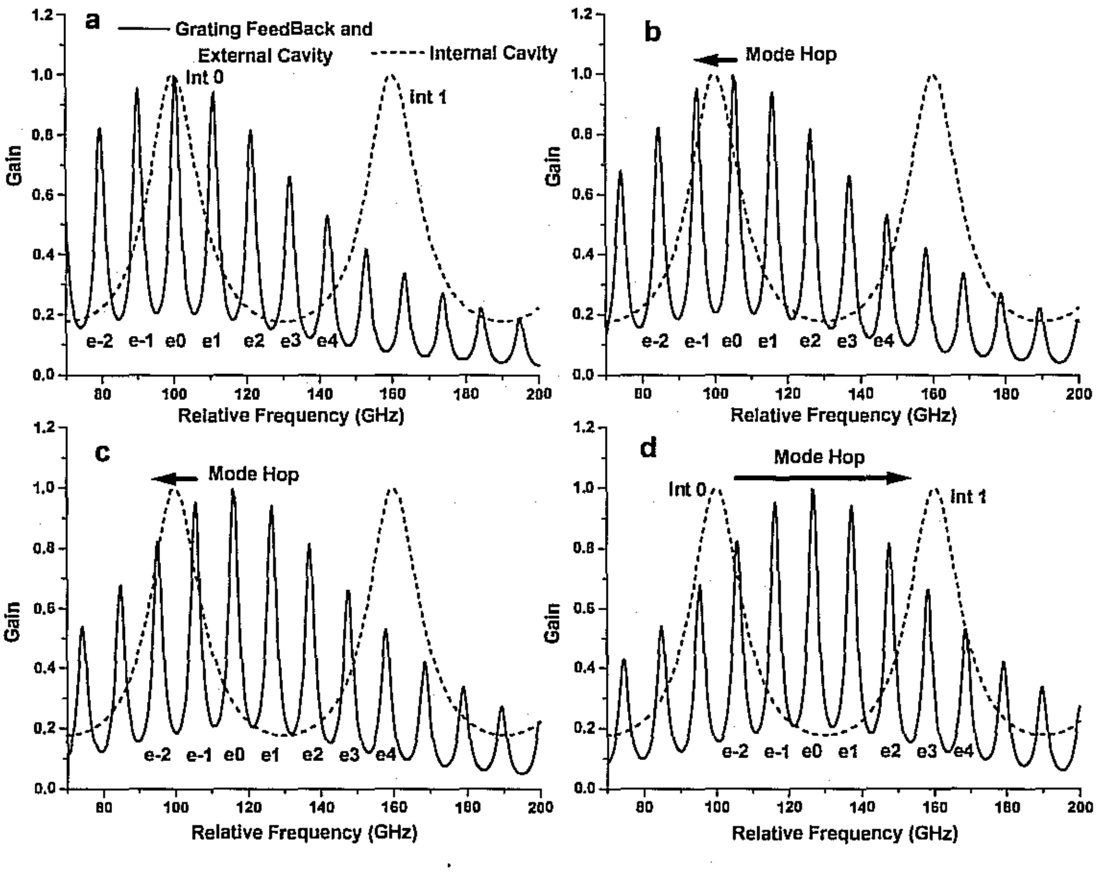


Figure 9: Series of graphs showing showing how the external and grating feed back mode shifts as the grating angle is changed.

Figure 9 shows a series of pictures of the External and Internal cavity modes as the grating angle is decreased. The pictures show only two of the internal modes labeled Int 0 and Int 1. For reference, we have also labeled some of the external modes e-2, e-1, e0, e1...e4. Graph **a** of Figure 9 is for the same grating angle shown in Figure 8, where the laser is oscillating in external mode e0. As the grating angle is decreased, mode e0 is shifted to higher frequency, shorter wavelength, until the point shown in graph b. At this point, the overall gain in external mode e-1 is about equal to that in mode e0 and, as the grating continues to move, the laser will jump into mode e-1. As the angle is decreased further, the laser will reach the point shown in graph c and the laser will hop to mode e-2. Finally, in graph d, the maximum of the grating feedback frequency is about half way between internal modes Int0 and Int1. As the angle continues to decrease, the laser will make a relatively larger mode hop and lase in external mode e3 under internal mode Int1.

You should notice that during this change in angle, the laser has swept through the same small frequency range "under" Int0 several times. After these changes, the laser moved to a new frequency defined by Int1 with a rather large gap of frequencies in between. To be able to cover the entire frequency range, we need to be able to change the position of the internal modes. This is done by changing the laser current. To tune the laser to the correct wavelength for the rubidium transitions, both the correct grating angle and laser current must be found. The procedure for doing this is discussed in the next section. The next section will also describe a clever trick in which both the grating angle and laser current are swept simultaneously at rates such that both the internal mode Int0 and the maximum of the external modes e0 change in frequency together resulting in long (20 GHz) mode hop free scans. An understanding of the Figures 8 and 9 should help you visualize how this is accomplished.

III. REFERENCES.

Camparo, J. C. 1985, "The Diode Laser in Atomic Physics," *Cont. Phys.* **26**, 443.

Möller, K. D. 1988, *Optics*, (University Science Books).

Wieman, C. E. and Hollberg, L. 1991, "Using Diode Lasers for Atomic Physics," *Rev. Sci. Instrum.* **62,** 1.

Yariv, A. 1991, *Optical Electronics*, 4th edition (Holt, Rinehart and Winston).

Initial Setup – What to do first

These instructions will help you set up your laser for the first time and align it. The step-by-step setup will take an hour or two, and when you have carried out these steps your laser will be tuned to the Rubidium resonance lines.

1. Select a room for your diode laser. The room should be closed so that you can dim the room lights, but most importantly so you can have absolute confidence that no stray laser beams can escape and potentially cause harm to anyone. Unpack the various components from their shipping containers and place everything on a table with plenty of room to work.

2. Before making connections to the laser head ground yourself to remove electrostatic voltages. Remove the protective plug from the laser head 9-pin D-connector. Connect the laser to the controller using the 9-pin D-cable provided, which plugs into the back of the controller. 9 pin Kabel fehlt

3. Connect the Rubidium cell cable to the back of the controller. Note the polarity of the banana plug heater wires does not matter. The polarity of the blue thermocouple connector does matter. It should only plug into the blue receptacle one way.

