System Components

NJA-5 Mode-locked Ti:Sapphire Laser • Version 1.1

Latest Upgrade: May 6, 1996

This manual contains information on the subsystems forming the NJA-5, including:

- the NJA-5 femtosecond oscillator
- the NJA-3E driver
- the optional PointMaster™ pump beam stabilizer
- the TO-1 transport optic

Credits

The NJA-series is the result of a collaboration between Clark-MXR Inc. and the group of Professor Frank Wise of Cornell University, Ithaca, New York.

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Graphic Symbols Explained

The following graphic symbols are used throughout this manual to draw your attention to situations or procedures that require extra attention. They warn of hazards to your eyesight, damage to equipment, and necessary performance specifications.

Performance Specifications. You should follow these instructions without deviation.

Eye protection required. Looking at laser beams can cause permanent eye damage.

Graphic to draw your attention to a warning or important note.

Wear protective gloves when handling sensitive optical components. Skin oil on optical components may make them worthless.

Do NOT touch any optical components with your bare hands.

1. Eye Safety

1.1 Safety Rules

The lasers you will be working with are sources of intense optical radiations. Their safe use depends on your being aware of their unique characteristics and treating them with the respect due to instrumentation that can cause serious bodily harm.

The optical output from the Argon-ion laser and the NJA-5 can cause serious damage to the eye, including loss of vision, when viewed directly or when reflected off another object. The radiation generated and amplified by the Ti:Sapphire is in the near IR wavelength range where the sensitivity of the retina is minimal. When the Ti:Sapphire laser is operating in the near infrared, the weak appearance of the beam may **mislead** you into believing it is of low intensity and therefore of little concern. At almost every stage of the system alignment procedure, the intensity of the beams from the laser and laser pump sources can be high enough to cause burns or eye damage.

The wavelengths, pulse energies, and operating power emitted by the NJA-5 and its pump laser are listed in Table 1-A. Use this table and good sense to decide what level of eye and skin protection is needed.

Table 1-A

Laser parameters affecting the user's safety

Laser	Wavelength (nm)	Power	Pulse Energy
Argon-ion	460-520	< 20 W	Continuous wave
Ti:Sapphire Oscillator NJA-5	700-1000	< 2W	< 20 nJ

950330

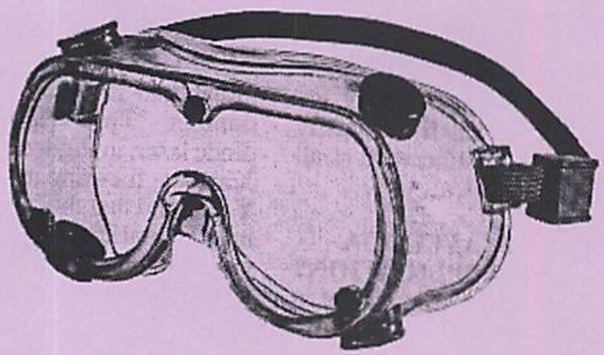
■ **Post the laser parameters (shown in the preceding chart) near the laboratory to alert everyone to the presence of laser radiation.**

Please see original manufacturer's manual for additional safety information.

Read the safety instructions of the CDRH certified ion laser you will be using to pump the Ti:Sapphire oscillator. Incorporate their recommendations into your standard practice.

Do not be mislead! Intense coherent and incoherent radiation is emitted from the Ti:Sapphire Rods when they are being pumped by other lasers. The beam from the Ti:Sapphire Oscillator can cause serious EYE DAMAGE even when it appears to be of low intensity! AVOID EXPOSURE! Wear LASER SAFETY GOGGLES.

- **When setting up or aligning the system or subsystems, KEEP ALL BEAMS BELOW EYE LEVEL. *Never* look in the plane of propagation of the beam.**



Remember that safety goggles *can be a hazard as well as a benefit*. To protect the eyes from the laser beam, the goggles must attenuate to the point where the beam is no longer visible. Therefore, the user can be exposed to **flesh burns** or **clothing fire** without seeing it happen. *Be aware of this potential*. Follow the specific recommendations called for in this manual at various stages during the alignment procedure.

- **Assemble and operate this system in an enclosed room. Periodically inspect the area for stray beams and reflections. Block those that propagate outside of the working area during assembly and alignment. Avoid uncontrolled reflections.**

- **When servicing the system do not wear jewelry (*for example*, rings, chains, etc.) that might pass through the laser beam line. Uncontrolled reflections may result!**

The laser beams can remain collimated over large distances and remain a hazard far from the original source. Clearly mark the door to the room with warning signs and interlocks connected to the two pump lasers to prevent accidental exposure to the beams.

- **Post warning signs that alert others to the presence of laser radiation.**

Do **NOT** operate the system while untrained personnel are present. Warn anyone in the area where beams are located of the dangers associated with laser beams. **Verbal warnings** help to ensure that others in the area are *not* injured by stray radiation.

- **Limit access to the equipment to trained personnel who have a need to use it.**

The Eye Protection Required symbol warns you that **serious bodily harm** may result from exposure to radiation either present in the area, or radiation that may be created when doing the step detailed along side it (*see also* Graphic Symbols Explained at the beginning of this manual).

- **Observe and understand the symbol that follows.**

- **Remember, safety is your responsibility! Follow these safety procedures when working with this product.**

1.2 Safety Interlocks

Following CDRH regulations the NJA-5 cover is interlocked. The input shutter will automatically close when the NJA-5 cover is lifted

It may be necessary at time to defeat this interlock. Do this only in accordance with the safety measures presented above

The interlock can be defeated by pulling it up, as shown on Figure 1-A.

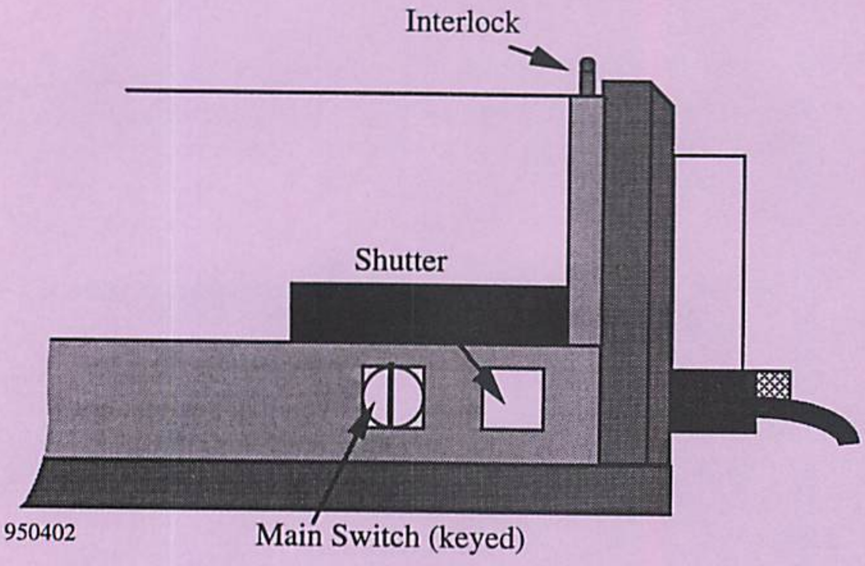


Figure 1-A

Location of cover interlock.

- **Use great caution when operating the NJA-5 with the interlock defeated. Always contain the Ti:Sapphire beam within the NJA-5 enclosure.**

2. Site Preparation

2.1 Laser Room

The Clark-MXR NJA-5 femtosecond oscillator is designed to operate under standard laboratory conditions.

- Water and electricity must be available (*See* below).
- The room temperature must be stable to +/- 2° C, and the humidity level must be maintained at all times below the condensation point.
- The site must be reasonably free of sources of vibration.
- The site must be clean. The cleaner the facility, the less often cleaning of the optics will be required.
- The airflow in the room (air conditioning) must be directed away from the lasers. Turbulent airflows will disturb the laser system and degrade its short term stability.
- The laser table must be well lit. If an overhanging platform is located above the table, it may be necessary to install some additional lights. The light level control must be easily accessible as some of the alignment steps call for a darkened room.
- The table temperature must be stable to +/-2° C.
- The table top surface must provide some type of anchorage points located on a regular basis (such as a 1" or 25 mm grid).
- For safety, the laser site access must be restricted (*See* Chapter 1, Eye Safety).

2.2 Utility Requirements

2.2.1 Argon-Ion Laser

For your convenience, we provide the following information for the most commonly found argon-ion lasers (Coherent Innova® 310, Coherent Innova® 90, Spectra-Physics BeamLok™ 2060). Please refer to your argon-ion original manufacturer's manual for update information and for instruction on other models. Clark-MXR, Inc. makes no warranty or representation, either expressed or implied with respect to this document.

2.2.2 Coherent 310

Electrical Connections

- 3Ø, 208 VAC (± 10%).
- The system draws a maximum of 65 A.

■ **Do not exceed the input voltage. Use a transformer to bring it to within the specified range.**

- The service box should be less than 3.6 m (12 ft.) from the power supply.

Water Connections

Cooling water may be supplied from an open-loop system consisting of a tap water source and a direct connection of the outgoing flow to a drain. The diameter of the incoming service line should be at least 15.9 mm ($^{5}/_{8}$ in.). All hose connections are U.S.A. garden hose variety.

- The minimum flow rate is 9.5 l/minute (2.5 gal/min).
- The inlet temperature must be stable to ± 1.0° C.
- The inlet temperature must be stable in the range 10–35° C (50–95° F).
- The differential pressure range is 152–276 kPa (22–40 psi).
- The maximum static input pressure is 620 kPa (90 psi).

2.2.3 Coherent I-90

Electrical Connections

- 3Ø, 208 VAC (± 10%). (*See* Coherent, Inc. manual for line frequency specification.)
- The system draws a maximum of 50 A.

■ **Do not exceed the input voltage. Use a transformer to bring it to within the specified range.**

- The service box should be less than 2.9 m (9.5 ft.) from the power supply.

2.2.4 Spectra-Physics 2060

Electrical Connections

- 3Ø, 208 VAC (+10% – 5%).
- The system draws a maximum of 60 A.

■ **Do not exceed the input voltage. Use a transformer to bring it to within the specified range.**

- The service box should be less than 3.6 m (12 ft.) from the power supply. Connect the green lead of the power cable to the *earth ground*, not the neutral. Connect the remaining three leads to the legs of the three-phase service; the sequence is not important.

Water Connections

Cooling water may be supplied from an open-loop system consisting of a tap water source and a direct connection of the outgoing flow to a drain. The diameter of the incoming service line should be at least 15.9 mm (5/8 in.). All hose connections are U.S.A. garden hose variety.

- The minimum flow rate is 11.3 l/minute (3.0 gal/min).
- The maximum inlet temperature is 30° C (86° F).
- The minimum differential pressure is 172 kPa (25 lb/in.^{2}).
- The maximum input pressure is 517 kPa (75 psi).

The water pressure must be stable throughout the work period. Large pressure changes, even for short periods, will affect the stability of the Argon-ion laser and the Ti:Sapphire oscillator. If your water system is subject to frequent pressure changes you should install a pressure-regulating tank ahead of the Argon-ion laser.

- The water hardness should be < 100 ppm calcium.
- The pH level should be in the 7.0 to 8.5 range.
- The maximum particulate size should be < 200 µm (diameter). A water filter is provided with the Argon-ion laser. It must be installed in the water supply line. The direction of the flow is marked on the filter case.
- The heat load is < 21 kW (1224 BTU/min).

A closed-loop cooling system can be used to regulate the pressure, temperature, and flow rate of the cooling water, and to avoid buildup of scale in the plasma tube. This can enhance the stability of the laser, improve its performance, and prevent premature tube failure due to reduced cooling efficiency. Any such system must meet or exceed the cooling requirement listed above.

2.2.5 NJA-5 Ti:Sapphire Oscillator

Electrical Connections (For feedback electronics)

US/Japan Version 60 Hz, one phase, 110 VAC (+10% – 15%).

The system draws a maximum of 2 A.

European Version 50 Hz, one phase, 220 VAC (+10% – 5%).

The system draws a maximum of 2 A.

A minimum of two outlets is required. Note that additional outlets will be needed for the power meter, the oscilloscope, the autocorrelator, etc.

Water Connections (for Ti:Sapphire rods cooling)

Water may be supplied from an open-loop system consisting of a tap water source and a direct connection of the outgoing flow to a drain. All water connections are Swagelok-type connectors.

- The flow rate is very limited. Typically a few liters per hour.
- The maximum inlet temperature is 24° C (75° F). For optimum stability, the temperature must be stable to ± 1° C during the work period.
- The pH level should be in the 7.0 to 8.5 range.
- Install a water filter if high level of undissolved solids are present.
- Install a valve in the line of the Ti:Sapphire rod cooling water to limit the water pressure under 10 psi.

2.2.6 Nitrogen

The oscillator needs to be slightly pressurized with clean, oil-free, water-free Nitrogen.

- The Nitrogen must be provide at a pressure no higher than 0.2 Bar (2.9 PSI) through a $^1/_4$" OD, $^1/_8$" ID tubing.

The Nitrogen over pressure is used to keep the optics clean of dust contamination, to lower the water vapor level, and to stabilize the laser. *For optimum long-term stability the oscillator needs to be pressurized with dry Nitrogen at all times.*

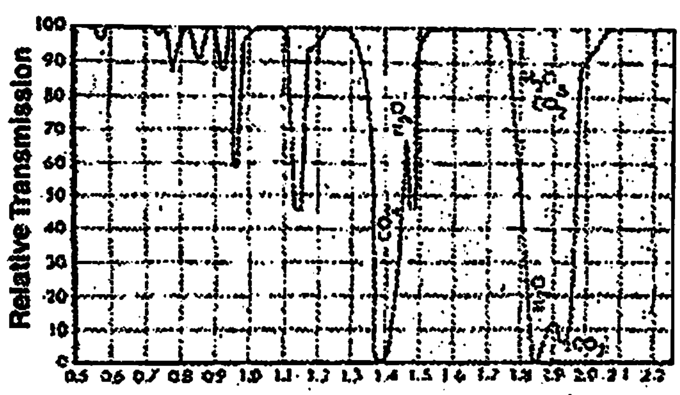


Figure 2-A

Air transmittance.

