Kapteyn-Murnane Laboratories Inc.

Serial Number: G061202

Date: 2/15/2007

Tested By: G. Taft

Pump Laser: Millennia

Pump Power (W): 4.50 (on controller)

CW Output Power (mW): 270

ML Output Power (mW): 390

Crystal Micrometer (mm): 5.800

CM2 Micrometer (mm): 3.430

P7 Micrometer (mm): 1.070

P8 Micrometer (mm): 2.330

Spectrum Type: Gaussian-shaped

FWHM (nm): 82

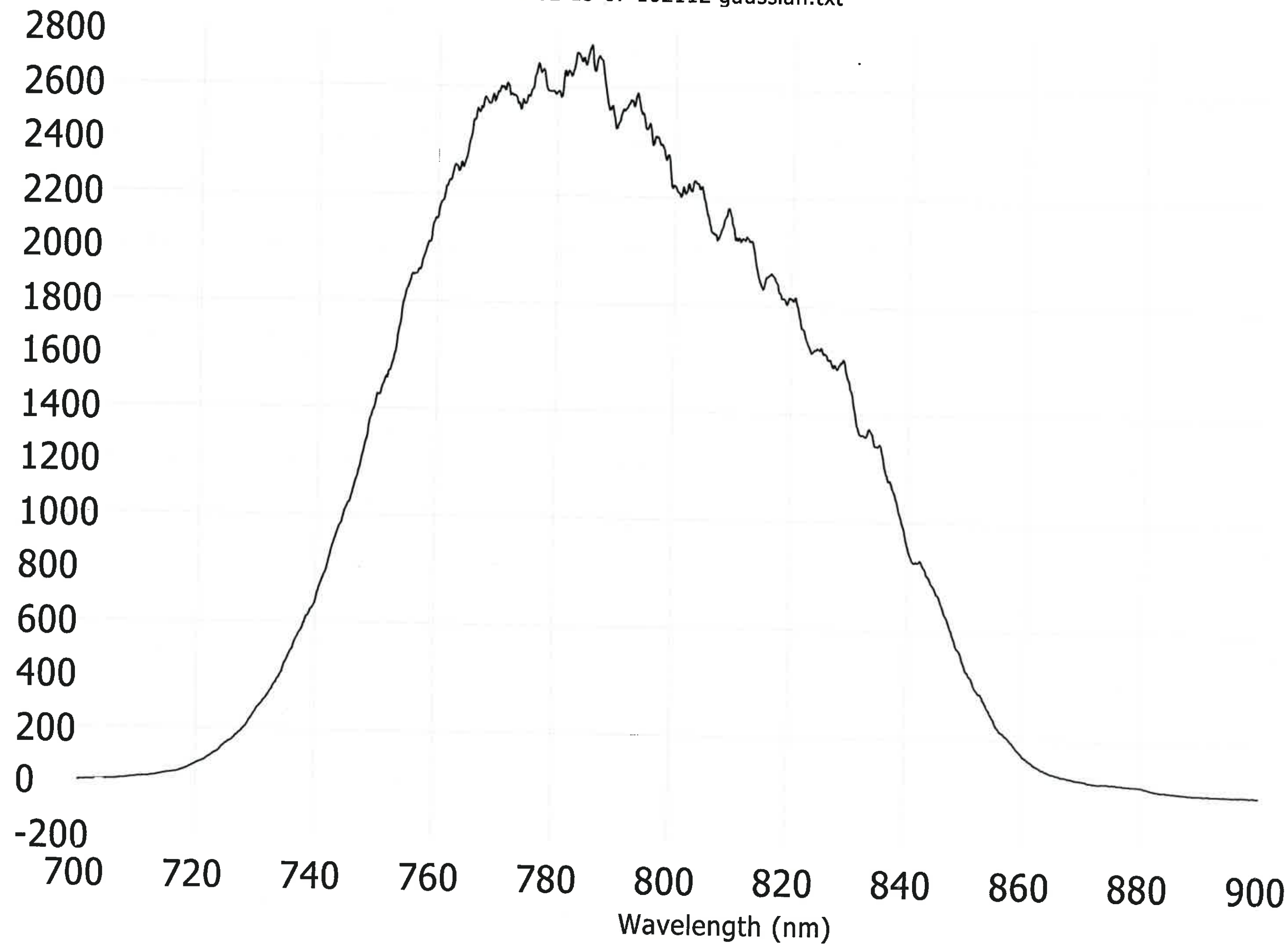
Exposure Time (ms): 10

Boxcar Width (pixels): 10

Spectra to Average: 1

Notes:

Spectrum File: G061202 02-15-07 102112 gaussian.txt



Since the micrometer settings depend on pump laser type and alignment, they are shown here only for an example of typical settings. Customers can note the relative positions of the prisms (P7 and P8) when tuning the spectrum.

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Pump Power (W): 4.50 (on controller)

CW Output Power (mW): 260

ML Output Power (mW): 380

Crystal Micrometer (mm): 5.800

CM2 Micrometer (mm): 3.430

P7 Micrometer (mm): 0.870

P8 Micrometer (mm): 2.440

Spectrum Type: broad bandwidth

FWHM (nm): 107

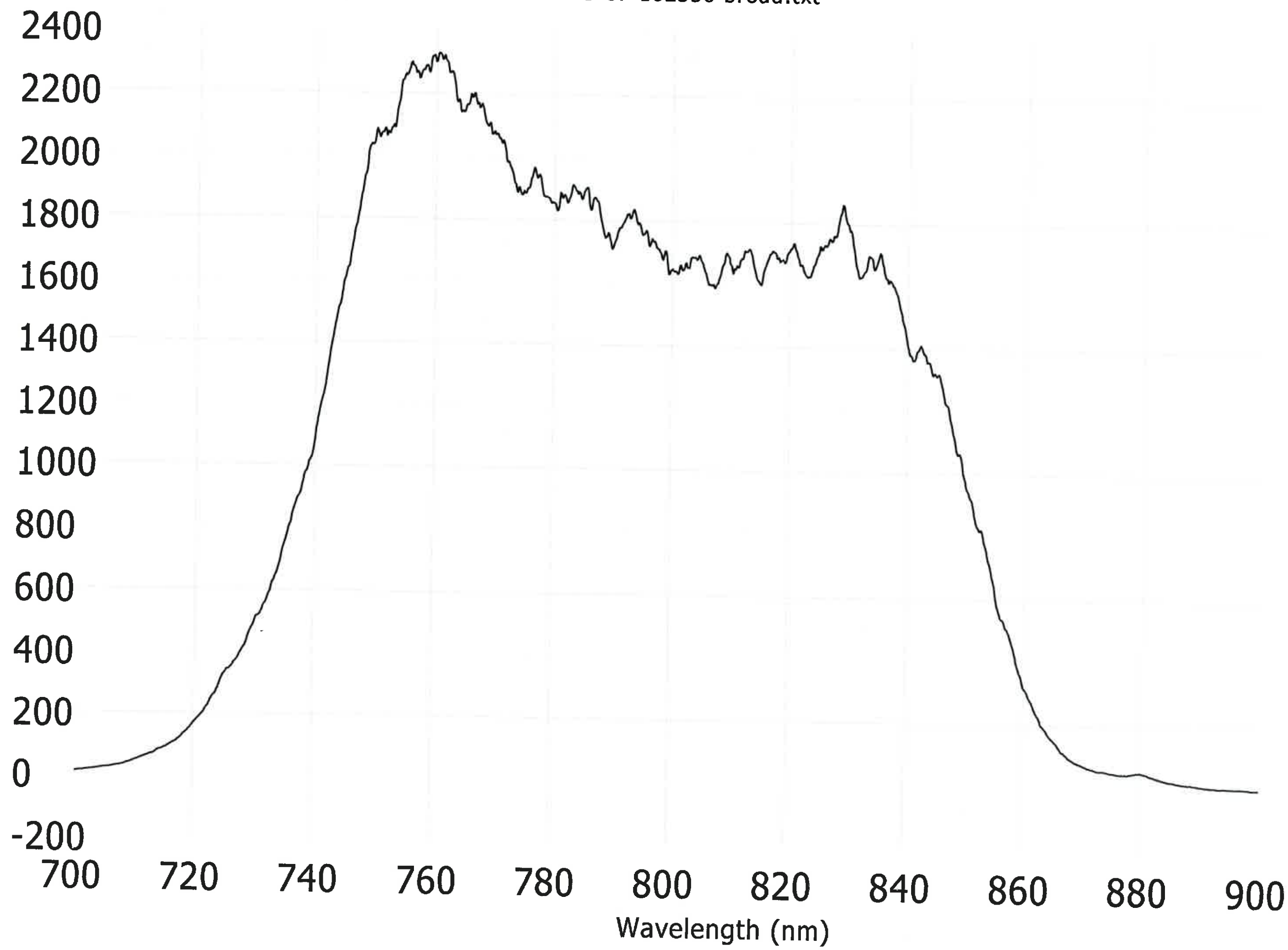
Exposure Time (ms): 10

Boxcar Width (pixels): 10

Spectra to Average: 1

Notes:

Spectrum File: G061202 02-15-07 102550 broad.txt



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Kapteyn-Murnane Laboratories Inc.

Instruction Manual

Griffin Ti:Sapphire Laser

September 12, 2006

A parts list can be found on the last page of this manual.

Table of Contents

A Frequently Asked Questions (FAQ) document follows the manual, with its own Table of Contents.

1. Introduction

The standard Griffin laser uses a ~10% output coupler, and typically requires ~4.5 Watts of CW 532-nm or argon-ion (all-lines) pump power, in a clean, TEM_{00} mode. The Griffin laser is shipped pre-assembled and pre-aligned. However, it is our tradition to provide ultimate flexibility and independence for our customers; and, therefore, we include detailed assembly and alignment instructions (Section 7) in this manual. You should not need to perform these drastic changes unless you decide to make major changes to the optical components, or layout of your laser. We recommend that you contact KMLabs before making any major changes to the optical cavity.

2. Duplication

This document is copyrighted, and duplication is allowed only for personal use with laser S/N G0612O2. As you may be aware, this basic laser design was originally described in a document "Mode-locked Ti:sapphire Laser" which was widely distributed within the ultrafast laser community. This laser is based on that design; however, the improvements we have made on the design are proprietary to KMLabs. We are supplying a quality product at a very reasonable price, and would appreciate that you not distribute this document or duplicate the design in any way. Anyone who wishes to do so can produce a laser with similar performance using the "free" version of this document.

3. Safety

The Griffin laser is a class IV laser system, which can cause serious eye injury. WEAR PROPER EYE PROTECTION AT ALL TIMES. Since this laser involves significant radiation in *both* the green and the IR, full protection is difficult but not impossible. We typically use two types of laser protective spectacles for alignment. Goggles designed for 532-nm or argon-ion laser beams are useful to block the pump light while still being able to observe Ti:sapphire fluorescence and obtain lasing action. NOTE: Goggles designed for 532-nm are not necessarily appropriate for Ar+, and vice versa. You should be sure to purchase goggles that are designated for the pump wavelengths you will be using. Once the laser action is achieved, Laser-Guard Broad-spectrum "B" goggles provide some protection at both 800 nm and in the green, while still giving reasonable visibility. It is important to note, however, that the optical density of these goggles is moderate at 450-550 nm and at 700-900 nm, and may not provide full protection in all situations. Once the laser is operating and when the pump beam is fully enclosed, goggles using BG39 glass (for example, available from Kentek) can provide excellent usability and protection at 800-nm. Since each laboratory has its own set of safety issues, you should research your own safety needs. The following safety and warning label stickers are affixed to your Griffin Ti:sapphire laser:

Figure 3.1: Danger label, with specifications located near the exit aperture.

Figure 3.2: Interlock defeated labels (2) affixed to both sides of the entrance shutter defeat flag.

Figure 3.3: Model/Serial # label affixed to the green-input side panel of the laser.

Figure 3.4: Interlocked cover label affixed on the side panel, just below the lid-handle.

4. Registration

Users are requested to send complete contact information to Kapteyn-Murnane Laboratories, to allow us to send software upgrades and other product information. Please include the laser serial number, contact name, complete mailing address, telephone, FAX, and e-mail addresses. This information can be e-mailed to: registration@kmlabs.com, or FAXed to: 419-821-2284.

5. Initial Setup

Your Griffin laser was aligned and tested at the factory before it was shipped. Therefore, the main task in setting up the Griffin at your facility is to align the pump laser beam into the Griffin cavity. The following instructions will help you do this.

IMPORTANT!!! **NEVER adjust the hex screws for the horizontal and vertical tilt on the curved mirror mounts (numbers 4 and 6 on Figure 5.2) unless you are VERY sure that it is necessary.** These adjustments were made at the factory, and should never need adjustment, unless mirror 4 or 6 has been loosened at some point. If, during the following procedures, you believe that you will need to adjust any of these tilts, we highly suggest that you contact KMLabs to verify this before proceeding.

A) Unpacking

1.) Open the wood crate by unscrewing the bolts to the cover of the box.

2.) Carefully remove the Griffin laser box from the crate. It is fairly heavy, so it is a good idea to have two people lift it.

3.) Remove the plastic wrap from the Griffin laser box and all of the packaging material inside the box, being careful not to bump any of the adjusting knobs.

4.) Remove the foam inserts between the micrometers and the translation stages.

Figure 5.1: Remove these foam inserts.

B) Pump laser and overall system layout

Before securing the Griffin laser to your laser table, you will need to determine the best way to direct the pump laser beam into the Griffin laser. Figure 5.2 shows the dimensions of the Griffin laser and where the pump beam enters the cavity. Figure 5.3 shows several different pump beam configurations and lists advantages and disadvantages for each one. The green pump beam needs to enter the Griffin laser with "P" polarization (parallel to the optical table), level, and at a height of 84 mm above the optical table. Any mirrors that are used to steer the pump beam must be very stable, since the stability of these mounts directly influences the stability of the Griffin laser. Also, the green beam should be fully enclosed in beam tubes or other housing which prevents air currents from blowing dust through the beam. The following steps will help you determine the best setup for your pump laser and Griffin laser. Following these steps, section "B" gives detailed instructions on aligning the pump beam.

1.) Determine the polarization of the green pump laser beam. Most pump lasers emit "S" polarized light (perpendicular to the optical table).

2.) The Ti:sapphire oscillator requires the green beam to be "P" polarized (parallel to the optical table). Therefore, it likely will be necessary to rotate the polarization of your green laser beam by 90 degrees.

3.) The green beam must enter the Griffin laser at an 84-mm beam height above the optical table, which corresponds to the center-line of the two curved mirrors (mirrors 4 and 6 in Figure 5.2). Because of these requirements, you probably will want to use an out-of-plane periscope in your pump beam-line, to: (a) rotate the polarization and (b) adjust the beam to be level and 84-mm above the optical table.

4.) KMLabs offers a very sturdy periscope for this purpose. If you are using your own optics here, be forewarned that the stability of these optics is of utmost importance in obtaining long-term stability for mode-locking. If you have purchased the KMLabs pump optics set, the optics "tower" rotates the polarization, turns the beam 90 degrees, and shifts the beam height up or down. Set up this tower so that the first reflection diverts the beam vertically, squarely "up" or "down" (depending on the starting height of your beam), while the second reflection diverts it back into the horizontal plane and turns it. This mount has no spring-loaded adjustment, since we have found that adjustable mirrors placed at these odd angles are extremely vibration-sensitive and can easily cause the laser to stop mode-locking. The mirror mounts can be loosened with a hex key to adjust the beam to hit the next mirror at an exact 84-mm beam height (corresponding to the center height of the Griffin laser, relative to the optical table). Horizontal beam adjustments can be accomplished by sliding the entire tower on the table without rotating it.

5.) Generally you will need at least two mirrors to steer the green pump beam into the Griffin cavity. One of these mirrors is provided (mirror 2 in Figure 5.2). Figure 5.3 shows the location of other pump steering mirrors. Although it is possible to use the periscope mirrors to obtain a level beam at a height of 84 mm, these mirrors can be difficult to adjust properly.

Unless you are experienced making such adjustments, we recommend that you use two mirrors in a "z-fold" configuration (see Figure 5.3 (d)) for easy control of the beam height and levelness. We have found that broadband dielectric mirrors (e.g. Newport's BD.1) mounted in *stable* mirror mounts work well for steering the pump beam.

6.) Once the pump beam is aligned (see below), it is highly recommended that the pump beam be fully enclosed in beam tubes. This is a good safety practice which will also increase the stability of the Ti:sapphire laser by preventing air currents from blowing dust through the pump beam.

7.) Considering your table layout, place your green pump laser so that the green beam propagates less than two meters before entering the Griffin laser. KMLabs highly suggests that you arrange your Griffin so that the long edge, closest to the prisms, is near the edge of your optical table, and the pump laser is in the center of the optical table as shown in Figure 5.2.