4. Make sure the laser power switch (located on the left side of the controller, on the front) is in the **off** position. Then plug in the laser controller power cord and turn on the main power switch (located in the back, near the power cord).

5. When the power is turned on the Cell Temperature controller (LED display on front panel) will first reset and then display the cell temperature. In a few minutes the cell temperature will rise to its factory established set-point temperature of 50 °C.* You may check and/or change the cell temperature set-point as follows:

a) Press the leftmost button on the cell temperature controller; marked by a circular arrow. The temperature controller will read SP1.

b) Press the rightmost button on the cell temperature controller; the cell set-point temperature (in degrees C) will be displayed.

c) Press the up/down arrow buttons to change the set-point. Start with a temperature of 50 °C.

d) Press the rightmost button; the display will read SP2

e) Press the leftmost button twice; the display will read RUN momentarily, then it will read the cell temperature.

f) The cell temperature should read near the set-point after several minutes. You may proceed with the next step before the final temperature is reached. The Cell Temperature controller is **not** critical to operation of your diode laser. It merely improves the signal strength by increasing the rubidium density in the cell. See Theory section for a plot of Rb pressure versus temperature.

* A starting temperature of 50 °C was chosen to give a nice strong absorption signal (about 90%). Once you become familiar with the system you may want to work at a lower temperature.

Trouble shooting: If the controller is not working as described please refer to the Apparatus section of the manual under Cell Temperature Controller for how to configure and set your controller. It is possible your controller became reset during shipping or by a student (the ever-present scapegoat).

6. Check the Diode Laser temperature:

a) Use a voltmeter to read the TEMPERATURE SET-POINT in the MONITORS section of the controller chassis. This voltage should equal the Temperature Set-point recorded on the data sheet shipped with your laser. If it does not, adjust the 10-turn potentiometer on the back of the chassis to obtain the correct set-point.

$V_{SP} = V_{LD}$ 1

b) Make sure the LASER TEMPERATURE INDICATOR lights are both off. If either of these is on, then the laser temperature has not yet reached its set-point temperature. With a voltmeter connected to the LASER DIODE TEMPERATURE pin jacks, you may monitor the laser temperature.

LEDs kann man nicht tra

→ 2,8 V V eingestel

Poti: 5,8

Operating note: The diode laser frequency depends on temperature. If not set correctly, you may not be able to get your laser to tune to the Rb resonance lines. The optimal temperature was determined at TeachSpin and is recorded on the data sheet.

7. PUT ON SAFETY GOGGLES. Your laser typically runs with an output optical power of 10-30 mW, all concentrated into a narrow, intense beam. Staring directly at the Sun sends about 1 mW into your eyes, **and this is already enough to cause permanent eye damage.** To make matters worse, the laser light has a wavelength close to 780 nm, which is nearly invisible. Practice proper laser safety – anyone that is in the room and can see the laser, should wear safety goggles when the laser is on.

8. Set the laser CURRENT potentiometer fully counterclockwise (low current) then turn the LASER POWER switch on.

9. Locate the IR viewing card. The sensitive area of the IR card is a dull orange color. This contains a polymer that absorbs UV light from the ambient lights in the room, especially fluorescent lights. The polymer molecules are then excited into a metastable state, and incident IR light from the laser can induce a transition that emits visible light. (Note the IR card will not work well if the room lights are off for an extended period.) The IR card allows you to "see"(actually locate) the laser beam even when you are wearing your protective goggles, since the goggles do not block the visible light emitted by the polymer.

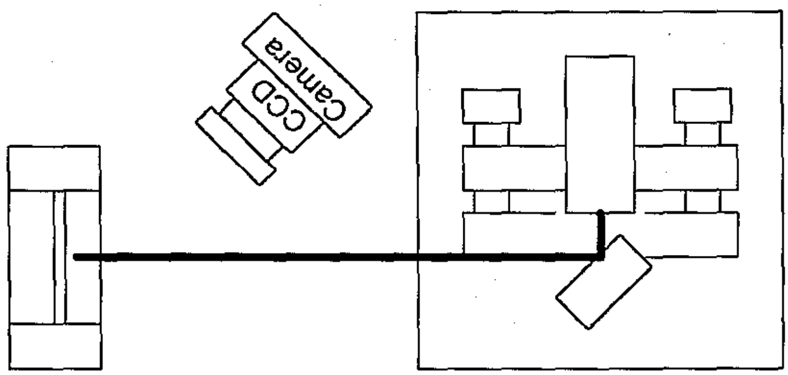
10. Hold the IR card at the laser output (the hole in the plastic cover of the laser) while you turn up the laser CURRENT knob. You will need to turn the knob 3-4 turns before the beam becomes detectable on the card.

11. Assemble the TV camera:

a) Connect the power cable to the 12V power supply provided, and connect the output cable to the TV monitor. You should see an image on the monitor.

Adapter fehlt

b) Place the TV camera mounted on an optical post into a post holder. Then the camera can conveniently be placed on the optical table with the laser and other optical



Buisness Card
in Card Holder

components.
Operating note: The camera lens can be focused over a broad range of working distances, from infinity to as close as a few centimeters. The focus is adjusted by turning the lens. Do NOT shine the laser beam directly into the TV camera, for this may damage the CCD sensor.

Figure 1. External Cavity Alignment

13. Place a business card so that it intercepts the laser beam and focus the TV camera on the card, see Figure 1. Dim the room lights and turn the laser current to zero. Now increase the current while watching the TV monitor. You will see a light spot that becomes slightly brighter as you increase the current. Your diode laser is below threshold, it is not lasing, but only acting as an LED. As you continue to increase the current you will observe a sudden brightening of the beam spot and the appearance of a speckle pattern characteristic of lasing. Adjust the current so that the laser is just above threshold. $V_{LC} = 100\Omega$ You can measure the laser current with a voltmeter. A diode current of 50 mA. will give 5.0 Volt output on the LASER CURRENT in the MONITORS section. You can compare your measured value with the threshold current recorded on your data sheet. A lower threshold current represents better optical alignment. Do not be concerned if your threshold current is slightly higher than that recorded on your data sheet. You will align the cavity in the next few steps after which you can measure the threshold current again.

