

Titan-CW

CW Ti:sapphire laser

Operation Manual

1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction and Manual Outline

The Titan-CW series lasers generate, tunable radiation from wavelengths below 700 to beyond 1000 nm. Based on the Ti:sapphire crystal, the lasers provide Watt-level output powers in a broad wavelength span around the peak operating point at 800 nm, when optically pumped by the output of argon-ion or similar visible-wavelength lasers. This introductory section provides a brief discussion of the basic physics of Ti:sapphire and a general description of the system. A more specific treatment of the Titan-series of products appears in Section 2. You do not have to read the first two Chapters to proceed with the installation and operation of the Titan-CW series system; they are for your reference use and we hope they will be of interest to you in understanding the basis for operation of Ti:sapphire lasers.

Important!

We do urge you to start any installation first by reading Section 3, which covers the safety aspects of the Titan-CW series devices. The combination of power output and operating wavelengths of these lasers are more than sufficient to be hazardous to your both your eyesight and your skin, as well as being sufficient to ignite a fire under the right conditions, and we strongly advise you to be aware of the location of output beams and the safety features of these lasers.

1.2 Theory

Ti:sapphire (Ti^{3+} ions in an Al_2O_3 host crystal) is a solid state laser medium characterized by an unusually broad gain bandwidth, which allows laser operation over a wider frequency tuning range than other CW solid state or dye lasers.

Energy levels

The use of Ti^{3+} as the active ion in Ti:sapphire places the laser in the class of 3d-transition-metal systems that also include Cr^{3+} -, Ni^{2+} - or Co^{2+} -doped crystals. The Ti^{3+} ion, with only one valence electron, has the simplest energy-level structure of all the laser-active transition-metal ions. The single 3d electron in isolation has a five-fold-degenerate, lowest-energy level, but once the Ti^{3+} ion is placed in a host crystal the degeneracy is lifted by the interaction with other nearby electrons in the host. In most crystals the dominant interaction splits the Ti^{3+} -electron levels into two main levels, a threefold-degenerate ground state, commonly labeled as 2T_2 , and a twofold-degenerate excited state, the 2E . It is between these levels that the laser transition in Ti:sapphire takes place. Higher-lying energy states of the Ti^{3+} ion require promotion of the single electron out of the 3d shell. The energy required to achieve such a transition is sensitive to the particular host crystal and for

Ti:sapphire appears to be large compared to the photon energies involved in the optical pumping or lasing processes. Thus, unlike other 3d-transition-metal lasers, particularly those based on Cr³⁺ and Ni²⁺ ions, the Ti:sapphire laser performance is not compromised by excited-state absorption of either pump or laser radiation.

Absorption and emission lineshapes

The considerable difference in spatial nature between the electronic wavefunctions for the ²T₂ and ²E states, combined with the strong interaction between the ion and host crystal, results in a shift in the relative positions of the Ti³⁺ ion and surrounding atoms when the Ti³⁺ electronic state changes. This shift leads to a broad linewidth for ²T₂ ↔ ²E transitions and to an absorption band higher in peak energy than the emission band, similar to the situation for dye-laser transitions. Figure 1 shows the absorption and emission bands for Ti:sapphire at room temperature. The ²T₂ and ²E states both undergo Jahn-Teller interactions with the host crystal, leading to the twin-peak nature of the absorption band and to the breadth of the emission band.

Dipole moment

The crystalline environment for the Ti³⁺ ion not only creates the levels needed for laser operation but can, by lowering the symmetry surrounding the ion, induce an electric dipole moment between the ²T₂ and ²E states. The trigonal symmetry for Ti³⁺ in sapphire is particularly effective in creating a large dipole moment, and this is reflected in the short (for solid state lasers) radiative lifetime of 3.8 μs for the Ti:sapphire laser transition. The resultant laser gain cross section for Ti:sapphire is much higher than that for other 3d-transition-metal tunable lasers, by at least an order-of-magnitude.

The most significant materials problem with Ti:sapphire has been the growth of crystals free of absorption in the laser wavelength region. The absorption has, by indirect evidence, been linked to pair transitions of Ti⁴⁺ and Ti³⁺ ions and has been recently reduced to insignificant levels by careful control of the crystal growth conditions, combined with post-growth annealing. It is this advance in crystal growth that has made it possible to commercially produce low-threshold, efficient CW Ti:sapphire lasers.

Ti:sapphire has a unique combination of properties as a laser medium. The gain bandwidth, as is clear from Figure 1, is extremely large: the half-gain points on either side of the peak span 3500 cm⁻¹. The peak gain cross section, approximately 3.5x10⁻¹⁹ cm², is comparable to that of the Nd:YAG laser.

The sapphire crystal has perhaps the most favorable combination of high mechanical strength and thermal conductivity of any actual or potential host material. The short lifetime of the upper laser level requires that any optical pumping source be much more powerful (in terms of pumping rate/volume) than that used for Nd:YAG or comparable systems. Fortunately, the physical properties of sapphire permit high pumping levels without either major optical distortion or destruction of the host crystal, similar to the manner in which the 3-level ruby (Cr:Al₂O₃) laser withstands pump energies sufficient to invert the ion population.