In order to lower the Nitrogen consumption, the NJA-5 oscillator is fitted with a low flow valve and flow meter.

2.3 Support Equipment & Supplies

The following equipment/supplies are required to setup, align, and operate the NJA-5 femtosecond oscillator.

- An Argon ion laser to pump the NJA. This pump laser should be capable of producing at least 5 Watts, all-lines power output (TEM_{00} in 514.5 nm component) or 4 Watts operating single line 514.5 nm, TEM_{00}.

■ It is extremely important that the argon laser be in good operating condition. The transverse mode must be a stable Gaussian profile. The pump beam pointing stability must be equal or better than 10 microradian (measured at the level of the NJA-5 enclosure input).

- Laser Safety Goggles for blocking the Argon-Ion and the NJA wavelengths. Similar to Newport Model G-LGS-A for Argon wavelengths and Model G-LGA for IR wavelengths, respectively. (*See* Chapter 1, Eye Safety)
- An optical table. Newport RS, KNS, MST series or equivalent.
- One analog oscilloscope (bandwidth greater than or equal to 300 MHz)
- One infrared viewer (FJW Find-R-Scope, or equivalent)
- One analog laser power meter (Range up to 10 watts, with sensitivity equal or better than 10 mW). Model Molectron Power Max 5100 with head PM10, or equivalent.
- One autocorrelator, model Clark-MXR AC-150, or equivalent. The autocorrelator must be able to measure pulses as short as 30 fs at 100 MHz. (Autocorrelators with large amount of glass in the beampath are inadequate)
- A pair of mirrors and mirror mounts to transport the beam from the oscillator to the autocorrelator. These mirrors must be able to support the pulse bandwidth without introducing any pulse distortion.
- A set of tools including a wrench set, screwdrivers, a set of U.S.-size Allen wrenches, a utility knife, a measuring tape, a ruler, and a voltmeter.
- Nitrogen (*See* above).
- Some optics cleaning supplies including: Spectroscopic or Research Grade Methanol and Acetone, lens tissue, powder-free gloves, several cans of dust-free and oil-free compressed gas.

2.4 Initial Inspection of the NJA-5

2.4.1 Open the laser enclosure lid by unlatching the handles near the laser enclosure end panels and lifting it.

2.4.2 Carefully check inside the laser enclosure for the presence of any transportation damage (Please notify us immediately of any damage).

2.4.3 Close the laser enclosure lid.

3. Quick Alignment

Your NJA-5 femtosecond oscillator was fully tested before shipping. At the end of the test procedure, two irises were positioned within the NJA-5 enclosure to mark the position of the argon-ion pump beam.

You should be able to quickly align your argon-ion laser and the NJA oscillator following the procedure described in this chapter. However, should your argon-ion laser (beam size, beam divergence, mode) be significantly different from the one used for testing at Clark-MXR, or should the oscillator cavity be significantly misaligned during shipment, you may have to follow a more in-depth alignment procedure (*See* Chapters 4, 5, and 6)

3.1 Initial Positioning

3.1.1 Position the Argon-ion laser and the transport optics as shown in Figure 3-A.

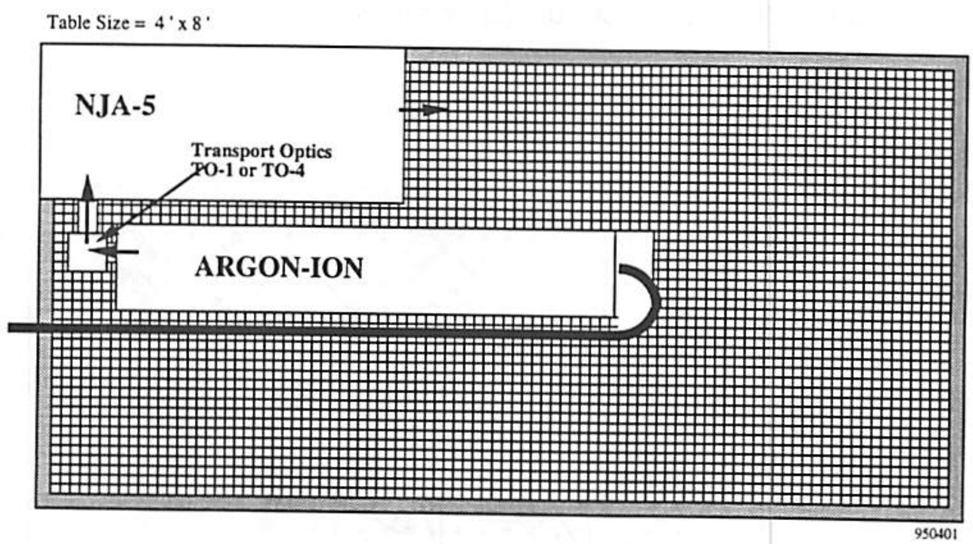


Figure 3-A

Location of the NJA-5 with its pump laser.

3.1.2 Secure the feet of the Argon-ion laser to the optical table. Once the laser is aligned, you do not want the argon ion laser to move relative to the NJA-5 laser. Therefore, you should have the laser firmly secured to your optical table.

3.1.3 Place the NJA-5 laser head onto the optical table next to the ion laser as shown in Figure 3-A.

3.1.4 Plug in the power cord.

■ **For your safety, we are providing our NJA-5 with a GFI (ground fault interrupt) power cord. Do not operate the laser without the GFI cord. You must press the "RESET" button the first time you plug it in.**

3.1.5 Open the NJA-5 enclosure by pushing the two latches towards each other and lifting the lid (*See* Figure 3-B).

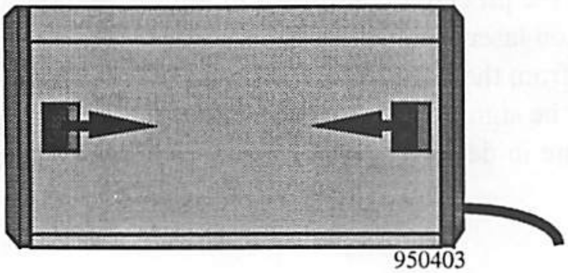


Figure 3-B

Location of the two lid latches.

3.1.6 Clamp down the laser base plate to the position (Shown in Figure 3-A) on the optical table using the random clamps provided in the laser enclosure (shown in Figure 3-C).

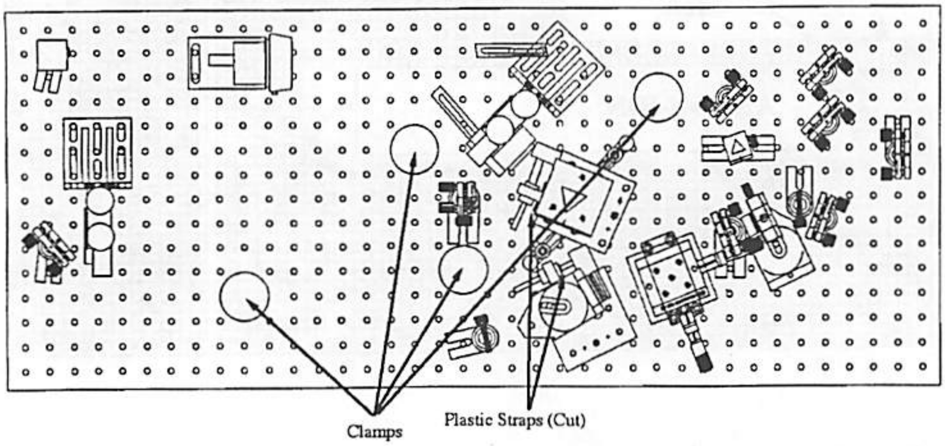


Figure 3-C

Removing transportaion restrains.

3.1.7 Cut and remove the plastic strap(s) around the translation stages under mirror CM3 and prism P2 (shown in Figure 3-C). Unscrew and remove the cap on the Ti:Sapphire rod and put it aside.

3.1.8 There is a concave mirror screwed down on the base plate. It will be used for observing the mode structure of the Ti:Sapphire laser output. Remove it for later use.

In the following steps you will have to operate with the lid interlock defeated. Please review the Eye Safety chapter before proceeding any further.

3.1.9 Pull up the cavity interlock switch. Turn the key clockwise, then push the shutter button (*See* Figure 3-D). The input shutter will open in about 10 seconds.

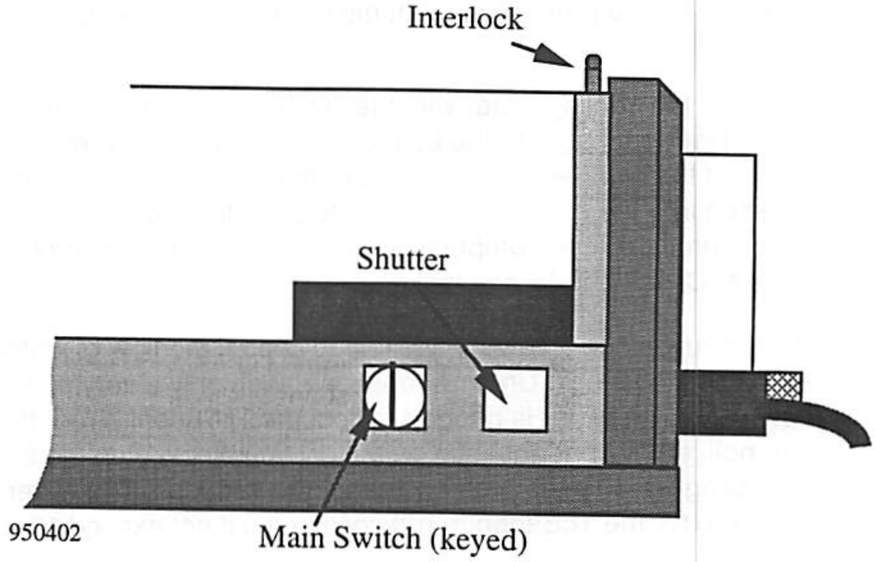


Figure 3-D

Location of the interlock, power key, and shutter control.

To improve long-term stability, the NJA-5 is provided with a build-in internal temperature stabilization system.

3.1.10 Press the “INDEX” switch on the temperature controller located in the side panel of the laser enclosure (*See* Figure 3-E). The green characters “SP1” will blink. The red number is the set temperature in centigrade the laser should run under.

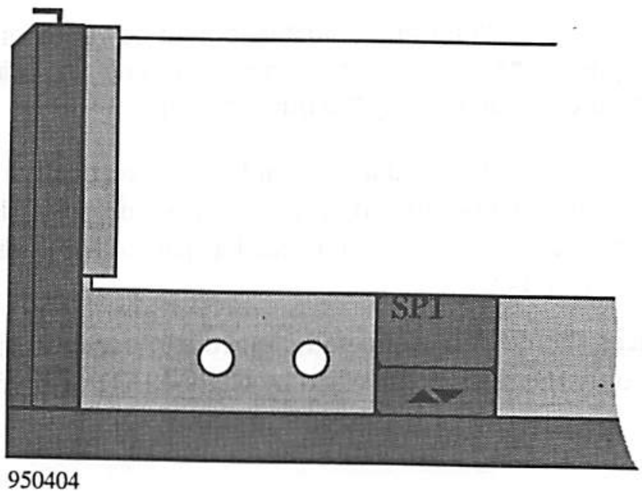


Figure 3-E

Location of the temperature controller.

3.1.11 Press the "Up" or "Down" selector to make the necessary temperature adjustment. After selecting the "set point," press the "Enter" switch. Finally press the "Index" switch.

The "set point" should be no more than 5 degrees Celsius above medium room temperature, which should be within ± 2° C (*See* 2.1), or intra-enclosure vortex may disturb the NJA-5.

Initially the entire NJA-5 cavity and enclosure may take up to 12 hours to reach its thermal equilibrium. It is important that the NJA-5 temperature be fully stabilized before proceeding with the rest of the alignment procedure.

3.1.12 Connect the cooling water with the flexible tubing (provided in the laser package) to the bulkhead connector on the end panel of the laser enclosure. Be sure that the metal inserts are pressed into the ends of the tubing, to provide a surface on which the fitting can compress, before attaching the tubing to the fittings. Check and fix any leakage.

3.1.13 You should place a valve in the line to control the flow of water to the cooling block. Under normal operation only a very small flow of cooling water is needed to cool the Ti:Sapphire rod. If you notice any condensation on the cooling block, then the flow of cooling water is too high and should be reduced. The water pressure for the Ti:Sapphire rod cooling must not exceed 10 psi.

3.1.14 Connect a source of dry nitrogen to the third brass bulkhead fitting.

A flow of 3 Standard Cubic Feet Per Hour of nitrogen is required to purge any dust particles from the enclosure and to reduce intracavity absorption by water vapor after the laser is aligned and covered.

3.2 Pump Beam Alignment

The Argon-ion laser should be located beside NJA-5 as shown in Figure 3-A.

3.2.1 Turn on the argon ion laser and adjust its output power to its lowest level (milliwatts). An extremely low power level is sufficient for the purpose of aligning the pump beam.

The pump beam from the recommended argon ion lasers is vertically polarized. The pump beam must be rotated horizontally to pump the NJA-5. This is accomplished with the periscope provided as part of the transport optics package TO-1 or TO-4.