14. The following steps are concerned with alignment of the external laser cavity. There is both a vertical alignment and a wavelength selective horizontal alignment. We suggest that you read the section of the manual on Diode Laser Physics before undertaking this procedure. We think you will find it much easier to follow the procedure if you have some idea of the physics behind these adjustments. This may be the most difficult procedure you will need to follow in this experiment. For the uninitiated it is very easy to totally misalign the laser, which can be both frustrating and time consuming. If you are not familiar with diode laser adjustment, we ask that you follow each step closely. If you have trouble or do not observe what is described in a given step, do not go on to the next

step! We have tried to anticipate possible problems and direct you to the solution. We also do not want to make you overly timid by this statement. Alignment of the external laser cavity is something that any experimental physicist can accomplish. You will need to become facile in the alignment, not only because your students may misalign the cavity, but also because eventually your diode will burn out, and you will have to replace it. This will involve an alignment of the cavity, starting from scratch.

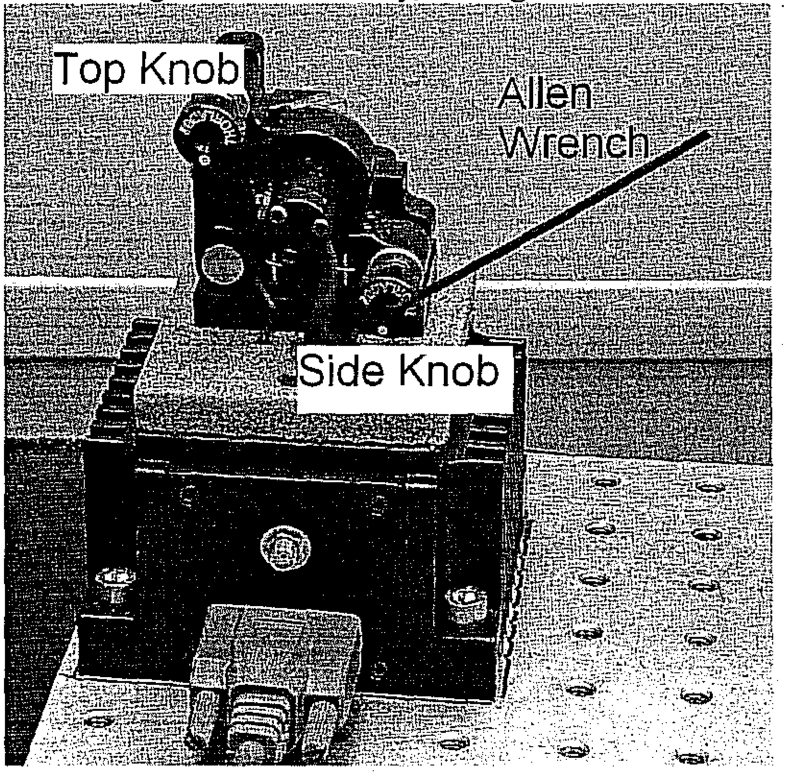


Figure 2. Picture showing TOP and SIDE Knobs used to align grating. Allen wrench is shown in Side Knob.

15. Vertical Alignment: Remove the plastic cover from the laser and set the current so that the laser is just above threshold. Adjust the TOP knob while watching the laser spot on the card using the TV camera. Keep track of where this knob started, and DO NOT TURN THE KNOB MORE THAN ONE HALF TURN. You may find it useful to use the 5/64" allen wrench placed in the back of the knob as a position indicator, it is also easier to make small adjustments of the knob by using the long arm of the allen wrench as a lever. You should see the laser spot change in intensity as the TOP knob is turned. If you rotate the TOP knob very slowly, you will notice that the bright "region" actually changes from bright to dim. These are modes of the laser. You should be able to distinguish six to ten of these modes, with fewer modes when the current is just above threshold. You are seeing different longitudinal modes in the external cavity defined by the grating and back facet of the diode. As you turn the top knob you are not only changing the grating angle but also the external cavity length. You have changed the cavity length by one half wave length when you move from one bright peak to the next. You will need to have to set the current just above threshold to see this clearly. This may

involve a few iterations of setting the TOP knob to give an intensity maximum and then adjusting the laser current. Figure 3 shows an oscilloscope trace of the intensity of the laser as the TOP knob is adjusted. For best alignment leave the laser in the middle of this vertical mode pattern. It is not necessary to sit right on one of the mode maxima, but only near the center of the mode pattern. The correct mode maximum will be set later with the side horizontal adjustment knob and piezo voltage.

Note that finger pressure on the knob also changes the grating alignment, so remove your fingers often during this adjustment. If you find it difficult to turn the knob with a light touch, then you can use the allen wrench placed in the back of the knob as a lever for adjustment.

It is not critical for operation of your laser that you achieve near perfect vertical alignment of the grating. You will get adequate laser performance by simply turning the TOP knob to the intensity maximum. However, it has been found that the better the alignment the better the operation of the laser. Better operation being defined as wider mode-hop-free scans.

If you are not able to see any change in laser intensity as you adjust the Top knob then STOP! Do not continue. Most likely both the SIDE and TOP knobs have both been moved by accident or during shipping. Please refer to "Aligning the external cavity" in the Apparatus section of the manual.

Operating note : The TOP and SIDE knobs are used to align the grating with respect to the diode. The lines on the grating run vertically. Figure 2 shows the diode laser with the cover off and the 5/64" allen wrench placed in the SIDE knob. The first order diffraction from the grating is directed back into the diode. The zeroth order reflection from the grating is the light you observe leaving the laser. The TOP knob rotates the grating about an axis that is parallel to the table top. Turning the TOP knob changes the vertical angle of the light diffracted from the grating. But to first order it ***does not*** *change the wavelength of the light that is diffracted back into the laser. The SIDE knob rotates the grating about an axis that is perpendicular to the table top. Turning the SIDE knob* ***does*** *changes the wavelength of the light that is diffracted back into the diode.*

16. Remove the index card and position the Rubidium Absorption Cell Assembly so that the laser beam passes through the center of the cell. You may use the IR viewing card to trace the path of the beam.

