SP2

Single Particle Soot Photometer

Laser Alignment Manual

DOC-0229

Revision C-2

DROPLET MEASUREMENT TECHNOLOGIES

2545 Central Avenue
Boulder, CO 80301-5727 USA

2545 CENTRAL AVENUE
BOULDER, COLORADO, USA 80301
TEL: +1 (303) 440-5576
FAX: +1 (303) 440-1965
WWW.DROPLETMEASUREMENT.COM

Trademark Information

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1.0 Introduction: Laser Cavity Performance

Figure 1 shows a schematic depiction of the pumped Nd:YAG plano-concave laser resonator at the heart of the SP2 spectrometer head. Particles in the aerosol jet intersect the laser beam within the resonator cavity.

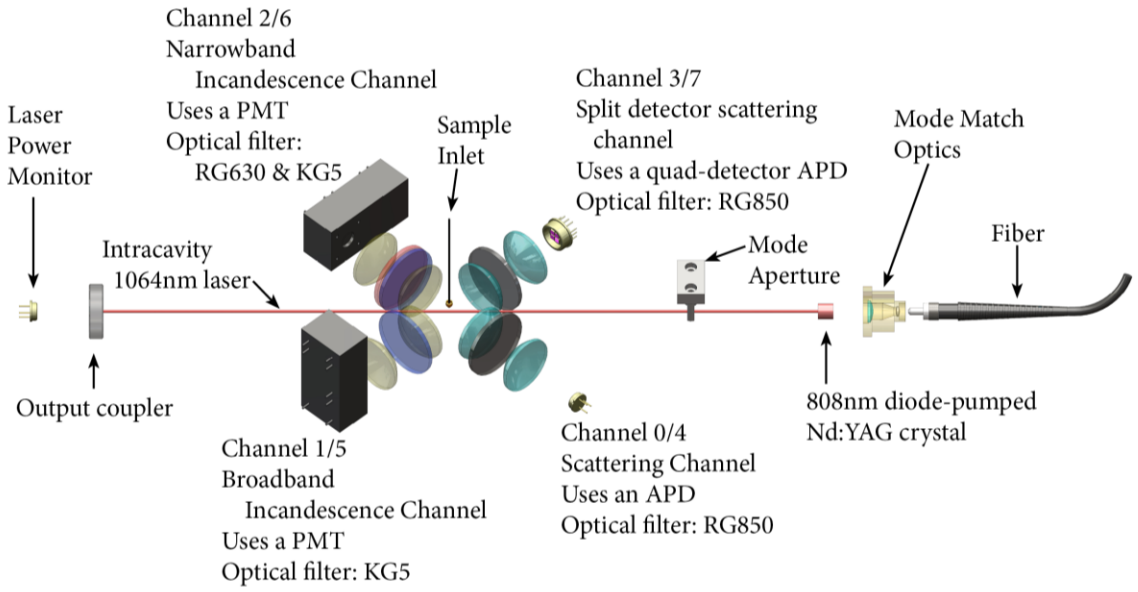


Figure 1: Nd: YAG Laser Resonator Cavity

Optimum performance of the SP2 is obtained when its laser beam is operating in the TEM_{oo} mode, in which the beam cross-section has a Gaussian profile. Higher-order modes will have multiple spots, which may not affect the measurement of black carbon incandescence, but will almost certainly limit the utility of the scattering data collected. In cases where very high-order modes are present, the incandescence data can also be compromised.

Intracavity laser power is also essential for peak measurement performance, and depends heavily upon proper alignment and the surface integrity of the optics which bound the cavity.

A minor adjustment of the Nd:YAG laser alignment can frequently restore instrument performance. If the signal shape from a purely scattering particle is significantly non-Gaussian, such an adjustment can usually restore the peak shape. Cleaning the delicate surfaces of the laser's optical components can restore lost power, but is often a last resort prior to their replacement.

2.0 Sequence of Laser Cavity Troubleshooting

A significant reduction in laser power is typically caused by either misalignment of the laser cavity or contamination of the laser optics. Total loss of laser power is usually the result of a failure in the pump laser system, or an occlusion of the intracavity laser beam by a mechanical component such as the mode aperture that was not secured properly.

Performance degradation is attributable to a non-Gaussian beam profile, a loss of beam power, or both. Table 1 identifies cavity-specific causes of these symptoms, and lists possible remedies.

Symptom	Causes	Remedies
Non-Gaussian beam profile	Misalignment of optical components	Adjust output coupler tip/tilt
	Misalignment of mode aperture	Realign mode aperture
Loss of power	Misalignment of optical components	Adjust output coupler tip/tilt
	Misalignment of mode aperture	Realign mode aperture
	Contamination or degradation of optical component surfaces	Clean surface of output coupler Replace output coupler Replace YAG crystal

Table 1: Causes and Remedies of Symptoms of Degraded Performance

Figure 2 presents the recommended troubleshooting sequence for restoration of lost power. Difficulty and cost increase as the sequence progresses.

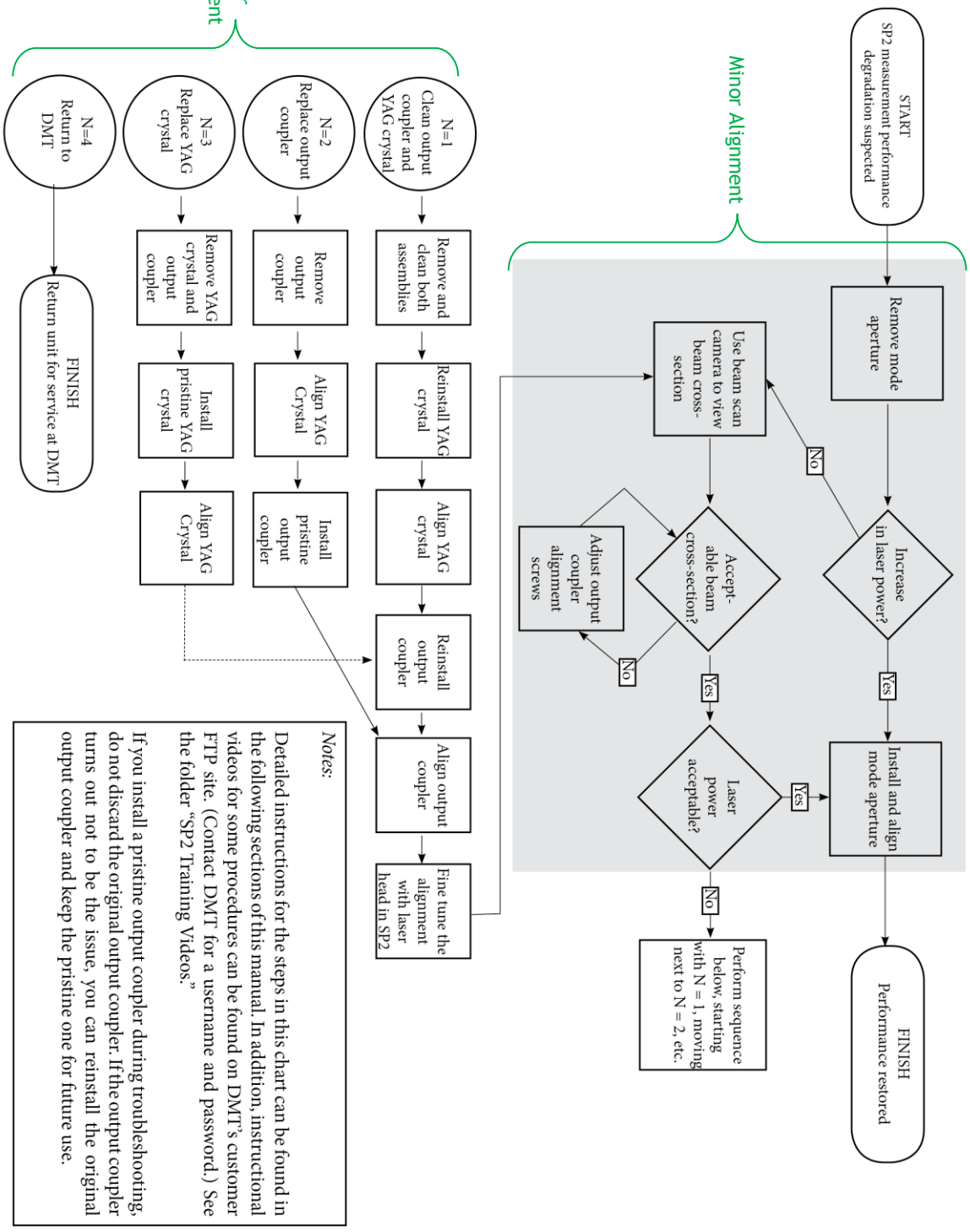


Figure 2: Troubleshooting Sequence

Noteworthy components of the SP2 spectrometer head are identified in Figure 3.

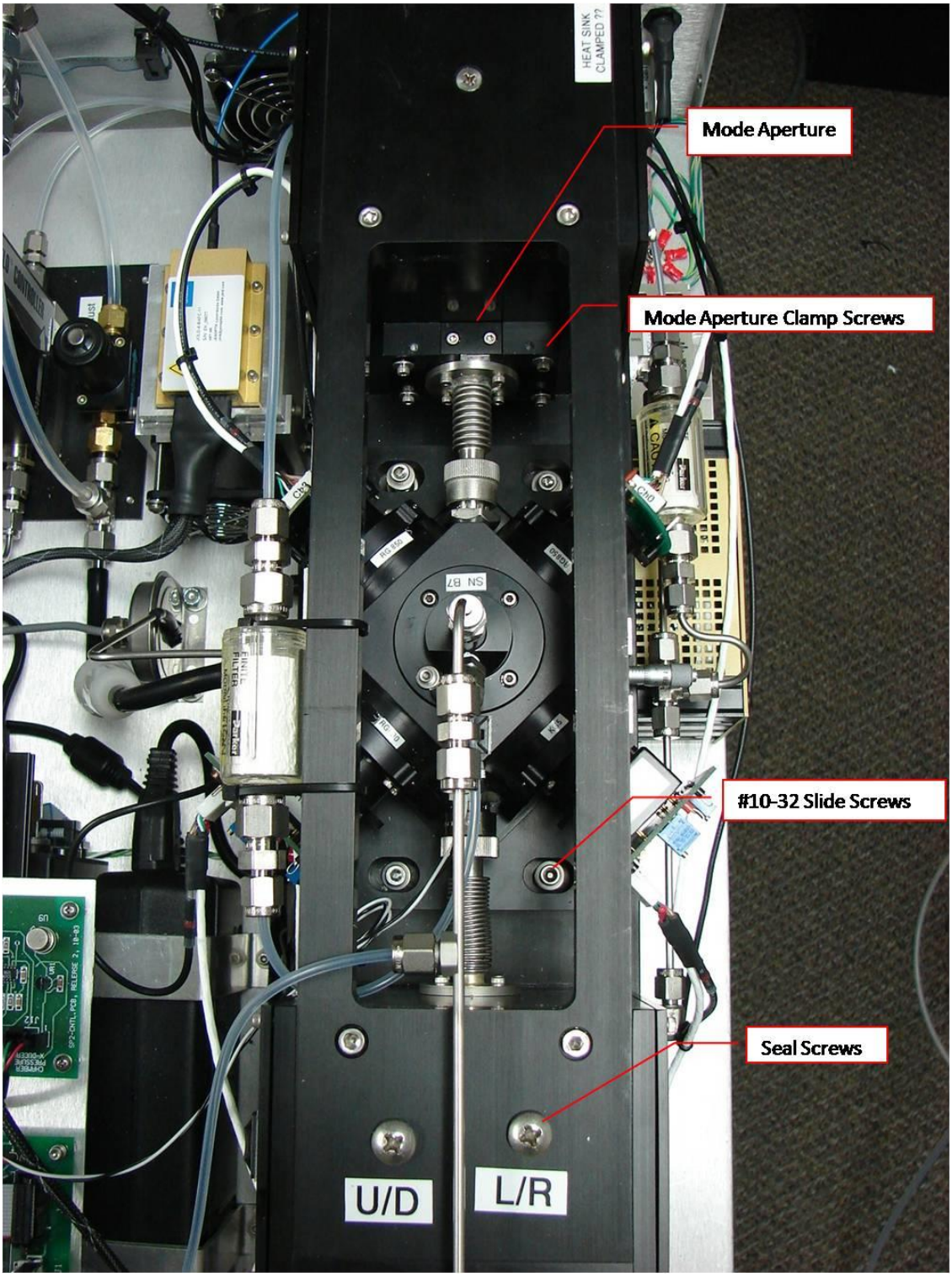


Figure 3: SP2 Spectrometer Head

3.0 Minor Alignment Process (Adjustments made without removal of core optical components)

A minor alignment adjustment of the Output Coupler or Mode Aperture, without removal of the spectrometer head, can frequently restore instrument power. If the signal shape from a purely scattering particle is significantly non-Gaussian, a small adjustment of the Output Coupler can usually restore the peak shape. When checking the beam profile with the beam scan camera, it is recommended that the Mode Aperture be removed from the optical path to ensure that the entire beam profile is shown in the beam scan image. A good way to do this is to remove the mode aperture and reinstall it upside-down, while maintaining the seal for the flow system to operate.