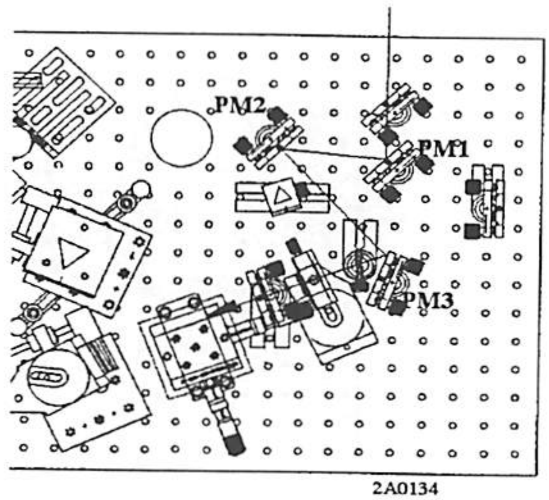
Under no circumstances should you use metallic mirrors to transport the argon-ion beam. Use only the mirrors provided by Clark-MXR with your NJA-5.

For users whose oscillator is factory-equipped with PointMaster™, please follow the instruction in the PointMaster manual before proceeding.

3.2.2. Reflect the beam at a right angle downward toward the surface of the optical table, where it is intercepted by a second beam steering mirror that redirects it parallel to the column of holes in the optical table and into the NJA-5 enclosure (*See* Figure 3-F).

Figure 3-F

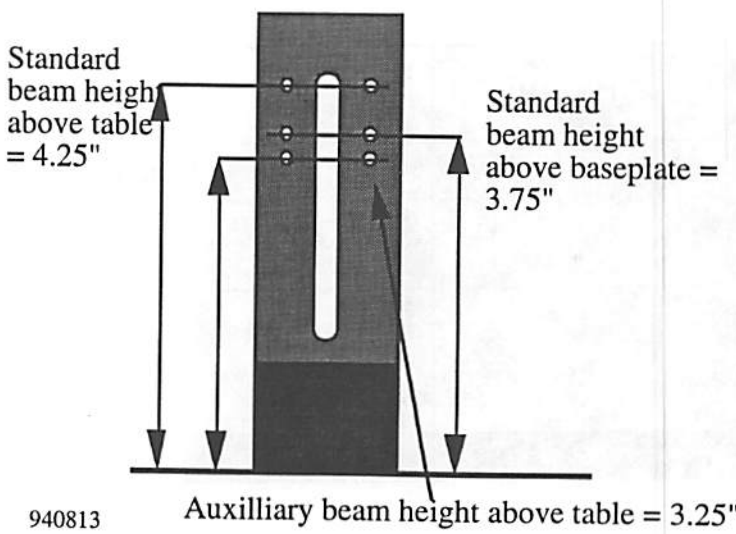
NJA-5. Pump beam entering the oscillator enclosure.



The redirected beam should be at a constant height of 4.25" (10.8 mm) above the optical table or 3.75" above the oscillator base plate. An alignment tool with holes at the proper height is provided (*See* Figure 3-G).

Figure 3-G

Alignment tool.



Before proceeding with the following alignment steps you must first let the NJA-5 reach its operating temperature (*See* above).

3.3 NJA-5: Rapid Alignment Procedure

Please review the laser cavity layout and the component nomenclature before proceeding. Note that the base plate of the laser is made with 1/4-20 tapped holes 1" apart. A alphanumeric coordinate is created for the convenience of locating the mechanical components as shown in Figure 3-H.

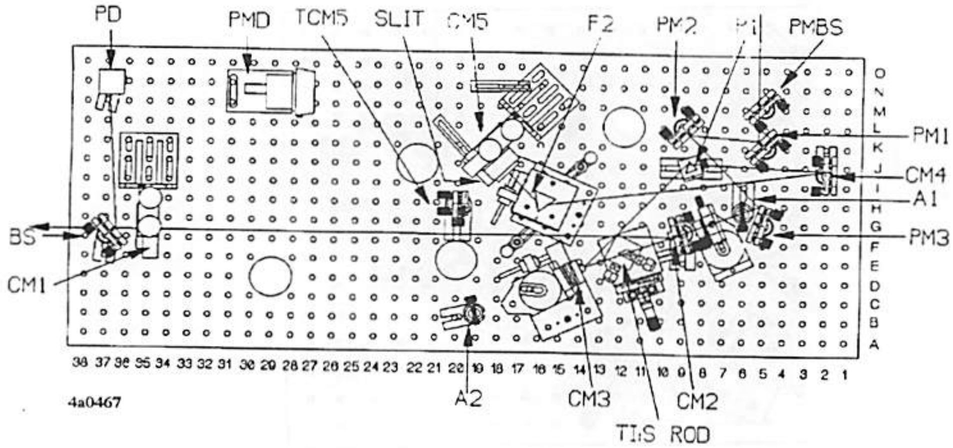


Figure 3-H

NJA-5: Alphanumeric hole coordination and component nomenclature.

3.3.1. Replace the laser enclosure cover. Center the incoming pump beam on the input port on the side panel of the enclosure cover (*See* Figure 3-I).

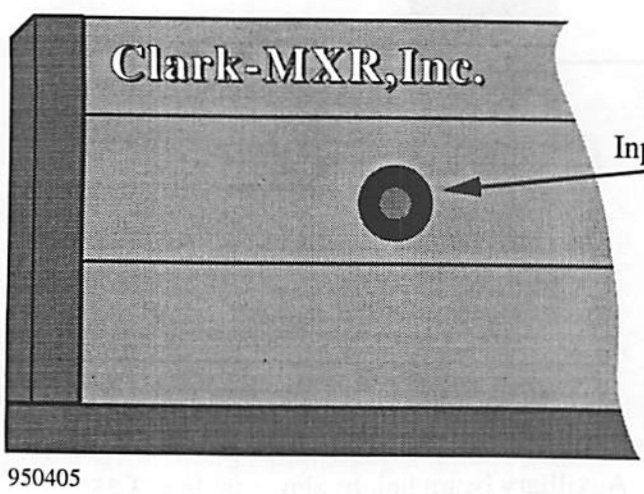


Figure 3-I

Pump beam input port.

3.3.2 Remove the cover, and proceed with caution.

If your NJA-5 if equipped with PointMaster, the pump beam will first pass through a beamsplitter (a small percentage of pump power is reflected towards the PointMaster quadrant detector).

The pump beam is reflected by mirror PM1 which is placed at location [K5] (*See* Figure 3-F) The beam should be at a constant height of 3.75" (9.55 mm) above the surface of the base plate.

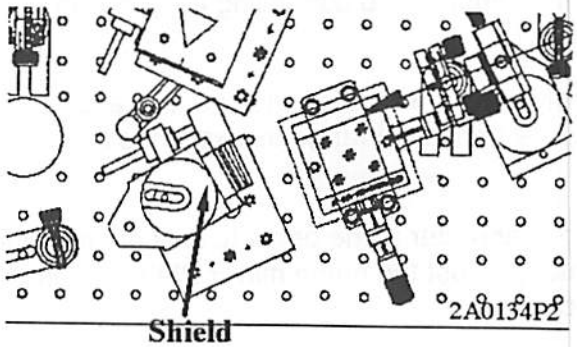
The beam is then reflected toward mirror PM2, which is positioned at [L9].

The pump beam is then reflected to mirror PM3, located at position [G5]. The beam should be centered on PM3 at the height of 3.75" (9.55 mm) above the surface of the laser base plate.

3.3.3 Remove the beam shield at the back of the mount for mirror CM3 (*See* Figure 3-J).

Figure 3-J

CM3 shield location.



3.3.4 Align the pump beam through the iris A1 before the pump lens L1 and the iris A2 after the mirror CM3. Use PM2 to align the beam to A1, then use PM3 to align the beam to A2.

3.3.5 Iterate PM2 and PM3 to center the beam on both irises as accurately as possible.

3.3.6 Open the irises A1 and A2.

■ Proceed with Caution. The NJA-5 should lase as you proceed with the following alignment steps.

3.3.7 For I-90 ion lasers, use aperture 6 or smaller; for I-310, use aperture 5 or smaller; and for SP 2060, use aperture 7. Turn the ion laser power up to 4 W.

3.3.8 Open the NJA-5 output shutter (lift up). Place a white card just after the exit and observe the output from the laser. The laser may lase at this point.

However, due to the relative inaccuracy of the aperture alignment technique, it is possible that the NJA-5 will need some additional adjustment before lasing. If this is the case here, proceed to 3.4.1.

3.3.9 Place a power meter in the beam to look at the output power and carefully adjust the pump mirror PM3 to optimize the output power.

The final optimization of the cavity alignment requires adjusting the cavity mirrors CM1 and CM5 (*See* section 3.4.5).

3.4 Pump beam final iteration

If the NJA-5 is not lasing after step 3.3.8, then the position of the mirror PM3 needs to be optimized.

3.4.1 VERY SLOWLY scan the horizontal adjustment knob on the PM3 mount (half-turn clockwise and back) while observing the target white card for lasing action.

3.4.2 If lasing does not occur, then move a fraction of a turn the vertical adjustment knob controlling the pump mirror PM3 mount. Repeat 3.4.1.

3.4.3 Very slowly continue adjusting the vertical alignment while scanning the horizontal range as explained in 3.4.1, until lasing occurs.

3.4.4 Place a power meter in the beam to look at the output power and carefully adjust the pump mirror PM3 to optimize the output power.

The final optimization of the cavity alignment requires adjustment of mirrors CM1 and CM5.

3.4.5 Adjust the pump power to obtain approximately 400 mW of output power.

3.4.6 Check the factory test report sheet for the proper bench mark for your specific laser (applies to lasers delivered after April, 1995).

On the test report, the pump laser that was used for testing is specified. If you are not using the same type of the laser, then it is possible that the position of the pump lens L1 along the pump beam propagation direction may need to be altered to improve the efficiency of the laser.

3.4.7 Translate the pump lens by rotating the ring on the mount to maximize the output power.

If you do not see power improvement, put the lens back to its original position.

3.4.8 Try to put minimum hand weight onto the lens mount to avoid in-plane (lateral) drift of the lens. If the lens drifts laterally, a power drop will be observed. You can correct the drift by adjusting the X and Y knobs on the mount.

3.5 Cavity modelocking

3.5.1 Plug in a BNC cable to the photodiode output port on the front panel of the laser enclosure and connect it to an oscilloscope with a bandwidth greater than 300 MHz. Set the scope to 1 ms/division, 50 mV/division.

3.5.2 Align the beamsplitter, BS, to maximize the signal output from the photodiode.

3.5.3 Replace the NJA-5 enclosure cover.

3.5.4 Install the beam tubes around the transport optics unit, TO-1 to the NJA-5 enclosure.

3.5.5 Start the Nitrogen flow (approx. 3 cubic feet per hour).

■ **The pump beam must be enclosed in beam tubes throughout its entire path from the argon laser to the NJA-5.**

This provides safer operation and avoids the air current around the pump beam that disturbs the laser stability.

The output power will drift until the laser reaches its thermal equilibrium.

3.5.6 Correct the power output drift by adjusting mirrors CM1 and CM5.

If you use PointMaster™ along with the temperature stabilization system, the power output should not drift more than a few percentage points once the NJA-5 cavity and enclosure have reached set temperature and thermal equilibrium.

3.5.7 Open the upper trap found on the NJA-5 enclosure lid.

3.5.8 Place your hand on the cap screw in the translation stage under prism P2. Take care not to block the cavity beam.

3.5.9 Move (by hand) the translation stage back and forth while observing the photodiode signal on the oscilloscope. The motion of the translation stage should initiate the modelocking process. The modelock train should be stable once you stop translating the stage.

3.5.10 If 3.5.9 fails to produce a stable pulse train, then adjust the CM3 knob (*that is*, the position of CM3) slowly in either direction while continuing to rock the P2 translation stage. (The CM3 knob is located in the front side panel of the laser enclosure, *See* Figure 3-K.)

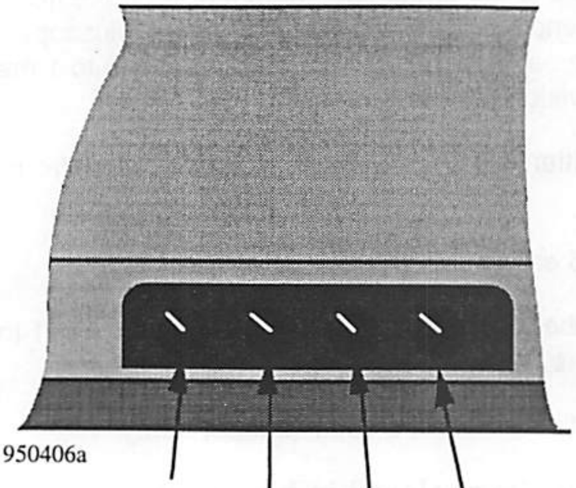


Figure 3-K

Laser parameter controls.

Once the optimum CM3 position is reached, the modelocked pulse train should be stable.

Follow the instructions in later chapters if you are unable to generate a stable modelock train or recover lasing of the cavity.

3.5.11 Close the upper trap.

See Chapter 6 for details on setting up the NJA-3E piezo-electronic starter.

4. NJA-5 Alignment Procedure: Pump Beam Alignment

Note: The following alignment procedure should be followed only when the simpler procedure outlined in Chapter 3 fails to produce satisfactory results.

4.1 Pump Beam Pre-Alignment

Follow section 3.3.1 to align the pump beam into the NJA enclosure. Ensure that all optics are clean.

Remember to lower the ion laser power to as low as possible for this procedure

4.1.1 After completion of section 3.3.1, close the input beam shutter by pressing the cover interlock switch on the end panel of the laser enclosure.

4.1.2 Remove the pump lens L1 *with* its adaptor from the lens mount by unscrewing the adaptor in the left side of the mount (*See* Figure 4-A).