TOP:

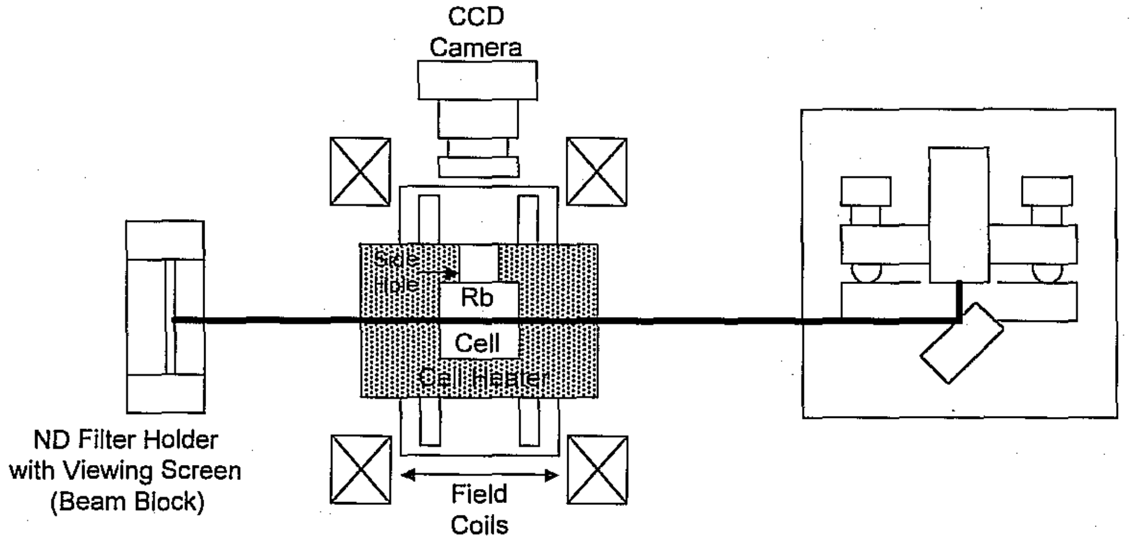


Figure 4. Setup for Observing Rubidium Florescence

17. Point the camera so it looks into the Rb cell from the Side Hole in the cell heater. If you place the camera up on the base of the cell holder you can position the camera so that it abuts the glass holder surrounding the Rb cell. It may also be helpful to dim the room lights since you will be looking for the fluorescence light emitted by the Rb atoms.

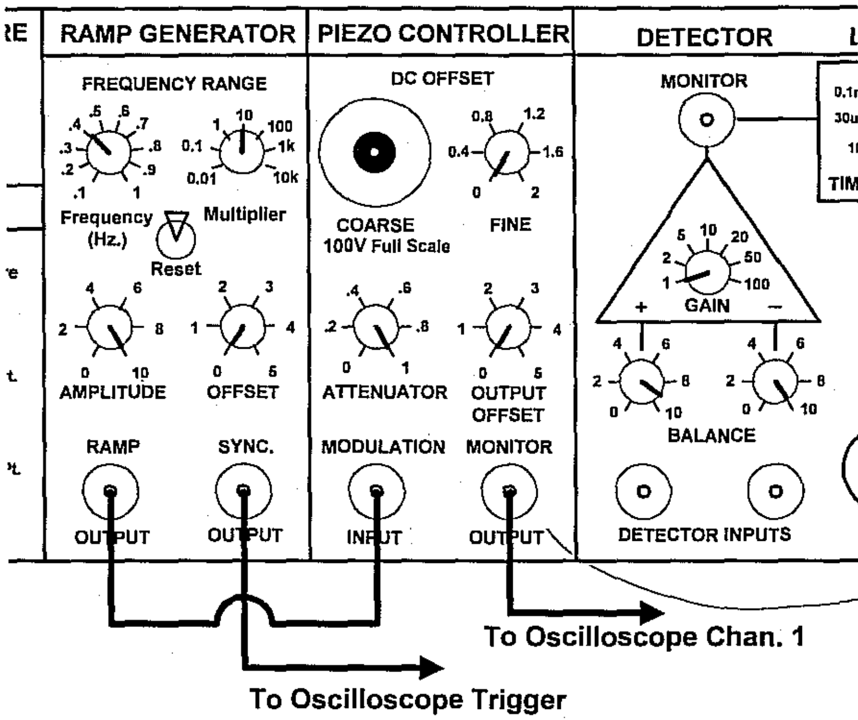
18. Run a BNC cable from the RAMP GENERATOR output to an oscilloscope. Run a second cable from the ramp generator SYNC OUTPUT to the 'scope trigger. Observe the output on the 'scope as you adjust the RAMP GENERATOR settings.

19. Turn the ramp amplitude down and connect the ramp output to the PIEZO CONTROLLER MODULATION INPUT. Use one of the short BNC cables.

20. Connect the PIEZO MONITOR OUTPUT to the 'scope. Turn the piezo OUTPUT OFFSET knob to zero. (The OUTPUT OFFSET changes the DC level of the monitor output. It does not change the voltage applied to the piezo stack. This control is used when locking the laser to an absorption feature and is not needed here.)

21. Set the ramp generator frequency to about 10 Hz. Turn the piezo ATTENUATOR knob to one (1). Set the ramp generator AMPLITUDE knob to ten (10) and use the DC OFFSET knob of piezo controller to produce a large-amplitude triangle wave that is not clipped at the top or bottom. The piezo MONITOR OUTPUT should have a signal that runs from about 3 volts to about 8 volts.

Operating note: The PIEZO CONTROLLER drives a small piezoelectric stack that moves the optical feedback grating. This scans the laser frequency (see the Diode Laser Physics section of this manual for more on how this works).



Funktioniert nu
mit T-Stecker
und einem offene
Ende -> 15
Widerste

22. Finding the Rb Fluorescence, Initial Horizontal Adjustment: Set the laser current to the value listed on your data sheet. You will need to connect a voltmeter to the LASER CURRENT MONITOR to accurately set the current. If the horizontal grating position has not been changed much during shipping or because of accidental adjustment, then you will see a flashing streak of light within the cell on the TV monitor. This is rubidium fluorescence. Atoms of Rb in the cell, absorb laser light at the atomic resonance frequency and re-emitting it in all directions. If you do not see any fluorescence do not despair. You only need to make a slight adjustment of the SIDE knob.