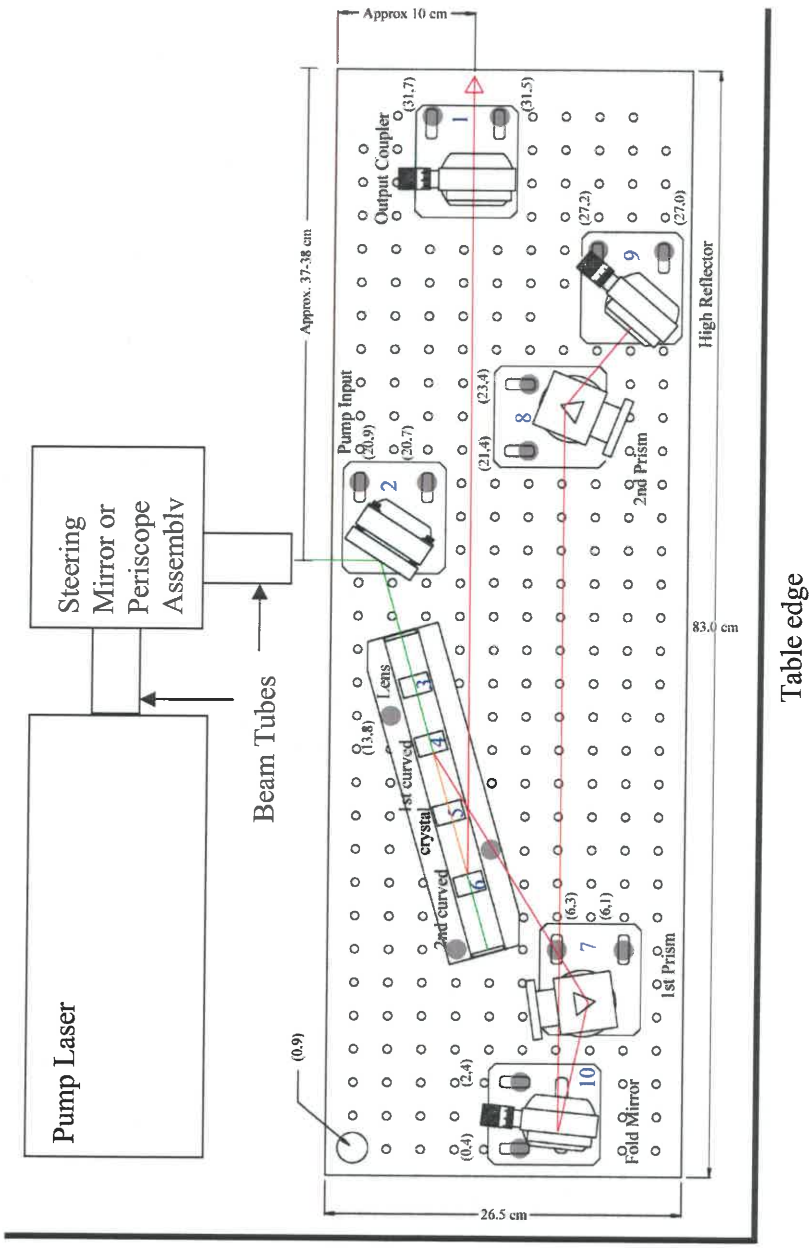


Figure 5.2: Basic layout of the laser, including number designations for the optics, and screw coordinate positions for the mounts. Alternate pump laser configurations are shown in Figure 5.3.

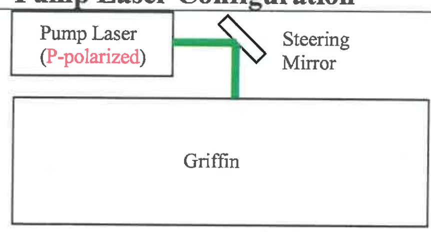
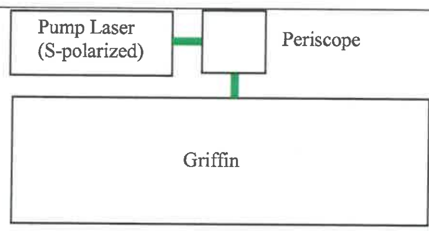
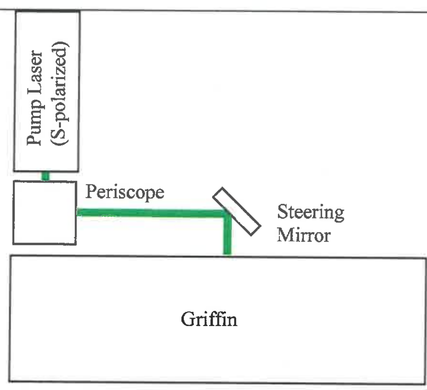
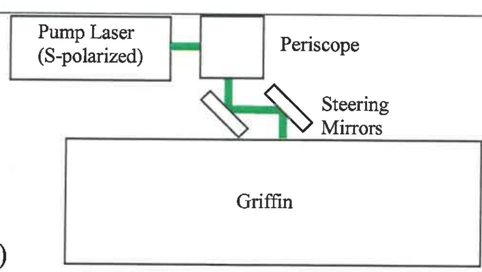
Pump Laser Configuration	Advantages	Disadvantages
(a) 	• Simplest • Least Expensive • Shortest beam path	• Beam exiting the pump laser must be: o Level o 84 mm above table o P-polarized
(b) 	• Relatively simple • Short beam path	• Periscope mirrors are difficult to properly adjust
(c) 	• Adjustable steering mirror is easy to adjust	• Requires more table space • Longer beam path
(d) 	• Provides easiest control over the beam height and direction	• Most expensive • Requires more table space • Longer beam path

Figure 5.3: Possible pump laser configurations and pump beam steering options.

C) Initial pump beam alignment
(See Figures 5.2 and 5.3):

When setting up the pump laser beam steering optics, start with the lowest possible pump power (less than 200 mW) to minimize eye and skin hazards. For a low-power, unfocused beam (less than 200 mW) you can use a white index card to see the beam while wearing laser safety glasses to block green light, since the card will give off some yellow fluorescence. Never place a card in a high-power beam, since it will burn and contaminate the optics with smoke.

1.) Before directing the pump beam into the Griffin oscillator, you should carefully clean the optics with pure methanol and optical quality lens tissue held with a pair of hemostats. Be very careful to avoid scratching any of the optics.

2.) Ensure that the pump beam entering the Griffin oscillator is P-polarized, and LEVEL at an 84-mm beam height relative to the table. All beams within the cavity should be level—parallel to the table top. If the green beam is vertically tilted, your laser will suffer from lower power and poorer stability.

3.) Place the entrance aperture tool into its dowel-pinned seat, just in front of the lens (item 3 in Figure 5.2).

4.) Adjust the green steering mirror outside of the Griffin laser to direct the low-power green beam through this entrance aperture tool.

5.) Ensure that the translational micrometer for mirror 6 in Figure 5.2 is in the CW position, as indicated in Figure 5.4.

6.) Use the green steering mirror (item 2 in Figure 5.2) inside the Griffin laser to direct the low-power green beam through the center of the iris just in front of the output coupler (item 1).

7.) Repeat steps (4) and (6) until the green beam passes through the center of both tools, simultaneously.

8.) Once the pump beam passes through the center of both tools it should pass through the exact center of the curved surface of the first cavity mirror (mirror 4 in Figure 5.2) and slightly to the side of the center of the second curved mirror (mirror 6 in Figure 5.2). The green beam should not clip any edge of the crystal, but it need not be centered in the crystal.

D) Initial IR fluorescence/lasing alignment
(See Figures 5.2 and 5.4):

At this point, you will optimize the laser for continuous wave (CW) operation. Initially, it is important to align in the CW mode before aligning for modelocked (ML) operation, since this is the easiest configuration in which to optimize the cavity alignment. You will align for lasing by overlapping the IR fluorescence spots.

1.) Ensure that the green pump laser is at minimum power.

2.) Verify that the green beam is aligned, as indicated in the previous section.

3.) Remove the alignment tool from before the lens and open the iris aperture in front of the output coupler.

4.) Check that the IR florescence spot reflected off of mirror (4) is intercepted by the first prism (7), the fold mirror (10), the second prism (8), and the end high reflector (9). Because the wavelengths are spread out at the second prism (8) and the laser typically operates in the near IR, only a small portion of the visible fluorescence spot will be intercepted by the second prism.

5.) Check that the co-propagating IR florescence and green beam are incident upon the output coupler (1).

Warning: at any time during the next series of steps you might achieve lasing. Therefore, you should employ Ti:sapphire laser safety for the rest of these procedures.

6.) Ensure that there is a beam block behind the second curved mirror (1).

7.) Turn up the green pump power to 5 or 6 watts. Do not pump with more than 7 watts. "Over-pumping" will make it easier to initiate lasing; but once you achieve lasing, turn the pump power down to 4.5 W.

8.) You should notice where the pump beam passes through the crystal by observing the bright red fluorescence path. *Never place a card or lens tissue in the high power pump beam since it will burn and contaminate the optics!* The pump beam should focus at the entrance face of the crystal. Since different pump lasers may have different divergence characteristics, you may have to adjust the lens position using the micrometer at its base.

9.) You should observe red fluorescence reflected from the second curved mirror (6) focuses ~10 cm past the output coupler (1) outside the Griffin box. Also, fluorescence from the first curved mirror (4) focuses to a horizontal line at the position of the "far" prism (8).

10.) Make sure that the beam is level. It should be at 59-mm throughout the cavity. You can check this by making a line on an index card at the appropriate height and then moving the card throughout the cavity—but not in the high power green beam!

11.) If the cavity is not already lasing, check the retro-reflection of the IR florescence at both of the end mirrors (1 and 9). Adjust the horizontal and vertical knobs for mirrors 1 and 9 to achieve overlap of the retro-reflected fluorescence. Retro-reflecting the fluorescence with the end mirrors (1 and 9), and repeated re-adjustments should brighten the fluorescence and lead to lasing. You can look for beam overlap at both ends of the cavity; i.e. look at the fluorescence at one end of the cavity, while blocking and unblocking the beam at the other end to observe the retro-reflected fluorescence. Another useful place to look for fluorescence overlap is between the two prisms, nearest the cavity subassembly (nearest prism 7).

12.) Alternately adjust the retro-reflection off mirrors 1 and 9 until lasing is achieved.

13.) Optimize the power and mode by alternately tweaking the horizontal and vertical tilt on both end mirrors (1 and 9); and then adjust the translation micrometers for the lens, second curved mirror (6), and the crystal.

14.) Repeat the optimization of each of these components, in a cyclic process, several times.

15.) You should be able to get more than 800 mW output power, but don't simply stop when you get there—keep trying until you are satisfied that you have as much output power as you can get. As you align the laser, keep checking that the red and green beams hit the curved mirrors at the same spot within one-half of a beam-diameter, so that the pump and cavity beams are collinear in the crystal. Since the green refracts a bit more the red as it enters the crystal, the spots are slightly displaced on the curved mirror when aligned for maximum power. Also carefully observe the spatial profile of the output beam to verify that it is TEM_{00}.

16.) Figure 5.4 shows a typical set of readings for this CW configuration. Verify that your measurements—particularly the separation between the two curved mirror mounts (4 and 6)—are consistent with Figures 5.4 and 5.6. If they are not, you may be in the wrong stability region of the resonator to obtain stable modelocking (see Figure 5.7). Bring the mirrors to a separation closer to the prescribed values, and then optimize the laser from that point.

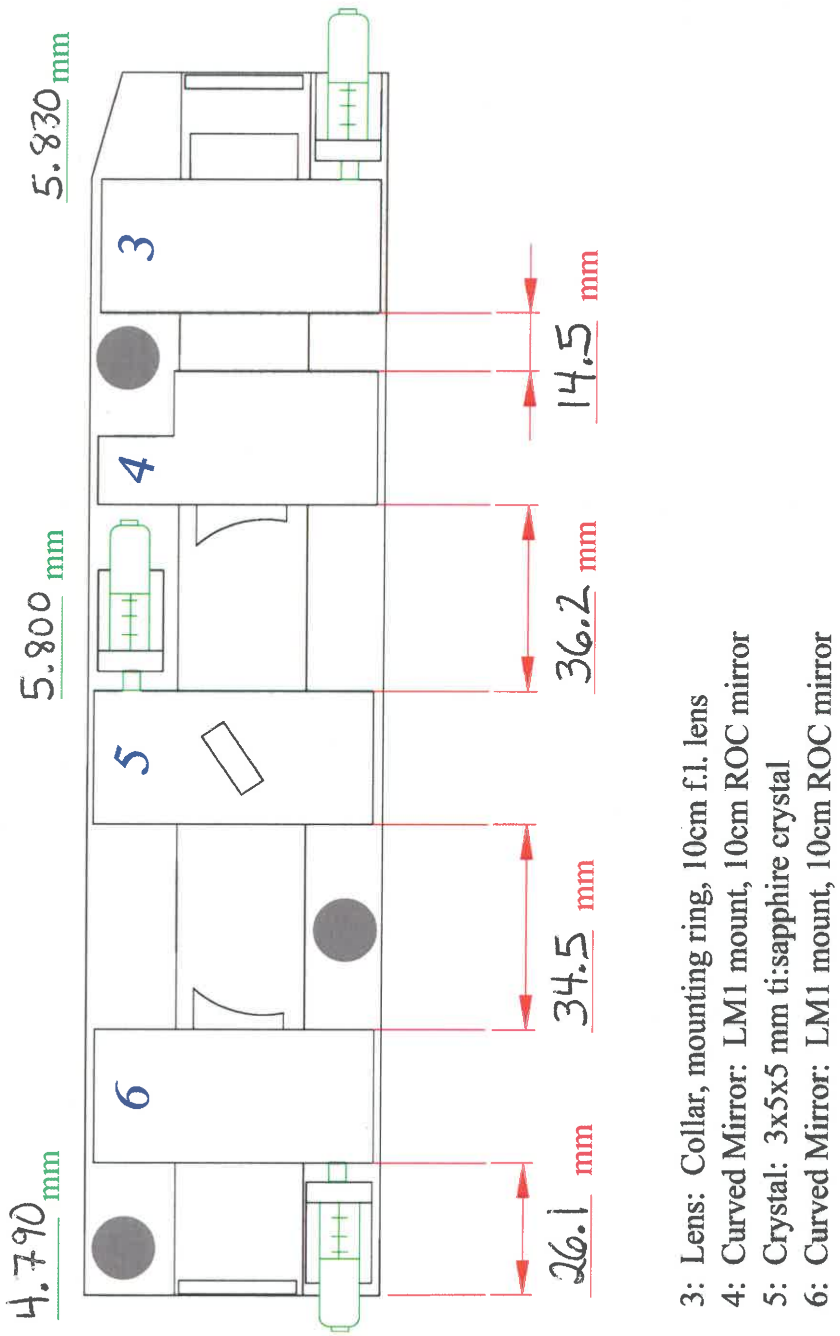


Figure 5.4: Detail on cavity subassembly. Measurements are approximate only, corresponding to C.W. operation of the laser with a ~10% output coupler.

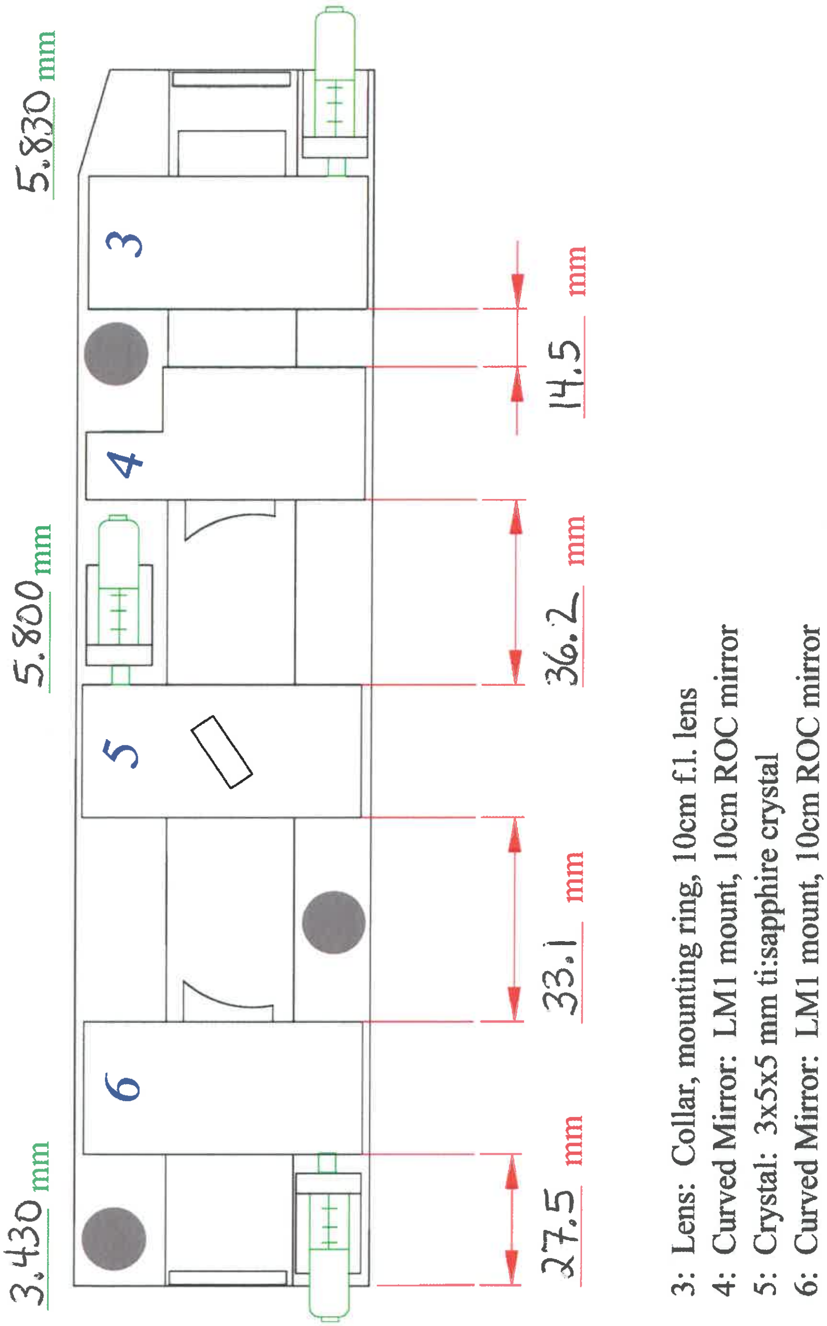


Figure 5.5: Detail on cavity subassembly. Measurements are approximate only, corresponding to **M.L.** operation of the laser with an ~10% output coupler.