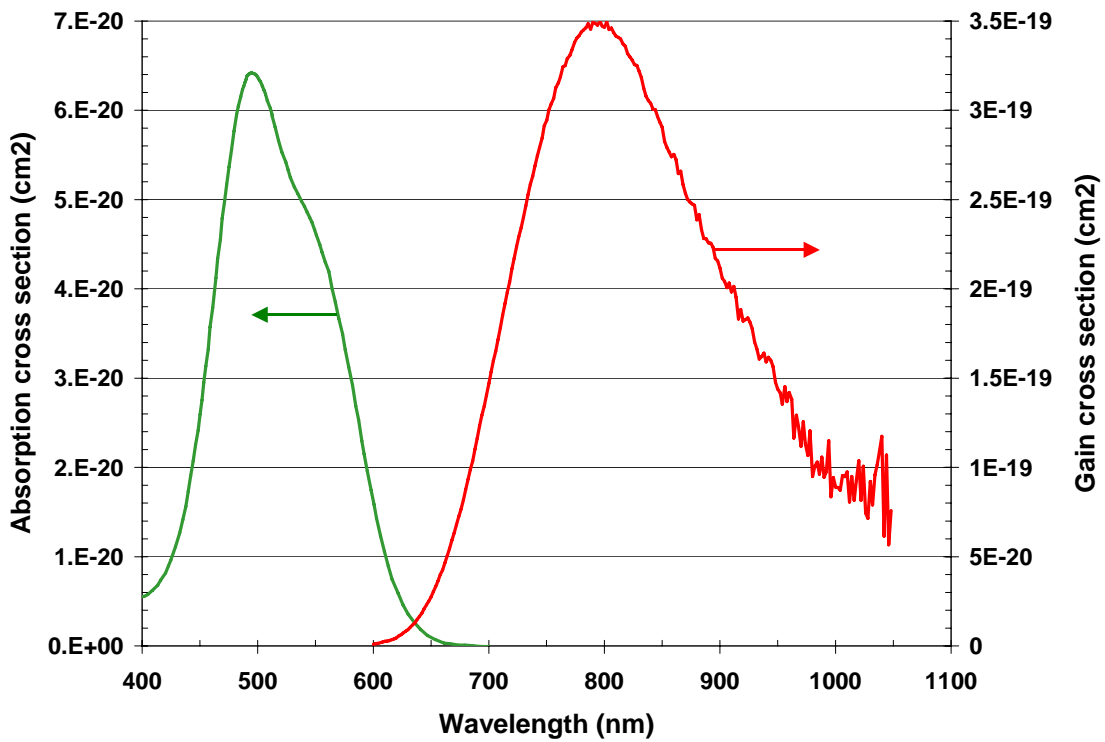


Figure 1. Absorption and emission cross sections for Ti:sapphire.

2.0 SYSTEM DETAILED DESCRIPTION

2.1 Optical Resonator

Standing-wave configuration

The Titan-CW series laser cavity is a four-mirror, astigmatically compensated design and is tuned by a three-plate birefringent filter developed especially for Ti:sapphire wavelengths. TEM₀₀ operation is achieved by optimum mode-matching of the pump beam.

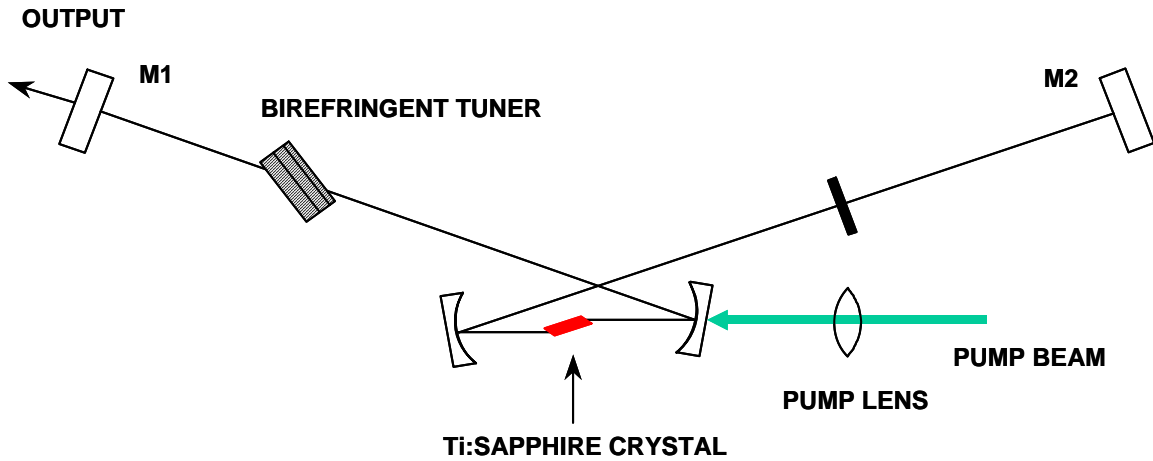


Figure 2. Design of standing-wave resonator

Ring configuration

By rotation of cavity mirrors M1 and M2, the Titan-CW cavity can operate as a ring. With the addition of an optical diode the ring oscillates in one direction, and efficient, single-longitudinal-mode operation is obtained.

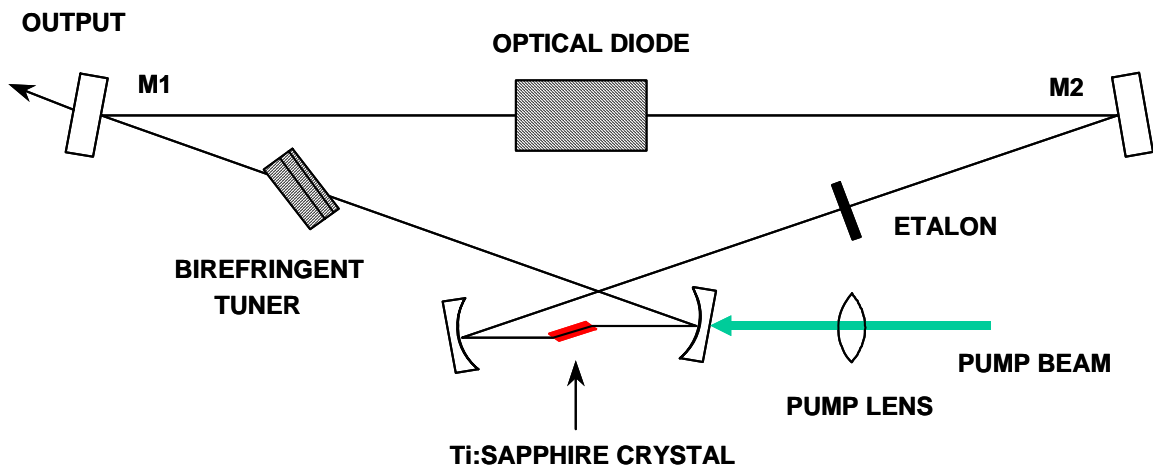


Figure 3. Design of ring resonator

High-gain,
flexible design

The high-gain design of the Titan-CW lasers permit broadband operation with small as well as large-frame argon lasers, and the Swing Resonator common to all can be changed from standing-wave to unidirectional ring for applications where true single-frequency output is required.

Two
configurations

Two general configurations of the Titan-CW laser are available. One, the "standard" package, features a unique, multi-port pumping geometry for maximum flexibility in arranging the relative locations of the pump and the Titan-CW lasers. The other "breadboard" package has all of the laser components mounted on an optical breadboard to allow the user easy experimentation with custom intracavity optics.