Put the 5/64" allen wrench (hex key) in the back of the SIDE knob and use it as a rotation marker. Remember the starting position of the wrench; you could even draw a little picture in your lab book. While you observe the TV screen looking for the fluorescence flash, slowly rotate the SIDE knob first one way and then the other. You should not need to rotate it more than one half turn in either direction. If still no fluorescence is observed, then return the SIDE knob to the starting position, and adjust the current in 3mA increments (about 1/3 of a turn) both above and below the Laser current recorded on you data sheet. At each new current setting rotate the SIDE knob again, so that you don't lose your position, always return the knob to its starting position before changing the laser current. If you do NOT see any fluorescence, first repeat the above steps again, doing them with care. You might have someone else go through the steps as well. It's easy to miss some detail and thus not observe fluorescence. In

SIDE

particular check the laser temperature, the vertical alignment, and make sure you are sweeping the piezo.*

If you still see no florescence then you can try making bigger excursions in the grating angle with the side knob (plus and minus one whole turn). It may be that the Cavity became grossly misaligned during shipping, refer to section A4-2. in the appendix for details on aligning the external cavity.

Once you see the florescence flash move the SIDE knob so that the florescence is always visible. Now adjust the laser current to make the florescence as bright as possible.

23. Connect a Photodiode Detector (PD) cable to the DETECTOR POWER output of the laser controller, and connect the Photodiode Detector output BNC to channel two (2) of the oscilloscope. Set the channel two (2) input coupling to DC, the gain to 5 Volts/div, and the vertical position so that ground is in the middle of the oscilloscope display. The signal from the Photodiode Detector is negative and saturates at about -11.0 volts. If you are uncomfortable observing a negative going signal, you can always use the invert function on your 'scope.

24. Put the Photodiode Detector in place to intercept the laser beam coming through the Rb cell. You can move the PD for alignment, or you can steer the beam using the first mirror. Use the latter for fine adjustments. You will have to adjust the Gain on the back of the PD. Bolt the photodiode down and make sure the beam is hitting the sensor. *Operating note: The laser and Rb cell are designed for a 4-inch height. The best alignment strategy is to use pointing mirrors to keep the beam height fixed at 4 inches.*

Operating note: In the present configuration there is a very high intensity beam (power per unit area) going through the Rb cell. This much power "saturates" the transition, resulting in very little total absorption of the beam.

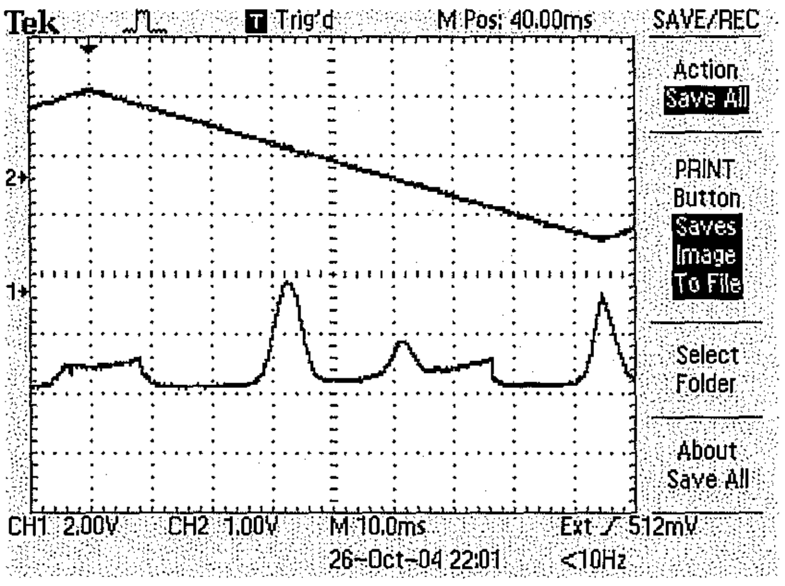
25. Assemble the glass neutral density filter in a fixed mirror holder and place it in a post holder. Please refer to the Optics section in the Apparatus Chapter of the manual if you are unfamiliar with putting optical components into mounts.

26. Place the attenuator between the laser and the Rb cell (not between the cell and photodiode). Adjust the PD Gain so you can observe something on the 'scope showing that light is hitting the PD. For the best performance you want the PD Gain to be as high as possible without saturating the PD. This keeps the noise from the PD at a minimum. The PD gain changes in 1,3,10 steps, a signal level of 2 to 6 volts is reasonable. Block the beam with your hand to convince yourself that the PD is detecting the transmitted laser light.

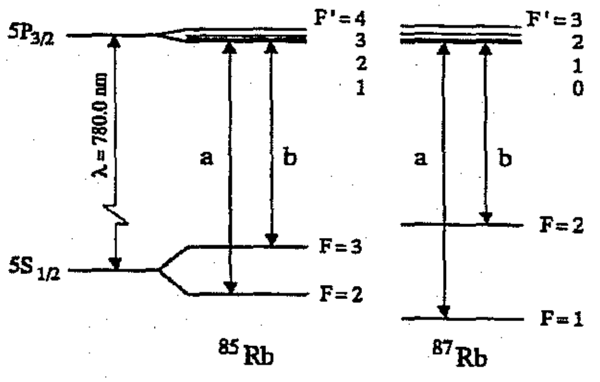
---

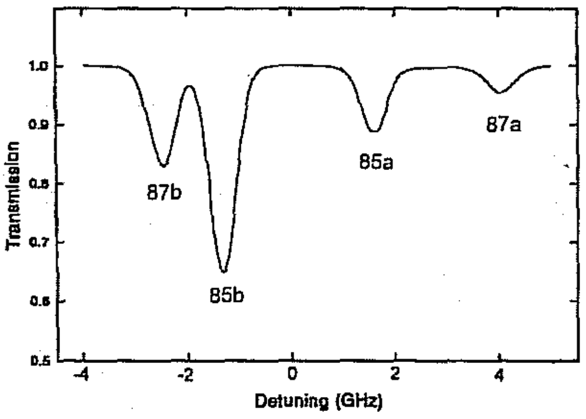
* You can check that the piezo is actually moving by doing the following. With the Ramp generator connected to the Piezo modulation input, turn the AMPLITUDE of Ramp to zero, change the ramp frequency to about 3 kHz. And then increase the AMPLITUDE. You should be able to hear the piezo vibrate. WARNING: Do not leave the piezo running at high frequency and amplitude for a long time. It will cause heating and damage to the piezo.