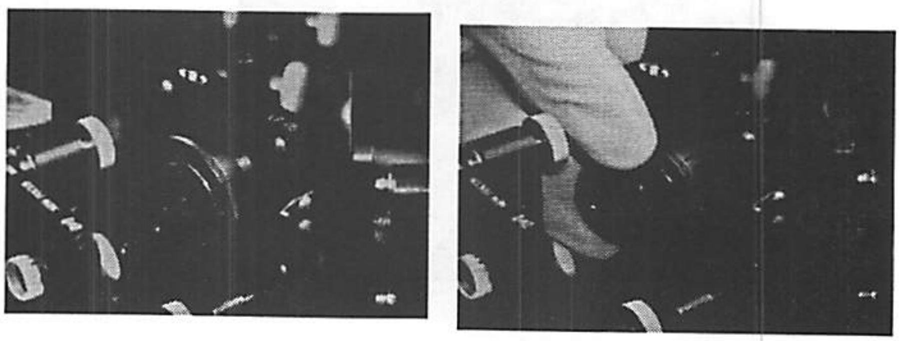


Figure 4-A

Lens L1: location and mounting.

4.1.3 Remove the mirror CM2 *with* its mounting adaptor from its mount. Leave the mount and post in place (*See* Figure 4-B.)

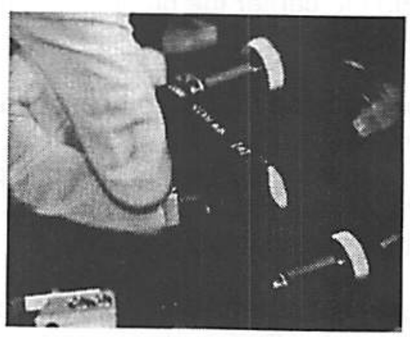


Figure 4-B

CM2: location and mounting

4.1.4 Remove the Ti:Sapphire rod cooling block (including the Ti:Sapphire rod) *and* the clamp from the X-Z translation stage (*See* Figure 4-C).

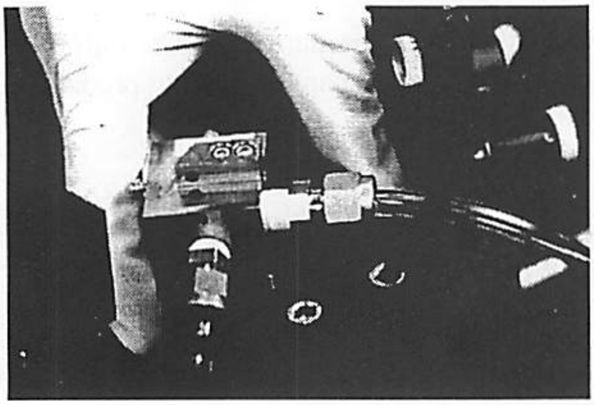


Figure 4-C

Ti:Sapphire rod: removal.

4.1.5 Remove the mirror CM3 *with* its mounting adaptor from the mount. Do **NOT** remove the universal base, nor the riser from the translation stage (*See* Figure 4-D).

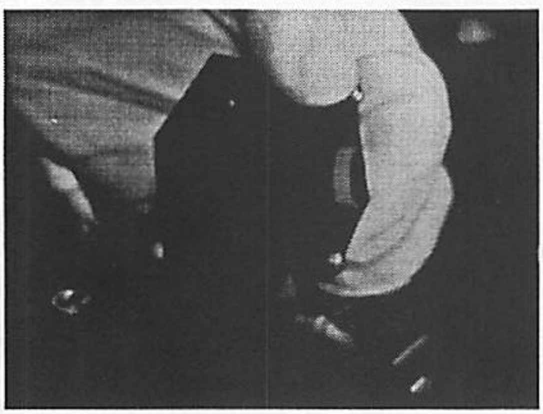


Figure 4-D

CM3: removal

4.1.6 Open the input shutter by pulling the cover interlock switch on the end panel and pressing the reset button on the side panel of the laser enclosure (*See* Figure 3-D).

4.1.7 Adjust mirror PM2 to center the pump beam through aperture A1.

4.1.8 Align mirror PM3 to bring the pump beam parallel to the Z-axis of the translation stage under the Ti:Sapphire rod (*See* Figure 3-F). The best way to accomplish this is to use parallax to bring the pump beam into the same visual plane as your eye and the back edge of the translation stage Z-axis.

4.1.9 Iterate the adjustment of PM2 and PM3 until both alignment conditions are met simultaneously.

4.1.10 Once the argon ion laser pump beam is parallel to the reference axis of the translation stage, check that the pump beam is at a constant height of 3.75" (or 9.55 mm) above the surface of the base plate. Use the alignment tool (*See* Figure 3-G).

4.2 Pump Beam Final Alignment

4.2.1 Close the input beam shutter by pressing the cover interlock switch on the end panel of the laser enclosure.

4.2.2 Replace the lens L1 and its adapter into its mount.

Make sure that the argon-ion pump laser is at its lowest power level.

4.2.3 Open the input shutter by pulling the cover interlock switch on the end panel and press the reset button on the side panel of the laser enclosure.

4.2.4 Center the pump beam on lens L1 by adjusting the X-Y knobs located on the top and side of the lens mount (*See* Figure 4-A).

If you cannot fully center the beam using the X-Y adjustment follow step 4.2.5. Otherwise proceed to step 4.2.11.

The focusing lens assembly L1 shown in Figure 4-A contains a plano-convex lens positioned in a 5-axis mount. The curved side of the lens should be facing towards the incoming pump beam. The lens should be held in the mount by a single retaining ring. If any extra rings are present they should be removed.

4.2.5 Check that the lens faces in the proper direction.

4.2.6 Check that there is only one retaining ring.

The lens mount is attached by a special post and post holder to a universal base that should be arranged as shown in Figure 4-A.

4.2.7 Loosen the screw in hole number [F7] that holds the lens mount base. Slide the base to center the beam horizontally in the lens. Adjust the height of the mount so that the transmitted beam is at a constant 3.75" above the optical table.

4.2.8 Opposite the PM3 side of the 5-axis mount there is a knurled ring. Rotate this knurled ring to uncover 1 mm of the fine non-black anodized thread on the side of the mount closest to PM3.

4.2.9 Translate the 5-axis mount along the direction of propagation of the beam so that the front edge of the knurled ring is 60 mm away from the spot where the pump beam hits mirror PM3.

4.2.10 Check that you simultaneously meet the conditions described under steps 4.2.7, 4.2.8, and 4.2.9. Then tighten the cap screw holding the universal base to the base plate.

4.2.11 Place the alignment tool between pump mirror PM1 and PM2. The beam should go through the small reference hole at the height of 3.75" (9.55 mm) in the middle of the three rows.

4.2.12 Observe the alignment tool face closest to the rod. You should see two diffused spots (Reflections from the first and second surfaces of the lens L1. Adjust the X and Y positions of the lens so that these two spots overlap (X and Y adjustments are made using the controls on the lens mount). Then, adjust the two angular controls on the mount so that the two overlapped reflections are centered on the argon beam. The pump beam should now be well centered in the lens.

4.2.13 Check again to be certain that the pump beam transmitted through the lens is still 3.75" (9.55 mm) above the laser base plate. Make any adjustments necessary to satisfy these conditions.

4.2.14 Close the input shutter.

4.2.15 Place the mirror CM2 with its adaptor into its mount (*See* Figure 4-B).

■ Make sure that the argon-ion pump laser is at its lowest power level

4.2.16 Open the shutter.

Do not interchange CM2 with CM3. Their coatings are different.

4.2.17 Translate Mirror CM2 if necessary until the pump beam is centered on the *concave* side of the mirror. The base should stay on row #9.

4.2.18 Check and set the gap between the CM2 mount back edge and the front edge of the L1 mount near the top adjustment knob to 61 mm. (*See* Figure 3-J.)

It is critically important that this measurement be made along the axis of the pump beam.

4.2.19 Verify that the mount adjustments on CM2 are in the center of their travel before performing the next step

Mirror CM2 creates two pump beam reflections. The reflection generated by the concave side of CM2 is larger than the other.

4.2.20 Rotate CM2 to have the small reflection blocked by the right edge of the 5-axis mount. The larger reflection should not be blocked by the lens mount.

4.2.21 Check that the beam propagates after mirror CM2 at the standard beam height.

4.2.22 Check and make sure that you simultaneously meet the conditions listed under 4.2.17, 4.2.18, 4.2.20, and 4.2.21. Tighten the base of CM2.

4.2.23 Close the enclosure shutter.

4.2.24 Attach the Ti:Sapphire rod and clamp onto the X-Z translation stage as shown in Figure 4-C.

■ Make sure that the argon-ion pump laser is at its lowest power level

4.2.25 Open the shutter.

The Ti:Sapphire crystal should be oriented as shown in Figure 3-F with the pump beam entering the first face of the crystal.

4.2.26 Position the translation stage so that the beam enters through the horizontal center of the crystal.

4.2.27 Loosen the Ti:Sapphire rod mount in the clamp.

4.2.28 Rotate the Ti:Sapphire cooling block to find the minimum reflection from the Ti:Sapphire crystal Brewster entrance.

4.2.29 While observing the pump light reflected by the front surface of the Ti:Sapphire rod, slightly rotate the rod cooling block. You want to find the position (rotation) reflecting the minimum amount of pump light. You may have to adjust the x-axis micrometer to keep the beam centered on the face of the Ti:Sapphire rod.

4.2.30 Tighten the clamping screw that holds the block in the bracket clamp.

4.2.31 Position the front face of the rod 51.5 mm from the front face of mirror CM2 by adjusting the Z-axis micrometer screw on the translation stage.

4.2.32 Finally, check that the transmitted beam is at 3.75" (9.55 mm) above the surface of the laser base plate.

The pump beam should now be well centered horizontally in both the entrance and exit face of the Ti:Sapphire rod.

It is not a problem if the pump beam is off the vertical center of the rod.

5. Alignment Procedure, 5-Mirror, 1-Prism Cavity

The NJA-5 alignment procedure is divided in three main steps:

1. Alignment of the pump laser as covered in Chapter 4.
2. Alignment of a cw cavity (5 mirrors, 1 prism), as covered in this chapter.
3. Alignment of the self-modelocked cavity (5 mirrors, 2 prisms) as covered in Chapter 6.

The cw laser cavity consists of: the gain fold of the cavity (*that is,* the rod and two focussing mirrors), the output coupler, one prism, the folding mirror and the end mirror. This configuration is illustrated in Figure 5-A.

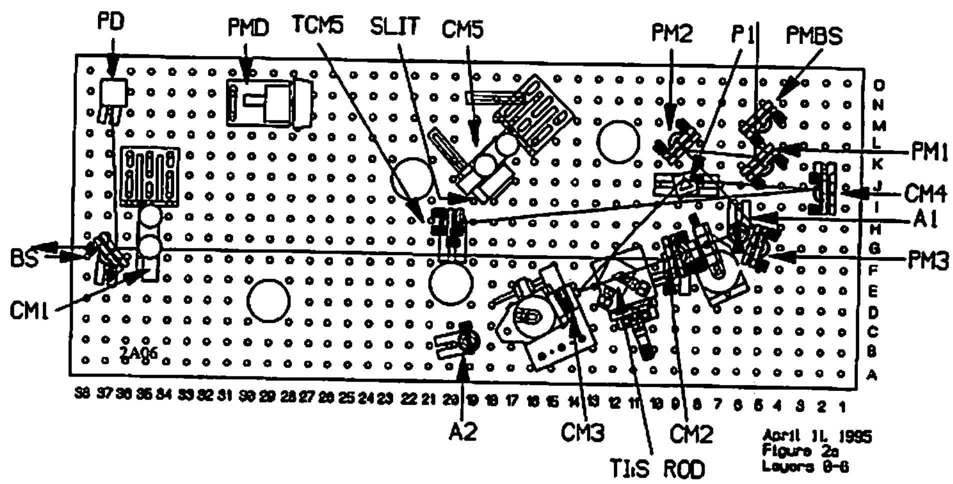


Figure 5-A

Cavity layout for continuous-wave operation.

5.1 Output coupler (CM1)

CM1 is the output coupler of the laser.

5.1.1 Check that mirror CM1 is tightly secured in its mount.

Changing the output coupler

Your NJA-5 was fully tested before shipping. The output coupler is inserted correctly. If you need to replace the output coupler, then carefully follow the instructions below:

5.1.1.1 A one inch adapter is required to install the output coupler in the Gimbal mirror mount (*See* Figure 5-B).

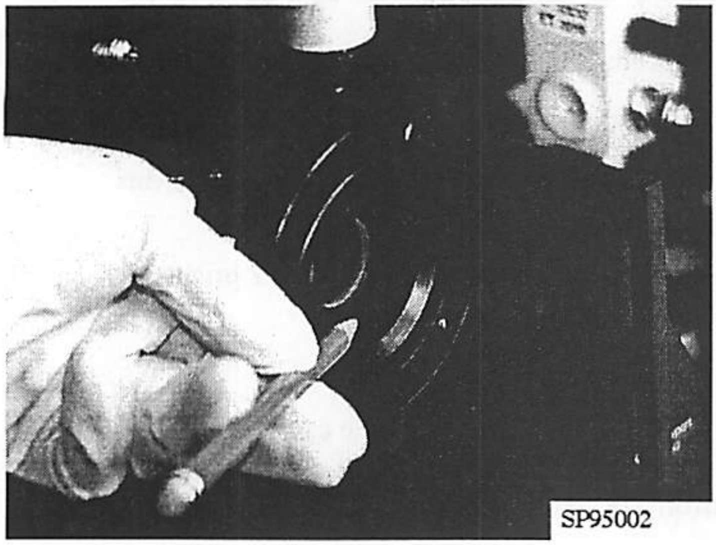


Figure 5-B

Mounting CM1.