3.1 Equipment

3.1.1 Required Tools

- Beam scan camera
- Two 5/64 ball-end hex drivers, screwdriver handle preferred
- One 3/32 ball-end hex drivers, screwdriver handle preferred
- One 5/32 long stem ball-end hex driver, screwdriver handle preferred
- Multi-bit tool set such as a Chapman set having changeable screwdriver and hex bits
- Aerosol generator and 0.24-0.28 micron PSL particles.

Note: The terms "hex" and "allen" are used interchangeably throughout this document to describe a screw driver of hexagonal cross section.

3.1.2 Recommended Tool

- SP2 mode aperture alignment tool

3.2 Step-by-Step Instructions

3.1. Run the SP2 for 15-30 minutes with a filter on the inlet to remove as many particles as possible from the instrument. (Leave the filter in place until step 3.28 is reached.)

3.2. With the laser operational, record the YAG power voltage reported in the SP2 software.

3.3. Shut off the laser and then the sample pump.

3.4. Remove the top cover from the SP2 analyzer chassis, and wait 1-2 minutes for all flow to stop.

3.5. Remove the mode aperture by removing the two 4-40 Allen head screws with a 3/32" driver and lifting the mode aperture straight up. It is useful to remove the screws and then use needle-nose pliers to grasp the aperture and remove it. Take care not to lose the O-ring. See Figure 4.

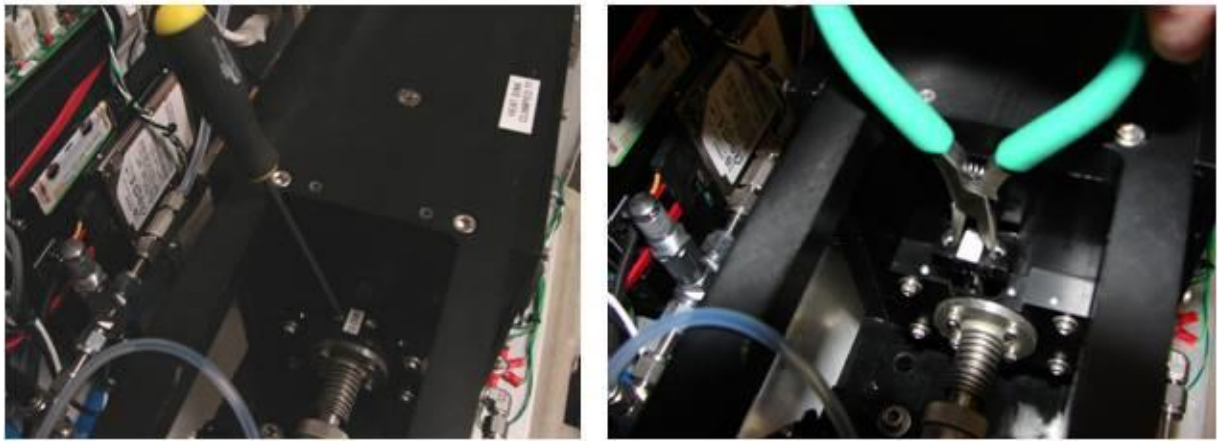


Figure 4: Mode Aperture Removal

3.6. Turn on the laser current and DO NOT TURN ON THE SAMPLE PUMP. Make note of the YAG power reading, and turn the laser off. If the YAG power has increased by more than 10% over the measurement made in step 3.2, realignment of the mode aperture can increase the laser power.

3.7. If the laser power does not increase by more than 10%, it is recommended that the beam mode be evaluated also to insure the laser is in optimum operating condition. This will be checked in the following steps.

3.8. Reinsert the mode aperture in an upside-down orientation, while leaving the small O-ring underneath it, and screw it in place. (This creates the necessary seal for the SP2 flow system, while at the same time ensuring that the mode aperture is not blocking the laser.) See Figure 5.

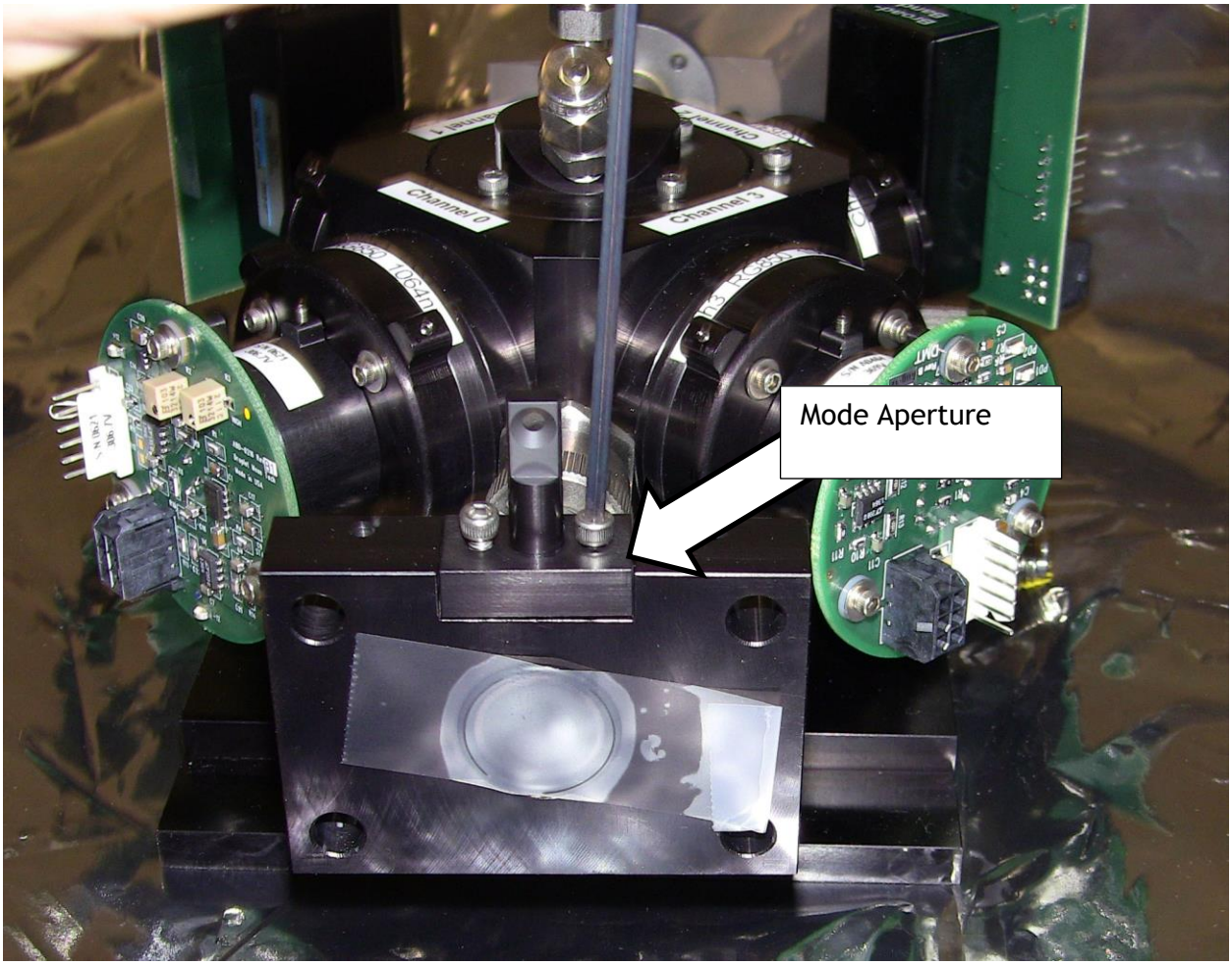


Figure 5: Installing Mode Aperture in Upside-Down Position

3.9. Remove the laser power monitor from the coupler end of the laser frame. The laser power monitor should be set aside. It may be necessary to remove the right side panel from the SP2 to access the screws on the laser power monitor. The reference to the right side of the SP2 is as viewed from the front of the instrument.

3.10. Install the beam scan camera. Consult *DOC-0175* for details of beam scan camera installation or operation.

3.11. With the Mode Aperture installed in the upside-down position, turn on the flow system. Wait for the sample flow to stabilize at its set-point. Turn the laser current down to approximately 1800 mA, and turn on the laser.

3.12. Observe the laser mode. A beam profile depicting the desired TEM_{oo} mode is shown in Figure 6, while an undesired higher mode (note the non-Gaussian pattern) is shown in Figure 7. If the laser mode is satisfactory, and the problem is low laser power, the optics may be contaminated. It is recommended that the user proceed to later sections of this document to pursue optics cleaning or replacement, per the

recommended troubleshooting sequence given in Figure 2. If the laser mode is unsatisfactory, proceed to step 3.13.

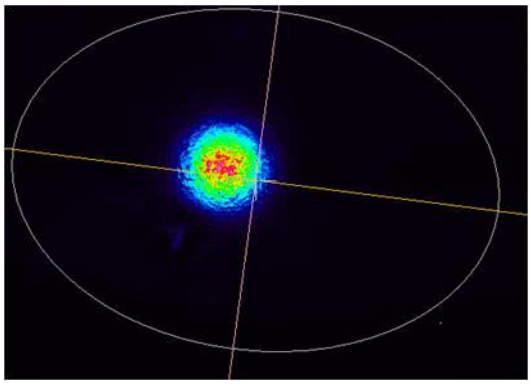


Figure 6: Satisfactory Beam Profile

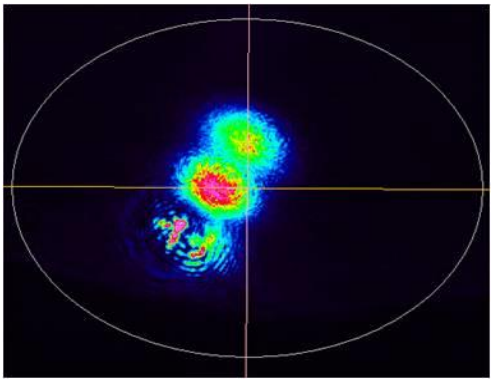


Figure 7: Undesired Higher Mode

3.13. Turn off the laser current, and then the flow system. Wait 1-2 minutes for all flow to stop before continuing.

3.14. Remove the two Phillips head (cross-recess) sealing screws in the top of the coupler chamber. See Figure 8.

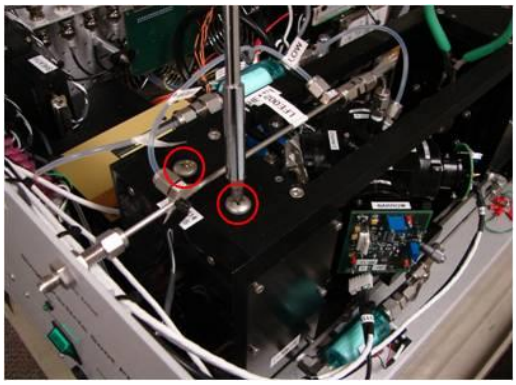


Figure 8: Coupler Chamber Sealing Screws

3.15. Insert a 5/64" hex driver into both of the holes on the top of the coupler to engage the coupler adjustment screws. As the drivers are inserted, make sure that the adjustment screws are not turned. Figure 9 illustrates the drivers properly engaged. (Two walls have been removed in this figure to improve the view). For SP2 instruments with serial numbers less than 020, the drivers must be inserted at a slight angle to contact the adjustment screws (Figure 10).