27. You should see a 'scope signal that looks something like this:



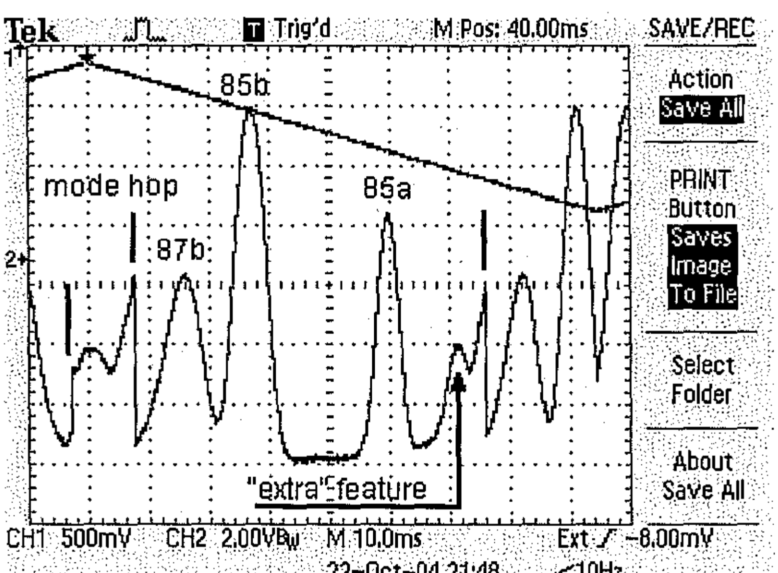
The upper trace is the piezo monitor, which shows the voltage on the piezoelectric stack as a function of time. The lower trace is from the photodiode, showing absorption dips due to the Rb vapor. If the laser scanned "perfectly" in frequency (that is no mode hopping), you would see just some fraction of the Rb absorption spectrum. The energy levels of ^{85}Rb and ^{87}Rb and the Doppler broaden spectrum are show below:



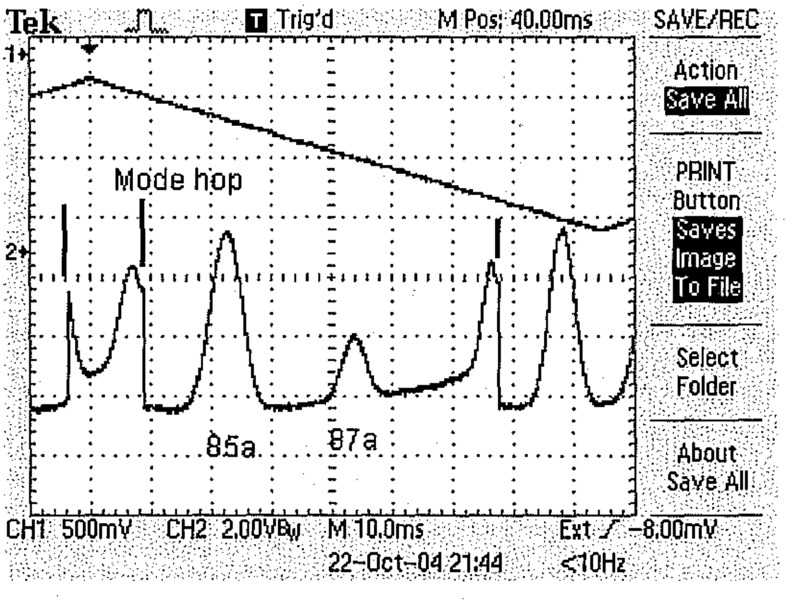


The absorption dips in your trace are interrupted by various "mode hops" – when the laser frequency jumps suddenly. Refer to the Diode Laser Physics section for a discussion of mode hops. Observe how the signal changes when you vary the laser current and the piezo drive parameters. Please explore the parameter space.

28. Horizontal modes, final horizontal adjustment: Adjust the laser current and piezo voltage so that a "nice" absorption spectrum is centered on the oscilloscope. This takes a little practice. As with the vertical adjustment, there are also horizontal modes. These modes are slightly different, in that turning the horizontal adjustment screw changes **both** the external cavity length and the grating angle. You can move through two or three of these modes by changing the piezo DC LEVEL voltage. Place the 5/64" allen wrench (hex key) in the back of the SIDE knob with the long arm of the allen wrench sticking out at about a 45° angle. (See picture at step 15). You will use the allen wrench as a lever to gently move through the horizontal modes. Watch the oscilloscope display as you gently push on the end of the allen wrench. You should be able to identify six to eight modes in which the Rb absorption is still visible on the oscilloscope. You want to set the Side knob in the middle of this mode pattern. You might notice that the modes at the ends have a shorter and more erratic scan over the Rb absorption. You do not need to make an exact adjustment with the Side knob as the Piezo DC OFFSET voltage can be used to fine tune to the mode. With proper alignment and laser current adjustment you should be able to set a scan that covers the first three lines in the absorption spectrum (87b, 85b, and 85a as shown below).