5.1.1.2 The mirror surface coated with the partially transmitting coating must face the gain medium. The AR coated mirror surface must face away from the gain medium.

Inverting the position of the output coupler within its mount will result in a laser that may lase cw, but will certainly not modelock (due to excessive intra-cavity glass).

5.1.2 Coarsely align the output coupler. Its front surface should be facing mirror CM2.

You may want to reread the "Eye Safety" section located at the front of this manual before proceeding.

5.1.3 Increase the ion laser power to 4 Watts. (*See* to 3.3.3 for the recommended argon-ion aperture size.)

5.1.4 Adjust mirror CM2: the IR fluorescent spot generated by the gain medium must pass through mirror CM1 and then through the enclosure exit port.

■ **Note: Reducing the room light level should help with this step.**

5.1.5 Place a white card in front of mirror CM1 to intercept the fluorescence. You should see a central bright red spot surrounded by a halo. The bright spot appears to be cross shaped with its vertical axis being longer than the horizontal. The cross should look quite sharp, but will not be fully focused. If it is focused, the distance between the mirror CM2 front surface and the pump beam entrance side surface of the Ti:Sapphire rod is too long. This distance should be 51 mm to 52 mm (*See* 4.2.30).

5.1.6 Place your alignment tool near hole number [G26]. Adjust the alignment tool position, so that the larger aperture is centered on the fluorescence propagating from CM2 to CM1.

5.1.7 Align the output coupler CM1 to redirect the fluorescence through the large aperture of the alignment tool.

5.2 Cavity Mirror CM3

Mirror CM3 collimates the Ti:Sapphire emission and directs it towards prism P1. It is critically important that the translation stage found under CM3 be parallel to the pump beam.

5.2.1 Should you need to realign the translation stage proceed as follow:

5.2.1.1 Remove the universal base that is on the stage.

5.2.1.2 Loosen the single screw that attaches the translation stage to the baseplate.

5.2.1.3 Align the translation stage using the "line of sight" technique described in 4.1.

5.2.1.4 Tightly secure the translation stage to the base plate.

5.2.1.5 Center the translation stage in the middle of its traveling range.

5.2.1.6 Replace mount CM3 onto the stage.

5.2.2 Place mirror CM3 with its adaptor into its mount.

Your NJA-5 was fully tested before shipping. Mirror CM3 is inserted correctly. Should you need to replace this mirror, carefully follow the instructions below:

5.2.2.1 Place the concave mirror CM3 in its mirror mount adaptor.

5.2.2.2 Secure the mirror using the adaptor set screw.

5.2.2.3 Install the mirror and its adaptor in the mirror mount. The concave surface should face towards the Ti:Sapphire rod.

Mirror CM3 is NOT equivalent to mirror CM2. Do not interchange these two optics.

5.2.3 Adjust the lateral position of mirror mount CM3 to ensure that:

5.2.3.1 The residual pump beam falls on the center of mirror CM3.

5.2.3.2 The distance from the front surface of the mirror CM3 to the nearest Brewster face of the rod is 50 mm (± 0.5 mm).

5.2.3.3 The residual pump beam reflected by mirror CM3 propagates at an angle of about 45° with respect to the row of holes on the breadboard. (The exact angle will be determined in a later step.)

5.3 Prism P1

The P1 prism base should be positioned between holes J8 and J10.

5.3.1 Check that the base is butting up against the screw located in J8 as shown in Figure 5-A. Tighten the attachment screws.

5.3.2 Adjust Mirror CM3 to satisfy the following conditions:

5.3.2.1 The residual pump beam reflected by mirror CM3 should pass through the prism near its apex.

5.3.2.2 The beam should propagate from CM3 to P1 at a constant height of 3.75" (9.55 mm).

The prism P1 must be carefully oriented to the "angle of minimum deviation" position. You will later need to repeat this procedure accurately while positioning prism P2.

5.3.3 Remove the mirror CM4 from its mount and let the fluorescence go through the mount. Use an IR viewer to observe the diffracted fluorescent spot on the laser enclosure end panel.

5.3.4 Rotate the prism while observing the diffracted fluorescence. As you rotate the prism you will notice that the diffraction angle decreases, reaches a minimum, and then increases again.

5.3.5 Repeat the above procedure observing the short wavelength part of the fluorescence and turning the prism clockwise until you reach the "minimum deviation" position.

You may need to view the transmitted fluorescence at some distance away from the prism to get a good reading of the minimum angle of deviation. CM4 can be used to redirect the fluorescence away in order to increase your accuracy.

5.3.6 The refracted beam from the prism must propagate at the standard height of 3.75" (9.55 mm). Adjust the beam height using the tilt table knob nearest the prism apex.

5.4 Cavity Mirror CM4

The position of mirror CM4 defines the prism's separation, thus ultimately controlling the width of the pulses generated by the NJA-5.

5.4.1 Position CM4 with its mirror mount at position K3 where it should intercept the residual pump beam. The spot corresponding to the 514 nm line should strike the mirror on the location in-between the center and the right edge of the mirror CM4.

5.4.2 The distance between the apex of prism P1 and the front surface of mirror CM4 is approximately 130 mm.

This distance is optimized for pulses with a 12 to 14 nm bandwidth. The position of CM4 can be optimized for other bandwidths, as shown in Table 5-1.

To generate shorter pulses you must reduce the prism separation. This is done by moving CM4 toward P1.

Note that for bandwidths greater than 15 nm, the pulses may be significantly chirped while propagating through the output coupler. This frequency-chirp can be eliminated with the help of an extra-cavity pulse compressor.

Please contact Clark-MXR for details.

To obtain longer pulses, the prism pair separation must be increased. This provides more negative dispersion for a given cavity material parameter.

The mount CM4 can be moved back as far as the enclosure allows. You may even rotate mount CM4 to gain an additional inch. (In this case, do not forget to invert the mirror as the pulses must be reflected by the front surface.)

Table 5-1

Pulse duration as function of CM4 position.

Prism-CM4 separation	Bandwidth supported	Pulse Duration
110 mm	35 nm	< 30 fs *
130 mm	12-14 nm	60-80 fs
150 mm	8-10 nm	>100 fs

950345

NOTE: Whenever the position of CM4 is altered, you must carefully realign P2 as described as follows.

5.5 End Cavity Mirror TCM5

■ **As you align the end mirror TCM5, the NJA-5 may lase. Proceed carefully after reviewing Chapter 1, "Eye Safety."**

To align the temporary end cavity mirror TCM5 you must first clear the optical pathway.

5.5.1 Loosen the set screw and disconnect the flexible shaft from the adjustment screw on the translation stage under the prism P2.

5.5.2 Remove the whole prism P2 ASSEMBLY from its position by loosening the two clamps that hold the translation stage.

5.5.3. Adjust mirror CM4 so that the green pump beam passes directly over the base plate location at E33.

5.5.4 Adjust mirror CM4 so that the beam is at a constant height of 3.75" (9.55 mm) above your laser base plate.

You may notice two sets of pump beam reflections: one set is associated with reflections from the front surface of mirror CM4, and the other set with reflections from the back surface of CM4.

5.5.5 Rotate the mirror and mirror holder within the mirror mount so that these two sets of pump beam spots are vertically displaced from each other. This makes the alignment of the mirror CM4 easier. The beams reflected from the front surface are the set that lie in the same plane as the fluorescence from the rod which can be seen with the IR viewer.

5.5.6 Place a card in front of the auxiliary cavity end mirror TCM5 to block the cavity beam.

5.5.7 *With the help of an IR viewer*, you should see a horizontally elongated fluorescent spot. Position TCM5 to be centered on the fluorescence strike. (The exact position is a function of the location of CM4. TCM5 should be at or in the vicinity of [G20]).

■ **With the help of the IR viewer, verify that no beams or reflections escape from the NJA-5 enclosure.**

5.6 CW operation, 1-prism cavity

You will now align the mirror TCM5 to bring the laser into the cw operation mode.

5.6.1 Place a white card just to the left of prism P1 as shown in Figure 5-C. This card should intercept the Ti:Sapphire fluorescence reflected by mirror TCM5 back onto mirror CM4, and then toward prism P1.

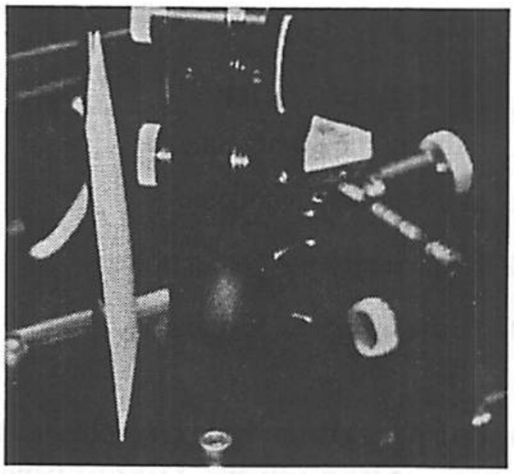


Figure 5-C

Location of P1 and alignment target card.

5.6.2 Using an IR viewer, look for a fluorescence strike on this card. As you turn the horizontal alignment adjustment of mirror mount TCM5 you will eventually see a fluorescence mark and the shadow of the prism.

■ **Proceed with *Caution*. The NJA-5 may lase at any time during this procedure**

5.6.3 Adjust the horizontal alignment of TCM5 so that the bright fluorescent line disappears into the shadow of the prism. Watch for a flash of light that indicates that the cavity is in alignment and lasing.

When the vertical and horizontal alignments are correct the cavity will lase. If it doesn't, evidently something is not aligned properly. Check the following:

5.6.3.1 The fluorescence reflected back from mirror CM1 overlaps the fluorescence from the rod at the level of CM2. Place the alignment tool in-between CM1 and CM2 and let the fluorescence center go through the larger reference hole in the tool. Check and make sure that the fluorescence reflected from CM1 is back to the center of the reference hole.

5.6.3.2 The vertical height of the fluorescence from mirror TCM5 is overlapping the fluorescence from the rod at the level of P1. (This should be very close to the standard height of 3.75" (9.55 mm).

5.6.4 If the laser is not lasing, place a large area non-biased photodetector after the output coupler and connect it to a ammeter.

5.6.5 Adjust mirrors CM1 and TCM5 to maximize the photocurrent.

5.6.6 If the NJA-5 still does not lase, translate mirror CM3 to maximize the photocurrent intensity.

5.6.7 As a last resort the pump lens L1 can be translated to maximize fluorescent intensity.

5.7 CW operation, Optimization

You will need a power meter to optimize the cw alignment.

5.7.1 Place the power meter after the output coupler.

5.7.2 Adjust CM1 and TCM5 to maximize the output power.

5.7.3 Translate mirror CM3 to either direction to maximize the output power.

■ **In the following alignment procedure be extremely careful to avoid any eye hazard. Although the Ti:Sapphire beam looks dim by eye, it has a power level of hundreds of mW. Use your IR viewer to check around for stray beams.**

5.7.4 Intercept the output beam with the mode tool concave reflector. Reflect the beam towards a non-reflective target as shown in Figure 5-D.

5.7.5 Observe through an IR viewer to make sure the output beam is TEM_{00} mode. If it is not, translate CM3 until it is.

5.7.6 Adjust the position of the pump focusing lens L1. Rotate the knurled knob that translates the lens along the direction of propagation of the pump beam until power output is at a maximum. It is very important that the optimum position is NOT too close to the end of the travel range.

■ **Try not to put too much hand weight onto the lens mount. The spring-loaded X and Y axes may drift under pressure.**

5.7.7 Adjust CM1 and TCM5 again to maximize the power output.

5.8 Transverse Mode Optimization

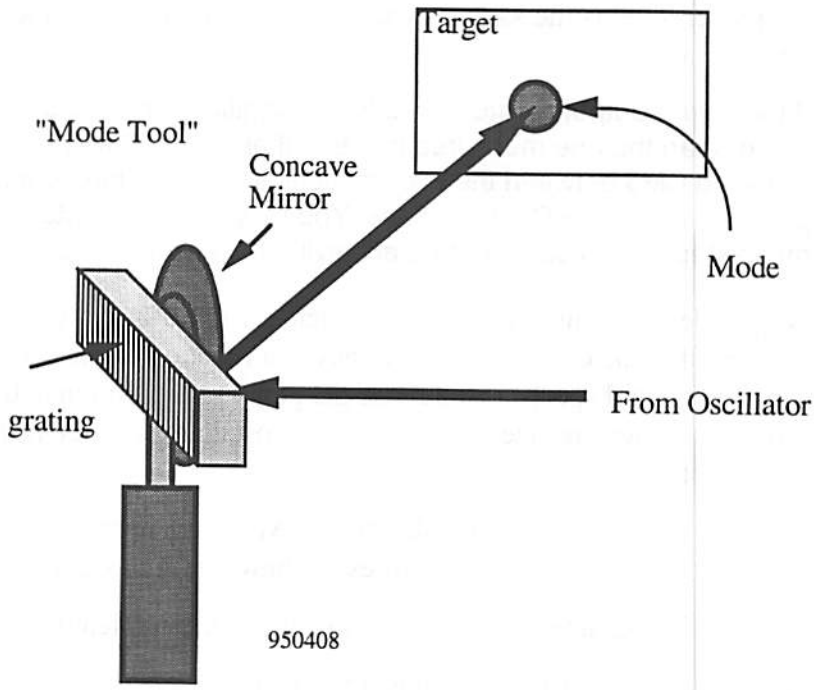
After this initial power maximization procedure, you need to optimize the output beam transverse mode. This is a critically important process. It will determine how well your NJA-5 modelocks. Therefore, extreme care should be taken in the next steps.

In the following alignment procedure be extremely careful to avoid any eye hazard. Although the Ti:Sapphire beam looks dim by eye, it has a power level of hundreds of mW. Use your IR viewer to check around for stray beams.