Broadly tunable,
efficient
operation in the
near-infrared

The broad gain bandwidth of the Ti:sapphire medium allows CW operation over an unprecedented wavelength range. No single dye can match the tuning span of the Ti:sapphire laser. The high-gain, SEO Titan-CW lasers combine broad tunability with low-threshold, efficient operation. Even with low-power argon pump lasers, hundreds of milliwatts of power output are available, and 300 nm of tuning is obtained.

Optimized
mirror sets

Conventional, low-loss dielectric mirrors are not capable of providing high reflectivity over the extraordinary tuning range of the Ti:sapphire laser. SEO has developed three basic sets of cavity mirrors to provide coverage of the Ti:sapphire operating wavelengths, consistent with the goal of maximum range with minimum pump powers. There is considerable overlap between adjacent sets in wavelengths covered, to aid the user in changing mirror sets, and laser operation in the important region from 780-900 nm is obtained with no mirror changes.

Power-level
limit

SEO research on CW Ti:sapphire lasers has shown that the maximum power output is limited by pump-induced, thermo-optical distortion in the Ti:sapphire crystal. Typically, the Titan-CW series of lasers have a linear relation between pump and output power levels up to a certain pump level. Above that level, the Titan-CW beam changes from a TEM₀₀ mode to a higher-order mode (or modes) and both the amplitude stability and tolerance to pump-beam misalignment are degraded. The current Titan-CW specification is for linear, TEM₀₀-mode operation up to and including 10 W of incident pump power, and a maximum TEM₀₀-mode power output of 2 W at 800 nm.

Change!
Higher-power
operation

Titan-CW lasers can operate at higher output-power levels if the standard Ti:sapphire laser crystal is replaced by a longer crystal with lower titanium doping. (The Titan-CW series laser crystal mount has sufficient cooling capacity to handle the largest commercially available argon-ion pump lasers.) At a

given pump power, the Titan-CW laser with a non-standard laser crystal operates with lower gain and is not recommended for use with small-frame, argon-ion pump lasers. At present, higher-power systems are available only with the breadboard package. Those with applications requiring higher power levels than 2 W should contact SEO for information on price and delivery.

Pump-laser issues

The output-power stability of the Titan-CW series of lasers is determined to a great extent by the stability of the pump laser, in terms of both amplitude and beam pointing. A more subtle issue is related to the quality of the pump-laser beam. The lowest threshold and highest slope efficiencies for the Titan-CW series lasers are obtained when the pump laser mode is truly TEM₀₀, not a distorted Gaussian or a mixture of TEM₀₀ and higher-order modes. If the pump-beam quality deviates too far from the diffraction limit the Titan-CW laser output beam will become multimode.

The standard package

The standard package for the Titan-CW series contains the Swing Resonator, mounted with two pump-directing mirrors on a unique, machined-aluminum baseplate. Even with the cover on the standard package, easy access to several of the key cavity adjustments is possible. A pivoted mounting arrangement for one of the pump-directing mirrors allows pumping from three directions.

The breadboard package

The Titan-CW laser is also available with all the Swing Resonator components mounted on a 1' x 2' stainless-steel-skin optical breadboard. Attached to the breadboard are two custom endplates and a cover, as shown below. By employing standard breadboard mounting components the user can add to the Titan-CW laser custom intracavity optics such as rapid-tuning elements, absorption cells, doubling crystals and mode-locking modulators. Pump-beam-directing mirrors in differential-screw gimbal mounts are available from SEO for use external to the breadboard package.



Additional
features

The Titan-CW series of lasers include a broadband halfwave plate in a rotatable mount, positioned in front of the pump lens for optimum orientation of the pump-beam polarization. The pump lens is mounted on a precision, micrometer-adjusted translation stage for accurate focusing of the pump power in the Ti:sapphire crystal; a multiple-position holder for the lens allows different focal lengths to be used to accommodate a variety of pump-beam characteristics. The laser crystal is bonded to a removable copper base and all the cavity mirrors are mounted for ease of changing tuning ranges. An intracavity etalon is included for fine tuning and differential-screw gimbal mounts are used to hold the two flat mirrors in the Swing Resonator.

Specifications

Power Output (at 800 nm)

Standing-wave or ring cavity

250 mW (3 W Pump Power)

500 mW (5 W Pump Power)

750 mW (7.5 W Pump Power)

Minimum Tuning Ranges (pump power 5 W or greater)

Short-band 700 - 820 nm

Mid-band 780 - 900 nm

Long-band 890 - 1020 nm

Spectral Linewidth (5 W pump power)

Standing-wave cavity < 2 GHz

Unidirectional ring cavity < 40 MHz

Output Beam

TEM00, horizontally polarized

1-mm diameter (approx.) at exit

Cooling Requirements

Water, 10-75 psi, 65-80[degree]F

Notes on
Specifications

1. SEO characterization of the Titan-CW series lasers is done with Coherent Innova argon-ion pump lasers. SEO reserves the right to derate certain specifications if other pump lasers are used with the system.
2. The power-output specifications are considerably lower than those indicated by the tuning curves shown in this brochure, in order to account for possible variations in production-level performance of the Titan-CW series lasers. SEO intends to periodically review the specifications and revise them if appropriate.
3. Output amplitude noise and power stability for the Titan-CW series lasers are functions of the characteristics of the particular pump laser, pump relay system and the Titan-CW operating wavelength. The frequency stability of the ring laser is also determined the above factors as well as the temperature stability and acoustical noise of the laser environment. Please call SEO for more information on these subjects.

3.0 SAFETY

3.1 Safety Hazards

There are several safety hazards which must be considered when operating, maintaining and servicing Titan-series lasers.

Radiation hazards

All Titan-CW series lasers are Class IV laser products, as are the pump lasers required to operate them.

WARNING!

IRREVERSIBLE DAMAGE MAY RESULT FROM EXPOSURE TO ANY LEVEL OF THE RADIATIONS GENERATED BY THESE LASER DEVICES.

Protective eyewear is recommended. Under normal operating conditions, the laser output is accessible only at the output aperture, and in all cases appears only when the pump laser output is directed into the system. It is necessary during installation and some service operations to energize the system with the laser head cover removed. Laser radiation is then accessible along most of the optical beam path inside the laser head.

CAUTION!

SERVICE OPERATIONS SHOULD BE PERFORMED ONLY BY TRAINED SERVICE PERSONNEL. IN NO CASE SHOULD SERVICE BE ATTEMPTED WITHOUT CONSULTING SEO SERVICE PERSONNEL.

Collateral radiation at the Ti:sapphire and pump laser wavelengths is also accessible along most of the laser beam path when the laser is operated with the head cover removed. Such operation is necessary only during installation and some service operations.