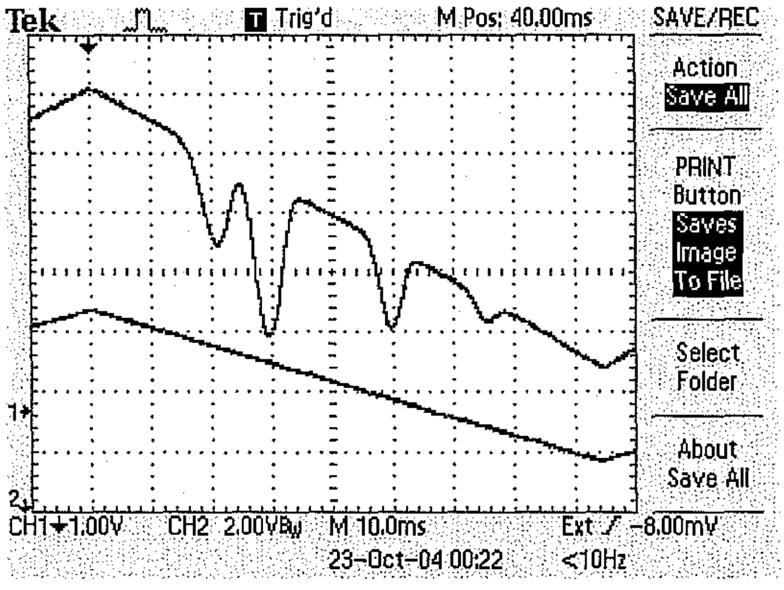


You may notice a few "extra" features at the ends of a scan right before a mode hop. These feature look like (and are) replicas of the strong 85b and 87b absorptions and appear near where you would expect to find the 87a absorption. The "extra" features are associated with relaxation oscillations in the diode laser. (See Diode Laser Physics Section). By reducing the laser current and adjusting the Piezo DC LEVEL, you should be able to get a nice scan showing the 85a and 87a features. This is shown below.



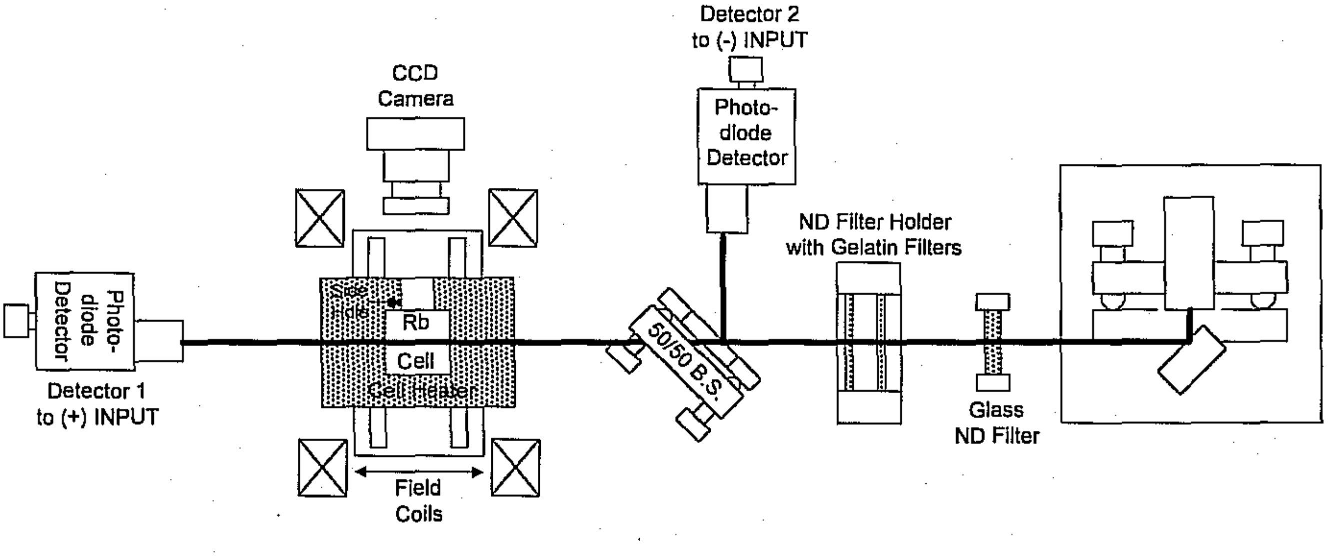
29. A **simultaneous current** and **piezo modulation** will allow a larger scan range without mode hops. (See the Diode Laser Physics section for an explanation.) Set the laser CURRENT ATTENUATOR knob to zero. Attach the BNC splitter "F" connector to the RAMP OUTPUT on the RAMP GENERATOR. Plug one BNC from the RAMP OUTPUT to the MODULATION INPUT of the PIEZO CONTROLLER, and the second BNC from the RAMP OUTPUT to the CURRENT MODULATION INPUT.

30. Turn the ramp generator amplitude up to maximum, and watch what happens when you turn up the current attenuator knob. With some tweaking you should be able to produce a full trace over the Rb spectrum. The oscilloscope invert function has been used to show the trace in what "looks" more like an absorption spectrum in the diagram below.

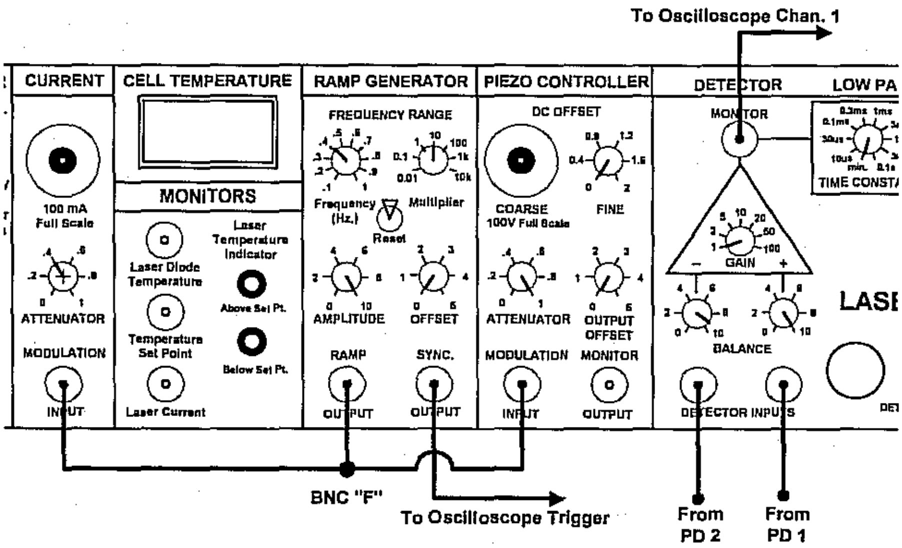


Note the correspondence to the expected atomic Rb spectrum shown above. *Operating point: The depth of the lines depends on the length of the Rb cell and the atomic density, the latter depending on cell temperature. You can explore this by changing the cell temperature.*