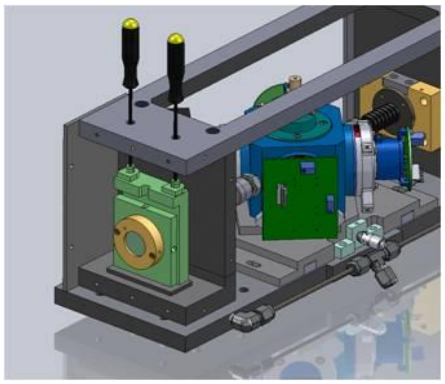


Figure 9: Tip/tilt adjustment of output coupler mount

Figure 10: Angled entry of drivers in older systems

3.16. Turn on the laser without the flow system running. While turning the Allen drivers slightly, less than 1/16th of a turn, observe the laser modes on the beam scan display. Adjust both drivers until the SP2 YAG laser mode shows TEM_{00}, as depicted in Figure 6. One driver will move the modes (the pattern of maxima and minima) in the vertical direction, and the other in the horizontal direction. Once the laser mode is adjusted, carefully remove the drivers while observing the mode on the display to insure that removing the drivers does not change the coupler alignment.

3.17. Turn off the laser current and install the two sealing screws removed in step 3.14.

3.18. Remove the beam scan camera and reinstall the laser power monitor.

3.19. Turn on the flow system, and wait for the sample flow rate to stabilize. Turn on the laser at the current used in 3.6. Compare the YAG power to that measured previously. If the power does not return to a satisfactory level, proceed to Section 4.0 to pursue

optical cleaning or replacement (per the troubleshooting sequence), or simply return the SP2 to DMT for service. If the laser power is satisfactory, record the laser power value and continue.

3.20. Turn off the laser current, and then the sample pump, and reinstall the mode aperture in its proper orientation. *Make sure to put the O-ring on the mode aperture first, and then reinsert aperture and O-ring into the Mode Aperture block. Placing the O-ring on the block and then reinserting the aperture can damage the O-ring, as the mode aperture has sharp edges. It is possible for pieces of the O-ring, if cut, to hang into the beam path.*

3.21. Again, start the sample flow and let it stabilize. Turn on the laser current and record the YAG power. If the power is within a few percent of that measured in Step 3.19, there will be no need for a mode aperture adjustment. You may proceed to Step3.26 to adjust the position of the detector chamber, which ensures the sample jet is aligned with the new beam position. Otherwise, continue with the following steps to adjust the mode aperture position.

3.22. If the right side panel has not been removed from the SP2 chassis, remove it at this time. Loosen the four holding screws in the mode aperture block very slightly. The block should move when moderate side force is applied, but be not so loose that the O-ring behind the block is not in good contact with the YAG crystal chamber. See Figure 3.

3.23. If the mode aperture adjustment fixture is available, install it with two clamps and two fasteners as shown in Figure 11. The adjustment of the mode aperture should be done in the chassis. It may be necessary to cut or move some of the wire ties on the top of the laser frame to mount the aperture adjustment fixture. If the adjustment fixture is not available the mode aperture can be moved manually as shown in Figure 12.

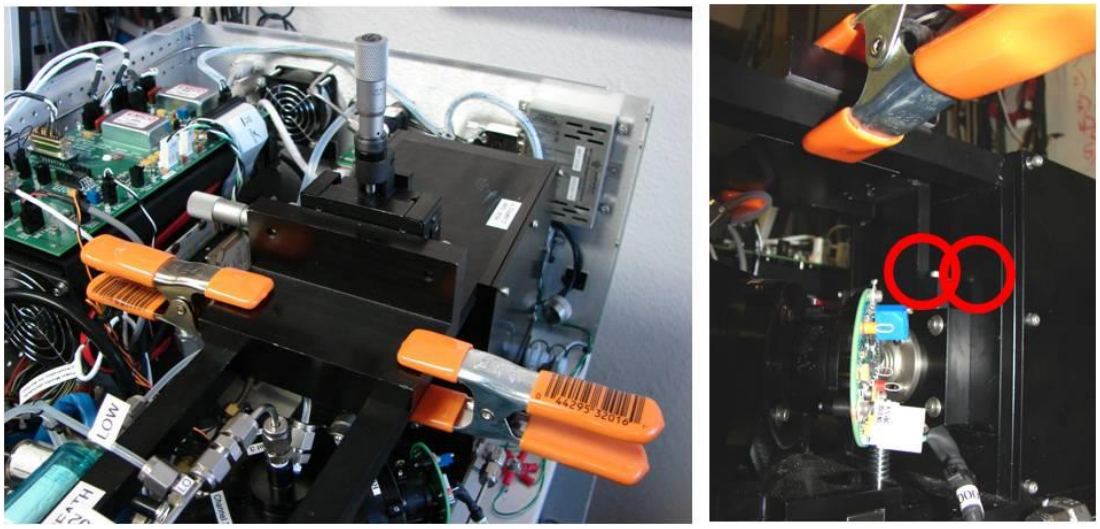


Figure 11: Attachment of Mode Aperture Alignment Tool

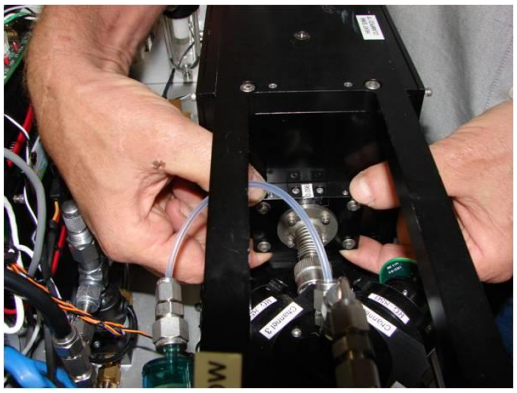


Figure 12: Manual mode aperture alignment

3.24. With the sample pump and laser both running, make adjustments to the position of the mode aperture block. While making these adjustments, monitor the YAG laser power to maximize the YAG power reading. The springs in the mode aperture tool usually do not apply sufficient restoring force to move the holder when the screw is backed out. Finger pressure opposite the direction of the screw is recommended, as depicted in Figure 13.

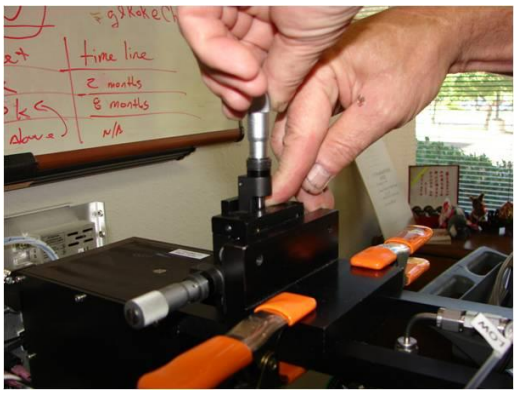


Figure 13: Application of extra force to assist stage springs

3.25. When the optimum laser power has been obtained, tighten the mode aperture block holding screws by small amounts at a time, alternating between the screws on opposite sides, until the mode aperture block is firmly secured in place. Do this while monitoring the YAG power to ensure that the power is not reduced in the tightening process. The optimum laser power should be at least 90% of that measured in Step 3.19. The adjustment fixture can now be removed, if it was used.

3.26. After adjusting the position of the coupler, or other optical components, the beam position is likely to have been moved slightly. The sample jet must be aligned to the new beam position to ensure that detection peaks from scattering particles have a Gaussian shape. Loosen the two 10-32 slide screws (Figure 3) that hold the chamber slide plate to the base of the YAG laser frame, by approximately one half turn. Record the position of the micrometer head that moves the chamber slide plate, and

back the micrometer out by 0.012 inches (twelve tick marks on the micrometer). Make sure the chamber has moved also by pushing it towards the micrometer. Tighten the two screws that lock the chamber in position.

3.27. Prepare an aerosol generator or other source of particles that can provide approximately 0.24-0.27 micron PSL particles at a nominal concentration of 300/cc.

3.28. Remove the filter from the SP2 sample inlet, and connect the particle stream to the inlet. After the concentration has stabilized, record data for 20,000 particles. Record the position of the chamber as given by the micrometer along with the data file numbers.

3.29. Loosen the two screws holding the chamber slide plate, and advance the micrometer inwards by 0.002 inches (two tick marks on the micrometer). Retighten the screws. Start a new data file, and repeat the recording process for another 20,000 particles at the new chamber position.

3.30. Continue this process, moving the chamber in 0.002 inch increments, and recording new 20,000 particle files, until the chamber is 0.012 inches (twelve tick marks) past the original position recorded in Step 3.26.

3.31. Following the completion of the chamber slide scan, remove the particle stream and put the filter back on the sample inlet. Using PAPI, or some other data analysis software, process the chamber slide data. Generate a histogram of each of the files collected at the different chamber positions. Figure 14 shows an example of the histogram response as the jet crosses the laser beam. When the position of the jet is optimized in relation to the laser beam, the distribution from that position will be the most symmetric, and have the highest center-peak height (as read on the horizontal axis in this example). See position 212 in Figure 14. As the jet moves to either side of this position, the histogram will be spread out asymmetrically on the left side, indicating a larger number of particles not passing through the center of the beam, and reflecting less of the laser's light. When the optimum position of the chamber is determined, move the chamber to that position as measured by the micrometer. It is recommended that the chamber be moved out beyond the optimum position and then moved inward with the micrometer to the optimum position. Tighten the chamber locking screws, and, if system performance has been restored, reinstall the side and top panels on the SP2 chassis.

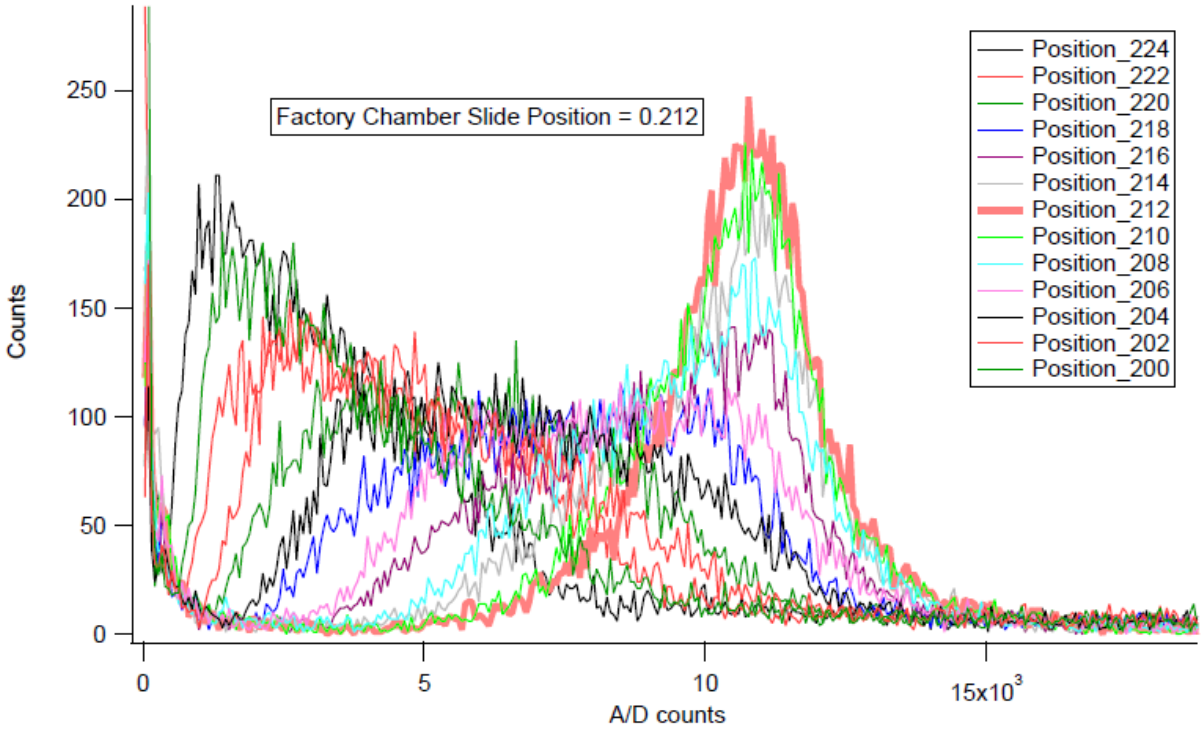


Figure 14: Histogram Response as Chamber Plate is Translated

4.0 Major Alignment Process (Includes removal, cleaning, and installation of core optical components, and Full Alignment procedure)

If the minor alignment process does not restore the necessary laser power, the next step is to clean (or replace) and realign the "core optical components." These include the following items:

- Output coupler
- YAG Crystal
- Mode Match optics
- Pump Laser Fiber-Optic face

Because a large section of the coupler's surface is exposed to the interior of the cavity (not partially occluded by the mode aperture, like the YAG crystal face), the output coupler is the most susceptible to a contamination event. However, since it is necessary to take apart the

spectrometer head to remove, or clean, any of the core optical components, it is recommended that ALL of these components be inspected, and cleaned while the spectrometer is disassembled, to save time. If proper optical cleaning techniques are used, the optical surfaces should not be adversely affected by the cleaning process. For video instruction on the correct cleaning techniques, please visit the DMT FTP site (dmtftp.dropletmeasurement.com) to download the SP2 optical cleaning training videos. Users will need a username and password to access this site; contact DMT to obtain this information.