3.2 Safety Features

All Titan-CW series lasers have been equipped with a number of safety features designed to protect the operator under normal operating conditions. Appropriate laser safety eyewear must be worn during laser operation.

Protective housings

The laser head enclosure is mechanically rigid and provides protection from all laser and collateral radiations generated inside the laser head. These radiations are accessible under normal operating conditions only at the front laser aperture and only when the beam shutter is open.

WARNING!

OPERATION OF THE LASER WITH THE HEAD COVER REMOVED MAY RESULT IN EXPOSURE TO HARMFUL ELECTROMAGNETIC RADIATION.

Beam shutter and
operating
controls

Under normal operating conditions, hazardous radiation is only accessible at the output aperture, and only when the beam shutter is open. All operating controls required during normal operation are positioned such that the head cover may remain in place, thereby preventing exposure to collateral radiation.

Warning labels

The Titan-CW series lasers are labelled as required by FEDERAL REGULATION 21 CFR 1040.10,11 to indicate radiation hazards.

4.0 INSTALLATION, INITIAL SETUP AND ALIGNMENT

4.1 Environment and Services

The unit is designed for use indoors in a laboratory or clean, dry, dust-free industrial environment. While the mechanical components used in the Titan-CW laser are chosen for their thermal stability, best performance from the laser will occur in an environment in which temperature changes are both small and slow. The use of water cooling requires that the system never be stored in an area where the temperature drops below 32 F (0 C) unless all the water is drained from the cooling hoses and crystal module.

4.1.1 Mounting

The alignment of the pump laser beam with the Titan-CW laser is critical. For optimum system performance, both the pump and Titan-CW lasers should be mounted on a dimensionally stable platform, such as an optical table. In situations where both low amplitude noise and frequency jitter are desired, the optical table should be vibration-isolated. In the following discussions, we assume that the platform is an optical table.

4.1.2 Cooling water

The laser crystal is water cooled, and requires water at a nominal flow rate of 0.1 GPM or above. The maximum recommended inlet water temperature is 27 C (80 F). Higher temperatures will not damage the system but will degrade the laser performance. The minimum operating temperature is determined by the dew point of the surrounding atmosphere, and must be high enough to prevent condensation of water on the laser-crystal polished faces. The maximum recommended water pressure is 75 psi. Cooling water comes in contact with plastic, stainless-steel, nickel and copper surfaces in the system and thus no de-ionizing cartridges are needed for closed-loop coolers with compatible materials. Use of coolers with aluminum in contact with the water should be avoided. If tap water is used, the water should be free of large particulate matter or algae. The latter can deposit in the cooling channels and eventually reduce cooling effectiveness. Where absolute frequency stability of the laser is important, SEO recommends the use of a temperature-controlled source of cooling water. The heat load from the crystal is no more than the power supplied by the pump laser, and thus very modest closed-loop coolers can be used. Please call SEO for suggestions on vendors for temperature-controlled coolers.

4.1.3 Pump laser optics

It may be necessary to use more optics for directing the pump laser beam into the Titan-CW laser than are normally supplied with the system. SEO can furnish additional gimbal-mounted dielectric-coated mirrors; please call for further information. In case you wish to use your own optics, make sure they are of high

optical quality and are capable of operating at the power densities generated by the pump laser. SEO has observed pump-beam distortion problems with prism-based beam directors, due to thermal effects in the prism material, and thus these components should be used with caution.

4.2 Unpacking

Titan-CW lasers are packaged to prevent damage to the unit under normal shipping conditions. If the shipping container shows signs of severe external damage the shipper should be notified and you should retain the container in case a damage claim needs to be filed. When possible the shipping container, if serviceable, should also be kept, as it can be used to return the laser for factory service and/or upgrades. Each system is packed with accessories and a parts list; the latter should be used to check if all the items have been removed from the container. If there are any discrepancies please notify SEO immediately. Once the laser has been removed from the container and is in a clean environment, you should remove the top cover and carefully check that all mechanical and optical components are rigidly mounted, without altering any of their adjustments. If any problems are found, please call SEO for assistance; do not attempt to align and operate the laser.

4.3 Initial Setup

SEO strongly recommends that the initial installation and operation of the Titan-CW lasers be done by a representative from SEO. Independent of whether you or SEO installs the laser, the first step to be taken is planning of the layout of the pump and Titan-CW lasers on the optical table. If at all possible, the distance between the pump laser and Titan-CW laser should be minimized, in order to reduce the effects of pump-laser beam wander and table flexure on the Titan-CW output power. (For safety purposes, after the laser is aligned you should cover over with non-flammable tubing or boxes as much as possible of the exposed pump beam. The pump-laser beam should be level with respect to the table and, as close as possible, be adjusted to a height of approximately 4.65 in. (11.8 cm). We suggest that the pump-laser position on the table, once determined, be fixed by clamps or other fittings to prevent misalignment caused by accidental pump-laser movement.

4.3.1 Cooling Water Connection

Please refer to Section 4.1.2 for information on cooling-water requirements. Each system is supplied with plastic water couplings mated to those on the body of the laser. The couplings are designed to be attached to 3/8"-ID flexible hoses; the use of hose clamps over the fittings is recommended. The couplings are of the double-ended shutoff design, which allows virtually leak-free making and breaking of the connections. After the connections are made, you

should remove the cover on the Titan-CW laser, turn the water supply on and check for leaks. If any leaks are apparent on the inside of the laser, please call SEO for assistance.

4.4 Pump-beam alignment

To obtain operation from the Titan-CW system, you must align the pump beam so that, in the Ti:sapphire crystal, it is exactly coaxial with the TEM00 mode of the Titan-CW laser resonator. Provided that the Titan-CW resonator alignment has not been disturbed during the process of shipping and installing the unit, proper pump-beam alignment is sufficient to obtain Titan-CW laser operation, although some adjustment of the resonator is typically needed to maximize performance. Generally, pump alignment is the most critical part of the entire installation procedure and is also the only one in which harm can be done to the Titan-CW system, and thus the following instructions should be followed closely.

4.4.1 Preliminaries

As a start, turn on the cooling-water flow to the laser, and make sure that the water temperature is warm enough to prevent condensation on the faces of the Ti:sapphire crystal.

Turn on the pump laser with either the pump-laser shutter closed or a block in the beam before the beam enters the Titan-CW laser and allow some time for the pump laser to warm up.