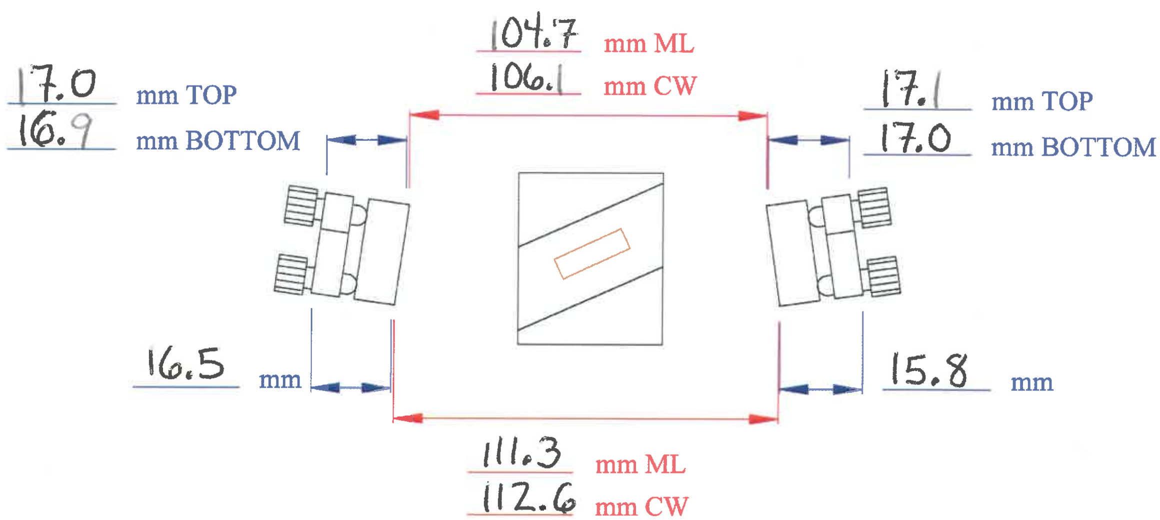


Figure 5.6: Detail on approximate cavity mirror adjustments to obtain the correct beam entrance/exit angles. Dimensions correspond to the thickness, measured with a caliper, between the face of the mount and the anodized aluminum base, as drawn.

E) Initiating Modelocking

(see Figures 5.5, 5.6 and 5.7)

Now you should be ready to mode-lock the laser. Use a spectrometer to observe the spectrum from the laser, and let the output beam propagate a few meters so that you can observe the mode shape. You can use a mirror to project it on to a card close to where you are working. Note that using a lens to expand the mode can cause misleading distortions to the beam. A fast photodiode is also helpful, and is provided with your laser (see the Introduction to Electronic Controls section later in this manual).

1.) Make sure the laser is adjusted for maximum CW power and for a round near-TEM_{00} mode, as instructed in the previous section.

2.) Translate BOTH prisms so that the beam is within 1 and 2 mm of the prism apices. THE LASER WILL NOT MODE LOCK WITH EXCESS PRISM GLASS.

3.) Translate the second curved mirror (mirror 6) inward, towards the crystal, until the beam looks elongated vertically, as shown in Figure 5.7. As you do this, the CW power will drop. If the power drops below about 200 mW before the mode elongates, stop translating, and then adjust the horizontal and vertical tilt on the output coupler (1). This should increase the power.

4.) Keep bringing the curved mirror in, and peaking up the CW power with the output coupler adjustments until you have vertical elongation, and approximately 300 mW of CW power. It is normal for the power to randomly fluctate by tens of milliwatts when adjusted at this CW position. The micrometer position should be similar to, although not necessarily the same as, that given in Figure 5.5.

5.) Move the crystal and lens to fill in the center of the oval mode, if necessary. It is normal for the vertical elongation to be very extreme in some cases, and appear more like a vertical stripe than an oval.

6.) The spectrum should become "jumpy" when the output coupler mount is tapped. Pushing the prism translation stage with your thumb, should then cause the laser to self mode-lock. Don't be afraid to be moderately vigorous since the mounts are very stable. Alternatively, you can set up the electronic controller, and use the "start" function to rapidly translate the "far" prism (8) back and forth. You can leave the computer "starting" continuously while you adjust the laser. The laser should start to modelock spontaneously when the correct cavity configuration is reached. When aligned properly, the modelocked laser mode is perfectly round and energy efficient, while the CW mode is oval and blurred, with less power than in the mode-locked case (about 50% less). You are getting close when:

- The spectrum becomes "jumpy" when a component is tapped, or the CW spectrum is broader when not tapped.
- The spectrum has two or more wavelengths separated by the bandwidth of the modelocked pulses (~20-80 nm).

- The photodiode signal becomes very noisy when the mirror mounts are tapped.

If you are using the electronic controller, remember to **turn off the "start" function** once the laser is modelocked (or if you suspend work temporarily). A single "click" on the "start" button will accomplish this.

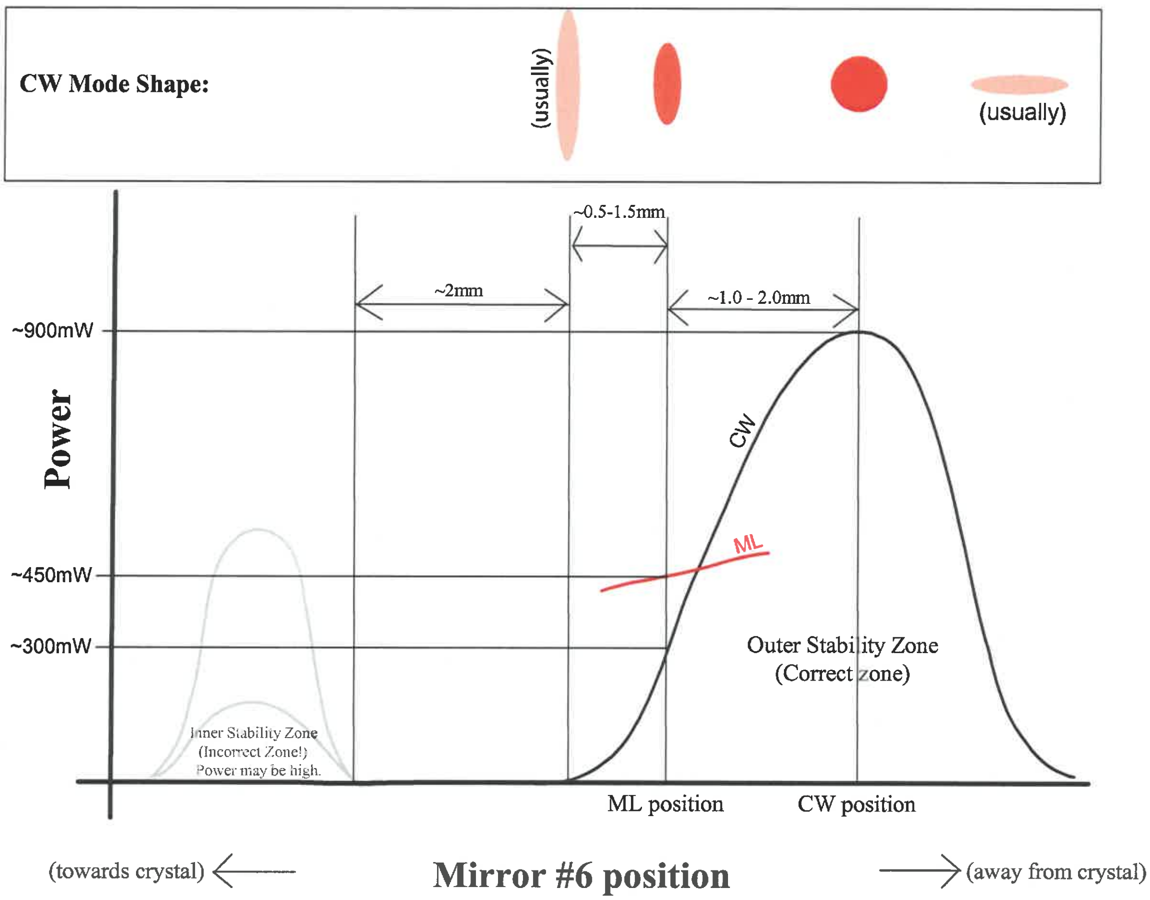


Figure 5.7: Approximate mode shapes and power for various positions of the second curved mirror (#6). The proper position of this mirror for mode-locked operation is at the inner edge of the outer stability zone.

In general, we have found that by translating only the crystal and the second curved mirror (components 5 and 6), we can find the modelocked mode. This mode is much smaller than the CW mode. Although the beam should start close to the apices of the prisms, once the laser is mode-locked, the end prism can be translated into the beam to get a broader-bandwidth output. Although it might take you a while at first, after you gain experience in what to look for, you will have no problem aligning for modelocking. Please refer to the Frequently Asked Questions Document which follows this manual for more information on particular subjects.

Often, there is some CW light co-lasing with the mode-locked light, which appears as a narrow line superimposed on the spectrum. The best way to get rid of this is to turn down the pump power. Often, if modelocking is difficult to start, fine adjustments to the translation of the second curved mirror (6) will allow you to find a position where starting is easier. Typically the best position is where the "discrimination" between modelocked and CW operation is a factor of two increase in power when modelocked.

When the laser first modelocks, the bandwidth of the spectrum will likely be less than the maximum possible bandwidth. By adjusting the prisms (varying the amount of glass in the beam), and by optimizing the crystal and mirror alignment, you should be able to find the broad-bandwidth, short-pulse "mode". Typically, this is a spectrum with a bandwidth (FWHM) of >60 nanometers. For the very shortest pulses, we sometimes find that adjusting the prism *separation* is helpful as well; however, this is a more difficult adjustment that should only be attempted by experienced customers.

F) Entrance / Exit Shutters

The entrance shutter is spring-loaded, and should be placed at the entrance of the pump beam so that if the cover is taken off of the laser, the pump beam is automatically blocked. This shutter prevents inadvertent exposure to the laser by unqualified persons who might remove the laser cover. Next to the entrance shutter, bolt-down a post holder in a position such that the entrance shutter "flag" can depress the entrance shutter to defeat the interlock.

The exit shutter is controlled with a manual knob on the outside of the laser enclosure.

6. Daily Procedures

A) Start-up

If the Ti:sapphire laser was modelocking reliably when last pumped:

1.) Turn on the KMCtrl software if you are using it.

2.) Ensure that the Ti:sapphire output is blocked.

3.) Allow a low power green beam (e.g. 0.2 W) into the Griffin laser.

4.) If everything appears safe, turn up the pump power to operating level (typically about 4.5W).

5.) Do not adjust anything in the oscillator for several minutes, allowing it to warm up. Approximately 3 minutes is a minimum, but 20 minutes should be sufficient.

6.) After warm up, check that the CW output power is similar to what it was the last time you used the laser.

7.) If the CW output power is notably lower than when the laser was last used, it is likely that the laser has not sufficiently warmed up. Refer to the "Jitter and Thermal Drift" section of the FAQ document at the end of this manual.

8.) If the CW output power is only slightly lower, you can adjust the horizontal and vertical knobs for *either* mirror 1 or 9, to maximize the power.

9.) Initiate modelocking, and observe the bandwidth. Adjust the prisms as necessary.

B) Shut-down

1.) Before shutting down, note the CW and ML output power in the modelocked position, for reference the next time the laser is used.

2.) Block the green pump beam from entering the cavity.

3.) Turn off the KMCtrl software, if you were using it.

7. Instructions for Detailed Construction/Alignment

Your laser was shipped pre-aligned. Therefore, you should NOT need to perform *any* of these steps unless you are reconfiguring, or somehow re-constructing your oscillator. We advise you to contact KMLabs first, if you believe that you need to proceed with the following adjustments.

The main sub-assembly for this laser is preassembled. Refer to Figure 5.2 for one possible laser layout. The laser kit is designed for maximum flexibility since you might prefer a different configuration. However, you should keep the same general cavity layout; i.e. the same distances and angles between all cavity components. Variation of the cavity repetition rate is also possible, but we recommend that you first get the laser working with the standard layout, and then change the end-mirror positions to alter the repetition-rate. From our experience, the entrance direction of the pump beam is not critical, although its alignment with the axis of motion of the translators is critical for easy optimization.

A) Basic Opto-Mechanical Construction

5.) Do not adjust anything in the oscillator for several minutes, allowing it to warm up. Approximately 3 minutes is a minimum, but 20 minutes should be sufficient.

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The main sub-assembly for this laser is preassembled. Refer to Figure 5.2 for one possible laser layout. The laser kit is designed for maximum flexibility since you might prefer a different configuration. However, you should keep the same general cavity layout; i.e. the same distances and angles between all cavity components. Variation of the cavity repetition rate is also possible, but we recommend that you first get the laser working with the standard layout, and then change the end-mirror positions to alter the repetition-rate. From our experience, the entrance direction of the pump beam is not critical, although its alignment with the axis of motion of the translators is critical for easy optimization.

A) Basic Opto-Mechanical Construction

Refer to Figure 5.2 for the basic laser layout. As roughly sketched in red, a line drawn from mirror 4 should pass through prism 7, at a 32 degree angle with respect to the long axis of the laser setup. 32 degrees corresponds to a "Y" translation of 7.5 inches for every 12 inches of "X" translation. The apex of prism 7 lies approximately at the point (x,y) = (4.5,2.0). If the cavity were not folded, a line drawn from the apex of prism 7 to the apex of prism 8 would be at –10 degrees, as defined by the angle of minimum deviation due to prism 7. The beam from prism 8 to end-mirror 9 is again at an angle of 32 degrees. The addition of the fold mirror has a minimal effect on the operation of the laser, but the angle of incidence on this mirror should be minimized (<~20°) to avoid limiting the bandwidth of the laser. Finally, the beam from the subassembly to the output coupler is parallel to the array of holes in the breadboard.

If not already done, bolt the subassembly, the prisms, and the mirrors to the breadboard in the layout of Figure 5.2. Carefully clean all the optics, using methanol and lens tissue if an aerosol duster is insufficient.

Mirrors mounts 1, 9, and 10 (see Figure 5.2), and the prism bases are all constructed using a cam-pin in the side of the riser base, which locks into a brass cam bolt, sticking up through the baseplate. To disassemble the riser base, use the square edge an Allen wrench (i.e. not a ball-driver), to pull out the cam-pin by loosening it and then "snagging" it with the edge of the wrench and pulling it straight-out. Loosen the cam-pin to align the prism location and rotation. You must adjust it for minimum deviation of the laser light. You can do this by letting the refracted fluorescence propagate as far as possible (several meters if possible) and rotating the prism for minimum deviation of that fluorescence.

B) Basic Optical Alignment

If you are beginning from scratch, you should remove all optics on the subassembly (optics 3, 4, 5, and 6 on Figure 5.2). Begin by aligning the pump beam to propagate parallel to the linear motion of the components on the subassembly rail. This can be verified by ensuring the pump beam passes through the aperture tool when the tool is inserted at either end of the subassembly with all optics removed. Note that the beam must be level with the table at the correct height—check level using a ruler or the beam aperture tool over the longest distance possible in your table setup. **BE METICULOUS.**

If not done, assemble the lens mount (3). The lens should be inserted into the mounting ring with the curved face up, in contact with the retaining ring. The lens-mounting ring should then be threaded into the adaptor, on the side nearest the green source. The green beam should enter through the curved face of the lens. Adjust the height, and horizontal of the lens so that it does not deviate the pump beam. (Observe this by again placing the alignment aperture tool at the far end of the subassembly). Translate the lens along the rail to make sure the beam remains undeviated as it is moved.

If not already assembled, place the crystal in the bottom-half of the copper crystal holding block, with a piece of indium foil in between. Put another piece of indium foil on top of the crystal, and then put on the top copper piece.

Insert optics 4, 5, and 6.
If necessary, loosen the three screws for the base of optic #4 and slide it within the slots to ensure that the green beam passes through the center of the optic.
Slide the crystal block along its diagonal track to find a location where the pump beam passes through near the center of the crystal, and evidences the least scatter. Securely tighten the crystal mount.
If necessary, loosen the two screws holding the base of optic 6, and adjust so that the green beam hits a couple of mm *off* center on the optic. (That allows you to rotate this optic, or swap with optic 4, if a spot is damaged.)
View the scattered light of the pump beam from above, and adjust the position of the focusing lens to place the waist at the crystal. The exact waist position can be difficult to determine, but always start by erring with the lens closer to the crystal, so that beam size when passing through the first cavity mirror (4) is relatively large. FOCUSING THE PUMP BEAM AT FULL POWER DIRECTLY INTO A CAVITY OPTIC WILL RESULT IN DAMAGE TO THAT OPTIC.
Adjust the horizontal and vertical hex knobs on optic 4 so that the large (~1cm diameter) fluorescence spot at the first prism (item #7) is intersected by the prism, and the beam is at a height of 59mm. Typically only 70% of this fluorescence spot needs to pass through the prism when properly aligned. The angle: crystal-to-mirror#4 / mirror#4-to-prism should be 16 degrees.
Adjust the horizontal and vertical hex knobs on optic 6 so that the reflected green beam is centered within the output coupler, and at the 59mm height. The angle: crystal-to-mirror#6 / mirror#6-to-output coupler should be 16 degrees.
Ensure that both prisms are at minimum deviation. (See "minimum deviation" in the FAQ document at the end of this manual).
Continue with the instructions in section 5. part C.

C) Notes for long-pulse operation

When optimally adjusted, this laser generates a bandwidth of 50-70 nm FWHM, corresponding to a pulse duration of 10-15 fs. Longer-pulse operation is possible by narrowing the spectrum of the laser by (a) adjusting the prism insertion, and (b) narrowing the tuning slit. However, the tuning slit only can be narrowed to an aperture approximately equal to the CW mode size; at smaller apertures the intra-cavity power is attenuated. Operating at a longer pulse duration is possible, however, by replacing the prism pair (normally fused silica) with a prism pair using more-dispersive glass—for example, a pair of SF18 prisms. This configuration is useful if pulses of 40-100 fs are needed. However, keep in mind that the mode-locking mechanism in this laser is somewhat weaker in the long-pulse configuration, which can make the modelocking a bit harder to start. The pump power should be ~4.5-5.5 watts, with an output of ~500 mW. Generally, we have found that the other adjustments (i.e. 10-cm curved mirror positions) remain similar to the short-pulse case. The optimal output coupling also seems to be about the same, although we have investigated this question less thoroughly. It is advised that the user contact KMLabs for further information before reconfiguring the laser in this way.

8. Electronic Controls

The laser controller consists of a USB controller card and software to serve two distinct purposes: to control the oscillator's bandwidth and central wavelength, and to provide an electronic synchronization output, locked to the oscillator.