5.8.1 Place the mode tool on the output beam and reflect the beam towards a target as shown in Figure 5-D.

Figure 5-D

Setup for transverse mode observation.

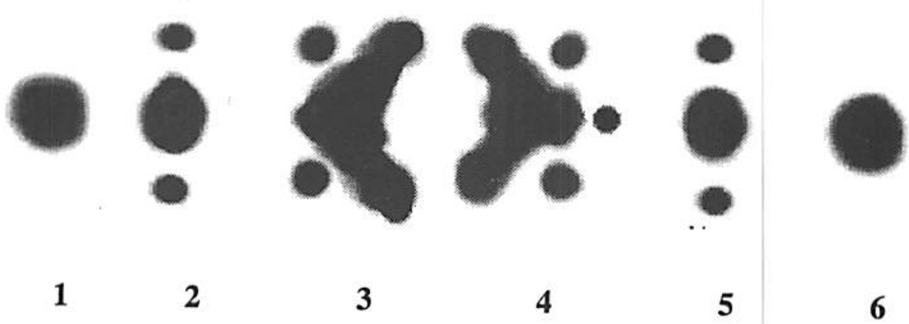


5.8.2 Translate mirror CM3 back and forth while observing the target with your IR viewer. You should see a series of mode structures similar to those shown on Figure 5-E.

These mode should be seen when the distance between the front surface of mirror CM3 and the closest surface of the Ti:Sapphire rod is in the 50 mm ± 0.5 mm range.

Figure 5-E

Mode structures observed when scanning CM3.



The two positions #1 and #6 correspond to TEM_{00} mode.

5.8.3 Translate mirror CM3 to the TEM_{00} position farthest away from the Ti:Sapphire rod. Measure the output power and record this value. (Lower the pump power if the output power from NJA exceeds 600 mW.)

5.8.4 Translate mirror CM3 to the TEM_{00} position closest to the Ti:Sapphire rod. Measure the output power and record the number.

If the output power level is the same as was measured in 5.8.3, then the cavity is well aligned.

5.8.5 If the power output recorded in 5.8.4 is significantly lower or higher than the one measured in 5.8.3, then adjust CM1 and translate CM3 between the two positions to balance the output power in these two CM3 positions. You may have to iterate these steps a few times before achieving the desired result.

P

At the TEM_{00} mode positions, a conversion efficiency of 10% or greater is desirable. Note that the conversion efficiency is a function of the divergence, mode quality, and spectral content of the pump laser. You may try to vary the ion laser aperture size to optimize your oscillator's efficiency (see Section 5.9 for details).

The cavity is well aligned when a translation of CM3 over approximately 0.5 mm generates a series of mode structures as shown in Figure 5-E.

A good alignment is characterized by the following additional features:

- The output power is highest at the positions #1 and # 6.
- The output power levels are nearly equal at positions #1 and #6.
- There is a local minimum between positions 1 and 6.
- Mode #2 and mode #5 may not be very pronounced.
- Mode #3 and mode #4 are close to the so-called "angel fish" mode and they are very close together.

Obtaining good TEM_{00} modes at positions #1 and #6 and the "angel-fish" mode is the primary goal for the cw-cavity alignment.

P

5.9 More on Mode Optimization

As shown in 5.8, the horizontal adjustment of CM1 and the position of CM3 determine the output mode structure of the laser.

First time users often are not able to meet the criteria listed in 5.8.5 (they may find the TEM_{00} modes, but not the full mode series described above). Should you encounter this problem you may try to iterate the adjustment of CM1 horizontal and CM3 positions while observing the output mode structure.

5.9.1 Start at an arbitrary CM3 position. Align the cavity to maximize the output power. Record this value.

5.9.2 Turn the horizontal adjustment of CM1 a quarter turn counter-clockwise.

5.9.3 Scan CM3 through its range while observing the output mode structure. Look for a mode shape close to the angelfish modes. Repeat 5.9.2 and 5.9.3 a few times until such a mode structure is present.

5.94 If unsuccessful, go back to the initial alignment and repeat steps 5.9.2 and 5.9.3 turning the horizontal adjustment of CM1 clockwise.

5.9.5 Leave CM3 on position where angelfish mode occurs. Scan the horizontal of CM1 until a distinct angelfish mode occurs as shown in Figure 5-E.

5.9.6 Return to the regular alignment procedure at 5.8.3.

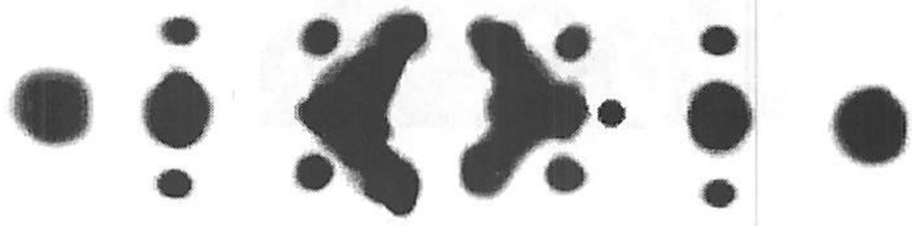
If this approach still fails to generate the proper mode sequence, we recommend that you start the alignment procedure over again.

6. NJA-5 Alignment Procedure, Modelocked Operation.

You must be able to reproduce the mode structure series shown in Figure 6-A before proceeding with the modelocked alignment procedure described in this section.

Figure 6-A

Transverse mode series .



1 2 3 4 5 6

6.1 Pre-aligning the modelocked cavity.

You will now add a second prism to the cavity, replace mirror TCM5 with mirror CM5, and finally add the wavelength tuning element. This procedure is relatively simple as most of the cavity elements are already aligned (Please do NOT adjust any of the cavity elements unless specifically instructed to do so).

EYE PROTECTION REQUIRED

6.1.1 Center the alignment tool on the beam propagating from CM4 to TCM5, as close as possible to prism P1. Use the large aperture size so that it just begins to cut into the beam diameter.

■ **Do NOT move this alignment tool until the cavity alignment is finished.**

6.1.2 Remove the piezo mounted mirror CM5 from its gimbal mount. Slide aside the slit assembly after loosening the base clamp. (*See* Figure 6-B.)

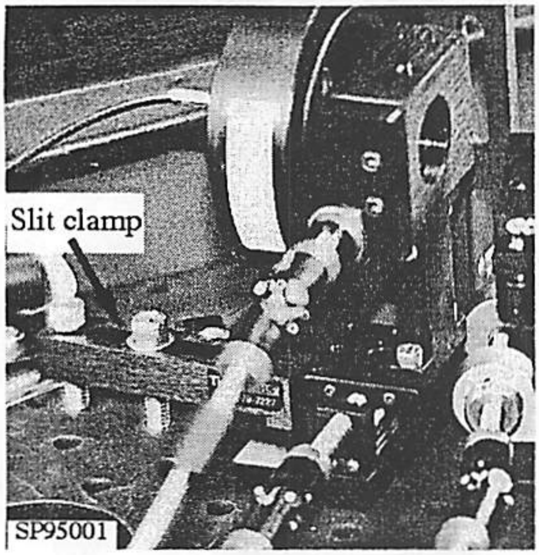


Figure 6-B

Slit clamp location.

6.1.3 The gimbal mount should be attached to the breadboard as shown in Figure 6-C. The coarse orientation of the mount is determined by rotating it so that position [L17] is accessible from the first slot nearest the lower-right section of the base as shown in Figure 6-C.

The gimbal mount should be centered with respect to the opening in the enclosure lid.

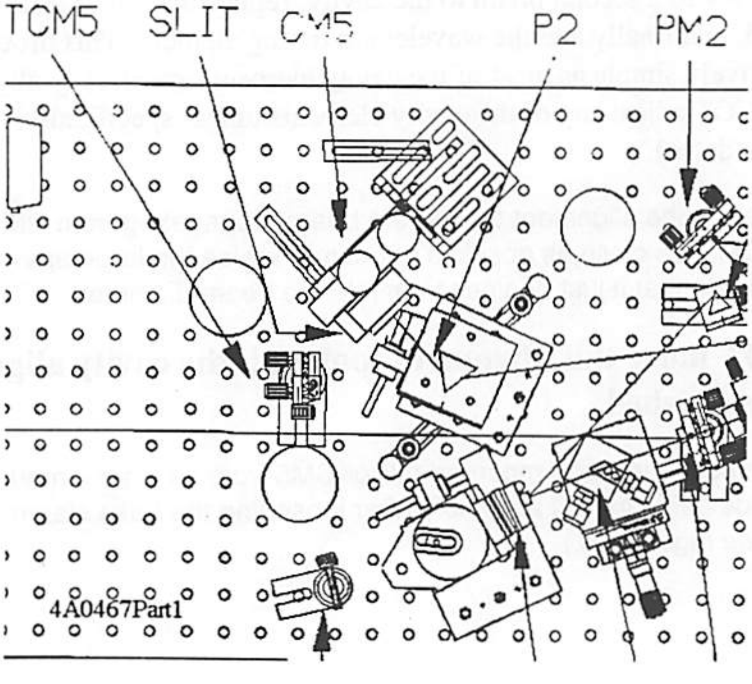


Figure 6-C

Location and orientation of gimbal mount CM5.

6.1.4 Tighten the screw to fix the position of the assembly.

6.1.5 Check the apex of the prism P2 is pointing along the line of travel of the translation stage. This is important.

6.1.6 Orient prism P2 as shown in Figure 6-C.

6.1.7 Slide the entire prism assembly P2 into the beam propagating from CM4 to TCM5. You want to intercept only part of the laser beam (*that is*, a portion of the beam will still propagate towards TCM5, while the rest will be diffracted towards CM5).

6.1.8 Position and orient P2 to direct the diffracted portion of the beam towards the center of the CM5 mirror holder.

6.1.9 Slide slightly P2 to intercept the entire beam. The cw-cavity should stop lasing. The fluorescence spot diffracted from the prism P2 should be horizontally elongated. Keep in mind that it is apertured by the alignment tool.

6.1.10 Place a card just in front of mirror mount TCM5.

■ **In the next step you will temporary remove one of NJA-5 side safety shields. You must reposition this protective shield after completion of step 6.1.15.**

6.1.11 Remove the internal protection side panel located behind CM5. Let the fluorescence diffracted by P2 propagates through the center of the CM5 mount.

6.1.12 Place a white target card to intercept the fluorescence. The vertical edge of the card will be used as an horizontal position reference.

6.1.13 Rotate the *whole prism assembly* P2 around an imaginary vertical axis near the prism apex. Search the angle of minimum deviation as explained in Section 5.3.4. Use the same criteria as with prism P1.

This is a difficult alignment step which must be accomplished with great care and patience. The modelocked performance of the NJA-5 depends critically on the careful alignment of the prism pair. Practicing a few times the alignment of P2 is strongly recommended.

6.1.14 Clamp the P2 assembly in place using the BC clamps shown in Figure 6-C.

6.1.15 Adjust the tilt of the prism mount to maintain the beam at a constant height of 3.75 inches (9.55 mm) above the surface of the base plate.

■ 6.1.16 Replace the protection side panel.

6.1.17 Place the mirror CM5 in its gimbal mount. Lock it firmly in place (*See* Figure 6-D).

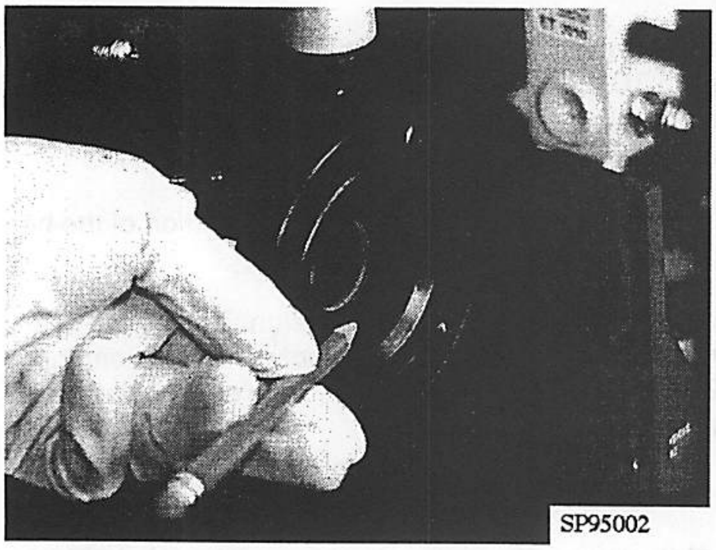


Figure 6-D

Locking the end cavity mirror in mount CM5.

■ When the next alignment step is completed, the NJA-5 will again lase. Follow the safety rules presented at the front of this manual.

6.1.18 Center the fluorescence reflected by mirror CM5 onto the alignment tool's aperture (*See* Section 6.1.1). You may need to first coarsely adjust the CM5 mount position by loosening the screw that holds the mount riser bracket. Tighten the screw and the clamp after the fluorescent spot is roughly on target.

6.2.19 If the NJA-5 does not lase, check:

- the prism P2 diffracts the proper amount of the fluorescence towards CM5 (*See* 6.1.9 for the shape of the florescence spot from the prism P2).

- the optical surfaces of the prism P2 are clean. If necessary, clean as instructed in Chapter 8.

6.1.20 Before proceeding further, check that the NJA-5 enclosure lid can be positioned without interfering with the gimbal mount CM5.

6.2 Installing the wavelength control hardware

The NJA-5 is now ready to generate femtosecond pulses.

6.2.1 Optimize the alignment of CM5 to reach roughly the same output power output level than that obtained in the 1-prism, 5-mirror cw cavity.