Before opening the shutter or removing the block, set the operating point of the pump to operate the pump just over threshold, so that a minimum of power is generated. This reduces the risk of damaging the crystal during the initial setup. Only tens of milliwatts of CW power are needed in the initial stages of alignment.

WARNING!

IRREVERSIBLE EYE DAMAGE MAY RESULT FROM EXPOSURE TO ANY LEVEL OF PUMP-LASER OUTPUT.

Make sure that, in the following, you are aware of the location of the pump beam and any possible beam reflections. Once the pump-beam alignment is complete, we recommended that laser safety glasses be worn to protect against the pump laser output.

With the pump laser output applied, check, if appropriate, to make sure that the pump beam is properly located in any external beam-directing optics.

Remove the cover of the Titan-CW laser and follow the instructions below

- 4.4.2
Pump rough
alignment:
Breadboard Laser
- The two external pump-beam mirrors supplied with the breadboard laser should be positioned and adjusted to direct the pump beam through the center of both the pump input aperture on the Titan-CW endplate and the waveplate aperture on the pump lens assembly. If possible, you should position the external mirrors so that the pump beam falls near their centers, and make sure that the mirror adjustments are not near their extreme points when the beam is correctly aligned.
- 4.4.3
Pump beam
position in
crystal
- With the pump beam in rough alignment you should observe the focused beam passing through the Ti:sapphire crystal, with the resultant generation of deep-red fluorescence as viewed through the orange plastic cover over the crystal module. The beam should pass through the crystal. If the beam is far off from this position, you should double-check the rough-alignment procedures, and, if necessary, make adjustments. If the beam is still off, major misalignment of the Titan-CW system may have occurred during shipping and setup, and you are advised to call SEO for assistance. It is particularly important that the pump beam not be focused on the interface between the laser crystal and the heat sink, as damage to the crystal can result with this condition at high pump powers. (You are doing all this initial alignment with low power, right?)
- 4.4.5
Pump-lens
position
- The translation stage holding the pump lens/waveplate assembly is set for optimum operation with a typical small-frame, argon-ion pump laser, under conditions in which the pump output aperture is located in the range of 0.5-1.5 meters away from the pump input aperture of the Titan-CW laser. In most cases only a small adjustment of the lens position is necessary for optimization of your particular system, and this is best done later on in the setup procedure. If you observe that the focus of the pump beam is clearly not in the region of the crystal you can adjust the translation stage accordingly. Access to the focus adjustment in the Standard configuration is made by sliding open a small cover on the side of the laser. We recommend that you first note down the factory setting on the translation-stage micrometer, as a point of reference. If a focus at the crystal can still not be achieved at any position of the stage there may be problems with the pump laser or the optics used to relay the pump beam to the Titan-CW laser; please call SEO for assistance.
- 4.4.6
Waveplate
adjustment
- The waveplate is set by SEO to rotate the polarization of the pump laser beam from the vertical direction (typical for argon-ion lasers) to the horizontal direction appropriate for the Brewster-face orientation of the Ti:sapphire crystal. The broadband design of the waveplate is optimized for half-wave operation in the wavelength region from 485-515 nm. The best method to

check that the pump-beam polarization is optimized is to observe the pump reflection off the input face of the Ti:sapphire crystal. With the pump laser output still at a minimum you can place a white card and view the reflection. The optimum polarization has a minimum of reflected intensity.

If you suspect that the incoming polarization is not perfectly vertical you can gently loosen the Allen-head setscrew(s) holding the mounted waveplate in place, rotate the plate for the minimum reflected power and gently tighten the screw(s) again. It is common for pump lasers to not have perfect linear polarization and, in addition, the pump-beam relay optics may make the polarization somewhat elliptical. Thus, you should not expect that the reflected light will go away completely as the waveplate is rotated. If your pump-laser beam, as it enters the Titan-CW laser pump input, is horizontally polarized, you can remove the waveplate entirely. However, in the initial alignment we recommend that you keep the waveplate in place, properly rotated, as it is a useful reference aperture for alignment of the pump beam position.

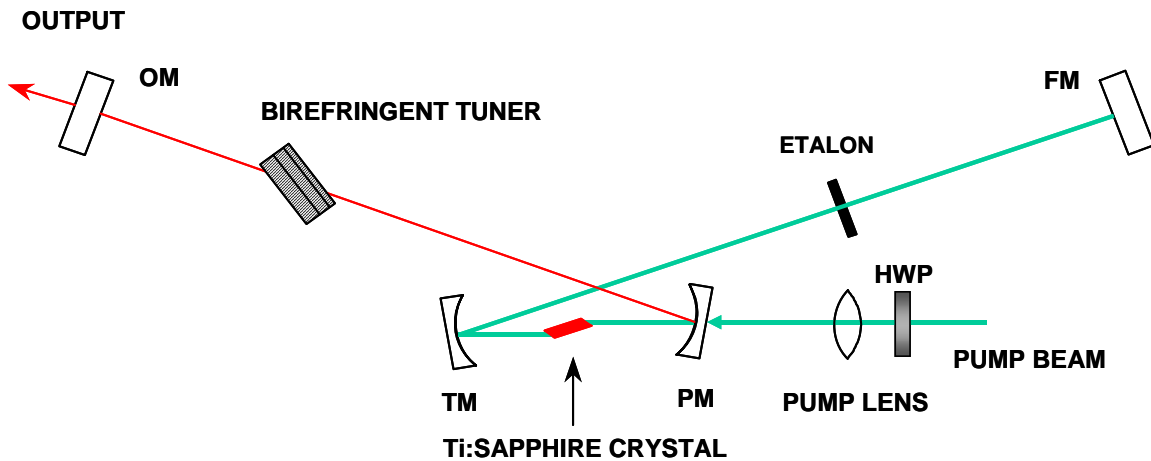


Figure 4. Pump-beam path and mirror designations.

4.4.7
Pump fine
alignment

Figure 4 shows the path of the pump beam through the Titan-CW laser cavity. Following Figure 4, we refer to the four mirrors in the Titan-CW laser cavity as the pump mirror (PM), turning mirror (TM), flat mirror (FM) and the output mirror (OM). The PM, TM and FM all have highly reflective coatings at Titan-CW laser wavelengths and highly transmissive coatings for the argon-ion laser wavelengths in the range 488-515 nm. However, there is enough reflection at the pump wavelengths to observe the pump beam after it has passed through the FM, and this condition is used as an aid in alignment. All Titan-CW lasers are shipped with a marker indicating the correct reflected pump beam position behind the FM. For the Standard laser a special alignment part is placed behind

the FM mount and fastened down with a small dab of cement; after alignment is completed you can remove the part by applying enough pressure on the part to break the cement bond. For the Breadboard laser a piece of white tape or other marker is fastened to one of the breadboard endplates.