The laser control software must be installed before connecting the USB board to the computer. To install the software, simply insert the CD containing the KMCtrl software into the CD ROM drive of your WindowsXP computer, and then wait a few seconds for the installation program to start. If the installation program does not start automatically, browse the CD using Windows and double-click on the "setup.exe" file. Follow the instructions on the installation program. If the installation was successful, the software should be located on your computer's hard-drive at C:/Program Files/KMLabs/KMCtrl 4.5. After the installation, leave the installation CD in the CD-ROM drive to install the USB drivers (see below).

After the software has been installed, plug in the board's power supply and connect the power cable to the board's power connector. Then connect one end of the USB cable to a USB port on your computer and the other end of the cable to the USB connector on the board (located next to the power connector). After connecting the USB cable, the computer should detect the board and will open the "Add New Hardware Wizard". Do not allow the wizard to search the internet for the best driver. Instead, when the wizard gives you the option to search the computer for the best driver for your device, select the CD-ROM drive as the location to search for new drivers. It is recommended that you use the same USB port every time you use the KMControl board. If you use a different USB port after the original driver installation, you will be prompted to allow the computer to search for the driver. You can simply have the computer find the drivers automatically on your computer.

To run the program, select "KMLabs/KMCtrl 4.5" from the Windows "Start" menu. The first time the program is run, follow the "Rezero Prism/Slit" procedure described below to set the initial stepper motor positions.

Note: It is recommended that you turn off screen savers or power-saving options on your computer to prevent interference with the laser control software. If you are using a laptop or notebook computer, it is recommended that you plug in the computer's power cord instead of using battery power.

A) Spectral Controls

The spectral controls allow you to computer-control both of the laser prisms and a tuning slit. By "jogging" one of the prisms (i.e. moving it quickly back and forth), the controller can start the laser modelocking. Also, the controller allows the user to optimize and tune the laser spectrum remotely through adjustment of the prisms and tuning slit.

The tuning slit and prism motor both connect through a DB-25 connector and extension cable to the end of the USB board. (Note that these are translational, not rotational motors.) The tuning slit is pre-assembled. Use the 1" diameter by ¼" thick shim and the black-anodized baseplate to mount the slit in your laser assembly. The tuning slit can be placed along the cavity laser beam anywhere near the dispersed end of the cavity, i.e. on either side of the end-prism (8). The stepper motor for the prisms should be mounted such that prism #1 (as marked on the back of the motor) is item number 8 (in Figure 5.2) and prism #2 is item number 7. To attach these motors, use the small adapter plates supplied with the motors. Remove the micrometer after unscrewing the set screw for the micrometer mounted on the prism translation stage. This set screw is located under the plate on the translation stage and requires a 1/16" allen wrench. Unscrew the two 6-32 screws at the end of the translator, and then pass the two new (slightly longer) 6-32 screws through the adapter and into the vacant holes in the translator. The stepper motor bolts onto the adapter using the two short 6-32 screws. Do not further disassemble the translators. Tighten the adapter plate in a position that allows unrestricted movement of the translator.

The first time that you run the program, follow the "Rezero Prism/Slit" procedure described below to set the initial stepper motor positions.

The position of the intra-cavity prisms, and the tuning slit position and width can be varied by clicking on the appropriate controls on the program's front panel. The "units" for the position are steps—each step is 0.0005 inches, or 12.7 microns. Alternatively, if a valid wavelength calibration file has been selected, clicking on the "wavelength" control will set the prism and tuning slit positions according to the stored calibration positions (interpolating between calibration points if necessary).

B) Rezero Prism/Slit

Before using the motor control program, you must set the zero positions of the motors. To do this, select "Rezero Prism/Slit" from the "Operate" menu. Another window will open with some arrow buttons to control the prism and slit positions. First, hold down the top left arrow button for the prism 1 control until the prism motor stops moving. Prism 1 is the one closest to the end mirror (item number 8). The motor will move relatively slowly during this process, but you should be able to see the motor shaft retracting. When the shaft stops moving, the sound made by the motor changes. Some of the shaft will be sticking out when the motor is in the fully retracted position. After the motor stops moving, briefly press the right arrow button (less than one second) to engage the prism stepper motor and remove any backlash. The prism 1 motor is now at its zero position. Repeat this procedure for the prism 2 motor.

Now, you will need to adjust the tuning slit to its zero position. In the following instructions left and right are defined as the directions when looking at the front (slit) side of the tuning slit. For the following instructions, please refer to Figure 8.1. Hold down the left arrow button for the left slit blade until the left slit blade stops moving. Then, do the same for the right slit blade by pressing the left arrow button for the right slit blade. Briefly press the right arrow button for the right slit blade to engage the motor. Finally, hold down the right arrow button for the left slit blade until the slit blades just touch. At this point, all of the motors should be in the proper zero positions. Press the "Make Current Positions Zero" button to register the changes and return to the main window.

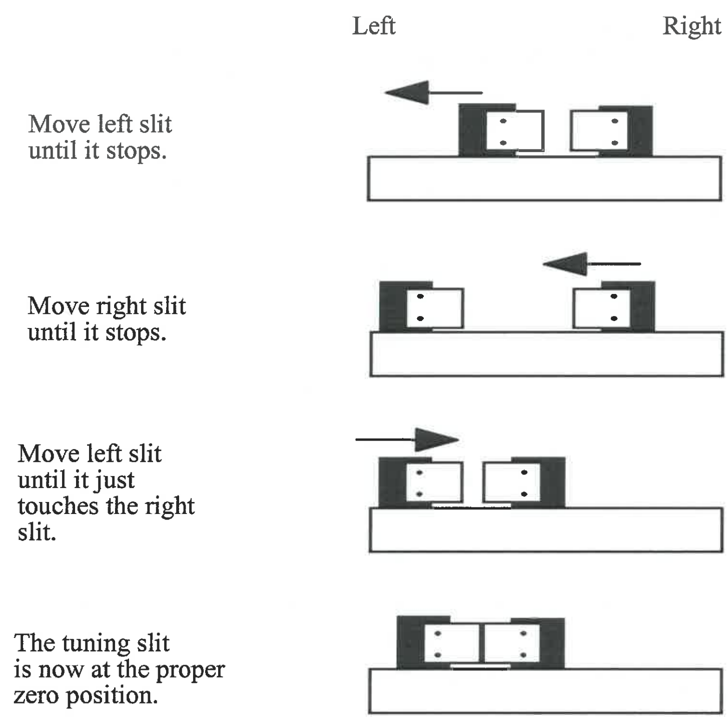

Figure 8.1: Tuning slit setup procedure.

C) Wavelength Calibration

Use the following procedure to store wavelength calibration settings for the tuning slit and prism. You will need a (customer supplied) spectrometer to measure the output of the laser in order to perform this calibration.

1. Select "Laser Wavelength Calibration" from the "Operate" menu to display the "Wavelength Calibration" menu.

2. Select "Add Point" from this menu.

3. A new window will open with a slider control. Move the slider to the current operating wavelength or enter the wavelength in the wavelength box.

4. Press the "Add" button to add this point to the wavelength calibration table and return to the main window.

5. Delete any incorrect/obsolete calibration points by selecting "Delete Point" from the "Wavelength Calibration" menu. A window will open showing a list of all calibration points. Click on the wavelength of the point you wish to delete, and then press the "Delete" button.

6. Adjust the laser to a new wavelength and repeat the procedure. In general, a few calibration points are sufficient for tuning across the range of the laser. If less than two calibration points are in the table, the wavelength control on the main window is disabled.

7. Once you are satisfied with the calibration, you need to save it to a file by selecting "Save" from the "Wavelength Calibration" menu. Once you have saved the calibration file, the program will automatically use this same file the next time you run the program.

After performing the calibration procedure, you can move to a particular wavelength by clicking on the "wavelength" slider or holding down the wavelength arrow buttons. The program will interpolate between calibration points to approximate the desired wavelength as closely as possible. If you find that the wavelength calibration is off by a constant wavelength shift, you can select the "Shift Calibration" option from the "Wavelength Calibration" menu. Although the program will automatically load the last saved wavelength calibration file, you can also load other wavelength calibration files by selecting the "Load" option from the "Wavelength Calibration" menu.

D) Starting Modelocking

To start the laser modelocking, click on the "Start Laser" button. This will cause prism 1 (Item #8 on Figure 5.2) to "jog" back and forth once in a motion that will start the laser modelocking. If you are adjusting the laser to obtain modelocking, you can "jog" continuously by clicking on the "Continuous Starting" button. Clicking on this button again will turn off the continuous starting. Do not leave the laser continuously jogging for extended periods of time.

E) Front Panel Controls

Start laser: Clicking this button will "jog" the laser prism 1 to initiate modelocking.

Continuous Starting: Clicking this button will continuously "jog" the laser prism. This can be useful when aligning the laser.

Wavelength slider control: can be used to tune the laser wavelength if a valid calibration table is loaded.

Prism Translation slider control: used to move the prism to control the amount of dispersion in the laser cavity. This can be adjusted to optimize the bandwidth of the laser.

Tuning Slit Position slider control: adjusts the position of the tuning slit inserted in the laser cavity near the dispersed (prism) end of the cavity. This can be used, along with prism adjustments, to tune the laser wavelength.

Tuning Slit Width slider control: adjusts the width of the tuning slit. This can be used, along with prism adjustments, to narrow the laser bandwidth to obtain longer pulse duration.

Arrow buttons: The arrow buttons next to each slider control are useful for making small adjustments. If an arrow button is held down, the corresponding slider control will change slowly at first; then, after a few seconds it will change faster.

F) Preferences

Select "Preferences…" from the "Edit" menu to display a window containing the following program settings and options:

Motor Speed (steps/second): is the rate at which the motors will step when adjusting the prism and tuning slit with the slider controls. Generally, 300 steps/second is a good value. The maximum allowed value is 300 steps/second, since setting the motor speed higher than this can cause the positions to become un-calibrated.

Maximum Idle Time (seconds): After the motors have been idle for this amount of time, the current positions are saved to the disk.

Jump Distance for Prism: is the number of steps corresponding to a laser-starting "jog." Generally, a value of "10" works well to start the laser.

Jump Speed for Prism: is the rate at which the prism moves when doing a laser-starting "jog." Generally, 300 steps/second works well. The maximum allowed value is 300 steps/second.

Maximum Slit Width: is usually about 700 steps. If this is set too high the slit position may become un-calibrated.

Beep When Started?: Checking this box will cause the computer to beep every time the laser is started.

Read Handheld Controller?: a PC game pad or joystick can be used to control the prism and slit and to start the laser. (See below)

Set Start Position: Sometimes the laser will not start from the desired prism and tuning slit positions. In that case, you can select a start position where the laser easily starts. When Use Start Position? is checked, the laser will always start from this special position. Once the laser is started, the prism and slit will be moved back to the previous positions.

Remote Operation COM Port: Commands sent to one of the computer's serial ports can be used to control the laser remotely. If "none" is selected, the serial port is ignored. Otherwise, this control should be set to the appropriate serial port. (See below)

Laser Frequency (Low): If a frequency counter is being used to monitor laser modelocking, the laser will be (re)started if the rep-rate of the laser falls below this value. The default value is 60 MHz.

Laser Frequency (High): If a frequency counter is being used to monitor laser modelocking, the laser will be (re)started if the rep-rate of the laser is above this value. The default value is 100 MHz.

Minimum Spectral Width (nm): If an Ocean Optics USB2000 spectrometer is monitoring laser modelocking, the laser will be (re)started if the spectral width falls below this minimum value.

Monitor Photodiode for Restarting: If an unbiased photodiode (e.g. Thorlabs FDS010) is connected to the D SMA connector (see Figure 9.1), the USB board can be used to monitor the modelocking status of the laser. If this option is enabled, the laser will be (re)started when the board detects an un-modelocked status. If attempts to start the laser are unsuccessful after 30 seconds, a message will be displayed, and the user will be asked if this option should be disabled. See the "Introduction to Pulse Train Electronics" section below for more details.

Monitor Spectrum for Restarting: If an Ocean Optics USB2000 spectrometer is being used to monitor laser modelocking, the laser will be (re)started if the spectral width falls below the specified minimum spectral width. If no significant peak in the spectrum is detected, as would be the case if the laser beam no longer enters the spectrometer, the laser will not be (re)started. If attempts to start the laser are unsuccessful after 30 seconds, a message will be displayed, and the user will be asked if this option should be disabled.

G) Handheld Controller

A PC game pad or joystick connected to the PC's game port can be used to control the prism and tuning slit. Make sure the joystick driver software is properly installed and the correct game pad or joystick is set up in the WindowsXP control panels. The handheld controller is linked to the "arrow" buttons on the front panel as shown in Table 8.1.

	Game pad left	Game pad right	Game pad up	Game pad down	Button A	Button B
Prism 1 left	x					
Prism 1 right		x				
Prism 2 left	x					x
Prism 2 right		x				x
Slit left	x				x	
Slit right		x			x	
Slit open			x		x	
Slit closed				x	x	
Longer Wavelength			x			x
Shorter Wavelength				x		x
Start laser					x	x

Table 8.1: Buttons on the handheld controller.

H) Serial Port Remote Control

Instructions can be sent to one of the computer's serial ports in order to control the laser remotely. The remote computer must be set up to communicate using the following protocol: 9600 baud, 8 data bits, 1 stop bit, no parity, no flow control. A simple communication terminal program works well in conjunction with a numerical keypad. The commands are the numbers 1 through 9 corresponding to the functions shown in Table 8.2.

7 decrease wavelength	**8** open slit	**9** increase wavelength
4 slit left	**5** start laser	**6** slit right
1 prism left	**2** close slit	**3** prism right

Table 8.2: Serial port remote control commands.

The desired serial port must be set in the "Preferences" menu. If everything is working, the program will echo the commands it receives. Any ASCII characters other than the numbers 1 through 9 will have no effect on the program. Holding down the numbers on the numerical keypad of a remote online computer will have the same effect as holding down the arrow buttons on the front panel.

9. Introduction to Pulse Train Electronics

The Griffin laser also includes an unbiased photodiode. To use the pulse train electronics, connect this detector to the "D" SMA connector (see Figure 9.1). The USB board provides a 5-volt bias to the center pin of this SMA connector. **If you apply additional bias, you will likely damage the photodiode.**

Place the photodiode to monitor, for example, the residual laser energy reflected from one of the Brewster faces of the laser crystal—the one which is free of residual green pump laser light. The following signals will be available:

1.) The board will output an electronic signal with a frequency that is equal to the repetition rate of the laser, divided by an integer. This lower frequency signal is useful for triggering electronic devices that must be synchronized with the laser output.

2.) The board will provide a binary signal to indicate whether the laser is modelocked (+3 V) or not (0 V).

3.) Amplified digital (~3 V peak-to-peak) and analog (~40 mV peak-to-peak) outputs from the photodiode are also available from this board. These signals can be used to monitor the oscillator's repetition rate and the stability of the output pulse train.

A) Frequency Divider

To set the frequency of the frequency divider output, select "Set Frequency Divider" from the "Operate" menu. A dialog box will open, allowing the user to enter the repetition rate of the laser (in MHz) and the desired output frequency (in kHz). Note that the desired output frequency must be lower than the repetition rate of the oscillator. The frequency must be set each time the KMCtrl program is run.

NOTE: The user must *separately* measure the repetition rate with an oscilloscope. You can measure the repetition rate by connecting an oscilloscope to either the "C" or "E" (digital or analog) SMA connector.

The reduced frequency output signal will be available at the "B" SMA connector (see Figure 9.1). If you cannot see this signal:

1.) If you are observing on a scope, ensure that the scale on the scope you are monitoring is correct for a ~3V peak-to-peak signal with 1 M-Ohm termination.

2.) Block and unblock the photodiode. This can "reset" the circuit.

3.) Ensure that the photodiode is getting sufficient signal. If you are using the reflection off of a face of the crystal, you should have the diode less than 10 cm from the crystal, and the reflection should be centered on the active area of the detector.

4.) It is also possible that the diode is getting too much signal! Try moving the photodiode slightly.

NOTE: If the photodiode is monitoring signal clipping from the tip of a prism (instead of off of the face of the crystal) you will vary your signal every time you adjust the prism insertion.

B) Modelock Detector

"A" and "F" SMA connectors are both digital outputs that are high (~3 V) if the laser is modelocked or low (0 V) if the laser is operating in a continuous wave mode. "A" differs from "F" in that the low-to-high transition is delayed by ~1/4 second from the initiation of modelocking. This feature is very useful for amplification systems, where damage can result from allowing a CW or building pulse to enter the amplification ring.

For example, "F" can be used to re-initiate modelocking, and then the signal from "A" can be used to re-start the pulse picker safely *after* the seed pulse has had time to build up.

The laser control software can be set to monitor this modelocking signal and restart the laser if necessary. To enable this option, select "Monitor Mode-Locking for Restarting" in the "Preferences". If attempts to start the laser are unsuccessful after 30 seconds, a message will be displayed, and the user will be asked if this option should be disabled.

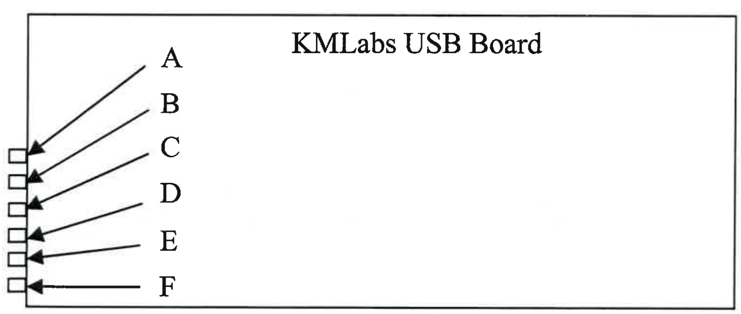

Figure 9.1: Location of the SMA connectors on the KMLabs USB board.