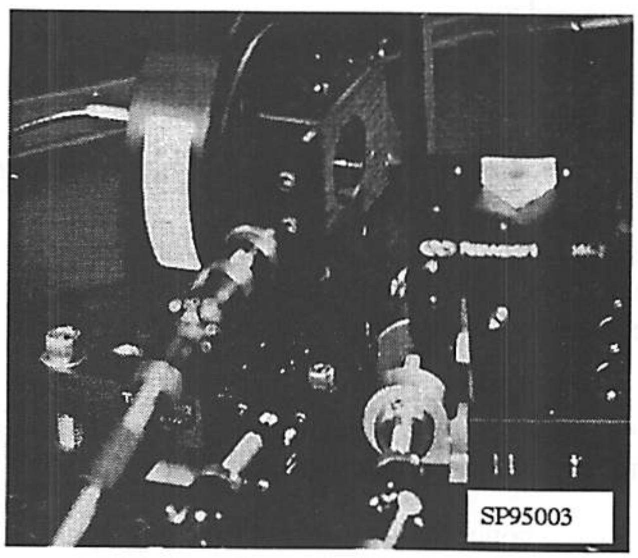
If the 2-prism, 5-mirror cavity does not lase, translate the prism P2 out of the beam and optimize again using TCM5. Then insert P2 again and optimize the cavity.

You will now insert the slit assembly in the cavity. The function of the slit is to control the bandwidth and to select the operating central wavelength.

6.2.2 Position the slit assembly between the prism assembly P2 and the end mirror CM5 as shown on Figure 6-E.

Figure 6-E

Location of slit.



6.2.3 Check that the adjustment screws should point in the direction shown in the Figure 6-C

6.2.4 Clamp the slit assembly at position [K20].

6.2.5 The translation stage to which the slit is attached should be centered in its range of travel and its jaws opened to about 3 mm separation.

6.2.6 Center the cavity beam into the slit opening by positioning the slit such that the cavity produces the highest output power.

6.2.7 Connect the flexible shafts to the control screws on the slit assembly so that the slit aperture and central position can be controlled from the outside of the NJA-5 (*See* Figure 6-F).

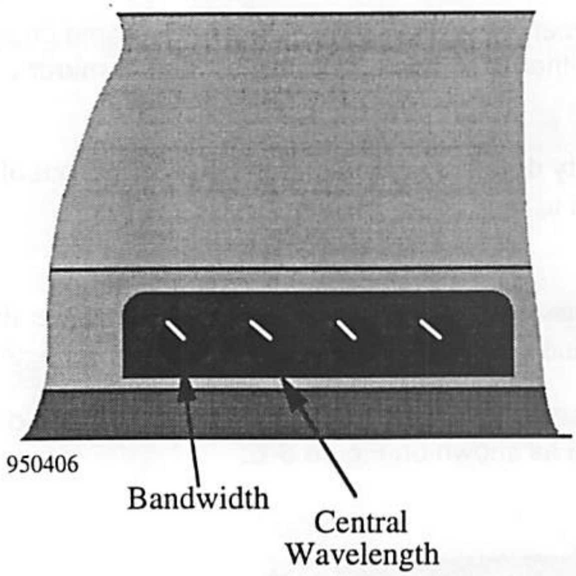


Figure 6-F

External control for the slit.

6.3 Installing the NJA-3E Starter

A fast photodiode (PD) is included with your NJA-5 (*See* Figure 6-D.) You will use this fast photodiode to monitor the generation of the femto-second pulses and to provide a feedback signal to the NJA-3E electronic starter

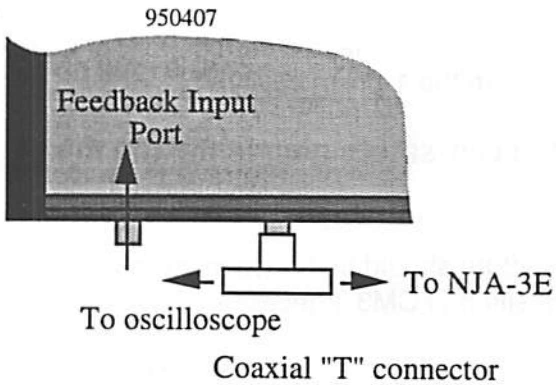
6.3.1 Adjust the beamsplitter BS located near the output coupler to direct part of the output beam onto the photodiode.

The output of the photodiode is connected to the front panel through a coaxial cable.

6.3.2 Place a BNC "T" on the photodiode output port. Connect one side to a 50 Ω oscilloscope input using a coaxial cable. Connect the other side of the "T" to the front panel of the NJA-3E (*See* Figure 6-G).

Figure 6-G

Photodiode signal outputs.



6.3.3 Connect the BNC located on the back panel of the NJA-3E to the feedback input port (*See* Figure 6-G.)

6.3.4 Connect the feedback input port to the mirror CM5 using the special BNC to SMB coaxial cable.

6.3.5 Set the oscilloscope vertical scale to 2 mV/division. Set the horizontal sweep rate to 1 ms/division.

6.3.6 Adjust the beamsplitter to maximize the oscilloscope signal.

You are now ready to modelock the NJA-5.

6.4 Modelocking the NJA-5

6.4.1 Check that the NJA-5 is producing about 400 - 600 mW with 4 Watts of pump power.

■ In the next step you should be careful NOT to endanger yourself or others with the Ti:Sapphire beam.

6.4.2 Use the mode tool to observe the spatial mode structure coming from the laser). While translating CM3, you should see mode #1, #3 & #4 (usually very close together) and mode #6. (*See* Figure 6-A.)

6.4.3 Translate mirror CM3 so that it is near the #3 & #4 modes.

6.4.4 Check the cavity beam is near the tip of prism P1 (without clipping the beam). If it isn't, then correct by adjusting as detailed in the Section 5.3.

6.4.5 Use an IR viewer to observe the beam in prism P2. Translate the prism so that the beam is going through it and close to the apex.

6.4.6 Slightly misalign mirror TCM5 or place a card in front of it to avoid accidental lasing on the 1-prism cavity.

■ **Wear the appropriate laser safety goggle for the next steps.**

6.4.7 The output mode structure should be between the #3 and #4 modes. Adjust the position of CM3 if necessary.

Now you want to create a "noise burst" that will initiate the modelocking process.

6.4.8 Rapidly pull the translation stage under P2 to translate the prism through the beam, while watching the output of the photodiode on your oscilloscope.

Be sure that your hand does not block any of the intra-cavity beam. You should see on the oscilloscope the momentary formation of an "unstable" pulse train under an envelope that collapses when you stop pushing the prism. Normally the pulse train will collapse when you stop moving the prism.

You must now find a cavity configuration where this pulse train is stable when the prism is NOT moving. Fortunately this can be done optimizing only the position of CM3.

6.4.9 Repeat the above step while translating the mirror CM3 slowly in either direction. When you find a region where the pulse train formation seems to be more steady, hold the prism in that position to see if a stable pulse train forms. When you are close to the optimum CM3 position alignment, the initial motion of the prism will cause the pulse train to form. When you stop moving the prism the pulse train should be stable.

6.4.10 Continue moving the CM3 translation stage slightly. You should reach a region where the pulse train is particularly stable, and the output spectrum is broad.

As you translate the cavity mirror CM3, you may need to stop periodically to adjust the end-cavity mirrors to optimize the power output.

6.4.11 Verify that the translation stage to which the slit is attached is at the center of its travel range, and the slit width opening is approximately 3 mm separation. The beam should be centered on the slit.

6.4.12 If necessary center the monitoring beam onto the photodiode.

6.4.13 Optimize the cavity alignment for maximum power output. Lower the pump power if the NJA-5 output power is greater than 500 mW.

6.4.14 Fine tune the cavity alignment to maximize the height of the pulse train on the oscilloscope (*that is*, the peak power).

6.5 Getting familiar with the modelocked unit

At this stage is worth spending some time gaining experience with the behavior of the NJA-5.

6.5.1 Even weak air currents may strongly disturb the performance of your laser. You should close the NJA-5 cover (you should be able to reach prism P2 through the trap located in the lid) and install the beam tubes from the ion laser to the NJA-5 enclosure.

■ **Before proceeding further you should check that the argon-ion laser beam path is fully enclosed.**

6.5.2 Observe the mode structure series as function of the position of CM3. Note the range over which the modelocking process can be induced by moving the prism.

6.5.3 Using the grating located on the back of the mode tool, observe the bandwidth as function of the position of CM3. Note the range over which the modelocking process can be induced by moving the prism

6.5.4 Observe the spectrum and its bandwidth while adjusting the width and position of the slit. Try to clip the beam slightly with the slit. You may at times notice some “bright” spots. These are caused by cw components that is concurrent with modelocked operation. Try adjusting the slit and/or pump power to eliminate these cw spots.

6.5.5 The NJA-5 bandwidth is a function of the cavity dispersion. This is set by the intra-cavity prism pair separation and by the amount of glass inserted in the cavity. Moving P2 into the beam will increase the amount of intra-cavity glass of the prism P2. This will results in a larger bandwidth .

6.5.6 When you add glass, you also will need to open the slit for stable performance. This exercise can be push only to some extend: the GVD of the prism material cannot be fully compensated by the GVD created by the prism separation (*that is*, higher order terms do not cancel). If too much glass is added to the cavity, the modelocking will become unstable and eventually will go back in a cw-mode.

Ultimately you should obtain a *stable* output pulse train with spectrum free of cw components.

6.6 NJA-3E, Automatic Start-up

The NJA-3E electronics package provides a means to automatically initiate modelocking from a laser operating in the cw mode.

There are 4 adjustments on the front panel.

THRESHOLD:

This analog adjustment allows you to set the maximum voltage level at which the NJA-3E goes into action.

3-POLE SWITCH:

AUTO: In the "Auto" position, mirror CM5 is activated only to re-initiate modelocking (*that is*, when the photodiode signal falls below a certain value set by the "THRESHOLD"). This is the standard position after the initial alignment.

ON: In the "ON" position, mirror CM5 is constantly activated. This position is used during alignment of the laser.

OFF: This is a standby position. The actuator is inactive.

FREQUENCY: This analog adjustment is used to set the perturbation frequency

GAIN: The analog gain adjustment is used to control the amplitude of the motion of mirror CM5.

6.6.1 Turn on the NJA-3E, and switch the 3-pole switch on the front panel to the "ON" position. You will hear a buzzing sound generated by the piezo activator.

In this mode the NJA-3E constantly activates mirror CM5. The frequency and amplitude of this perturbation can be varied from the NJA-3E front panel.

6.6.2 Place the NJA-3E front switch to the "AUTO" position.

In this mode the NJA-3E activates the mirror CM5 only when the input signal falls below a certain threshold.

6.6.3 Adjust the threshold so the NJA-3E will (i) be active when the laser lases cw and (ii) be inactive when the laser is modelocked.

6.6.4 Adjust the frequency and amplitude gain until the NJA-3E automatically brings the laser into its modelock mode of operation.

The end mirror CM5 is attached to a piezo-activator. Each piezo activator has a particular set of resonance at which it is most effective. Finding the exact setting may take some experimentation (you may have to adjust CM3 slightly!).

Often setting the FREQUENCY and GAIN to create a few percent modulation across the top of the pulse train is quite effective.

Once the piezo actuator is set, the NJA-5 will automatically be pushed from cw-operation to modelock operation.

If you have difficulty operating the NJA-3E you may want to look again at the mode series shown in Figure 6-A and start again the alignment from that point.

Ultimately, you will begin to develop a sense of which adjustments to make to optimize the performance of your particular laser.

Read Chapter 7 on operational notes *before* proceeding any further.

7. Daily Operations

7.1 Turn-on Procedure

7.1.1 Turn on the water cooling to the ion laser and to the Ti:Sapphire rod (if not already turned on).

7.1.2 Close the output shutter of the NJA-5.

7.1.3 Turn on the ion laser.

■ **The argon beam should be fully enclosed.**

7.1.4 **Adjust the ion laser pump power to its operational parameters** (*that is,* the same parameters as the previous operating day).

7.1.5 Let the ion-argon pump laser reach its operating temperature.

It is important that the ion laser be allowed to stabilize thermally before attempting to operate the NJA-5. Thermal changes in the ion laser will produce (a) mode change and (b) beam pointing directional change — effectively shifting the position of the pump beam with respect to the Ti:Sapphire rod.

Do yourself a favor, do not try to align the NJA-5 until the argon has fully warmed up. You will only make matters worse if you do so. ***Wait*** until the argon laser is warmed up. (Patience is a virtue!) Once the argon is warm, the NJA-5 will operate without any realignment.

7.1.6 If your laser is equipped with PointMaster, turn on the high voltage, press the "pre-align" key, press the "lock" key, and press the "F1" key.

7.1.7 Switch the NJA-3E electronics to the "AUTO" mode.

The NJA-5 laser should modelock immediately. If not, activate the mod-elocking manually with prism P2.

Units that are not equipped with PointMaster may require minor cavity readjustments to compensate for argon-ion beam wander.

7.2 Daily shutdown procedure

7.2.1 Record the operating argon-ion pump power and NJA-5 output power.

7.2.2 Set the NJA-3E 3 poles switch to the "OFF" position.

7.2.3 If your NJA-5 is equipped with PointMaster, then press the "lock" key, press the pre-align key, and turn off the high-voltage. Do **NOT** turn off the AC power.