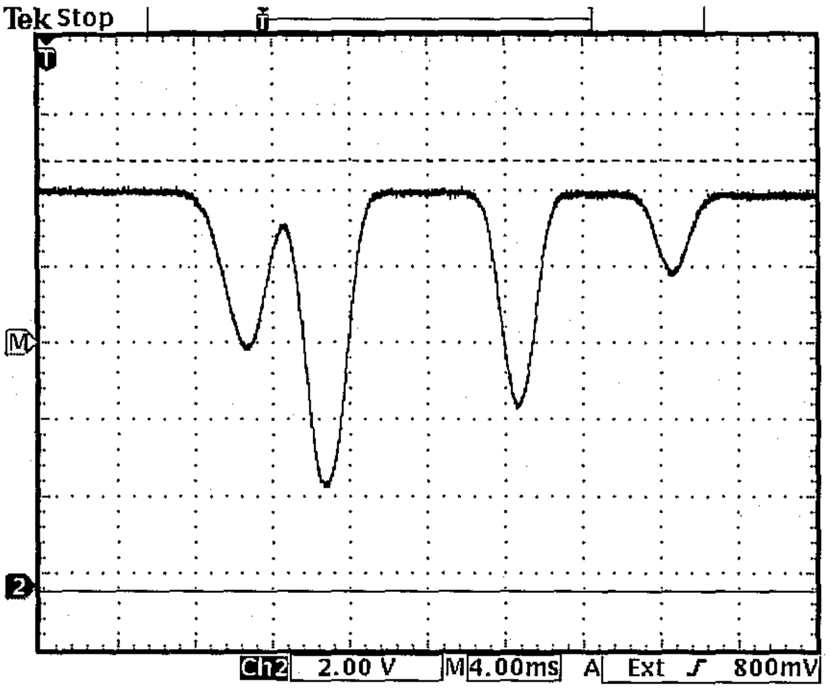
31.) You can see in the above that the background intensity changes considerably with the scan. This is because you are now scanning the laser intensity (via the current) together with the laser frequency (via the piezo). You can correct for this effect in a number of ways. One way is to digitally record a spectrum with the cell in place, and then record a second spectrum with the cell removed, and finally divide the two signals in software. This has the advantage that only a single photodetector is needed, but the disadvantage that the two traces are not recorded simultaneously. Another way to accomplish this is by using a second photodiode, as in the following layout:



31.) You will need to place the 50/50 Beam splitter in a mirror mount. Please refer to the Optics section in the Apparatus Chapter of the manual if you are unfamiliar with putting optical components into mounts. With this experimental configuration one detects two simultaneous signals, one with and one without the Rb absorption, and then subtract the spectra. You will use the Detector electronics on the Laser Diode Controller.



32.) Connect the BNC from the Photodiode Detector 1 to the (+) DETECTOR INPUT. Set the BALANCE knob above the (+) INPUT to 1.0 (fully CW). Set the GAIN to 1. Connect a BNC Cable from the first MONITOR OUPUT to channel 1 on the 'scope. Change the BALANCE knob and observe the effect on the 'scope. Position a second Photodiode Detector to intercept the beam that has been split off by the Beam Splitter. Connect the BNC from Photodiode Detector 2 to the (-) INPUT. Set the BALANCE knob above the (-) INPUT to 1.0 (fully CW) and turn BALANCE knob above the (+) INPUT to 0. Adjust the Gain on Photodiode Detector 2 for a "good" (2-6 volts) level and position the photodiode for a maximum signal. Now increase the BALANCE knob above the (+) INPUT to 1.0 and adjust the BALANCE to get a spectrum as shown below.



The trace shows an excellent correspondence to the expected spectrum, with all four Rb absorption dips on a flat background. Note, however, that the subtraction technique does not immediately give an absolute measurement of absorption, while the digital method does.

Operating note: You should always be wary that zero light on a photodiode may not correspond to zero voltage output. You can check this by simply blocking the beam and noting the voltage

All Finished

At this point the initial alignment is complete, and you are ready to move on to the more sophisticated spectroscopy experiments. You may need to realign the grating feedback from time to time, following the above procedures. If not disturbed, however, the alignment will likely be stable for months.

Shutting Down

If you are not using the laser for a few hours for some reason, you can you can leave the controller on. Then the diode laser and the Rb cell will stay at their operating temperatures and be ready to go when you need it.

BUT TURN THE LASER CURRENT OFF. You should turn the laser current down, and the laser power switch off, whenever you leave the lab. This is a safety precaution, plus it will prolong the life of your laser. With use the diode laser will eventually burn out and need to be replaced, so leave the laser itself off when not in use.

It's okay to leave the ramp generator and piezo controller on and running at whatever setting you wish (for examples, the settings determined above). You can also leave the Rb cell temperature at whatever setting you wish. Then these will be set up when you want to use the laser – just turn on the laser power switch and turn up the current. After the laser warms up briefly, you should have essentially the same spectrum you had when you turned the laser current off.

We do not recommend leaving the controller on overnight and unattended even if the laser current has been turned off.

Trouble shooting: Ken I have left off the trouble shooting section. I have tried to cover most of the ground in the body of the document.

Topics not covered:
1.)Damaged Diode. I have no experience with damaged diodes. Is this at all likely to happen when they first get the diode? I'm not sure what the striations are. Could we make a picture of this along with a nice looking beam profile?
2.) Moving collimating lens. I don't see any reason why this should need adjustment until the time when the users have to put in a new diode. I have found that correct lens adjustment is the most crucial step in getting good performance (long mode hop free scans). I have a nice procedure to follow for correct adjustment of the lens. It starts with observing beam shape as you state. The final crucial step is looking at the threshold current as you minutely tweak the lens position. The grating is removed, the lens is tweaked, (I put a scratch mark on the side of the lens holder so that lens position can be recorded and repeated.), the grating is put back on, the grating is aligned, and the threshold current is measured and recorded, and then the process repeated for a new lens position until the point of minimum threshold current is found. I think this is too much for first time users to do, and should be unnecessary as the lens will be set at Teachspin before shipping.