4.1 Time Requirements

Unfortunately, there is no way to evaluate the quality of the optics without checking their performance, all together, in an operational SP2 laser system. Following any removal and re-installation of the core optical components, a full alignment is usually required.

The following Steps in the "Major Alignment Process" are listed in the order that they should be undertaken for the most efficient use of time, and for the highest probability that normal function of the SP2 will be restored by following this section only once. With practice, this process can be completed in about three hours, but will typically take much longer for newer users.

You may choose not to undertake all of the major alignment process at once. However if you are going through the process in an effort to troubleshoot low laser power, for example, and you clean or replace the coupler only, and this does not fix the problem, you will need to repeat the bulk of the process to check the other optics.

4.2 Dangers of ESD Shock

Warning: There are components inside the SP2 that are sensitive to Electro-Static Discharge (ESD) and can be rendered non-functional if subjected to ESD shock. It is a good practice to wear a ground strap, and/or other means of ESD protection, while working inside the SP2. The detector boards are especially sensitive, and care must be taken when handling and removing the detector chamber, particularly when the detectors are unplugged. Please contact DMT if you need recommendations for safe handling procedures.

4.3 Tools

4.3.1 Required Tools

- Beam scan camera
- SP2 Laser Alignment Fixture, alignment pin holes
- 2 5/64 ball end Allen drivers, screwdriver handle preferred
- 3/32 ball end Allen driver, screwdriver handle preferred
- 9/64 ball end Allen driver, screwdriver handle preferred
- 5/32 ball end Allen driver, screwdriver handle preferred
- 3/16 ball end Allen driver, screwdriver handle preferred
- 1/16 ball end Allen driver, screwdriver handle preferred
- 1.5 mm L style Allen wrench
- #1 Phillips head screwdriver (modified)
- 9/16 open-end wrench
- 7/16 open-end wrench
- Multi-bit tool set, such as a Chapman set, having changeable screwdriver and Allen bits
- Optical cleaning supplies, Absorbond TX404 cleaning wipers and 100 % HPLC grade ethanol.
- Finger cots or powder-free gloves (gloves are recommended)

4.3.2 Additional Recommended Tool

- SP2 mode aperture adjustment tool

4.4 Step-by-Step Instructions

Note: All references to "front", "back", "right", and "left" are with respect to the instrument as viewed from the front.

4.1. The laser frame (spectrometer head) must be removed from the chassis to proceed. Turn off the laser and sample pump, and shut down the SP2.

4.2. Remove the top and right-hand side panels from the SP2 chassis, if they are in place.

4.3. Disconnect all electrical connections to the spectrometer head and detector chamber: the Bendix connector (for crystal temperature control) at rear, laser power monitor from front, detector signal and power connections, and chamber temperature sensor.

It will be necessary to cut some wire ties to remove some of the cables from the spectrometer head.

4.4. Disconnect the exhaust flow connection at the base of the detector chamber on the left side. If you have an older SP2, disconnect the line to the pressure transducer from the left side of the chamber. Remove the Sheath flow connection from the side of the sample jet assembly. Remove the laminar flow element (LFE) from the inlet by removing the nut at the bulkhead fitting on the front panel and the nut where the LFE mounts to the jet assembly. Lift the tube carefully off the jet assembly, and slide it back to come out of the front panel bulkhead.

4.5. Remove the 8 socket head cap screws that hold the side cover at the right rear of the laser frame (covering the YAG chamber).

4.6. CAREFULLY loosen the Swagelok UltraTorr nut on the rear of the laser frame where the pump optical fiber passes through (Figure 15). Screw the nut all the way off, and let the nut and the O-ring compression fitting gently rest on the fiber.

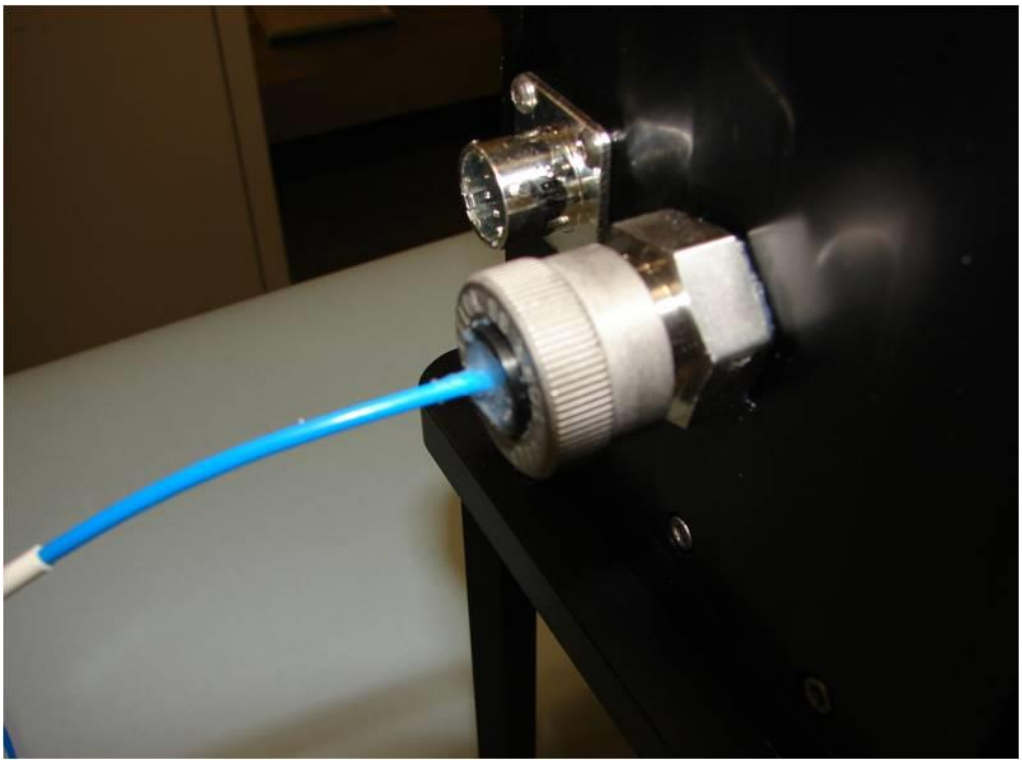


Figure 15: Ultra-Torr Fiber Passthrough Fitting

4.7. Disconnect the SMA fiber connection from the pump optics inside the laser crystal chamber. Look inside the crystal chamber with a light to see the SMA fiber connector screwed onto the fitting. Using both index fingers, reach in and unscrew the nut, as shown in Figure 16. Avoid twisting the optical fiber or bending any section of it into a radius of less than 6 cm. After about 6 turns, the nut will be loose and the puck around the fiber can be pulled back and out of the UltraTorr fitting; Figure 17 shows the items integral to the fiber passthrough. Once the fiber is loose, place a cap on the

fiber end if one is available, or set it aside carefully to avoid scratching or contaminating the polished Fiber-Optic face.

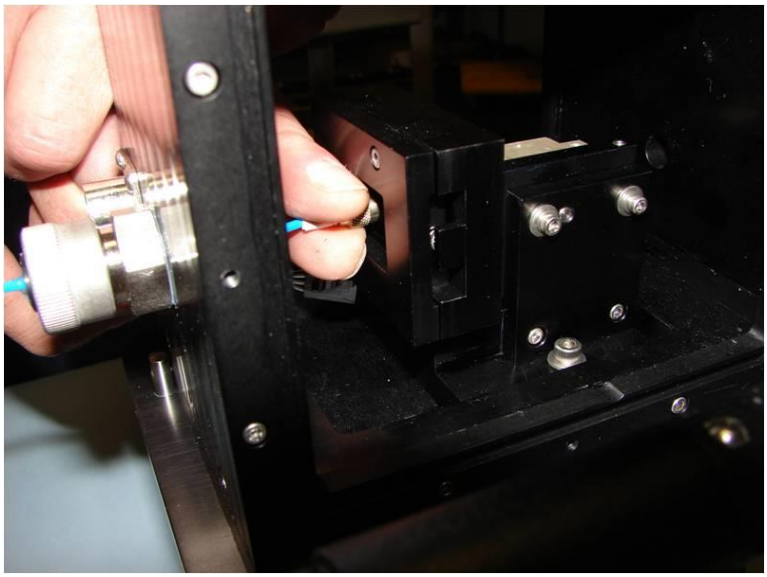


Figure 16: Unscrewing SMA Connector

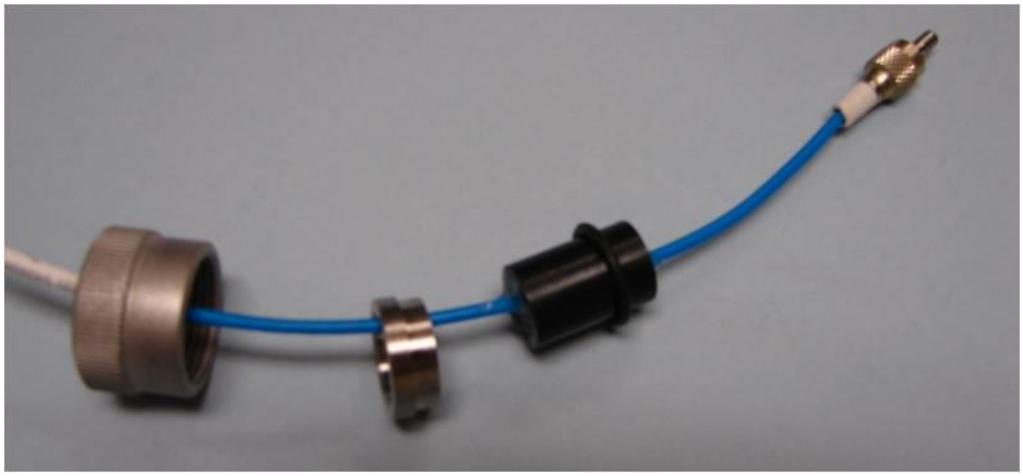


Figure 17: Components of Fiber Passthrough

4.8. Check the laser frame to insure all connections have been removed.

4.9. The laser frame is secured to the chassis by four screws that fit through the U-shaped support into the bottom of the laser frame. On some SP2 instruments the fasteners are hex head bolts, and it will be necessary to reach through the U supports and unscrew the bolts. Newer instruments have a hole through the base of the instrument to access the hex drive socket head screw. Remove all four fasteners. The laser frame can now be removed from the instrument.

4.10. Assemble the SP2 laser alignment fixture (Figure 18). Seat the laser frame against the three locator pins of the alignment fixture. Secure the frame to the fixture with a ¼-20 cap screw at the two locations indicated in Figure 19.

Figure 18: Assembled SP2 Alignment Fixture

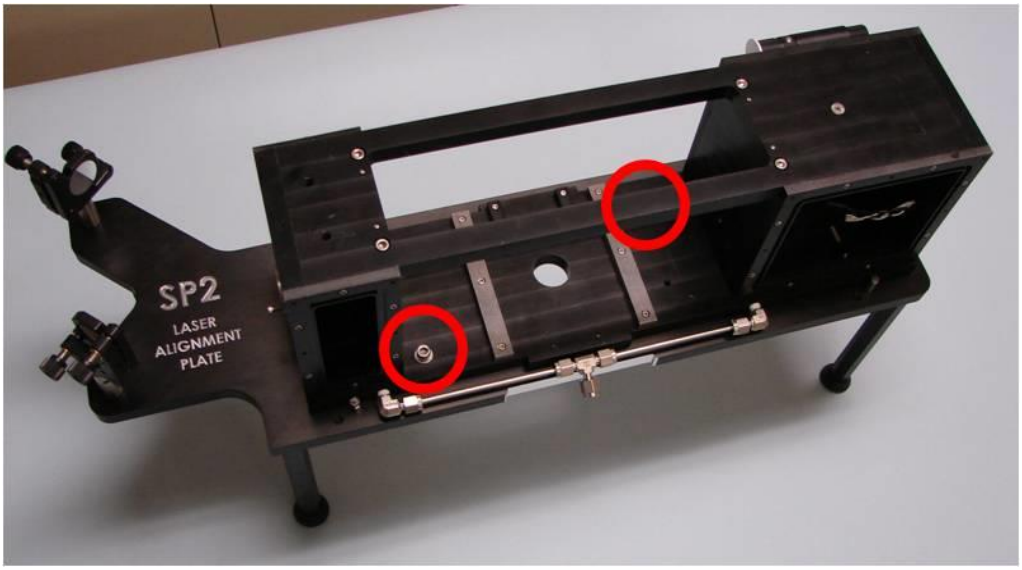


Figure 19: Frame-to-fixture fasteners

4.11. The chamber must be removed from the laser frame for the alignment process. On older instruments, you must loosen the four 4-40 Allen drive socket head cap screws from the inlet jet, and remove the inlet jet from the chamber to get the chamber out of the frame. The tip of the jet is very delicate and the jet needs to be set in a location where this tip will not be damaged. On newer instruments, it is not necessary to remove the jet.