Important note

In general, you will observe two pump-beam reflections from the TM, one from the inner, high-reflector-coated mirror surface and another from the outer surface. The latter reflection comes to a near-focus at the FM and should not be used for pump-alignment purposes. The correct reflection, from the inner surface, appears as the larger spot behind the FM.

The pump rough alignment, described in Sections 4.4.2 and 4.4.3, should make it possible for you to use the two pump-beam mirrors to adjust the pump beam to go through the center of the waveplate and also hit the alignment mark behind the FM. After this adjustment is made, you should check that the pump is approximately centered on the PM, TM, and FM, and is still positioned in the laser crystal as described in Section 4.4.3.

4.5 Obtaining Titan-CW laser operation

In preparation for obtaining laser operation from the Titan-CW laser you should place an appropriate power monitor in the expected path of the laser beam. We have found that a large-area silicon photodiode (E.G.G. DT-100 or equivalent), with its DC output displayed on an oscilloscope, is a useful monitor in the initial stages of alignment. Other aids to observing laser operation are near-infrared-sensitive video cameras, viewers (image converters) and/or phosphor cards.

WARNING!

IRREVERSIBLE EYE DAMAGE MAY RESULT FROM EXPOSURE TO ANY LEVEL OF TITAN-CW-LASER OUTPUT.

Make sure that, in the following, you are aware of the location of the Titan-CW output beam and any possible beam reflections. Once the system alignment is complete, we recommended that laser safety glasses be worn to protect against the laser output.

4.5.1 Setting the birefringent tuner

Unless the wavelength of the Titan-CW laser has been set at your request for a specific value, you should adjust the micrometer reading on the tuner drive to correspond to the lowest-threshold point for the installed mirror set. For the short-band, mid-band and long-band mirror sets the appropriate wavelengths are 770, 800 and 920 nm, respectively.

4.5.2 Inspection and cleaning

Before you increase the pump power to the required level you should inspect all the optical surfaces in the system, from pump-beam mirrors to the four mirrors of the Titan-CW laser cavity. If there is noticeable

scatter of the pump beam from any surface, due to the presence of large dust or dirt particles, you should attempt to remove the particles by blowing them off with clean, dry air or nitrogen. If the particles are still present, refer to Section ?? on cleaning optics. Of special importance is the cleanliness of the laser-crystal surfaces, as the focused pump beam at high power could vaporize dirt or dust on the surface and cause permanent damage to the crystal. Also, because of the small Titan-CW laser cavity mode in the crystal, scattering at the crystal can have a large affect on laser performance. The appearance of diffraction rings and/or scatter in the pump beam reflected off the crystal face can often indicate the presence of a dirty reflecting surface in the optical path between the pump laser and the crystal, or a dirty crystal face.

4.5.3 Pump laser power-up

At this point, you can proceed to increase the pump-laser output to a level over the Titan-CW threshold power. The threshold level is indicated on the Output Characteristics sheet for a specified wavelength, mirror set and cavity configuration. Typically, the level is indicated for operation at 800 nm, and if you are set for operation away from this wavelength you should expect a higher threshold. If the pump-laser beam direction shifts with increasing power you should realign the pump beam to maintain centering of the beam on both the halfwave plate and on the alignment mark behind the FM. As the pump level increases (up to a limit of 10 W) you should observe laser action from the Titan-CW system. If you do, proceed directly to Section 4.6 below. If you do not, first check for damage on any of the pump-beam delivery optics or on the Ti:sapphire crystal surface; if any is observed please call SEO for assistance. If there is no evident damage, follow the procedure in Section 4.6.2, below, for further adjustment of the pump mirrors. If laser action is still not observed with pump-mirror adjustments, follow the directions in Section (4.7?)*, which describe a complete alignment procedure for the Titan-CW laser-cavity.

4.6 System optimization

Optimization of the Titan-CW laser performance requires an iterative set of adjustments involving the pump mirrors, the laser-cavity mirrors and the pump focusing lens. The Titan-CW parameters requiring optimization are threshold, power output and beam quality. In a properly operating system, at least for pump powers below 10 W, there is, fortunately, no tradeoff amongst the parameters. The lowest threshold, highest power output and best beam quality can all be achieved simultaneously. In carrying out the optimization, you will find it helpful to monitor both the power output and the output beam pattern. The latter can be done by eye for wavelengths shorter than around 850 nm, but cameras, viewers or phosphor cards may be needed at longer wavelengths. We suggest that you follow the

order of adjustments below: pump mirrors, laser cavity mirrors and then pump focusing lens, with any iteration following that sequence.

Important note

As the output of the Titan-CW laser increases with better system alignment you should decrease the pump laser output in order to maintain the Titan-CW laser as close to threshold as practical. This helps to prevent adjustment of the system to a secondary maximum.

4.6.1
Pump-mirror
adjustment

All pump adjustments should be done initially with the fine (outer) controls of the pump-mirror gimbal mounts. Only if you run out of the range of the fine controls should you resort to use of the coarse (inner) control. You should first maximize the Titan-CW output by adjusting the azimuth and elevation controls on the pump mirror (M1) nearest the focusing lens, working back and forth between the adjustments if necessary. You should then examine the spatial profile of the Titan-CW laser output beam. In many cases, the output beam will not be circular, and the pump power will be well over the threshold value. In any case, at this point you should attempt to improve performance by "walking" the pump beam in the crystal, by successive adjustment of the two pump mirrors. If the mode appears to be a single, intense, circular spot, with no structure, i.e. a TEM00 mode, and the pump power required to maintain the laser just over threshold is close to the threshold value shown on the Output Characteristics sheet then your system should be close to alignment.