SMA connector	Function
A	Delayed digital output that is high if the laser is modelocked or low if the laser is operating in a continuous wave mode.
B	Divided frequency TTL output signal
C	Digital output corresponding to the amplified photodiode input signal
D	Photodiode input
E	Analog output corresponding to the amplified photodiode input signal
F	Digital output that is high if the laser is modelocked or low if the laser is operating in a continuous wave mode.

Table 9.1: Pin-out of SMA connectors on KMLabs USB board.

10. Spectrometer (customer supplied Ocean Optics USB2000)

This version of the KMControl program can control an Ocean Optics USB2000 spectrometer purchased separately from Ocean Optics. As of September, 2006, Ocean Optics is discontinuing this spectrometer. Therefore, these instructions are for customers who have already purchased a USB2000 spectrometer and wish to use it to monitor the performance of their Ti:sapphire laser. Several companies offer simple, compact spectrometers that include software applications you can use to monitor the spectrum of the laser. This is a very useful diagnostic tool, since you can monitor the spectrum while remotely adjusting the position of one of the dispersion compensating prisms. Maximizing the width of the spectrum, you can obtain the shortest duration pulses from your laser. Although measurement techniques such as Frequency-Resolved Optical Gating (FROG) or GRENOUILLE are necessary to fully characterize the pulses from your laser, measurement of the laser spectrum provides an estimate of the minimum duration of the laser pulses when they are properly compressed.

A) Spectrometer Setup

The software for controlling the Ocean Optics USB2000 spectrometer is built-in to the KMControl program; however, you must install the spectrometer drivers onto your computer. The first time the spectrometer is connected, the Windows "Add New Hardware Wizard" will ask you to specify a location for the spectrometer driver files. These files are located on the KMControl Installation CD. If the spectrometer is connected to the computer and the driver files are properly installed, you can display the spectrometer controls by selecting "Display Spectrum" from the "spectrum" menu of the KMControl program. The program will search for the attached spectrometer. If you have more than one USB2000 spectrometer, you should only have the spectrometer you want to use with the KMCtrl program attached the first time you select

"Display Spectrum". After the computer finds your spectrometer, it will make this the default spectrometer and use it the next time you start the program. If you want the computer to "forget" that this spectrometer is the default one, make sure that this spectrometer is not connected the next time you start the KMCtrl program. Then when you select "Display Spectrometer" it will clear the program's memory of the previous spectrometer. **You should always plug the spectrometer into the same USB port, since it may not be recognized in another port.**

After placing the spectrometer at a convenient place on the laser table, direct a portion of your laser beam into the hole of the silver threaded nut on the spectrometer while monitoring the spectrum graph. You should strive for a maximum intensity that almost saturates the detector. If the spectrometer saturates, a "saturated" warning will appear at the top of the spectrum graph. If the signal is too weak, make small adjustments to the position of the input beam and/or the spectrometer orientation. If the signal is too strong, you can place a neutral density filter or a piece of white index card or paper before the entrance of the spectrometer. You can also optimize the signal level by adjusting the exposure time; however, longer exposure times (> 500 ms) will make the KMControl program sluggish. The minimum exposure time is 10 ms. It is fine if the spectrometer is saturated when the laser is not pulsing, but is unsaturated when the laser is pulsing.

B) Scaling the Spectrum Graph

The vertical "Y" scale of the spectrum can be adjusted automatically by selecting "Autoscale Spectrum" from the "Spectrum" menu. Otherwise, you can adjust the scale manually by double-clicking on either the minimum or maximum value of the scale, typing the desired value, and then clicking on an empty (black) part of the window. You can change the horizontal "X" scale in the same way; however, the horizontal scale will not be automatically adjusted.

C) Dark Buffer Subtraction

Even when no light enters the spectrometer, it will display a "background" signal due to the electronic "noise" of the detector. For careful spectrum measurements it is necessary to eliminate this background signal. To do this, block the laser beam from entering the spectrometer, press the "Acquire Dark Buffer" button, and then unblock the laser beam. The background signal or "dark buffer" will be subtracted from all subsequent spectral measurements; however, you will need to repeat this procedure the next time the program is started or if the exposure time or ambient light level changes. The "Acquire Dark Buffer" button will blink when a new dark buffer must be acquired.

D) Spectrum Graph Cursor

To display a cursor indicator on the spectrum graph, select "Display Cursor" from the "Spectrum" menu. You can drag this cursor to a new location with your mouse or fine-tune its position by pressing the diamond-shaped buttons on the lower-right side of the spectrum graph.

The cursor's horizontal position (wavelength) and vertical position (intensity) are displayed below the spectrum graph. To the right of these indicators are some buttons that can be used to control the properties of the cursor. If you click on the button with the crosshairs, a small pop-up window will display several choices for changing the appearance of the cursor. One of the choices is "Bring to Center", which will move the cursor to the center of the spectrum graph. To the right of the crosshair button is a button with a lock on it. When the lock is closed, the cursor is locked to the spectrum plot. When the lock is open, the cursor is free to move anywhere on the graph; however, the "Y" position of the cursor will no longer correspond to the actual intensity of the spectrum. You can change the state of the lock by clicking on it and then choosing the desired state from a pop-up window.

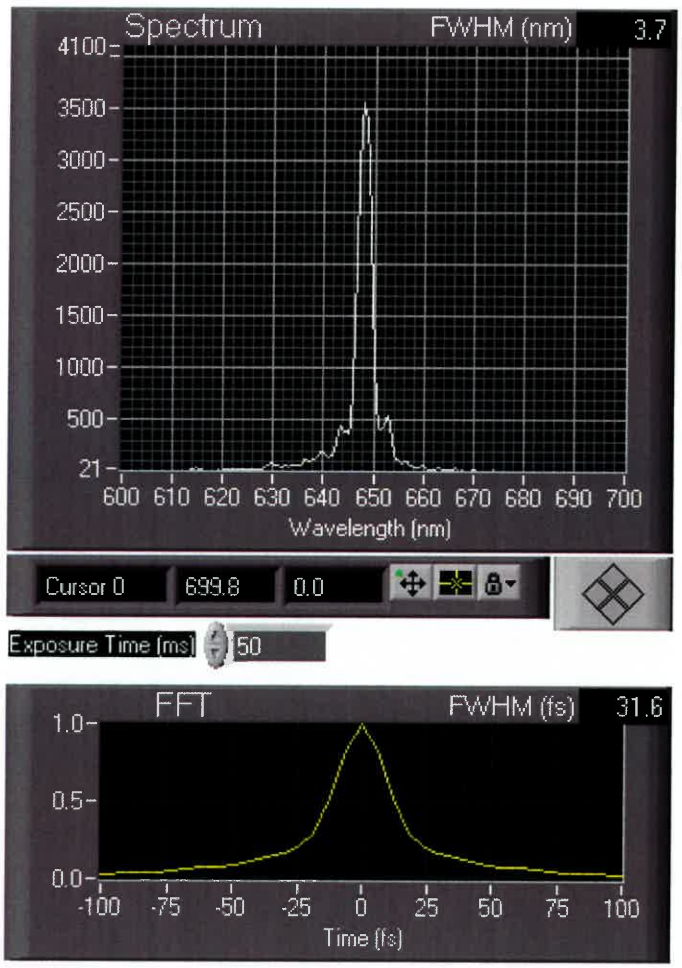

Figure 10.1: Spectrometer controls

E) Fourier Transform (FFT)

By performing a Fast Fourier Transformation (FFT) of the laser spectrum, the KMControl program displays an estimate of the shortest pulse that could be produced with this spectrum. The actual duration of the pulse exiting the laser and arriving at your experiment will likely be longer than this theoretical (transform-limited) pulse due to uncompensated dispersion in the optics through which the pulse passes. Therefore, it is important to actually measure the duration and shape of the pulse with measurement techniques such as Frequency-Resolved-Optical-Gating (FROG) or GRENOUILLE.

For the Fourier Transform to give an accurate prediction, dark buffer subtraction should be enabled. Also, ensure that the spectrometer is not saturated. You should adjust the maximum and minimum values of the wavelength scale to ensure there are several zero intensity values at both edges of the spectrum graph. The transform-limited pulse intensity versus time is displayed in the FFT graph below the spectrum graph. The Full-Width-at-Half-Maximum (FWHM) indicator shows the duration of this ideal transform-limited pulse.

F) Saving a Spectrum

You can save the laser spectrum to a spreadsheet file by selecting "Save Spectrum..." from the "File" menu. The wavelength values are saved in the first column of this file with the corresponding intensity values saved in the second column. Tab characters separate the columns. This file format can be read by many spreadsheet and graphing applications.

G) Spectral Sensitivity Correction Curve

Generally spectrometers are more sensitive to some wavelengths than others. Although this is usually ignored when measuring narrow bandwidth spectra, it can be more of an issue when measuring the wide bandwidth spectra associated with ultrashort laser pulses. A spectral sensitivity correction curve can be calculated for the spectrometer by first acquiring a spectrum of a white light source with a known blackbody temperature and then dividing the theoretical blackbody spectrum by the acquired spectrum. Once the spectral sensitivity correction curve has been calculated, it is then multiplied by all subsequently acquired "raw" spectra. If you determine that it is necessary to calculate a correction curve, here is the procedure to follow:

1.) Disable the default spectral sensitivity correction curve by selecting "Spectral Sensitivity Correction..." from the "Spectrum" menu. If a window opens stating that a spectral sensitivity correction curve is currently in use, press the "Disable Correction Curve" button on this window. Otherwise press the "Cancel" button on the window with the blackbody spectrum.

2.) Place a white light source with a known blackbody temperature near the spectrometer. (Note: a normal 60-watt incandescent light bulb has a blackbody temperature of approximately 2800 K.) Adjust the spectrometer exposure time so that the peak intensity is slightly less than 4095. Block light from entering the spectrometer and acquire a dark buffer.

Unblock the spectrometer. A good reference spectrum should now be displayed in the Spectrum graph.

3.) Select "Spectral Sensitivity Correction…" from the "Spectrum" menu.

4.) Enter the blackbody temperature (in K) of the light source.

5.) Adjust the filter level to reduce noise in the reference spectrum and correction curve.

6.) Press the "Save & Use Correction Curve" button, and then accept the suggested file name and location in the file dialog box.

7.) The location of the new correction curve will be saved in the KMCtrl preferences file when you exit the program. The correction curve will be loaded automatically and used each time you start the program.

H) Help Menu

There are two useful "Help" options found on the "Help" menu. The "Show Context Help" option displays a small help window that provides a description of every control and indicator in the program. Most of the information about the program found in this manual is also found in the pop-up help window. Simply move the cursor over the control or indicator to display information about it.

Another useful "Help" option is the ability to display this manual in Adobe's pdf format. The "Laser Control Manual" menu option will be displayed on the "Help" menu, if the file for the manual is located at C:/Program Files/KMLabs/KMCtrl 4.5. Adobe's Acrobat Reader must be installed on your computer in order to read this file. You can download a free version of this reader at Adobe's website (http://www.adobe.com).

Selecting "About" on the "Help" menu will display information about this version of the KMLabs laser control software.

I) Exiting the Program

After selecting "Exit" from the "File" menu, the current motor positions and preferences are saved to the hard drive, and then the program closes. You can also exit the program by clicking on the "X" box in the upper right corner of the program's window.

11. USB Board Pinout

DB-25 connector pin	Function	Wire color
1	Prism 1 motor Phase "L2"	Blue wire
14	Prism 1 motor Phase "L1"	Green wire
2	Prism 1 motor Phase "L4"	Black wire
15	Prism 1 motor Phase "L3"	Red wire
3	Prism 2 motor Phase "L2"	Blue wire
16	Prism 2 motor Phase "L1"	Green wire
4	Prism 2 motor Phase "L4"	Black wire
17	Prism 2 motor Phase "L3"	Red wire
5	Tuning slit motor #1 Phase "L2"	Blue wire
18	Tuning slit motor #1 Phase "L1"	Green wire
6	Tuning slit motor #1 Phase "L4"	Black wire
19	Tuning slit motor #1 Phase "L3"	Red wire
7	Tuning slit motor #2 Phase "L2"	Blue wire
20	Tuning slit motor #2 Phase "L1"	Green wire
8	Tuning slit motor #2 Phase "L4"	Black wire
21	Tuning slit motor #2 Phase "L3"	Red wire
9		
22		
10		
23		
11		
24		
12		
25		
13		

12. Troubleshooting

Most difficulties with operating or tuning the laser are a result of imperfect optical alignment. A more extensive list may be found in the FAQ.

Laser does not lase	Use the entrance alignment tool placed in front of the lens and the iris aperture in front of the output coupler to double-check that the pump beam is still correctly aligned. If so, then check for mirror damage, especially on the mirror that the pump laser first passes through (4). Check the pump power. If OK, then re-do the alignment procedure as described previously. Start by moving the second curved mirror (6) micrometer position to the "CW" position (see Figure 5.4). Get the laser lasing, optimize it by making sure the beam is not clipped by the prisms, and optimizing the end-mirrors for maximum power. Finally, move the second curved mirror back to the "mode-locked" position (see Figure 5.5).
Laser does not modelock	Clean the optics using an optical quality "air duster" and/or methanol moistened lens tissue. Try translating the second curved mirror (6) within a limited range (less than a mm), while continuously "jogging" the prism to look for mode-locking. Another possible problem: the prisms are positioned incorrectly. Too much glass inserted into the beam will prevent mode-locking.
Poor modelock stability	This is due to either dirty or damaged optics, misalignment, or (most commonly) to a poor pump laser mode quality or stability. Clean the optics, and check for damage—particularly on the first curved mirror that the pump beam first passes through (4). Being extremely careful for potential eye hazard, divert the pump beam, expand the mode using a CLEAN lens, and carefully observe the mode for defects. In particular, a dark "hole" in the center of the beam is an indication of non-TEM_{00} operation. If this is the case, refer to your pump laser manual to correct this problem. If you are using an argon-ion laser, you can try cleaning the Brewster angle windows on the argon tube and/or adjusting the output aperture. Another possibility is that the pump laser is suffering from intermittent power "dropouts." It is very important that the pump laser beam is fully enclosed in beam tubes or another enclosure that prevents air currents from blowing dust through the beam.
Laser does not tune to long wavelengths	You may be near the edge of your mirror set tuning range. Another possible problem is that the range of translation of the prism may be wrong. For long-wavelength operation, prism (8) near the end-mirror is positioned so that the shortest wavelengths graze past the prism tip, while the longer wavelengths are refracted. If the prism cannot be pulled out far enough to decrease the glass in the cavity, the tuning range will be affected. Carefully slide the prism mount without changing the prism angle to accommodate a more appropriate range of translation.

Laser does not tune to short wavelengths	You may be near the edge of your mirror set tuning range. Another possible problem is that the range of translation of prism (8) may be wrong. The short wavelengths of interest must be refracted by the prism, and must not graze past the prism tip. Carefully slide the prism mount without changing the prism angle to accommodate a more appropriate range of translation.

13. Parts lists for Griffin Laser

Bag	Description
A	Breadboarded Laser Assembly
S2	Tuning slit, mounting hardware, steppers for motor-controlled prisms, and adapter plates for fastening stepper motors to prisms
Q2	Assorted mounting hardware
M2	25-pin cable for computer connection, USB cable, power supply
N	USB laser control board
F2	Spring-loaded entrance shutter assembly, and override flag
V2	Instruction Manual, software CD, exit decal, warning labels
J2	Enclosure Hardware

Frequently Asked Questions for the KMLabs Inc. Ti:Sapphire Oscillators: Griffin, Cascade, Halcyon, MTS, Chinook & TS-Laser Systems

October 30, 2006

Table of Subjects:

Please consult the "Safety" section before implementing any of these suggestions.

Can't find your question in this list? Please let us know! We'll try to answer it for you, and add it to the list for future users. Email: kmlabs@kmlabs.com or call: 303-544-9068. Thank you!

Amplification:

Many users amplify our MTS, Chinook or TS-lasers, either with a regenerative amplifier setup, or a multipass amplifier configuration. The KMLabs oscillator is suited to either method. KMLabs also offers a high average power amplifier system. Contact KMLabs for details.

Bandwidth:

Also see: "Spectrum."

Problem A: The bandwidth is narrow.

Solution A1: Can the optics support the wavelengths you seek? Using the optics we provide, the laser should be tunable between about 750 to 840nm. The maximum achievable bandwidth will narrow at the extremes. You should achieve bandwidths supporting a sub-25 fs pulse over the entire tuning range, and a sub-15 fs pulse when centered at 780-800nm. For more recent lasers, you should achieve sub-12fs bandwidths, also, but not tunable.
Solution A2: Have you optimized the prism insertion? Gradually push in the first prism (nearest the subassembly), and pull out the second prism (nearest the high reflector). As you do so, you may need to peak up the power using the high reflector and the output coupler. Peak up the power only while CW, otherwise you will inadvertently sacrifice bandwidth for power. Iterate back and forth between pushing one prism in, and pulling the other out. At first it may seem that the two processes almost exactly cancel each other, but as you near an optimum configuration, very small adjustments will dramatically broaden the bandwidth.
Solution A3: If you find that the modelocking drops out as you increase the bandwidth, check to make sure that the discrimination between the ML and CW power is acceptably large. You should adjust the second curved mirror position so that you have an elongated CW mode, but then the fine tuning of this mirror position should be determined by comparing the power in the CW and ML modes. The ML mode should have >100mW more power than the CW mode. For example, if the CW mode has 400mW of power, the ML mode should have about 500mW of power. As you broaden the bandwidth, the power will drop somewhat, and the discrimination between ML and CW mode may no longer be adequate. A recommended range for the CW power is 350-400 mW.
Solution A4: Are the prisms set at minimum deviation? See "Minimum Deviation."
Solution A5: Is there something of a pedestal on one or the other side of the spectrum? I.e., do you see a broader, perhaps rather flat spectrum at 5-10% of the FWHM? If so, work to build up that pedestal, even if doing so appears to degrade the quality of the higher intensity component. Eventually, that pedestal should develop into a second "peak", and you can work to fill in the spectrum between the two.
Solution A6: Does the spectrum have very sharply concave sides, and a pointed peak? If so, the oscillator may be underpumped. Try slowly turning up the power of the green while watching the Ti:sapph spectrum. If the pointed spectrum fills out and becomes more Gaussian, the laser was underpumped.
Solution A7: Is anything clipping the beam? Is the slit closed down onto the beam? Is the beam hitting the very edge of an optic (in particular, the high reflector)?
Solution A8: Is the prism separation about 65cm? This number varies somewhat, depending upon the particular optics coating and the exact crystal, but is typically between 64cm and 66cm. If your laser is folded, be sure to measure from the first prism, to the fold mirror, and then from the fold mirror to the first prism.
Solution A9: See solution B3.