4.12. To remove the chamber from the center of the laser frame, remove the following:

- Four locking screws from the mode aperture block (four screws with large washers)
- Four screws from the bellows at the coupler end of the frame
- Two screws that hold the micrometer adjuster down
- Four screws, two with springs and two without, that hold the entire chamber assembly to the laser frame

The chamber can now slide out easily; use care that the mode aperture block and the bellows flange do not catch on the laser frame and damage the bellows. Also, take care not to lose the O-rings on either end.

4.13. Remove the two screws that secure the pump block filter that is located between the cavity and laser power monitor. There are two tapped holes in the pump block filter unit, and a 4-40 screw can be inserted to use as a handle to pull the pump block filter out.

4.14. Remove the 6 screws that hold the right side cover on the coupler chamber. Do not attempt to remove the left side coupler chamber cover, as it is sealed in place with silicone RTV.

4.15. The coupler mount is secured with two flat-head Phillips drive screws through the bottom of the laser frame. Because the depth of the cross-recess of flat-head screws is less than that of different head styles, the tip of a conventional #1 Phillips-head screwdriver must be ground down to improve its engagement into the flat-head screws, often between 0.06” and 0.10”. Using the modified #1 Phillips screwdriver, access these screws from the bottom, as shown in Figure 20. Use care when removing the coupler mount from the laser frame so that fingers do not touch the front or back of the coupler. Place the coupler and mount in a clean plastic bag so that debris cannot get on the mirror face.

Figure 20: Removing Output Coupler Mounting Screws

4.16. ***Note about SP2 Optical Cleaning:*** In all cases, where there is contamination believed to be present, the optical surface should be blown off using clean compressed air, before surface cleaning is attempted. This is to remove larger pieces of debris which could scratch the surface when cleaned.

4.17. Using finger cots or powder-free gloves, hold the coupler mount, and remove the coupler mirror from the adjustable mount. This will have two # 2 screws in the back. Set the coupler aside with the High Reflective surface facing up. The HR side has a gold ring around the circumference of the optic, and it is the side which was facing the adjustable mount.

4.18. The Texwipe TX404 Absorbond wiper is recommended for cleaning the all of the core optical components. Remove 3-4 sheets of cleaning wipers from the bag using tweezers, or a gloved hand, to avoid contaminating those sheets or the others in the bag. Make sure that all fingers in contact with the coupler mount or the wiper are covered with gloves or finger cots. Fold the stack of wipers in half twice, making sure

there are about 10 or more layers. Hold the folded sheet so that the folded edge is facing outward. Saturate the pad with optical grade solvent (ethanol is preferred), and shake the pad of excess solvent. Ensure that the optical surface is free of any dust or particulate that could damage the surface if dragged across, then make a single wiping motion across the face of the optic (Figure 27), "rolling" the wiper as it moves across the face so that fresh surface is continually exposed. Only one swipe across the face should be done at a time, and the used wipers should be disposed of. After one wipe across the coupler face, hold the coupler so that you can see light reflected on its surface, and watch as the ethanol evaporates. If the optical surface is very clean, the solvent should evaporate quickly and evenly, leaving no streaks. If you see portions of the surface where the solvent evaporates much more slowly, there is probably contamination still present, which the solvent is clinging to. If this is the case, another pass, with a new folded set of wipers, should be done.

Figure 21: Wiping the output coupler

4.19. Fasten the cleaned output coupler onto the mount, and set the mount aside in a clean bag to protect it.

4.20. Remove the far side cover from the crystal chamber of the laser frame.

4.21. The next step is to remove the YAG crystal and pump optics from the laser frame. On older SP2s, you must loosen the #10 nut that connects the top of the heat sink braid to the top of the laser frame. This requires a 3/8 inch open-end wrench. On newer SP2s, just loosen and remove the Philips head screw on top of the YAG chamber.

4.22. Remove the two # 8 Allen head screws that hold the YAG crystal assembly into the frame. Unscrew the fine-pitch threaded setscrew that pivots the YAG crystal assembly until you can no longer feel its tip inside the frame, but do not remove it completely.

Disconnect the power and temperature lines that go to the TEC element and the thermistor readout. The YAG crystal assembly can now be lifted off the pivot point. There is a spring that provides restoring force for the pivot of the YAG assembly; when the assembly is lifted, make sure this spring is captured. Figure 22 shows a complete YAG crystal and optical pump assembly removed from the SP2.

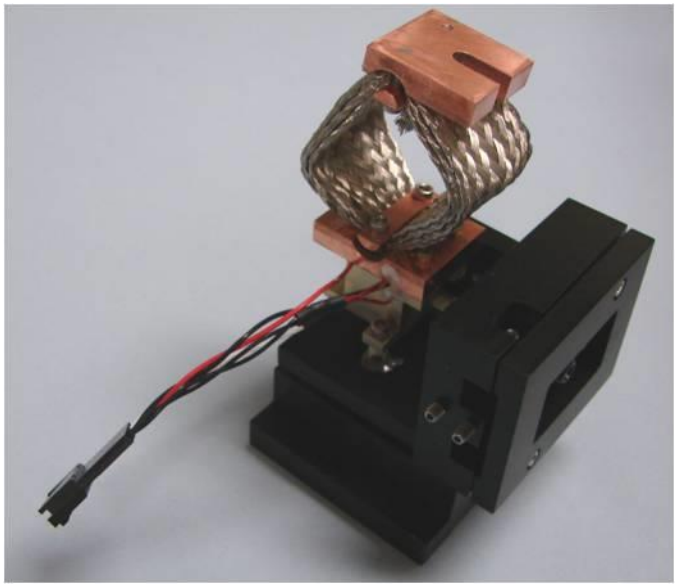


Figure 22: YAG Crystal and Optical Pump Assembly

4.23. Remove the three 4-40 screws that attach the YAG crystal holder to the YAG base, as shown in Figure 23. The white ceramic spacers are attached to the base on older SP2s, but are loose on newer SP2s, so keep track of them.

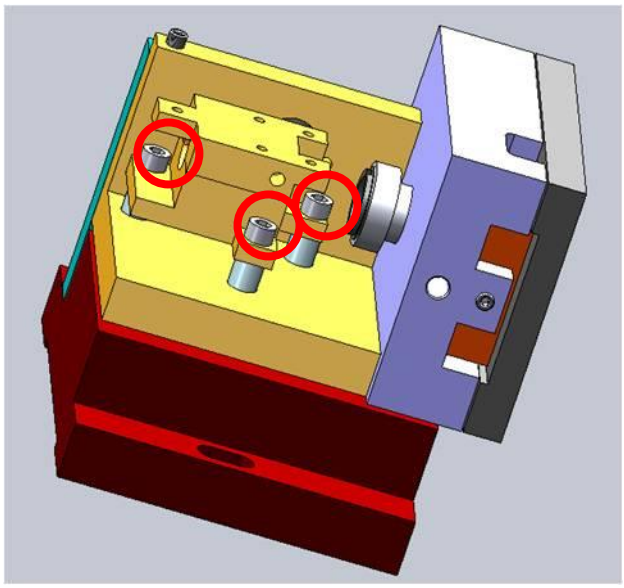


Figure 23: Fasteners securing YAG crystal holder to pump base

4.24. To access the YAG crystal on older SP2s, the thermal management assembly (TMA) must be removed and then the YAG crystal holder taken off and split to remove the crystal for cleaning, because the screws holding the two parts of the crystal holder together are between the crystal holder and the TMA. On newer SP2s it is not necessary to remove the TMA, because the crystal holder screws are on the bottom, and you should skip to step 4.26, if this applies to your SP2.

4.25. Remove the TEC and the TMA by taking out the three 2-56 screws securing the TMA to the crystal holder (Figure 24). When these screws are removed, take note of the tension on the screws, as it is important not to tighten them too tightly when reassembling the unit. Also pay attention to the orientation of the Thermo-Electric-Cooler (TEC) before removing, because if the TEC is put back in upside down, a thermal runaway condition will result when the SP2 software attempts to regulate the crystal temperature. The unit must be handled carefully as the parts will be attached at the connector.

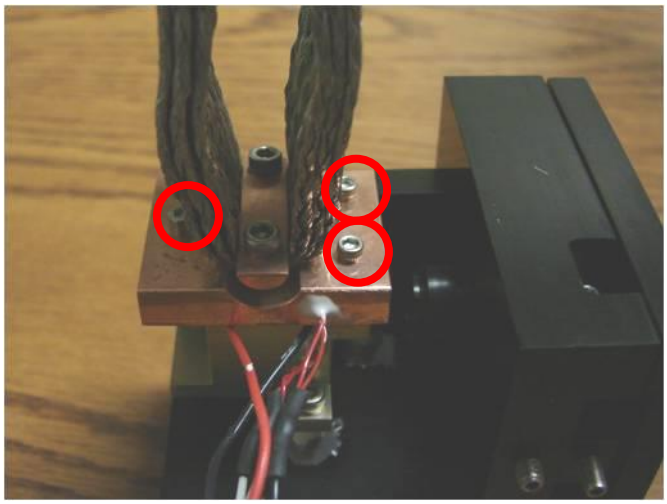


Figure 24: Three fasteners secure TMA to YAG crystal holder

4.26. While wearing gloves, grasp the YAG crystal holder and remove the two screws that hold the halves together (Figure 25).

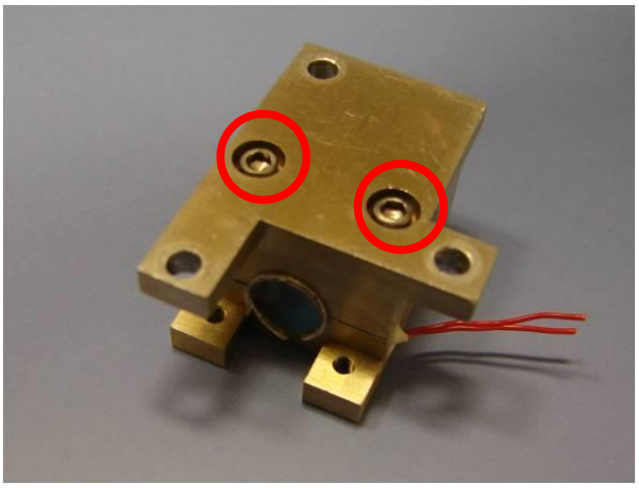


Figure 25: Screws securing halves of YAG Crystal Holder together

Separate the two halves, using a knife if necessary to pry them apart. The YAG crystal will often stick in one of the halves of the holder, and it will need to be removed by pressing on the EDGE of the face of the crystal with a gloved finger. Use minimum pressure to dislodge the crystal. As shown in Figure 26, the YAG crystal is cushioned in the holder with indium foil.

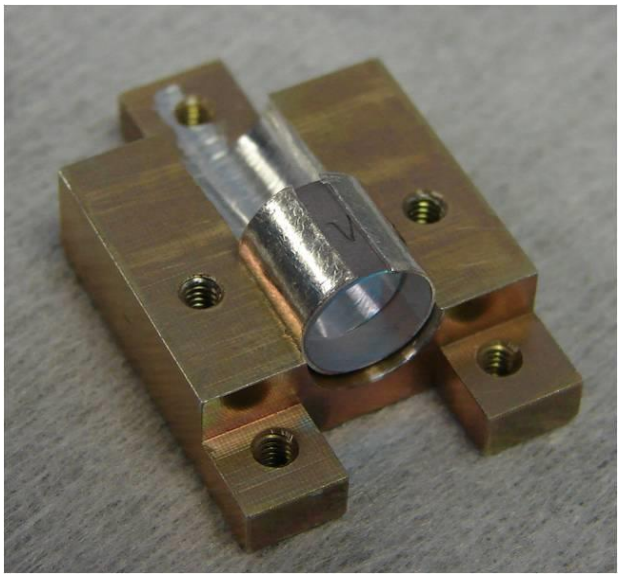


Figure 26: YAG Crystal cushioned in holder

4.27. Carefully peel back and remove the Indium foil from the crystal without damaging the foil, if possible. If the foil becomes damaged in removing the crystal, replacement foil can be purchased from DMT or replaced using a 0.25 mm thick, 7 mm wide and 21 mm long strip of Indium foil.