4.6.2
Pump-mirror
walking

The process of "walking" involves successive angular adjustments of the two pump mirrors. (If you have come to this Section with no laser action yet observed, mirror walking is an attempt to obtain Titan-CW laser operation by using an orderly approach to changing both the angle and position of the pump beam in the laser crystal.) You should first make note of the readings on the fine controls on the gimbal mounts, as points of reference. As you may have to adjust the coarse controls, you should establish some way to mark their starting position as well; a line drawn with a felt-tip pen on the barrel of the coarse knob is useful. If the laser is operating proceed to Section 4.6.2. If not, you should start the search for laser operation by rotating the fine azimuth control on mirror M1 one-eighth of a turn clockwise and then rotating the azimuth control on mirror M0 an equivalent amount in the same direction. Continue with this procedure of back and forth adjustments until you observe laser operation or until you have rotated for two full turns on the fine adjustment knobs. Reset the fine controls to the original position and carry out the same procedure but with rotation of the controls in the counter-clockwise direction. In the absence of laser operation reset the controls to the original position, rotate the elevation controls one-eighth of a turn clockwise and perform the

same series of azimuthal adjustments two turns in either direction from the original position. Continue the pattern of elevation adjustments followed by azimuthal sweeps until you observe laser operation or have rotated the elevation fine controls two turns. Then, reset the elevation controls and do azimuthal sweeps while rotating the elevation controls clockwise. If you still have not obtained laser operation after all the adjustments outlined above, you should set the controls on the pump mirrors back to their initial positions (as closely as possible) and proceed to Section 4.7, which describes a general alignment procedure for the Titan-CW system.

4.6.3
Pump-mirror
walking:
operating laser

Observation of the Titan-CW beam can indicate which set of pump-mirror controls should be adjusted first to optimize the laser performance. If the beam cross section appears vertically elongated then the elevation controls should "walked" first; the azimuthal controls should be walked if the beam is horizontally elongated. (A circular beam with no apparent intensity nodes, the TEM₀₀ mode, typically indicates that the system is close to alignment, and you may start with either set.) First, note the Titan-CW laser output power. Then, rotate the fine control on one mirror (M1) in one direction. The output of the laser will drop, provided the controls on mirror M1 were previously adjusted for maximum output. Do not rotate the control far enough to turn off the laser. Next, rotate the equivalent fine control on the other mirror (M0) in the same direction and observe whether the laser output increases or decreases from the noted value. If it increases, continue successive adjustments of the mirrors until you have determined the position of maximum power output. If the power decreases, rotate the controls in the opposite direction and perform a set of successive adjustments until you have maximized the output. Then, carry out the same procedure for the other axis of rotation. Finally, check if the initial axis is still aligned for maximum output, and readjust the axis if it is not. At this point the output beam from the Titan-CW laser should be in the TEM₀₀ mode and the threshold for the laser should be close to the value shown on the performance data sheet included with your particular system. If neither of those conditions are met you may have reached a secondary maxima in the alignment of the pump beam, the Titan-CW laser cavity may be out of alignment, or the pump lens may not be in the optimum position. To determine if you are on a secondary maxima, try a longer-distance "walk" of the pump mirrors in both axes to make sure that you are at the correct alignment point. Minor realignment of the Titan-CW cavity and pump-lens adjustments are discussed in the next Sections.

4.6.4 Laser-mirror adjustments

The next major step in the optimization of the Titan-CW laser is adjustment of the controls on the flat mirror (FM) and output mirror (OM) gimbal mounts for maximum output. First, rotate the fine controls on the FM mount for maximum output power, working back and forth between azimuth and elevation to check for optimum alignment. Then, carry out the same procedure for the fine controls on the OM mount. Finally, observe the position of the Titan-CW intracavity beam on the surfaces of the FM and OM, by eye if the laser is operating at short wavelengths or by an infrared viewer, if you have one, for longer-wavelength operation. Another way to check beam location if you do not have a viewer is to take a one-inch-square piece of paper, punch a 2-mm-diameter hole in the center of it, place the paper over (but not touching) the mirror and move the paper around until you observe Titan-CW laser operation. The position of the hole will show the location of the Titan-CW intracavity beam. The beam should appear approximately centered on the mirrors. If it is, then proceed on to Section *.

If one or both of the beams is not well-centered, then the alignment of one or both of the concave cavity mirrors may have shifted from the factory settings. All of the Titan-CW intracavity optics, i.e. the birefringent tuner, etalon and, for the ring configuration, the optical diode, have been factory-aligned with the cavity beam centered on the flat mirrors, and thus you should try to obtain this condition in your system. Doing so requires angular adjustment of the concave mirror mounts, which lack the fine controls of the flat mirrors. You should make any adjustments very gradually, using the small Allen-head driver furnished with the Titan-CW system, and avoid adjustments large enough to turn off the Titan-CW laser. For systems in the standing-wave configuration, mirror adjustments must be done in pairs, similar to the mirror walking procedure used to align the pump beam. Any change in the turning mirror (TM) alignment requires an accompanying change in the orientation of the FM and a pump mirror (PM) adjustment must be done in conjunction with an OM re-alignment. If you have a ring-laser configuration any change in the TM alignment requires a FM followed by an OM adjustment and an OM followed by a FM adjustment must accompany a PM adjustment. If the beam is high on a flat mirror, the elevation angle of the appropriate concave mirror must be reduced, and so forth. Unlike the previous alignment procedure, you should operate the system with the pump laser at several times over threshold, in order to make the mirror adjustment process less critical. In all cases, a PM re-alignment also requires you to readjust the pump-beam mirrors, as the pump-beam direction is slightly affected by changes in the PM orientation.

4.6.5
Pump lens
adjustments

The final optimization is setting the correct position of the pump lens. While monitoring the output of the Titan-CW laser operating near threshold, you should rotate the micrometer adjustment of the pump-lens translation stage in one direction and then "walk" the pump mirrors in a search for a higher output power. If you can obtain higher power, continue rotation in the same direction, accompanied by pump-mirror adjustments, until the power is maximized. If the power drops, search for maximum output by rotating the micrometer in the opposite direction.

At this point you should be observing TEM₀₀-mode output from the Titan-CW laser and a threshold pump power comparable to the value indicated on the Output Characteristics sheet, if you are operating at the specified wavelength and with the same cavity configuration. Increase the pump power in steps and note the relation between the Titan-CW power output and the pump power. Compare your data with the factory data, if appropriate. As some pump lasers suffer from beam wander with increasing power output, you may want to check whether the Titan-CW pump mirrors need readjusting at different pump levels; often a slight readjustment of the pump mirror closest to the Titan-CW cavity will suffice. If the threshold and power output are not close to the expected values, try one more pass through the alignment procedure, starting with the pump mirrors, followed by the Titan-CW cavity mirrors and finally the pump lens. As you have been operating the Titan-CW system with the cover off, it is likely that the cavity optics have become dirty, and cleaning them can often result in a significant improvement in laser performance. Section 7.1 describes the correct techniques for cleaning optics, and should be read carefully before attempting any cleaning. Please do not hesitate to call SEO for any further assistance in the system setup.