Problem B: The laser is modelocked, but the spectrum has a hard edge.

Solution B1: Is anything clipping the beam within the cavity? That is the purpose of the computer-controlled slit. If you do not want such an edge, ensure that the slit edges are clear of the beam. Also, is the beam roughly centered on the high reflector?
Solution B2: Check the prisms for scratches or chips and also clean them. This would be typical of a damaged prism.
Solution B3: The oscillator may be running with positive dispersion. If that is true, the bandwidth should broaden as you pull both prisms out of the beam. (Beam near the tips.) If you do have positive dispersion, the bandwidth will typically not increase, at first, as you pull out the prisms, but then start increasing substantially as you near the zero dispersion point. Make sure you're peaking up the power by adjusting the high reflector and output coupler as you translate the prisms.
Solution B4: Check that the prisms are at minimum deviation.
Solution B5: Ensure a 16-degree angle between the line through the subassembly (along the pump beam) and: (a) the line through the first prism, and (b) the line through the output coupler. These angles are measured at the first and second curved mirrors, respectively.
Solution B6: Is your spectrometer cutting off past the wavelength you see as the laser cutoff? In other words, are you sure it is the laser that produces the hard edge, and not the spectrometer, itself?
Solution B7: Is the spectrum clipping somewhere outside of the laser?

Problem C: The bandwidth is unbelievably large. (Much more than 70nm FWHM).

Note C1: The MTS, Chinook or TS Lasers can often achieve over 100nm, but be sure that the following problems are not the cause:
Solution C1: The laser may be Self Q-switching. See "Self Q-switching."
Solution C2: The laser may be double pulsing. See "Double Pulsing."

Cleaning:

NOTE 1: Most pump lasers are followed by a periscope preceding the ti:sapphire oscillator. The upwards facing mirror will collect dust much more rapidly than the other optics. Clean that optic to improve your input pump power and stability. These pump input optics scratch relatively easily, so follow the directions below to avoid damaging the mirror by cleaning it.

NOTE 2: Always remember to clean BOTH sides of the lens, the BACK of the first curved mirror and the BACK of the output coupler, as well as the first surfaces of each optic. Any optic that involves a transmitted beam must be cleaned on both sides!!!

Problem A: The optics are dirty.

Diagnostic A1: If the beam seems particularly bright on one of the optics, the optic is likely to be damaged or dirty. Also, it may appear that the beam is split in two, because the main intensity of the beam is hitting a clean area, while the wing is hitting dirt, and so is scattered substantially. This results in the appearance that both components are equally intense. If the beam looks split, clean the optic to ensure that the problem is not just dirt.
Diagnostic A2: If the power, modelocking, or spatial-mode are unstable, one or more optics may be dirty.
Solution A1: First remove what you can with compressed air. NOTE that if you use an air can, the propellant may come out with the air, and further contaminate your optic. Prevent this by always holding the air can upright, and by beginning the air flow directed away from the optic, and turning the can toward the optic only once the air flow is in process.
Solution A2: We suggest cleaning all of the optics with a folded up lens tissue, held by a pair of hemostats, that is slightly dampened with methanol. Fold the tissue so that it is about the width of the optic to be cleaned, so that one full swipe cleans the entire optic, but does not drag over the mount. Do not over-dampen the tissue, or you will leave methanol on the optic, which will streak as it dries. We suggest using a dropper to put one or two drops of methanol onto the clamped tissue, then shake the hemostats a couple of times to "dry it." Then swipe the optic. If the optic is very dusty, swipe it once very lightly to remove large particles, then use a fresh tissue and swipe more firmly. This will help prevent scratches.

Clipping:

Problem A: While trying to achieve lasing, the fluorescence clips on one/several of the optics.

Solution A1: The fluorescence spot is very large at some points within the cavity. Try to center it on the optics (except M6), but don't worry if the spot is larger than the optic, and therefore some is lost. In particular, the fluorescence spot on the first prism will likely not fit entirely within the prism. It is best to begin by clipping mostly off of the tip of the prism.

Problem B: The spectrum appears to be clipped, (has a hard edge).

Solution B1: See "Bandwidth," Problem B.

Problem C: In an apparently good modelocking configuration, much of the spectrum appears to be clipped off of the tip of the second prism.

Solution C1: This is expected, especially when that prism is pulled out to the tip, and the laser is being run towards the red end of the spectrum.

Problem D: The laser beam appears to be clipping on the tip of the prisms, when in the modelocking configuration.

Solution D1: Yes, to initiate modelocking you do want the beam to be very near the prism tips. To ensure that you're not clipping too severely, observe the output power while adjusting the prism insertion. When you begin clipping severely, the power will drop dramatically. Then just re-insert the prism until the power stabilizes.

Collimation:

Problem A: The beam exiting the cavity diverges rapidly.

Solution A1: Is the pump laser beam well collimated as it enters the focusing lens on the subassembly rail? Does it have a good mode quality?

Solution A2: This is also indicative of higher order spatial modes. See "Spatial Mode." Adjust the translation of the second curved mirror and the crystal to collimate the beam.

CW Breakthrough:

Problem A: The laser modelocks, but with CW breakthrough. (The spectrum is broadband, but has a sharp spike somewhere within it.)

Solution A1: This is typically caused by overpumping. Try lowering the power of the pump laser. The CW should be clearly visible on a spectrometer trace. As you lower the pump power, the CW peak should diminish, and eventually disappear. The appropriate pump power depends greatly upon the pump laser being used, and the output coupler percentage. See "Pump Lasers."
Solution A2: Try adjusting the second curved mirror translation, particularly inward.
Solution A3: If you really want to avoid lowering the pump power, you might consider a slightly larger output coupling percentage. We have used output couplers in the range 3-25%, depending upon the available pump power.

Damaged Optics:

Problem A: The first curved mirror is damaged.

Solution A1: Make sure that it is actually damaged, and not just dirty. Block the pump laser and clean both surfaces of this mirror with denatured alcohol. As a next step, try cleaning with de-ionized water.
Solution A2: Try switching the two curved mirrors. They are arranged so that one of them is used at the center, and the other near the outside. So you will use two new spots when you switch them.

Problem B: The second curved mirror is damaged.

Solution B1: Make sure that it is actually damaged, and not just dirty. Block the pump laser and clean this mirror with denatured alcohol. As a next step, try cleaning with de-ionized water.
Solution B2: Rotate the mirror. The beams hits off center, deliberately so that you may rotate the mirror in order to use a fresh location should the mirror become damaged.

Problem C: The mirrors degrade over time. (A matter of years.)

Solution C1: This does occasionally happen, particularly with the curved mirrors, because of the green light. Try switching the two curved mirrors. The beam passes though the center of the first curved mirror, but off center on the second curved mirror. This is deliberate so that you can rotate the second curved mirror to a fresh spot and/or swap the two mirrors, for a fresh spot on both of them.

Divergence:

Problem A: The output beam seems to diverge quickly.

Solution A1: This may be a result of a laser that is misadjusted into an incorrect cavity configuration. Many cavity configurations will mode-lock, while the configuration that modelocks **robustly** is more restrictive. In the correct configuration, the laser output will have a modest, ~1 mrad divergence. Generally, these different configurations ("stability zones") can be accessed by linear translation of the subassembly components. Before proceeding, record the micrometer settings of the subassembly components for reference. Refer to your manual for the "factory" settings—perhaps these settings were inadvertently moved by large amounts. In particular, the first thing to check is the collimation of the fluorescence that is reflected from one of the 10 cm ROC mirrors toward the output coupler. By blocking the cavity somewhere in the prism end of the cavity, you can observe this fluorescence. It should come to its best focus about 10 cm **past** the output coupler, outside the laser cavity. If it does not, readjust this 10 cm mirror to change the collimation. It is also possible, however, that some of the other component positions must be moved as well to obtain stable mode-locked operation.

Double Pulsing:

Problem A: The laser is double pulsing (generating two pulses per round trip).

Diagnostic A1: The laser output power may be exceptionally high. (Also see "Self Q-Switching.")
Diagnostic A2: The output bandwidth may be exceptionally broad. (Also see "Self Q-Switching.")
Diagnostic A3: If the two pulses are well separated, you may be able to observe the double pulsing with a photodiode.
Diagnostic A4: If the two pulses are very close together, their interference will be manifested as a periodic modulation on the spectrum.
Diagnostic A5: The most difficult cases of diagnosing double pulsing arises when the two pulses are 10's of picoseconds apart. In that case, the spectral modulations are probably too fine to be observed, and also, the two pulses are too close together to be distinguished with a photodiode. In this case, observe the spectrum while decreasing the pump power. If you observe a sudden change in spectrum the laser may be double pulsing. In particular, a laser exhibiting no CW breakthrough at higher pump powers, but breaks through at lower powers is almost definitely double pulsing. See "CW Breakthrough."
Diagnostic A6: Since the two pulses are not in any way fixed in temporal separation, their separation will change over time, so if you have difficulty with diagnostic A5, within 5 minutes or so, the double pulsing should be visible via diagnostics A3 or A4.
Solution A1: Turn down the pump power. Even if everything looks okay and seems to be well behaved, the laser may be double pulsing if over pumped. See "Pump Lasers."
Solution A2: Are you sure that you're seeing actual double pulsing, and not just a reflection in the photodiode arrangement? If the "second" pulse has a smaller amplitude than the main pulse, and stays at a constant time delay relative to the main pulse, it is likely a reflection in the photodiode setup. If the second pulse moves in time, then it is a genuine double pulse.
Solution A3: Occasionally you can eliminate double pulsing by adjusting the translation of the second curved mirror. However, we do not suggest this technique, since it creates other problems in solving this one.

Fluorescence:

Problem A: Fluorescence is evident beyond the high reflector.

Solution A1: This is probably fluorescence at the short-wavelength end of the spectrum. This does pass through the mirror, and can be used in aligning the beam height within the oscillator.

Problem B: While trying to initiate lasing, the fluorescence spot seems too large to fit onto some of the optics.

Solution B1: See "Clipping."

Jitter and Thermal Drift:

Problem A: The laser behaves well when first aligned, but the power slowly drops, and the modelocking becomes unstable over a period of hours.

Diagnostic A1: This is probably caused by thermal drift, which is commonly due to thermal expansion warping the optical table or the pump laser. The table warms up because of the numerous power supplies near/on it. Some areas of the table swell more than others, misaligning the laser. This will typically misalign the vertical more than the horizontal.
Diagnostic A2: Turn on the pump laser and let it pass through the oscillator for several hours, but do not adjust anything. Leave all adjustments as they were at the end of the previous day (i.e. adjusted for a warm system). If the oscillator begins at a very low power, but warms to near the power level at the end of the previous day, you probably have some sort of thermal problem.

of the scattered light within the oscillator, from the crystal. As you pass by a position that lases, the crystal will appear to flicker.
Solution A8: Is your beam height exactly [4 inches for TS] [59mm for MTS and Chinook] above the table at all points? The fluorescence is often a large spot, and therefore hard to locate at 4 inches, just make sure that this spot is centered on 4 inches to your best guess. You can fine-tune the exact beam height once the oscillator is actually lasing.
Solution A9: Does the pump beam have a decent spatial mode? See "Pump Lasers."
Solution A10: Have you tried translating the lens in and out? This setting (included in your manual) is pump source-dependent. Your particular pump laser may require a different lens-to-crystal separation. (This is not a very sensitive adjustment. You should be able to turn the micrometer several revolutions in either direction before losing lasing.)
Solution A11: Does the laser still contain only KMLabs optics? Short pulse lasers impose very stringent requirements upon the cavity optics. We suggest that you consult KMLabs before swapping out any of the cavity optics.
Solution A12: Check that the fluorescence comes to something of a horizontal line focus about a centimeter or so before the second prism (P8). Then also, the fluorescence exiting the output coupler should come to a point focus about 5-10 cm outside of the output coupler. These foci are adjusted by translation of the crystal and second curved mirror (M6), respectively. (Note that the translation of the lens follows that of the crystal, so if you move the crystal, you will probably need to move the lens, also).
Solution A13: Not all of the fluorescence should hit the second prism (P8). Some should be clipped by the tip of the prism. Otherwise, the eventual position of lasing will be too far towards the back of the prism, and possibly be clipped.
Solution A14: For the MTS and the Chinook: Does the pump beam center on the alignment tool (when placed in the dowel-pin-seats just in front of the lens) and also on the iris at the output coupler, when the M6 micrometer is in the CW position?
For the TS: Does the pump beam pass through the center of the iris, and hit the center of the "+" marked on the back of the beam dump? (Since the "+" is marked on paper, turn the pump power down to its minimum before turning the beam dump around, with the paper-piece perpendicular to the subassembly rail.)

Problem B: The oscillator lases CW, but unstably.

Solution B1: See "Jitter and Thermal Drift."
Solution B2: Is the beam clipping somewhere? (Has a hair fallen into the cavity?)
Solution B3: Are all of the optics clean and damage free?
Solution B4: Is the crystal cool? The KMLabs oscillator should operate quite stably even without cooling.
Solution B5: If the oscillator is almost configured for modelocking, it may instead remain CW, but jump between individual different modes. (Spectral mode "hopping.") If you seek CW operation, adjust the prism insertion to prevent this hopping.
Solution B6: Is the pump laser stable?
Solution B7: Try peeking up the power by adjusting the high reflector and the output coupler, and if necessary the subassembly translators.
Solution B8: Is there a draft passing through the oscillator?

Minimum Deviation:

Note: "Minimum deviation" of the prisms is the angle at which the prism least deviates the beam from a straight path. This is important to ensure broad bandwidths and good modelocking.

Diagnostic A1: If your prisms are not at minimum deviation, this could affect both the power and the modelocking stability. (Note this is also true if the crystal is not set at minimum reflection of the green.)
Diagnostic A2: Ensure that your prisms are at minimum deviation by checking for spatial chirp on your output beam. An easy way to see this is to send a portion of the beam into a spectrometer, and see if the spectrum changes as you adjust the beam pointing into the spectrometer. If the spectrum is sensitive to horizontal tuning, the beam is probably spatially chirped, and you should re-align the prisms.

Problem A: How do I set minimum deviation for the prisms?

Solution A1: Direct the ti:sapphire fluorescence onto the first prism (the one closest to the subassembly). Loosen the 3/16" allen-wrench pin, located on the prism base, just below the stage (not the one near the bottom of the base.) This allows you to rotate the prism stage without translating it. Rotate the stage while observing the fluorescence passing through it, observing at a distance of at least a foot past the prism. The fluorescence will shift to one side. As you continue to rotate the prism, the fluorescence should stop shifting, and begin shifting back in the other direction. If it does not do this, try rotating the prism in the other direction. You want to fix the prism at the angle where the fluorescence is just about to shift back in the other direction. This is the point of minimum deviation. Holding the stage at this position, re-tighten the 3/16" pin. Now place the second prism (the one closest to the high reflector) into the beam leaving the first prism, and repeat the process detailed above, now with this second prism.

Solution A1: Some pump lasers (even new, diode-pumped sources) take many hours to thermalize, if the chiller has been off. If you are having drift problems, you should make sure that your pump laser chiller is not still warming up, and perhaps consider leaving its chiller on continuously, even when the laser is turned off. As the pump laser thermalizes, its pointing stability will be poor, and this will affect both the pointing stability and the power of your ti:sapph.
Solution A2: Treat the symptom by peaking up the power with the high reflector and output coupler knobs.
Solution A3: Treat the cause by removing heat sources from direct proximity of the optical table. In particular, pump laser power supplies generate enough heat to temporarily warp an optical table, even if they're just sitting on the floor beneath the table. You may want to move the power supply out from directly under the table.
Solution A4: Check the climate control of your lab. If the ambient temperature swings by 10 degrees Fahrenheit, that, too will warp the table.
Solution A5: Pump lasers that do not have active beam stabilization may experience drift in the beam pointing as they warm up.
Solution A6: Each time you turn on the system, warm it up with the pump beam passing through the oscillator for ~30 minutes before making any adjustments.
Solution A7: Are the pump laser's cooling lines free and clear? Occasionally we have found that the pump laser cooling lines become plugged or partially blocked, causing thermal instability.

Problem B: The laser is jittery.

Solution B1: Is the pump laser stable? Argon Ion lasers, especially, are a frequent cause of instability. See "Pump Lasers."
Solution B2: Are the mirrors and mounts transporting the pump beam to the oscillator very sturdy, and thermally stable? KMLabs sells a pump optics/mounts kit that is very stable: POPT, pump laser steering mirrors and mounts.
Solution B3: Are the optics dirty or damaged? See "Damaged Optics."
Solution B4: Is the power also higher than normal? A damaged optic may result in higher output powers. In this case, the damaged spot scatters light into other, higher order modes. These higher order modes may extract power more efficiently from a poor mode quality pump beam.
Solution B5: Is there anything in the beam path? A hair, fallen into the cavity can be especially troublesome.
Solution B6: Are any of the optics loose?
Solution B7: Is it mode hopping? See "Mode Hopping."
Solution B8: Is the laser self Q-Switching? See "Self Q-Switching."
Solution B9: Is there a breeze in the area of the laser?
Solution B10: Try removing a small amount of prism glass, in order to narrow the spectrum a bit. If this helps, you were probably on the very edge of positive dispersion, and so small fluctuations in the cavity "crossed" this transition.

Lasing:

Problem A: Following all of the steps in the manual, the oscillator still does not lase.