4.28. Prepare another stack of three TX404 Absorbond wipers. Fold them in half twice, and set them on a flat surface. Pour some ethanol on to the folded wipes, until the surface is well soaked with the solvent.

4.29. Hold the crystal in a vertical orientation between thumb and finger. Lightly, but somewhat firmly, slide one of the faces of the crystal across the soaked wipe in a straight line. Hold the crystal up and watch as the solvent evaporates from the crystal face. As with the coupler cleaning, watch for places where the solvent evaporates much more slowly. A quick, even evaporation usually indicates a clean surface. Flip the crystal over and repeat on the other side, using a different area of the folded wipes.

4.30. Reinstall the crystal. It is imperative that it is oriented such that its high reflectivity (HR at 1064nm) surface faces the mode match optics. The HR side can be identified by a shiny gold colored band encircling the face, and, in some cases, a mark (>) upon the side of the crystal cylinder “points” toward the HR face, as shown in Figure 26. It is important that during reinstallation the crystal be well wrapped with the indium foil.

4.31. With the wrapped crystal placed back into one half of the crystal holder in the correct orientation, carefully put the other half of the holder in place and line up the edges. Reinstall the two screws to hold the two halves together and tighten them to compress the foil and secure the crystal. Set this assembly aside.

4.32. To inspect the Mode Match Optics, loosen the setscrew holding the Mode Match Optics barrel in place and slide the barrel out of the vertical bracket of the YAG base.

4.33. Hold the barrel up in front of a white surface and look through it in both directions. If you see debris or other contamination there, these optical surfaces will need to be cleaned also. NOTE: The coatings on the mode match optics are delicate, and should only be cleaned if necessary. First try to remove the debris using clean compressed air. If the optic still looks dirty, it can be lightly cleaned with the corner of a folded Absorbond wiper which has been soaked with ethanol. Do not "scrub" the optic with the wipe. Make only one wiping motion, in only one direction, and repeat with a new wipe if necessary.

4.34. Once the Mode Match optics are clean, reinsert the barrel into the YAG base, until the barrel is about 1/8 inches (or about 3mm) from being all the way inserted, and tighten the locking setscrew.

4.35. If you removed the thermal management assembly from the crystal holder, put it back together as it was before. Put the crystal and TMA back on the ceramic standoffs. Reinstall the three 4-40 screws. Before they are tightened all the way, press on the side of the crystal holder so that you are pushing it toward the side wall of the YAG base, perpendicular to the optical axis of the crystal, and tighten the three 4-40 screws. This helps to get the YAG crystal in a position such that its HR side is parallel to the outer surface of the large mode match optic. NOTE: This is an important step. If these surfaces are not very close to parallel, you may have trouble getting the proper TEM_{oo} alignment later on.

4.36. The last of the core optical components is the Pump laser's Fiber-Optic face. It is important that this surface be clean and scratch-free to transfer optimum power to the mode match optics. If a fiber scope is available to inspect the fiber face, use it at this time. If not, you may proceed directly to cleaning the fiber face if you feel it may be contaminated. If you have accidentally touched the fiber face with your fingers, or are not sure if it has contacted anything, it should be cleaned.

4.37. The process for cleaning the fiber face is similar to that used to clean the crystal, except the fiber should be twisted slightly while running it across the wipes. Lay some folded, ethanol soaked wipes on a flat surface, and slide the fiber face across the wipes, while giving the fiber connector a slight twisting motion (about 90 degrees) to clean the surface. This may be repeated several times on new areas of the wipe. Set the fiber aside carefully to keep anything from touching its face. A fiber cap may be used if available.

4.38. Now, all of the core optical components should be clean, and ready for reinstallation and initial alignment on the SP2 alignment fixture.

4.39. Ensure the pump block filter has been removed (this should have happened in step 4.13.) Insert the MP-0722 pinhole into the pump block location. Fasten the MP-2347 pinhole into the crystal chamber side of the laser frame.

4.40. Turn on the alignment laser and adjust the mirrors of the alignment fixture so that the alignment laser beam has equal illumination around the circumference of both of the alignment pinholes. See Figure 27.

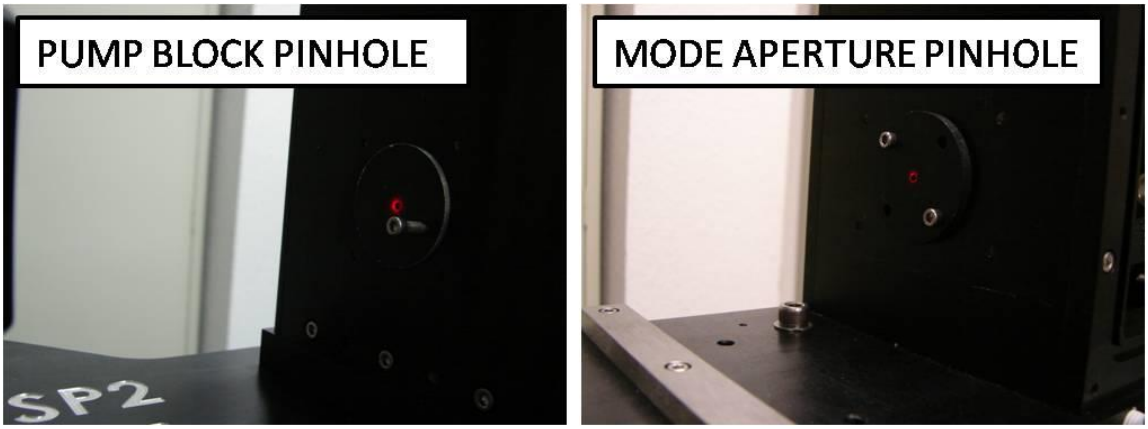


Figure 27: Alignment Beam Centered on Pinholes

4.41. Turn off the alignment laser and remove the pinholes from the laser frame.

4.42. Begin with reinstalling the YAG assembly into the crystal chamber. It is easiest to get it in by holding the assembly horizontally, with the TMA to the rear of the frame. Once it is inside, make sure to hold the horizontal adjustment spring in place, and rotate the assembly vertically. Push the assembly to the side to compress the spring, and press the assembly down on to the locating pin in the base of the crystal chamber.

4.43. Reinstall the two #8 horizontal locking screws into the base of the YAG assembly. Tighten them all the way down to fully seat the assembly onto the locating pin, then loosen them by about ¼ of a turn.

4.44. Put a small section of paper (Figure 28) between the YAG crystal holder and the mode match optics to avoid reflections from the mode match optics confusing the alignment procedure. Figure 29 details the YAG crystal assembly for the SP2 and the adjustment and locking screws. The adjustments provide for rotation and tip of the YAG crystal to align it on the optical axis. The rotation of the assembly is done via the 100 TPI screw on the laser frame. The tip is driven by an 80 TPI screw on the top of the assembly itself.

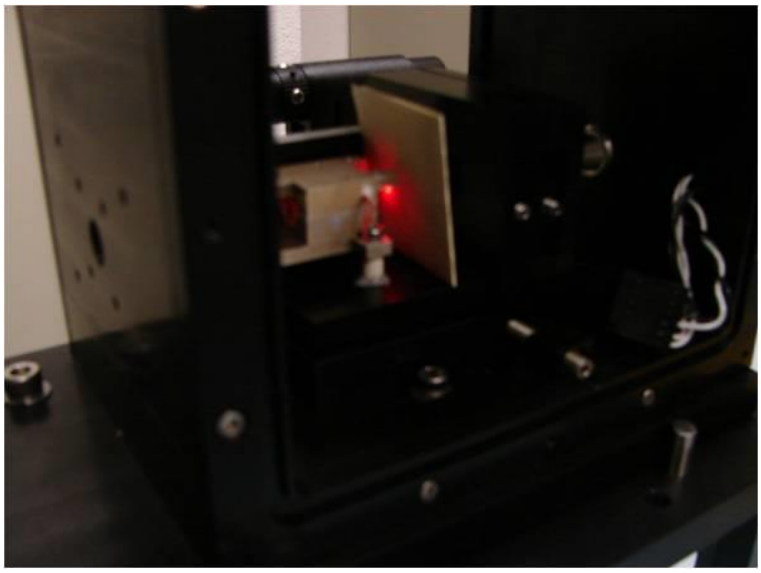


Figure 28: Paper between Crystal and Mode Match Optics

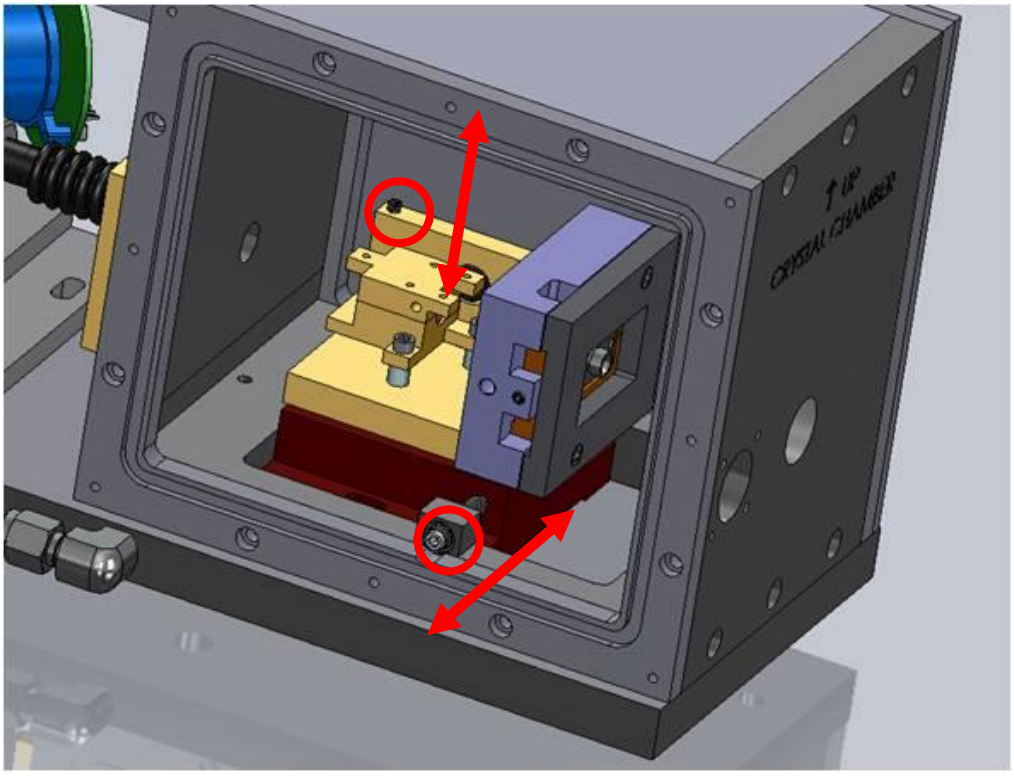


Figure 29: Adjusters that aim the YAG Crystal Assembly (thermal management assembly removed for clarity)

4.45. Turn on the red alignment laser, and begin tightening the fine-pitch threaded setscrew until it contacts and rotates the YAG base. When the light reflected from the crystal is returned to the front face of the alignment laser, make small adjustments until the

spot is lined up horizontally with the beam's source. If you cannot see the beam reflection, look for it inside the crystal chamber or on the rear of the coupler chamber. Figure 30 shows the alignment laser face, with two differing positions of the crystal alignment.