7.2.4 Close the NJA-5 input shutter by turning the key counterclock-wise.

7.2.5 Reduce the ion laser power output.

7.2.6 Turn off the ion laser.

7.2.7 Do **NOT** turn off the NJA-5 temperature stabilizer.

7.2.8 For faster turn-on, do **NOT** turn-off the water cooling to the Ti:Sapphire rod.

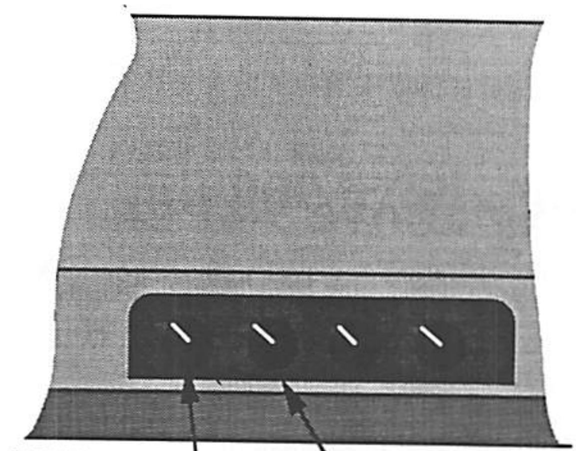
7.2.9 Turn-off the water cooling to your argon-ion laser after the manufacturer's suggested cooling period.

7.3 Wavelength Tuning (700 nm to 900 nm)

All NJA-5s are factory-tested and shipped with a set of mid-range optics (except for special orders). The mid-wavelength optics that came with your NJA-5 should cover the range from 750 nm to 880 nm. Tuning over this range is done by translating the position of the tuning slit (see Figure 7-A.)

Figure 7-A

Slit adjustment (width and location).



GVD is a function of the central wavelength. Thus, you may have to adjust the amount of intra-cavity glass while tuning. This is done by adjusting the position of P2 (see Figure 7-A.)

Should you need to operate outside of the mid-wavelength range, you will need to install another set of optics. At present, Clark-MXR offers two additional sets: (a) a short-wavelength range, and (b) a long-wavelength range. The short-wavelength optics allow operations from 700 nm to 830 nm. The long-wavelength optics allow operations from 860 to 990 nm.

When changing from one set to another we suggest that you proceed as follows:

7.3.1 Tune the laser to a wavelength where the installed mirror set overlaps the operating range of the new set of mirrors.

7.3.2 Check that modelocking is maintained. You may have to adjust the pump power to compensate for change in gain, and in output coupler transmittance.

Remember that the important parameter is the intra-cavity power. As long as you can maintain it at a constant level the laser should modelocked. Minor adjustments of the intra-cavity glass (insertion of prism) may be required to compensate for change in GVD.

7.3.3 Install the new mirrors *one at a time.*

7.3.4 Verify after each mirror change that you can again modelock the NJA-5.

7.3.5 Once the new mirror set is fully installed, tune to the wavelength of interest.

7.4 Operating above 900 nm

Nitrogen purging is necessary for operation at wavelengths beyond 900 nm.

When operating above 900 nm, do not open the enclosure.

7.4.1 Start from 880 nm (with the laser modelocked).

7.4.2 Tune the laser slowly to longer wavelengths. If modelocking suddenly stops, then increase the Nitrogen flow. You may have to wait, especially in humid operating conditions.

8. Maintenance

The NJA-5 requires no maintenance besides an occasional cleaning of the optics.

8.1 Optics Cleaning

Occasionally, it may be necessary to clean the optics and surfaces of the Ti:Sapphire rod. Indications that this may be necessary are a general degradation of the NJA-5 power output and its performance over a period of time.

Purging the NJA-5 enclosure with a slow flow of dry nitrogen helps keep the optics clean and reduces the need for optic cleaning. (In addition, an atmosphere of Nitrogen stabilizes the laser performance and its stability. See Section 2.2.6 for details).

■ **Before any optic cleaning, close the input shutter**

8.1.1 Blow any excess particles from the surface using a flow of dry nitrogen.

8.1.2 Fold a piece of lens tissue into a pad and clamp with a hemostat (usually provided with the ion laser).

8.1.3 Wet this pad with spectroscopic grade acetone or methanol, and shake off the excess liquid.

8.1.4 Make **one curvy stroke only** across the surface (Using the same cleaning pad more than once will spread contaminants over the optics, and may even damage the surface.)

8.1.5 Repeat the above step with a solvent-wetted clean pad if necessary.

We recommend that you use methanol for the first cleaning, and acetone for the final cleaning.

Do not use contaminated solvents!

Acetone and Methanol will not remove "water stains." For optical components that have been contaminated with water, first use distilled water to gently clean the surface and remove the water stain, then follow the instructions from 8.1.1 down.

9. Trouble Shooting

Standard NJA-5s are designed to operate with small frame ion lasers (4 watts pump). The NJA-5 output power is typically between 400 to 600 mW (at 800 nm). Pumping a standard NJA-5 at higher power will result in an unstable operation.

Should you have need for a higher output power, contact Clark-MXR for technical advise.

9.1 Low Efficiency

The NJA-5 efficiency (*that is,* the ratio between the output power and the pump power) is a function of several factors. As you may imagine, the "quality" of the NJA-5 alignment and the cleanliness of the cavity optics, are important factors. Just as important is the spatial quality, the spectral content, and the divergence of the pump beam. Less important are the rod cooling and rod doping.

The typical efficiency is 10–15 % (at 800 nm)

9.1.1 Argon-ion pump laser

Poor ion laser transverse mode quality is the most common cause of low conversion efficiency in Ti:Sapphire oscillators. The ion laser mode quality cannot usually be assessed through simple visual inspection (the eye saturates too easily). You will need some type of two-dimensional detector to quantitatively assess the beam quality of your argon-ion.

The highest efficiency is obtained with the TEM_{00} pump beam. Note that most argon-ion lasers operating in the multiline mode are likely to *not* be truly TEM_{00}. This condition will decrease the efficiency, but it is not critical as long as the beam transverse spacial mode is stable (*that is,* the transverse mode does not change with time).

The efficiency is highest for argon-ion lasers running single wavelengths on the 514 nm line. But multiline operation is perfectly acceptable.

Finally, the efficiency is a function of the argon-ion beam divergence. This dependency can be corrected to some extend by repositioning the pump laser lens

9.1.2 NJA-5 cavity alignment

The oscillator alignment, of course, is essential to have a good conversion efficiency *and* a good output mode structure. If you do not observe the series of modes illustrated in Figure 6-A, it is likely that your laser is poorly aligned.

Check that the beam is always maintained at a high of 3.75" above the base plate. Verify that the cavity optical components do not introduce any beam clipping (use an IR viewer). Pay special attention to the prism P2. The intra-cavity beam should be close to the apex, but well confined in the prism.

9.1.3 Pump lens alignment

As mentioned above, the pump laser beam divergence affects the efficiency. If you use a different ion-laser than the one used at Clark-MXR for testing, then it is likely the beam divergence will be different. Repositioning the pump lens may be necessary to correct for this divergence change. Follow the instructions in Chapter 5.

9.1.4 Optical losses

Dust on the surfaces of the optics will scatter light and lower the conversion efficiency of the laser. Clean the optics when necessary following the instructions in Chapter 8. Using a constant overpressure of clean Nitrogen should almost completely eliminate the need for optical cleaning.

9.1.5 Ti:Sapphire rod temperature

The efficiency of the Ti:Sapphire laser is a function of the Ti:Sapphire rod temperature. The higher the temperature, the lower the efficiency. Make sure the water cooling is cold (but not too cold!. You must avoid condensation at all costs).

9.1.6 Ti:Sapphire rod quality

The Ti:Sapphire rod quality affects the laser performance. The factory tests performed before shipping ensure the very crystal in your laser meets our demanding quality control criteria. In rare conditions, external factors such as feedback from other lasers or operation without cooling may degrade the quality of the rod. Simple visual inspection should reveal any damage to the rod.

- **Never inspect the Ti:Sapphire rod (or any optics) while the NJA-5 is lasing and/or pump by the argon-ion.**

Ti:Sapphire is extremely hard. You can clean it quite aggressively should any dust be attached to the rod end surfaces.

9.2 Poor Long-Term Stability

The long-term stability of your NJA-5 is to a great extend a function of the stability of your pump laser. The operating temperature is the other important factor affecting the long term stability

9.2.1 Beam pointing instability

Most argon-ion lasers suffer from poor beam pointing stability. This is the most common cause of drift in the NJA-5. A shift of a fraction of a pump beam diameter will drastically affect the stability of the NJA-5. This level of drift *cannot* be observed by the eye.

In general, this beam pointing drift will decrease (sometimes significantly) after a warm-up period. Thus, it is critically important that you let your argon-ion laser warm-up before attempting to align the NJA-5.

Clark-MXR manufactures a computer controlled device called PointMaster™ that will correct for beam-pointing drift. We have found that NJA-5s equipped with PointMaster™ are significantly more stable than conventional units. All NJA-5s are manufactured to be compatible with PointMaster™. Our in-house tests show that after the initial warm-up, NJA-5s equipped with PointMaster™ will stay modelocked indefinitely. Contact Clark-MXR for details.

9.2.2 Pump laser transverse mode instability

Any variations in the pump laser transverse mode structure will drastically affect the NJA-5. Most Argon-ion lasers are likely to be affected by this problem. In general, the pump laser mode will stabilize after an initial warm-up period.

In addition some transverse mode variations may be caused by water cooling pressure fluctuation. You can reduce this effect by installing a pressure tank on your water cooling system. See Chapter 2 for details.

9.2.3 Temperature drift

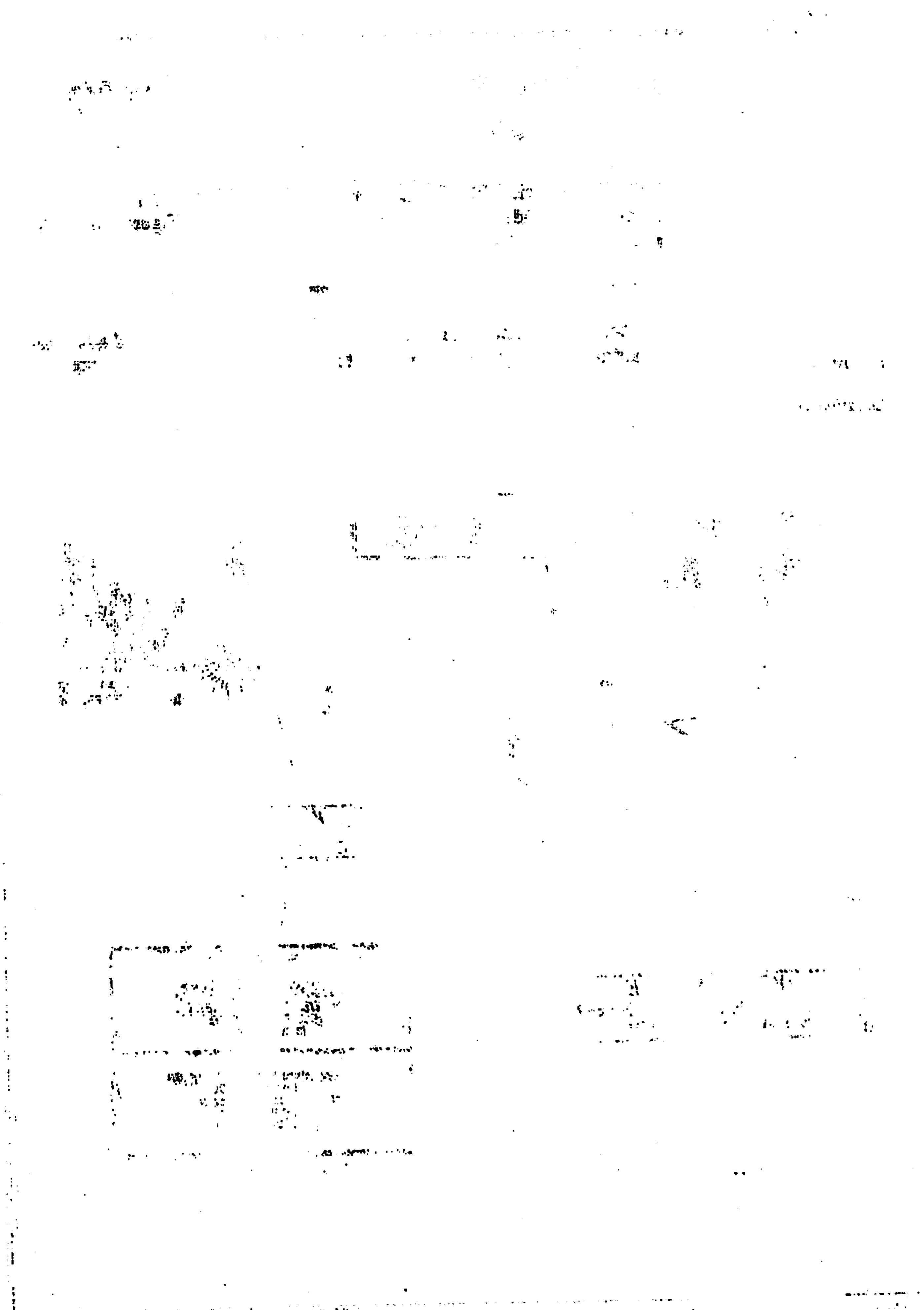
Temperature drift will affect the long term stability of your laser. Temperature changes can cause the argon-ion laser plasma tube to change shape, they will distort your optical table and physically move the whole ion laser frame relative to the Ti:Sapphire laser cavity. Certainly temperature drift will affect the alignment of your oscillator. To minimize these effects we have equipped the NJA-5 with a computer-controlled internal temperature stabilizer. This stabilizer should be left on at all times.

■ **Do NOT turn the temperature stabilizer off ever!**

The stability of the water used for cooling is also important. We recommend that you keep the temperature stable to within one or two degrees.

10. Theory

Work in progress. Contact Clark-MXR for a copy once available.



11. NJA-5, Location of the Safety Labels

In accordance with CDRH regulations, the location of the various safety labels that should be affixed to your NJA-5 are shown in Figure 11-A. Do not remove these labels.

Please refer to Chapter 1 for detailed (Eye) Safety information.

Caution: use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

Figure 11-A

Location of safety labels.