Solution A1: Is the second curved mirror mistakenly in the modelocking position? (Translated in towards the crystal?) Check the settings on pages 7 and 8 in your manual. The oscillator will lase much more efficiently and easily in the CW position.
Solution A2: Is the polarization of the pump laser correct? The oscillator requires "p" polarization: i.e. the pump laser polarized parallel to the table. See "Pump Lasers." SOME PUMP LASERS ARE "P" and SOME ARE "S"!
Solution A3: Is the pump power adequate? While it is not wise to over pump the laser once you've got it lasing (See "Double Pulsing"), it can be helpful to pump hard (5.0-5.5W) while you're trying to achieve lasing. Caution: When you're first setting up the oscillator, use the minimum pump power available. Do not turn up the pump power until you are satisfied that the beams are all level, and nominally well directed. Always wear your goggles. See "Pump Lasers."
Solution A4: Have you iterated back and forth, overlapping the beams in/out of the high reflector, and then in/out of the output coupler? Adjusting one of these will misalign the adjustments you've just made to the other one. You must therefore adjust one and then the other back and forth several times, until the overlap is adequate.
Solution A5: Has the fluorescence walked off of one of the optics as you have adjusted the alignment? Make sure the fluorescence is roughly centered in the end mirror, output coupler, fold mirror(s) (if present), and both prisms.
Solution A6: Are the irises fully open?
Solution A7: Are you fully blocking the beam all of the time that you are adjusting the output coupler and high reflector? If so, you may be passing over the lasing configuration without knowing it, since the signal is not allowed to build up. Be sure to actually check if it is lasing as you adjust the alignment. One way to do this is to observe the spontaneous emission ("glow") from the crystal. As the cavity begins to lase, the spontaneous emission will decrease, because the stimulated emission (lasing) increases. As a result, the crystal "glow" will dim. Of course, this is a much faster response than any power meter, so if you briefly "pass by" a lasing configuration, even if it is barely lasing, it will immediately "dim the glow". Therefore, once you are close to proper alignment, you can observe the glow to find initial lasing. (Be sure you've got on good glasses to protect you from the green, and be sure all potential ti:sapph beams are contained.) Don't look directly at the crystal, because even with your green-filtering glasses, you will bleach your visual sensitivity by prolonged observation of the spontaneous emission. Just look "somewhere nearby" within the cavity. Then adjust the vertical and horizontal of both the high reflector and output coupler, a couple of turns each way, coming back to the initial position before going on to the next adjustment. Then too, adjust the translation of the items on the sub-assembly back and forth, always watching for a dimming

Mode Hopping:

Problem A: The laser output is hopping between different spatial modes.

Solution A1: Make slight adjustments of the crystal translation, and then also of the second curved mirror translation.

Problem B: The laser output is hopping between different spectral/temporal modes.

Solution B1: Adjust the insertion of both prisms to achieve a stable bandwidth.
Solution B2: Clean all optics, and check for scratches and chips in all optics, especially the prisms.
Solution B3: See the suggestions under: "Modelocking Stability."

Modelocking:

Problem A: The oscillator lases well, and the CW power is fine, but it will not modelock.

Also see "Modelocking Stability" below.

Solution A1: Make sure that there is not too much prism glass in the beam path. Pull both prisms out so that the beam passes through the very tips. You can achieve this by retracting the prisms until the power begins to drop. Then re-inset the prisms just enough to bring the power back up.
Solution A2: Is the second curved mirror pulled in toward the crystal from the CW position? (See the micrometer setting included in your user manual.) This mirror should be translated to the position where the CW mode is a vertically elongated oval. If the peak CW power is approx. 800mW, this inner position should produce a CW power of about 350 to 450mW.
Solution A3: Is the CW output mode in the modelocked position a vertically elongated oval? If not, see "Spatial Mode Quality," Problem C.
Solution A4: Are any of the optics in backwards? If the beam is reflecting off of the back surface of the material, the pulses will suffer much greater dispersion within the mirror substrate than the prisms will compensate. Be sure that the ">" indicator on the side of the mirror points towards the cavity.
Solution A5: Occasionally, you may need to iterate back and forth between moving the second curved mirror slightly in towards the crystal and peaking up the power by adjusting the high reflector and the output coupler. Try "jogging" the prism between each iteration, to check for modelocking. This is particularly important if the laser stops lasing before the elongated mode appears as you move in the second curved mirror.
Solution A6: The green and red spot overlap on M6 (the second curved mirror) may not be correct. They should be perfectly overlapped vertically, and about half overlapped horizontally, both a few mm horizontally off from the mirror center. However, the red spot should be slightly more off center horizontally than the green spot. Often, the best way to achieve this is to walk the horizontal and vertical on the high reflector and the output coupler until the red and green spots are perfectly overlapped. Then peak up the output power by final horizontal adjustments of the high reflector and the output coupler. These final adjustments should serve to slightly offset the red and green spots by the correct amount. (In short, make sure that the red light is deviated less than the green light.) **NOTE:** If you can't seem to achieve good spot overlap, without losing power, you might be clipping off the edge of one of the prisms, or another optic. Since you are "walking the beam" as you seek this overlap, you will change where you hit an optic.
Solution A7: Are you over pumping? Try turning down the pump power by ¼ to ½ W. See "CW Breakthrough."
Solution A8: Is the beam clipping anywhere? (Has a hair fallen into the beam?)
Solution A9: Are the optics clean? (Mirrors, crystal, and esp. prisms?)
Solution A10: Is there too little prism glass? Depending upon your prism separation, you may need to re-insert the second prism somewhat. Try inserting it slightly, then jogging it to initiate modelocking, and continue these two steps, inserting the prism deeper and deeper. If this is not successful, retract the prism again before continuing your efforts, since it is most likely you'll find modelocking near the tips.
Solution A11: Ensure that the beam height is[4 inches for TS] [59mm for MTS and Chinook] throughout the cavity, i.e. behind the high reflector and output coupler, and/or just before both prisms. The beam should be as level as possible.
Solution A12: The pump beam may also be the problem. Do you know that the pump beam has a good mode? See "Pump Lasers."
Solution A13: Is the pump beam alignment through the ti:sapphire subassembly correct?
Solution A14: While the oscillator is NOT lasing (block one arm), check that the fluorescence comes to something of a horizontal line focus about a centimeter or so before the second prism (P8). Then also, the fluorescence exiting the output coupler should come to a focus about 5-10 cm outside the output coupler. These foci are adjusted by translation of the crystal and second curved mirror (M6).
Solution A15: Are the prisms at minimum deviation? See "Minimum Deviation."
Solution A16: Are you using the prisms provided by KMLabs with your kit? If the prisms are made of another material, their required separation will be different, at the very least.
Solution A17: Are the prisms bolted to the proper locations on the optical table? If the separation between the two prisms is substantially off, the intracavity dispersion compensation will be incorrect. They should be approximately 65cm apart.

Problem B: As you translate the prism, the output beam flickers, and perhaps seems on the verge of modelocking, but jogging the prism doesn't induce it.

Solution B1: Translate the prism rather slowly (taking about 2 seconds to push the stage fully in). When you get to a point where the mode starts to jump about, or seems almost modelocked, hold the stage at that position, and turn the micrometer in until it holds the stage there itself. Then fine-tune the prism insertion from there. This technique is useful in cases where greater prism insertion is necessary.
Solution B2: Try turning down the pump power slightly, by say ¼ to ½ Watt.
Solution B3: Try translating the second curved mirror in towards the crystal slightly more.
Solution B4: See Problem A, above.

Modelocking Stability:

Also see "Modelocking" above.

Problem A: The laser won't stay modelocked.

Solution A1: This is often caused by over pumping, which is effectively just complete CW breakthrough. See "CW Breakthrough."
Solution A2: The prism insertion may be incorrect. Try pulling the prisms slightly out. Then try various fine adjustments of the prism insertion.
Solution A3: Are all of the optics clean and damage-free? Especially check the prisms for dirt, scratches, and chips.
Solution A4: The second curved mirror should be translated to the position where the CW mode is a vertically elongated oval. If the peak CW power is approx. 800mW, this inner position should produce a CW power of about 350 to 450mW. The ML power at this same position should be about 100mW higher: 450 to 550mW. Try adjusting the position of the second curved mirror. Especially, try translating it in towards the crystal a very slight amount more (~1/10 turn of micrometer). A large discrimination between the CW and ML powers will help to prevent the laser from jumping from one mode to the other.
Solution A5: Is the pump laser stable and does it have a high quality high mode? Does the pump laser suffer from intermittent power "dropouts"? See "Pump Lasers."
Solution A6: Are there very strong breezes in the area? Is the laser unenclosed? This may cause dust to drift into the beam and interrupt the modelocking.
Solution A7: Is the CW output mode in the modelocked position a vertically elongated oval? If not, the modelocking will not be optimally stable. See "Spatial Mode Quality," Problem C.
Solution A8: Is there feedback from exterior optics? (Note that a retro-reflected beam from an amplifier can damage the oscillator.
Solution A9: Do you suspect that you need too much or too little prism glass to achieve modelocking? If so, check that the prism separation is correct, and that there is not extra material in the beam path. The prism separation should be correct if the prisms are bolted as indicated in the manual. In general, something like a 65-66cm separation is your goal. Extra material is most likely a problem if you've inserted any extra components into your laser, or if an optic is in backwards.
Solution A10: Are your prisms both at minimum deviation? See "Minimum Deviation."
Solution A11: Is the crystal temperature too high?
Solution A12: Is the pump power too low?
Solution A13: Does the pump laser have a good spatial mode? Does it have dropouts (particularly for some types of argon-ion lasers)?

Problem B: The spectrum is unstable. (Spectral mode hopping.)

Solution B1: See "Mode Hopping."
Solution B2: Clean all optics, including the BACK of the first curved mirror.
Solution B3: Check for scratches and chips in all optics, especially the prisms.
Solution B4: Try just generally tweaking the laser. Begin with the crystal translation, and then the second curved mirror translation.
Solution B5: Are spikes appearing within the spectrum? See "CW Breakthrough."
Solution B6: The laser may be double pulsing. See "Double Pulsing."

Problem C: The modelocking becomes unstable over a period of hours.

Solution C1: This may be a thermal problem. See "Jitter and Thermal Drift."
Solution C2: If your lab is not temperature controlled, you might need to cool your crystal. See "Cooling."

Power CW:

Problem A: The oscillator lases, but at low power.

Solution A1: The green and red spot overlap on M6 (the second curved mirror) may not be correct. The spots should be perfectly overlapped vertically, and about half overlapped horizontally, both a few mm horizontally off from the mirror center. However, the red spot should be slightly more off center horizontally than the green spot. Often the best way to achieve this is to walk the horizontal and vertical on the high reflector and the output coupler until the red and green spots are perfectly overlapped. Then peak up the output power by final horizontal adjustments of the high reflector and the output coupler. These final adjustments should serve to slightly offset the red and green spots by the correct amount. **NOTE:** If you can't seem to achieve good spot overlap, without losing power, you might be clipping off the edge of one of the prisms, or another optic. Since you are "walking the beam" as you seek this overlap, you will change where you hit an optic.

Solution A2: Ensure that the beam height is [4 inches for TS] [59mm for MTS and Chinook] throughout the cavity, i.e. behind the high reflector and output coupler, and /or just before both prisms. The beam should be as level as possible.

Solution A3: Have you repeatedly cycled through the initial alignment? Adjust the high reflector and output coupler, and then the micrometers on the subassembly. Go through all of these adjustments as many as ten times or more. Even if it does not seem much help, it may eventually add up to a significant increase in power. It is possible that each "round" increases the power by only a few mW, but the aggregate can be in the hundreds of mW. Note that such extensive adjustment is NOT necessary on a daily basis. In fact it is not a good idea on a daily basis, since you may walk off from optimal inadvertently, just because the laser is not yet warmed up for the day, etc. On a daily basis, it is a good idea to tweak ONLY the high reflector OR the output coupler.

Solution A4: Often, when you first achieve lasing, the prism insertion is not correct, and it is particularly common to find that the beam is going through the very back of one or both prisms (ie farthest from the tips). So the beam may be partially clipping off of the edge of a prism.

Solution A5: Is the pump laser power and mode quality acceptable? See "Pump Lasers."

Solution A6: Is the pump laser polarization correct? If it is perpendicular to the table, the oscillator will not lase; however, if it is partially rotated out of the plane of the table, the oscillator may lase, but at low power.

Solution A7: Is the crystal rotation very far from optimal? The crystal should be rotated for minimum reflection of the pump beam.

Solution A8: Are any of the optics dirty? Be sure that you clean the BACK of the first curved mirror, and the BACK of the output coupler, as well as the front surfaces.

Solution A9: Is the lens position correct? The reading listed in your manual is specific to the KMLabs pump laser. All pump lasers will focus at slightly different locations. The lens translation is fairly insensitive. Several full micrometer turns may be necessary.

Solution A10: Is the beam clipping on the edge of any optic?

Solution A11: Are the optics very old (several years)? Try switching the curved mirrors, see "Damaged Optics".

Problem B: The power drops slowly over a period of hours.

Solution B1: This is probably a thermal problem. See "Jitter and Thermal Drift."

Power Modelocking:

Note: Is the CW lasing power okay? If not, begin trouble shooting with the "Power CW" suggestions.

Problem A: The modelocked power is unstable.

Solution A1: This is likely to be caused by self Q-switching. See "Self Q-Switching,"

Solution A2: CW breakthrough may cause power fluctuations. See "CW Breakthrough."

Solution A3: Is area dusty?

Solution A4: Is the 2nd curved mirror too far in towards the crystal?

Solution A5: There are two stability regions in the laser. The "outer zone" is the desired one. The "inner zone" is the same, except the second curved mirror is moved in towards the crystal, past the desired modelocking position. Modelocking is best on the inner edge of the outer zone. The inner stability zone is about 1 or more full micrometer turns further towards the crystal. If you continue to translate this mirror towards the crystal from the outer zone, the oscillator may stop lasing, and then start lasing again, as you continue to move in the mirror, or, you may pass into the inner stability zone without losing lasing. To ensure that you are not in the inner zone, check that your micrometer reading is nominally that recorded in your manual. Also, try retracting the second curved mirror away from the crystal. When it stops lasing, continue retracting the mirror for another 1-2 micrometer turns. If the lasing does not restart, you were probably already in the outer zone. Return the micrometer to the lasing position.

Solution A6: Is the laser mode-hopping?

Solution A7: Are your prisms both at minimum deviation? See "Minimum Deviation."

Solution A8: Is the crystal temperature too high?

Solution A9: Is the pump power too low?

Solution A10: Does the pump laser have a good spatial mode? Does it have dropouts (particularly for some types of argon-ion lasers)?

Problem B: The modelocked power is exceptionally high.

Solution B1: The laser may be self Q-switching. See "Self Q-Switching."

Solution B2: The laser may be double pulsing. See "Double Pulsing."

Solution B3: A damaged optic may result in higher output powers. In this case, the damaged spot scatters light into other, higher order modes. These higher order modes may extract power more efficiently from a poor-mode-quality pump beam.

Problem C: I want to pump harder than 5W of green.

Solution C1: You may try, however, you will probably find that the modelocking and power become unstable due to the thermal load within the crystal. This is particularly likely to cause problems at pump powers above ~7W. Note that you may also need a higher output coupling in order to prevent CW breakthrough, and double pulsing. See "CW Breakthrough," and "Double Pulsing."

Problem D: Modelocked power is low.

Solution D1: Is the second curved mirror too far in towards the crystal? Adjust the position of the second curved mirror. However, be sure to maintain a good discrimination between the ML and CW modes, (≥100mW more when modelocked).
Solution D2: Only perform the following adjustment while monitoring BOTH the power out, AND the spectrum: While modelocked, make slight adjustments of the crystal position to increase the power WITHOUT disrupting the spectrum. (If you do this without monitoring the spectrum you will likely sacrifice bandwidth for power.)
Solution D3: Are you clipping off the tip of a prism?
Solution D4: Is the CW power okay? See "Power CW".
Solution D5: Is the spatial mode okay? See "Spatial Mode Quality."

Pulse Duration:

Problem A: The pulse is longer than desired.

Solution A1: Is the bandwidth sufficiently large to support the pulse duration you seek? As a rough estimate, to achieve a sub-15 fs pulse you need approx. 60nm FWHM of bandwidth at ~800nm central wavelength.
Solution A2: See "Bandwidth."

Problem B: The bandwidth supports a shorter pulse, but the pulse measured just after the output coupler is over 50fs in duration.

Diagnostic B1: Have you accounted for extra cavity dispersion? The intracavity prisms compensate for the dispersion accrued within the cavity, but they do not compensate for the final 1/2 pass through the crystal, and the full pass through the output coupler. Therefore, a sub-15fs pulse will disperse to 50fs or more as it exits the cavity.
Solution B1: Use a second prism pair, located just outside of the cavity to compensate for this dispersion, and also to precompensate for any sources of dispersion that exist on down the line. KMLabs sells an extra cavity prism pair for just this purpose: PPR, extracavity prism pair. These prisms are mounted just like those within the laser, leveled to the beam, and easily adjustable for positioning, rotation, and insertion.
Solution B2: Are there any external optics within the beam that add significant higher order phase? (e.g. an etalon has a sinusoidal phase.) Determine this by checking the pulse duration before and after these optics.
Solution B3: Are any of the optics inside the oscillator in backwards? If the beam is reflecting off of the back surface of the material, the pulses will suffer much greater dispersion within the mirror substrate than the prisms will compensate. Be sure that the ">" indicator on the side of the mirror points towards the laser beam. (It is very unlikely that the laser will modelock at all, should this be the case.)

Problem C: The pulse is short, following extra cavity compression, but then suddenly lengthens (2-3x longer) without a substantial change in the spectrum.

Solution C1: This is rare. It probably means that the time focus of the pulse within the oscillator has switched direction. We have solved this in the past by general "tweaking" the laser, until the pulse appears short again, (i.e. switches back). Often, just interrupting the modelocking, and restarting it is enough to temporarily alleviate this problem.

Pump Lasers:

Note 1: The KMLabs ti:sapphire oscillator may be pumped with the following sources: Argon Ion laser (512nm), or a diode pumped, 532nm source. See question A below.