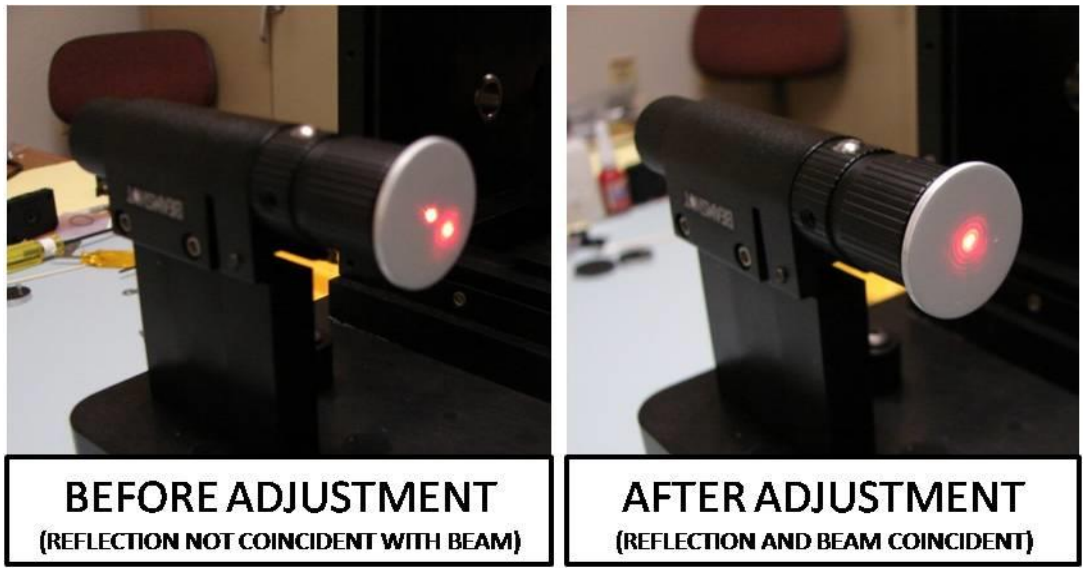


Figure 30: Beam and Reflection Coincidence

4.46. Reconnect the heat sink to the inside top of the crystal chamber. Reconnect the temperature control connector on the YAG assembly to the Bendix connector on the rear of the laser frame.

4.47. Now loosen by ¼ of a turn the two 4-40 screws which lock the vertical adjustment of the crystal assembly. . Adjust the vertical axis of the assembly by tightening or loosening the fine-pitch threaded screw on top of the YAG assembly side wall. Continue until the reflected spot is centered on the face of the alignment laser.

4.48. Tighten the horizontal and vertical locking screws and see if the beam reflection has shifted. If it has, loosen one axis at a time and readjust until the spot is centered, and both axes of adjustment are locked. It may take two or three tries to achieve a locked and centered crystal alignment.

4.49. Remove the piece of paper blocking the mode match optics. Place it somewhere between the crystal chamber and the coupler chamber to keep the reflection from the crystal and mode match optics from interfering with the coupler alignment.

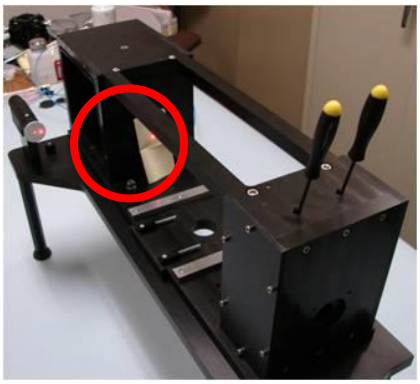


Figure 31: Paper Placed to Block Reflection from Crystal Face

4.50. Install the mounted coupler assembly by holding the assembly in place while reinstalling the two coupler mounting screws through the bottom of the alignment bench. This takes a little practice. It is easiest to push one of the screws up through the bottom with the screw driver, and hold the top of the coupler mount with one hand, while turning the driver with the other. Then put in the second screw, and tighten both screws.

4.51. Remove the coupler chamber sealing screws from the top. Insert the two 5/64 Allen drivers into the coupler adjustment screws, and adjust both axes of the coupler mount until the reflected spot is aligned with the center of the face of the alignment laser. NOTE: It is likely that you will see two reflections from the coupler. One of these spots will be small and sharp, and the other will be larger and a bit blurry. It is the larger spot that you need to align, as this is the reflection from the inner face of the coupler. Remove the two Allen drivers.

4.52. Remove the piece of paper blocking the crystal, and do not be alarmed if it looks like your crystal is no longer aligned. The crystal's reflected light is now passing through the coupler, and may appear to be off center.

4.53. Reinstall the pump block filter removed in step 4.12. Reinstall all of the laser frame side covers except the right side YAG chamber cover. Ensure that the O-rings that go beneath the covers are cleaned, and lightly greased with high vacuum grease.

4.54. The laser frame can now be removed from the alignment bench and returned to the SP2 chassis. Put all four of the screws into the bottom to secure the laser frame into the SP2 chassis, and tighten them. The fiber from the pump laser needs to be connected to the YAG crystal assembly; attachment is the reverse of the removal in steps 4.6 and 4.7. The fitting that the fiber mates to is somewhat difficult to see, and it is recommended that a flashlight be used to help view the insertion. Take care not to scratch or otherwise touch the face of the fiber SMA connector.

4.55. Connect the Bendix connector for the crystal temperature regulation (located next to the fiber entry on the back of the laser frame).

4.56. ***LASER SAFETY WARNING***: The next few steps involve turning on the Class IV SP2 laser with the side cover open and the detector chamber removed. If laser safety

precautions are not observed, damage to the eyes' retinas may result. This can lead to permanent blindness. It is recommended that anyone around the SP2 wear laser safety glasses with an Optical Density rating of OD 3 or higher for both 808nm and 1064nm wavelengths. It is also recommended that this work be performed in a room which can be locked, to prevent entry of personnel who are not equipped with laser safety glasses.

4.57. Now check and adjust the position of the fiber SMA connector in relation to the mode match optics. Place the Infra-Red indicating card, provided with the SP2 alignment kit, in front of the hole in the rear of the coupler chamber. While wearing laser safety glasses, start the SP2 software and turn on the SP2 laser at a current of about 2500mA.

4.58. By moving the card into and out of the beam, you can see where the light exiting the crystal chamber hits the coupler chamber. You may need to move the card closer to the YAG chamber to see the fluorescence on the card. If this is the case, you may need to adjust the Z position of the mode match barrel, or check to see if the light is making it out of the crystal chamber (it may be hitting the wall inside). If the light is not centered on the hole in the coupler chamber, as shown in Figure 32, the fiber X-Y position will need to be adjusted. Note: Figure 32 shows a Blue color to the laser light, but the light is actually Red/Infra-Red. This image was taken with an Infra-Red sensitive camera.

4.59. Turn off the SP2 laser. If the laser light was already centered on the hole in the coupler chamber in the previous step, then skip to Step 4.62.

4.60. To adjust the fiber X-Y position, begin by loosening the two fiber adjustment locking screws located on the rear of the YAG assembly. A Chapman wrench with a #6 bit (3/32 inch) is the easiest way to access the two locking screws. Figure 33 shows the locations of the locking screws as well as the fiber X-Y adjustment screws.

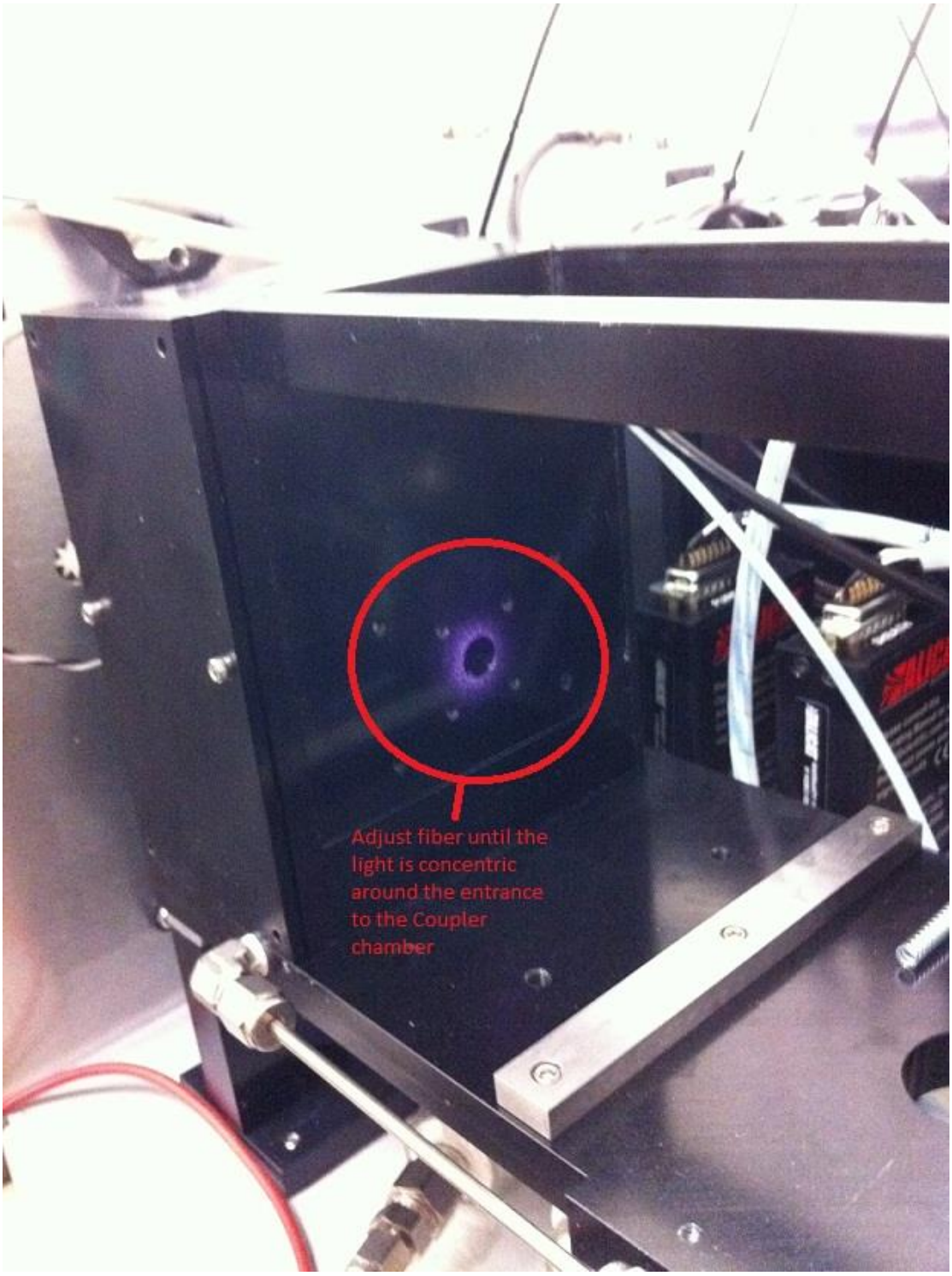


Figure 32: Light Concentric Around Entrance to Coupler Chamber

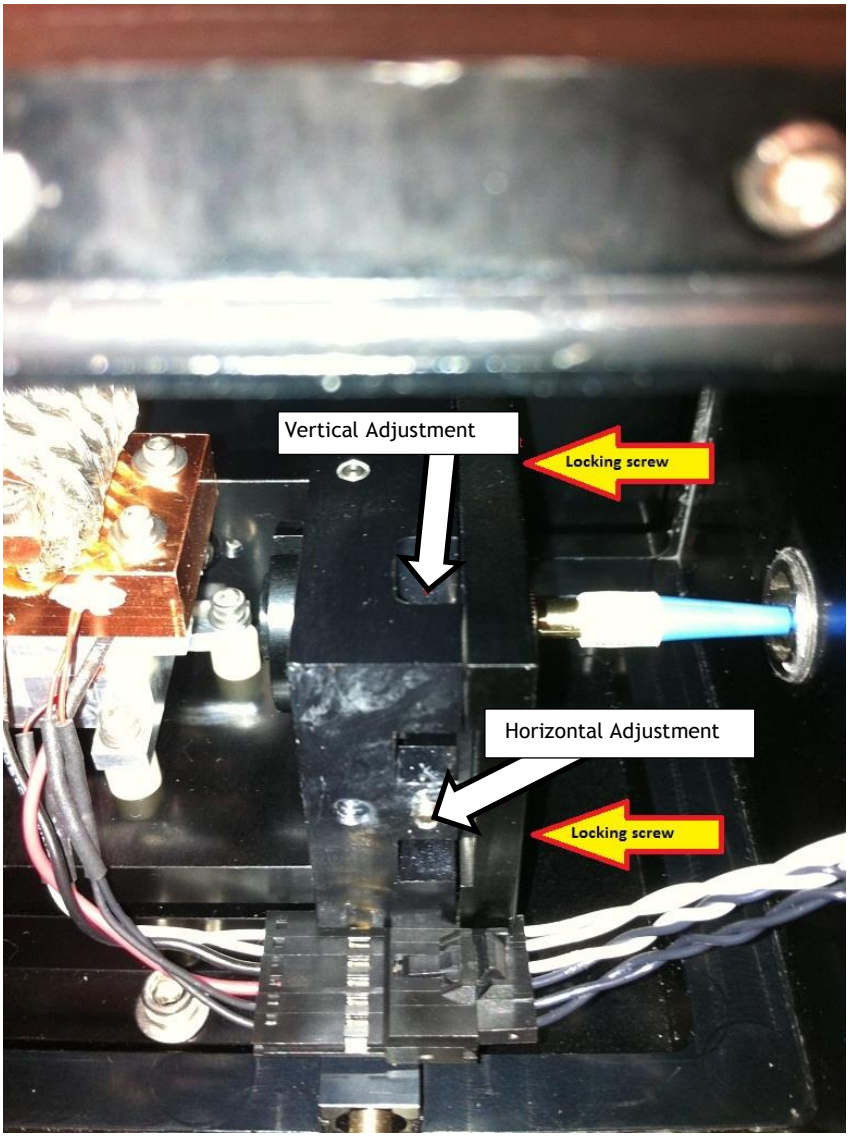


Figure 33: Locking and Adjustment Screws

4.61. With the locking screws loosened, turn on the laser again, and make adjustments to the vertical and horizontal position (X-Y) of the fiber with a 1.5mm Allen wrench. Continue until the light is centered on the entrance to the coupler chamber Figure 32. Tighten the two locking screws a little bit at a time, alternating between the two, until they are firmly secured but not overly tight. Turn off the laser.

4.62. Place the beam scan camera on the output of the laser frame, start the beam scan camera software, and place the two 5/64 Allen drivers back into the coupler adjustment screws. Turn on the laser at a current of about 2500mA.

4.63. While monitoring the beam scan image, make small adjustments to the coupler position until a stable TEM_{oo} Spot is achieved. The mode of the laser may not look like it is supposed to at this point, but just try to get a single spot shape to the beam.

4.64. The position of the mode match optics must now be checked or adjusted. Using a 1/16 inch Allen driver, loosen the setscrew holding the mode match barrel in place, move the barrel in or out in the Z direction with your fingers, retighten the setscrew, and observe the laser mode. Repeat this step, moving the barrel into different positions, to get the smallest, sharpest TEM_{oo} mode that you can. Note: the optimum position will be somewhere in the middle of the barrel's travel. If it is too far to either end, the spot will be a larger diameter, and less sharp. It may be necessary to adjust the coupler position by a small amount after moving the mode match barrel. Tighten the setscrew well, once you have the barrel in the best position. Turn off the laser and close the SP2 software. Shut down the SP2 power.

4.65. At this point all of the core optical components are cleaned and aligned, and the chamber and its electrical lines and flow lines can now be reconnected. Be sure that the sealing screws are put back into the top of the coupler chamber, and that all air and electrical lines are reconnected before starting the SP2 again. Put the laser power monitor back in place on the output of the laser frame. Check that all screws are back in place, and that the side covers are back on the laser frame.

4.66. When putting the detector chamber back in, set it at the center of its travel as shown in Figure 34, and put the Mode Aperture in place in the upside-down orientation.

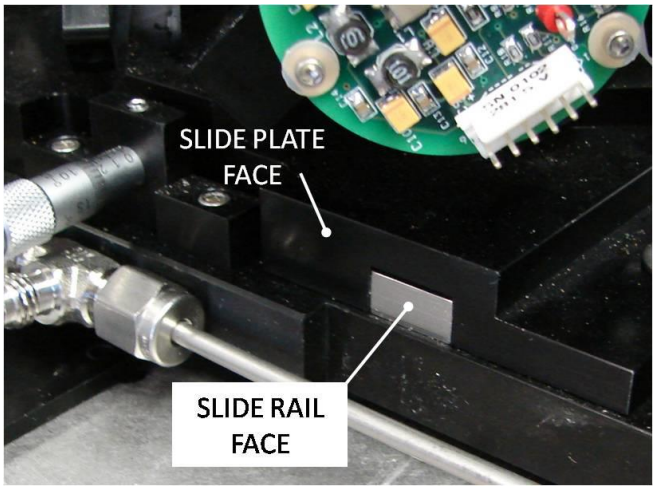


Figure 34: Centered chamber (coplanar slide plate and slide rail end faces)

4.67. Start the SP2 system and software, place a filter on the sample inlet and turn on the sample pump. Note: If the sample flow immediately goes to a reading of about -50 vccm, then something has been left open, or unsealed. If this is the case, turn off the sample pump quickly, and find what was left open. When the sample flow is stabilized at the set point, turn on the laser at about 2500 mA and wait about 5 minutes for the

laser to warm up. Make note of the YAG power reading in the software, and turn off the laser again.

4.68. Turn off the sample flow and wait 1-2 minutes for all flow to stop. Put the Mode Aperture back in its proper orientation, and proceed with Mode Aperture alignment, as described in the section 3.0 above.

4.69. After the Mode Aperture position is set and locked, proceed with the chamber slide position adjustment, as described section 3.0 above. It may be necessary to widen the range of chamber positions at which files are collected and compared, if the beam position was changed significantly.

4.70. The SP2 is now ready for calibration.

Appendix A: Tools and Replacement Items Available from DMT

DMT sells several kits to aid users in their SP2 laser-alignment efforts. These kits include the following types of items:

- Absorbond wipers
- Beam scan camera assembly
- Hex drivers
- Indium foil strip
- Laser alignment fixture
- Mode aperture alignment fixture
- Mounted output coupler assembly
- Nd:YAG crystal
- Wrenches

Contact DMT for details on specific kits.

Appendix B: SP2 YAG Pump Laser Storage & Handling Instructions

Storing the SP2 YAG Pump Laser

For SP2 YAG pump lasers purchased separately from the SP2 instrument, the laser is provided with a special protective box (Fig. 1). Keep the laser in this box until it is needed.

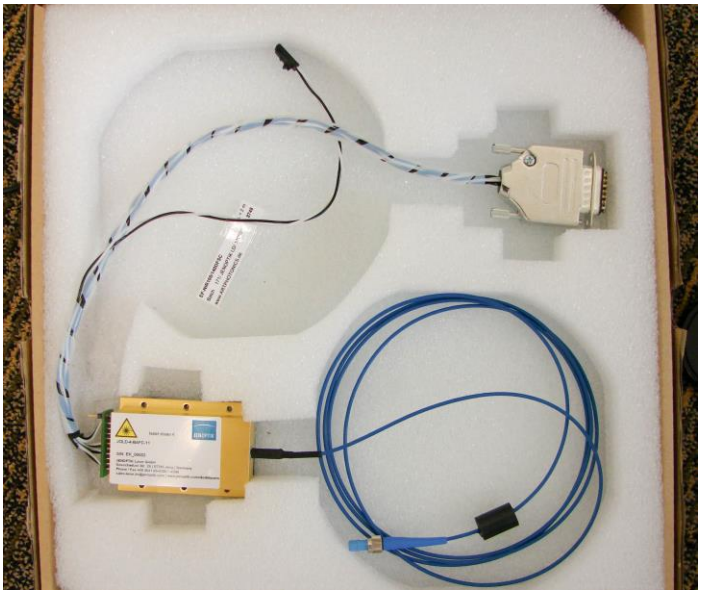


Figure 35: SP2 Pump Laser in Protective Box

Handling the SP2 YAG Laser

When handling all SP2 YAG pump lasers:

1. The power connector is provided with a plug that shorts the input and guards against damage due to static electric discharge. Keep this plug in place until the laser is to be immediately connected to the power supply. Attach this shorting connector to any laser that is removed from the power supply (Fig. 2).

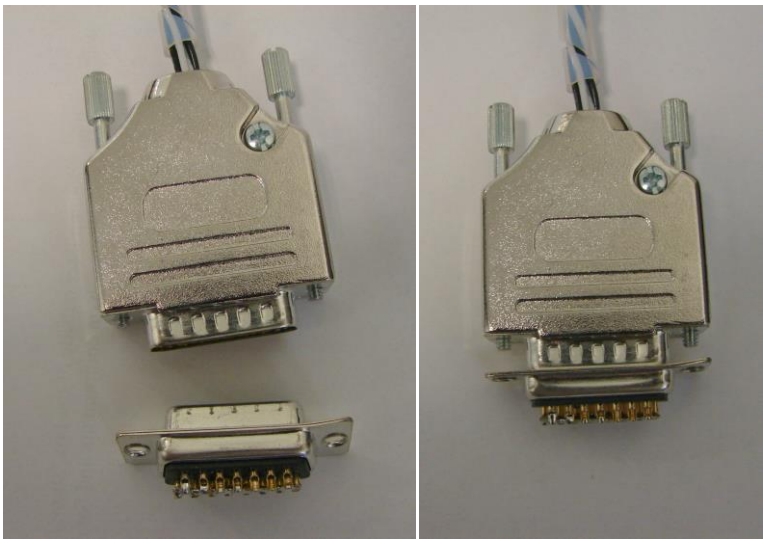


Figure 36: Shorting Plug Detached (left) and Attached (right) to Power Connector

2. Keep the protective cap on the SMA fiber connector end unless the fiber end is being cleaned or being attached to the YAG laser assembly. Immediately cap the end of any laser fiber that is removed from the YAG laser. Typically the fiber caps are a small plastic blue cap (Fig. 2), but others can be used.

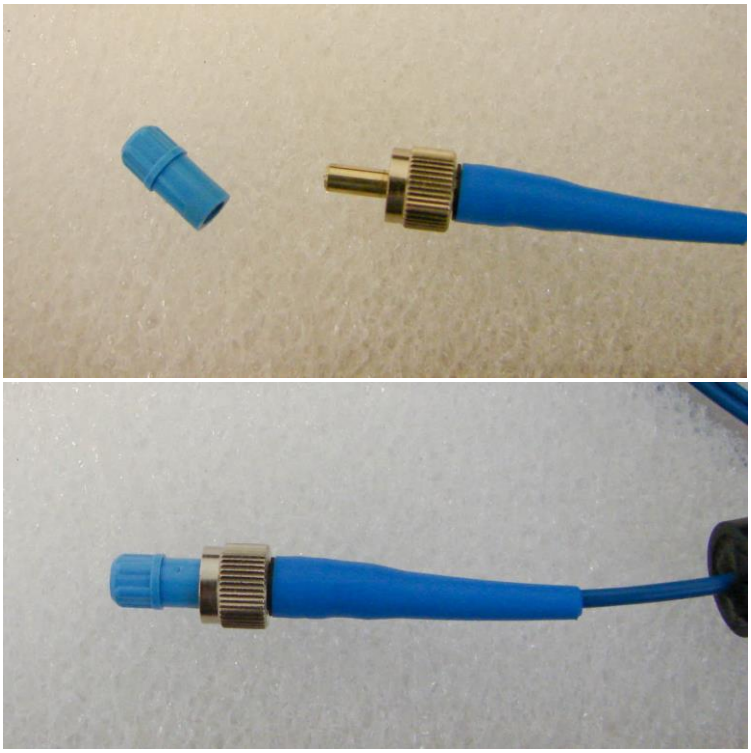
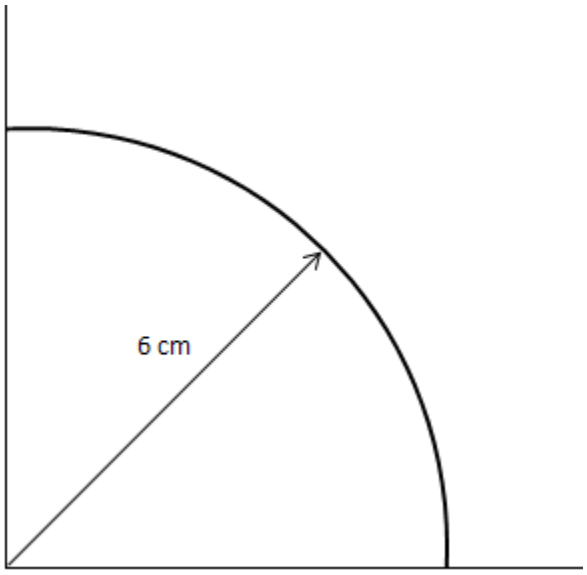


Figure 37: Protective Cap and SMA Fiber Connector (above); Cap Attached to Connector (below)

3. The minimum bend radius of the fiber is 6 cm. Bending the fiber at a smaller radius can break the glass fiber inside the sheath. If the fiber is broken, the laser will need to be returned to Droplet Measurement for repair. The following diagram is a 6 cm radius.



4. When handling the pump laser outside of the box, support the fiber and do not let it hang down, where it can catch on components and bend to the point of breaking.

Appendix C: Revisions to Manual

Rev. Date	Rev No.	Summary	Section
6-7-10	B	Added laser handling instructions	App. B
1-21-13	C	Updated and expanded manual	Throughout
4-22-13	C-1	Updated troubleshooting sequence diagram	Figure 2
7-2-14	C-2	Rearranged steps in alignment procedure so they are in chronological order	4.38-4.40