Note 2: The location of the lens within the subassembly is dependent upon the specific pump laser used. Therefore, while we have included a reading for this translation on the settings pages in your manual, you must re-determine this value for your particular pump source. However, this is not a particularly sensitive adjustment.

Note 3: The KMLabs ti:sapphire oscillator requires a "P" polarized pump beam. (That is horizontal, polarized parallel to the optical table.) Most pump lasers are vertically polarized, although some vendors now allow the customer to choose the laser's ultimate polarization. Starting with a vertically polarized pump laser, it is easiest to rotate the polarization via the use of a periscope. Typically, the beam height will require adjustment, anyway, so a periscope serves two purposes. Note that KMLabs sells a very sturdy pump laser steering assembly that accomplishes these tasks.

Note 4: The most frequent cause of instability within the KMLabs oscillator is due to pump laser instabilities, either within the pump laser, itself, or due to poor stability of the periscope and other optics directing the pump laser to the ti:sapphire oscillator. Note that KMLabs sells a very sturdy pump laser steering assembly, as an optional accessory to our ti:sapphire laser kits.

Question A: Are Argon Ion lasers acceptable as pump lasers?

Solution A1: The KMLabs ti:sapphire oscillator was originally designed using Argon Ion lasers, and they can be quite acceptable. However, old, unstabilized Argon Ion lasers are frequently the cause of instability in the ti:sapphire oscillator. See "Jitter and Thermal Drift." Also note that slightly more pump power is needed when using 512nm (vs. 532nm), as its overlap with the ti:sapphire absorption peak is slightly poorer. This is typically not a problem, however, since 5W is still quite sufficient, and most Argon Ion lasers produce >5W.
Solution A2: Ensure that the mode quality is okay. Does it produce 4.5W with a clean mode? (Aperture 7 or 8?) Argon Ion lasers often have poor mode quality. If the mode quality is poor, you can try turning the aperture down to about 6 or so. Failing Argon Ion tubes often create a "donut spatial mode." Your ti:sapphire oscillator will not behave well (if at all) when pumped with a donut mode. In this case you probably need to replace the Argon laser tube (or perhaps consider purchasing a new 532nm source). Check the pump beam spatial mode by diverting the pump beam, and expanding the mode using a CLEAN lens. Observe carefully for mode defects.

Question B: What pump power should I use?

Solution B1: This depends upon the type of pump laser, the ti:sapphire output coupling percentage, and to some extent upon the particular oscillator and its alignment. However, some estimates follow:
To begin, see "Safety."
Pump Beam Alignment: When you are just beginning to steer the pump beam into the subassembly: USE THE LOWEST PUMP POWER POSSIBLE! At this point you only need enough green to trace its path, you don't need enough to induce lasing. Wear your green-filtering goggles.
Initial Placement of Cavity Optics: When you are just beginning to place the remaining optics in their nominal locations on the table, you should still use a very low pump power, just enough to create detectible levels of fluorescence.
Initiating Lasing: Only once the fluorescence is horizontal throughout the cavity, and nominally well directed should you turn up the pump power. Wear green-filtering goggles throughout this entire process. A poorly aligned oscillator will lase more readily if it is pumped harder. Therefore, while you are trying to achieve lasing, you might want to turn the pump power up higher than you will use, once you achieve lasing. Try using 5.0-5.5 W at that point. Note that at some point during this process, the oscillator will begin lasing, and most green-filtering goggles do not protect against ti:sapphire wavelengths.
Optimizing Lasing: At this point you should turn the pump power down to the power suggested for modelocked operation, in the range of ~4.0-5.0W. Over pumping can cause many problems when trying to modelock the laser. See "CW Breakthrough," and "Double Pulsing."

Repetition Rate:

Note: Within limits, you can adjust the rep rate of your laser by adjusting the cavity length. However, as you lengthen the cavity, the beam divergence will eventually require you to insert a telescope into the cavity. As you shorten the cavity, you will no longer have the space for both prisms, at the correct separation.

Problem A: A rep rate substantially higher than 90MHz is required.

Note: Achieving rep rates as high as 100MHz should not be difficult at all for the TS and MTS lasers. This will be difficult with the Chinook. Higher is also possible, with more effort. As you implement the following suggestions you will need to adjust the subassembly. Generally speaking, the curved mirror nearest the arm being adjusted (in terms of optical path) should be re-optimized. Achieving higher rep rates will be somewhat easier with an MTS laser than a TS laser, since the components are more compact, and therefore easier to squeeze close together.

Solution A1: Begin by moving the prisms closer to the sub-assembly, and the end mirror closer to the second prism. Also, move the output coupler in towards the subassembly. Note that an approximately 2:1ratio in the lengths of the prism and output coupler arms provides the best stability, so move the components correspondingly.
Solution A2: The prism separation can also be decreased somewhat, perhaps as much as 5-7cm (ie a separation of approx. 60cm). However, that may make modelocking substantially more difficult; in which case you should return closer to a 65cm separation.
Solution A3: The rep rate can also be increased by using higher dispersion prisms, because the prism separation will be smaller, and so the cavity length will decrease. Note that this will narrow the obtainable bandwidth.

Problem B: A rep rate substantially lower than 90MHz is required.

Note: Achieving rep rates as low as about 75MHz should be possible simply by repositioning the optics in the TS laser. The TS laser is much more convenient for lower rep rates than is the MTS laser, since the optics will need to be spaced further apart, and the MTS is confined on a compact breadboard. This reconfiguration is not possible with the Chinook.

Solution B1: By inserting an intracavity telescope, you can extend the cavity to achieve rep rates as low as 15MHz; however, this adds complexity to the cavity configuration, and KMLabs does not recommend this, in general. If you require much lower repetition rates, you might consider the KMLabs Cascade, cavity dumped laser system.
Solution B2: If you need a substantially lower rep rate, you may use a Pockels cell or comparable pulse picker to select out only a fraction of the pulses. Note that in so doing you will lose the other pulses and their energy.

Problem C: A fast photodiode indicates that the laser rep rate is in the microseconds range.

Solution C1: The standard layout produces a rep rate around 90 MHz. A reading in the microseconds range probably indicates that the laser is self Q-switching. See "Self Q-Switching."

Safety:

The models MTS, Chinook and TS lasers are class IV laser systems, which can cause serious eye injury. **WEAR PROPER EYE PROTECTION AT ALL TIMES.** Since these lasers involve significant radiation in both the green and the IR, full protection is difficult, but not impossible. We typically suggest two types of laser protective spectacles for alignment. Argon-ion narrow-band goggles are very helpful to block out argon light but still observe ti:sapphire fluorescence and obtain initial lasing action. HOWEVER, IT IS IMPORTANT TO REALIZE THAT IT IS POSSIBLE FOR THE LASER TO START LASING WITHOUT THE USER NOTICING IT, PARTICULARLY IF IT STARTS TO RUN AT LONG WAVELENGTHS. THUS VIGILANCE IS REQUIRED AT ALL TIMES. Once the laser action is achieved, Laser-Gard Broad-spectrum "B" goggles provide some protection at both 800nm and in the green, while still giving reasonable visibility. It is important to note, however, that the optical density of these goggles is moderate at 450-550 nm, and at 700-900 nm, and may not provide full protection in all situations. Once the laser is operating, and when the pump beam is fully enclosed, goggles using BG39 glass (for example, available from Kentek) can provide excellent usability and protection at 800nm. HOWEVER, SINCE EACH LABORATORY HAS ITS OWN SET OF SAFETY ISSUES AND INSTITUTIONAL POLICIES, YOUR SHOULD RESEARCH CAREFULLY YOUR OWN SAFETY NEEDS AND REQUIREMENTS.
Also be sure to consult the safety requirements included with your pump laser. Note that the pump laser's power supply is potentially lethal, and should be serviced only by qualified technicians. Also, the input pump beam and the residual pump light exiting the ti:sapphire output coupler can burn clothing, paper, etc., as well as cause serious eye injury.
As a further precaution, we suggest that you ensure all laser beams propagate horizontally. When vertical adjustments are required, carefully align a periscope, ensuring that any back-reflections from optics beyond it are trapped before reaching the periscope. Even beams that are directly very slightly up from horizontal will reach "eye-height" if they are allowed to propagate far enough. Do not sit or stand such that your face is near the beam height.
Since each laboratory has its own set of safety issues, you should research your own safety needs.

Self Q-Switching:

Problem A: The laser appears to be self Q-switching.

Diagnostic A1: The telltale signs of self Q-switching are an exceptionally high power and/or exceptionally broad bandwidth (also see " Double Pulsing").
Diagnostic A2: Q-switching also manifests itself as power instability. (On the order of 10% power fluctuations.)
Diagnostic A3: You can determine if the laser is actually self Q-switching by observing the pulse train with a fast photodiode. The Q-switching rep rate will be in the microseconds range. Use an analog scope for this diagnostic. A digital scope will show similar modulations simply because the sampling rate is not in phase with the laser's rep rate.
Solution A1: While observing the self Q-switching with a photodiode, make slight adjustments to the high reflector. Typically, very little adjustment is needed.
Solution A2: Self Q-switching is a common symptom of under pumping. Try increasing the pump power, but make sure you don't then double pulse, or suffer CW breakthrough due to over pumping.
Solution A3: If solution A1 is not effective, try slight adjustments of the second curved mirror and/or crystal translations.

Spatial Chirp:

Problem A: The output beam suffers substantial spatial chirp.

Solution A1: This is almost surely due to improper prism adjustment for minimum deviation. See "Minimum Deviation."
Solution A2: This could also be an artifact of your measurement technique. Consult the instructions for your measurement system.

Spatial Mode Quality:

Note 1: If the output beam seems to generally exhibit very peculiar spatial mode behavior, you should make sure that the beam is not clipping off of the edge of an optic, or is not hitting damage or dirt on an optic.

Problem A: The output beam has a donut-mode shape.

Solution A1: This is usually caused by a failing argon pump laser tube. Check your pump laser mode quality. See "Pump Lasers."
Solution A2: It is possible that the first curved mirror has degraded over long-term use. See "Damaged Optics."

Problem B: The CW spatial mode is not a uniform circle.

Note B1: In general, if one looks at the beam with the eye, it may appear to have structure surrounding the central spot. This is particularly true when running very broad bandwidth-- energy at short wavelengths will be propagating in higher-order modes, and this is what one's eye is sensitive to. So the beam may not always look pretty, but the bulk of the beam energy is still in a TEM 00 mode. If the bandwidth is narrowed and moved more into the IR, the beam will look dimmer, but more regular.
Solution B1: Adjust the separation of the two curved mirrors.
Solution B2: Verify that the angles a) from the input-line of the green off to the first prism, and b) from the input-line of the green off to the output coupler, are both about 16 degrees.

Problem C: The CW spatial mode in the ML position is not a vertically elongated oval.

Solution C1: Is the CW spatial mode in the CW position acceptable? If not, see Problem B, above.
Solution C2: Does the pump laser have a good mode? "See Pump Lasers,"
Solution C3: Adjust the crystal and second curved mirror translations.

Problem D: The CW spatial mode in the ML position is a vertically elongated oval, but with structure.

Solution D1: Adjust the translation of the crystal and the lens.

Problem E: The beam on one of the optics looks split into two separate components.

Solution E1: Adjust the high reflector and output coupler by observing the output power and the green/red spot overlap on the second curved mirror. See "Power CW: Solution A1."
Solution E2: Ensure that the apparent split is not just scatter of the wings off of dust or damage. See "Cleaning: Diagnostic A1."

Problem F: The modelocked beam seems to have a lot of higher order structure around it.

Note 1: This apparent multimode structure in the visual characteristics of the beam is a signature of very broad-bandwidth operation. The pulse forming process in the cavity makes it possible to create a pulse where some wavelength components are in a different spatial mode than others. All wavelength components of a pulse must travel through the laser cavity with the same round-trip time. The shortest wavelengths, which are the ones visible to the eye, can keep "in synch" with longer wavelengths by following a slightly more circuitous path through the laser cavity; i.e. by propagating in a higher-order mode.
Note 2: Another cause of higher-order structure is CW "breakthrough;" i.e. some of the laser light is coming-out as CW emission, and is not part of the short pulse. This generally is visible as a "spike" in the spectrum. Check the spectrum. If there is CW, turn-down the pump laser by a few 10th's of a watt.

Diagnostic F1: Are you sure that this structure is co-propagating with your beam. Look at that structure over a fair distance (if possible several meters). If it is diverging very quickly, while the circular, intense portion remains collimated, you needn't worry with it.
Diagnostic F2: This is typical at the extreme short-wavelength end of the spectrum. It may just be that you have more signal in the visible than usual. Use an IR viewer that has been turned off for a few seconds to look at the beam. As the IR viewer signal fades, you will be able to clearly see the beam profile. If all of the structure is at the short wave (visible) end, the beam will appear as a clean circle through the viewer. Showing you that very little intensity is actually located within this structure.

Spectrum:

Also see "Bandwidth."

Problem A: The spectrum looks very noisy.

Solution A1: This is probably due to interference within your spectrometer. Ensure that any filtering technique or input angle is not causing this effect. Try alternative methods for attenuating the beam into the spectrometer, such as index cards, ND filters, paper, etc...

Solution A2: Is this noise periodic, but drifting? If so, the laser may be double pulsing. See "Double Pulsing."

Problem B: The spectrum, or CW lasing wavelength is very long or short, relative to 800nm.

Solution B1: This is most commonly caused by clipping off of the end high reflector. Make sure that the beam is centered on the high reflector. Since the beam is spectrally dispersed on this mirror, it may look like it is all "on the mirror" when in fact the longer wavelength components are clipping.
Solution B2: Have you adjusted the prism insertion? In particular, adjust the second prism insertion: pull that prism out, to achieve longer wavelengths, push that prism in, to achieve shorter wavelengths.

Problem C: The spectrum is very "blue" i.e. centered at too short wavelengths.

Solution C1: Is the second prism (closest to the flat high reflector) very deeply inserted into the beam? If so, pull it out to tune your laser to longer wavelengths.
Solution C2: Is the prism separation too large? They should be about 65cm apart.

Problem D: The spectrum seems to have very steep sides and a very flat top.

Solution D1: This is almost always a symptom of positive dispersion. You need to remove some of the prism glass, by pulling one or the other prism slightly out from the cavity. Typically, as you do this, the spectrum will all of a sudden broaden dramatically as you achieve the zero dispersion point, and will probably drop out of modelocking. Continue to pull the prism out of the cavity another ~1 mm, then restart the laser. The spectrum should look more normal.

Problem E: The spectral intensity has very "concave" sides, and is thus very pointed at the center, rather than having a smoother, more gaussean appearance.

Solution E1: Not always, but this is very commonly a symptom of under pumping. Watch the spectrum as you increase the pump power slowly. If the problem really is under pumping, the sides of the spectrum should fill in, as you increase the pump power. This spectral shape is also often accompanied by instability in the pulse train and self q-switching. The pulse train amplitude stability should settle down once the system is not underpumped.

Problem F: A spectrum outside the range of the MTS, Chinook or TS laser is required.

Solution F1: The ti:sapphire emission spectrum is broader than the optics within the cavity. Broader optics would be either lower quality, or lower efficiency. Therefore, if you want to center your spectrum outside the range that you can achieve with our standard optics sets, you will need new optics, centered on an appropriate wavelength. Note that the ti:sapphire emission is most efficient and stable when centered at about 800nm, so the farther you deviate from that wavelength, the more difficult alignment will be. KMLabs has optics for operation between 850-875nm in stock: call for information.

Stability:

Problem A: The laser power is not stable.

Solution A1: See "Jitter and Thermal Drift."
Solution A2: See "Self Q-Switching."
Solution A3: See "Lasing," Problem B.
Solution A4: See "Cooling."

Problem B: The modelocking is unstable.

Solution B1: See "Modelocking Stability."
Solution B2: See "Cooling."
Solution B3: See "Jitter and Thermal Drift."

Problem C: The spatial mode is unstable.

Solution C1: See "Mode Hopping."

Problem D: The spectral/temporal mode is unstable.

Solution D1: See "Mode Hopping."
Solution D2: See "Modelocking Stability."
Solution D3: See "Jitter and Thermal Drift."

Threshold:

Problem A: What is the pump threshold of the KMLabs ti:sapphire laser?

Solution A1: This depends upon whether you intend to initiate lasing at this power, or turn the pump power down to this level, once the oscillator is already modelocked. The specific numbers depend greatly upon the pump laser quality, and the oscillator optics.
Solution A2: Lower threshold operation can be obtained by using smaller ROC curved mirrors and lenses. Contact KMLabs about purchasing a low-threshold package, for >250mW, <15fs, <2.5W pump.

Tuning:

Problem A: I want the oscillator bandwidth centered at shorter/longer wavelengths.

Solution A1: If the current bandwidth includes the wavelengths you desire, you may select the desired band using the computer controlled tuning slit, included with your MTS, Chinook or TS-Laser kit.
Solution A2: If the full bandwidth does not include the desired wavelengths, adjust the insertion of the prism nearest the high reflector. Pull the prism out (less glass in the cavity) to achieve longer wavelengths. Push the prism in (more glass in the cavity) to achieve shorter wavelengths. Adjust the insertion in small steps. Between each iteration, adjust the insertion of the other prism (closest to the curved mirror). Typically, you will need to insert that prism, in order to achieve a greater bandwidth. Note that the insertion of the prisms may seem rather insensitive at first, and then when you near the zero dispersion point, small changes will have very substantial effect. Make very slight adjustments once you reach this point. Note that as you change the prism insertion you may need to peak up the power using the HR and OC adjustments. Do so while CW, so that you do not inadvertently sacrifice bandwidth for power.

Problem B: The bandwidth/center wavelength tunes in an unexpected manner.

Solution B1: Is one prism too far inserted? If the prism insertions are really very far off from optimal, the tuning characteristics may be counterintuitive. Back out both prisms so that the beam passes through near the tip of each, and then re-insert them, as instructed in the "Bandwidth" section.
Solution B2: Is the beam clipping off of the edge of an optic, a hair, or another component within the cavity? Are all of the optics clean?