Sections 5 and 6, below, discusses normal operational procedures for the Titan-CW laser, including changing of mirror sets and conversion back and forth between standing-wave and ring-cavity configurations.

4.7
Major
alignment

The following steps outline the alignment procedure for the Titan-CW laser. It is included to provide the experienced user with additional information that may be of use when altering intracavity components and otherwise modifying the laser. Please refer to Figure 4, above, for reference to the component mentioned below.

- 4.7.1 Attach water lines and circulate water. Turn on the pump laser with the power at the minimum visible level. Center the pump beam in the HWP and lens. Rotate the lens/HWP mount so that the pump light reflected by the HWP is incident between 3:00 and 6:00 on the input aperture (as observed from within). Set the micrometer

on the pump-lens translation stage to the center of its adjustment range.

- 4.7.2 Rotate the HWP to minimize the pump light reflected by the crystal. Rotate the stainless-steel block to further reduce the intensity of the reflected pump light.
- 4.7.3 Slide the stainless-steel block so that the pump beam is approximately centered, horizontally, in the crystal while maintaining the null reflection. The pump beam should be within 1 mm of the bottom of the 3-mm-thick Ti:Al₂O₃ crystal. If necessary, adjust the pump beam for the appropriate height.
- 4.7.4 Repeat [4.7.2]. Increase the pump power to several Watts and observe the pump light scattered by the crystal to verify that a well polished region of the Ti:Al₂O₃ crystal has been selected. Clean the crystal if necessary (see 7.1.2). Attach the stainless-steel block when properly positioned.
- 4.7.5 Adjust the PM to center the fluorescence imaged on the OC. The full angle between the pump beam and the PM [->]OC path (measured between the centers of the mirrors) should be 19.5°.
- 4.7.6 Adjust the TM so that the pump beam reflected by its concave surface is incident on the center of the FM. The full angle between the pump beam and the TM[->] FM path should be 19.5°.
- 4.7.7 Adjust the FM for retroreflection.
- 4.7.8 Achieve laser action by adjusting the OC for retroreflection. This may require iteration with 4.7.7. Use an IR viewer to observe the fluorescence on a card behind the OC.
- 4.7.9 Adjust the OC and FM mirrors to minimize threshold.
- 4.7.10 Adjust the TM and FM to center the intracavity beam on the FM while minimizing threshold.
- 4.7.11 Adjust the PM and the OC to center the intracavity beam on the OC while minimizing threshold.
- 4.7.12 Repeat 4.7.9. Adjust the position of the pump lens, while optimizing the alignment of the pump beam, to minimize threshold.
- 4.7.13 Using the calibration data supplied with the laser, set the micrometer on the birefringent filter (BRF) to a value that will result in a minimum threshold pump power for the mirror set in place. Insert the BRF between the crystal block and the OC. With the laser above threshold, observe the spots

reflected by the BRF with an IR viewer or vidicon monitor. Rotate the BRF mount to minimize the reflected spots while maximizing the output power. Without rotating the BRF, position it to maximize the available aperture. Attach the BRF mount when properly positioned.

- 4.7.14 Tune the BRF and adjust the OC and FLAT mirrors for minimum threshold.
- 4.7.15 Slide the OC mount to center the intracavity beam on the OC. Restore laser action and minimize threshold by adjusting the OC.
- 4.7.16 Attach the etalon between the TM and FM. Adjust the etalon for near-normal incidence by observing the pump light reflected back toward the FM.
- 4.7.17 To continue alignment for the ring configuration, follow the steps in Section 6.1.
- 4.7.18 Clean components as necessary.

5.0 OPERATION

It is assumed that Installation and Initial Setup have been accomplished as described in Section 4, and that the operator is familiar with system controls.

Caution

DO NOT ATTEMPT TO OPERATE THIS LASER BEFORE READING THE SAFETY SECTION OF THIS MANUAL (SECTION *).

5.1 Turn-on procedure

The Titan-CW laser requires only two things for operation, water cooling for the laser crystal and a pump laser. To operate the laser you should:

- 5.1.1 Turn on the water supply to the Titan-CW laser, and make sure that the water temperature is warm enough to prevent condensation of moisture on the surface of the Ti:sapphire crystal.
- 5.1.2 Apply the pump laser output to the Titan-CW laser. For best results, you should allow the pump laser to warm up before using it with the Titan-CW system. The amount of warm-up time varies among different types of pump lasers; consult with the manufacturer of the pump laser for information on the appropriate time.

5.2 Turn-off procedure

Turning off the Titan-CW laser is simple - turn off or block the pump laser beam and turn off the cooling water supply. The water can be turned off immediately after the pump beam is off.

5.3 Tuning the laser

The birefringent filter (BRF) is the main tuning element in the Titan-CW laser, and is adjusted by the micrometer on the top of the laser. The BRF has several resonances, or orders, that coincide with the gain spectrum of Ti:sapphire. Thus, depending on wavelength, there may be several settings on the BRF micrometer drive that correspond to the same wavelength. A calibration curve relating micrometer reading with wavelength, typically only for one mirror set, is supplied with each system. The curve, although derived with the use of a high-resolution wavemeter, can not be relied on to set the absolute Titan-CW wavelength in your installation, as the BRF resonances at a given micrometer setting shift with temperature. Also, any shift in the angle of the BRF with respect to the laser-cavity beam, due to the effects of laser realignment, will also change the relation between the micrometer reading and Titan-CW wavelength. We recommend that you use a wavemeter or calibrated grating spectrometer to monitor the Titan-CW wavelength in applications where the wavelength setting is critical.

The etalon supplied with the Titan-CW laser can be used for fine-tuning of the laser wavelength.

5.4 Changing mirror sets

Replacing the cavity mirrors with a set for an adjacent band is accomplished by first tuning an operating laser to a wavelength in which both mirror sets are capable of operation (the overlap region) and then replacing mirrors one at a time, carefully restoring the cavity alignment each time a new mirror is installed. We recommend that when changing between the short-band and long-band mirror sets you install the mid-band set as an intermediate process. If you were not involved in the installation of the Titan-CW laser, we suggest that you read over Section 4 in order to become familiar with the details of Titan-CW laser alignment and the terminology involved. Figure 4 shows a diagram of the Titan-CW laser-cavity layout. You should then follow the steps below:

- 5.4.1 The Titan-CW laser toolkit includes an alignment fixture that places an aperture at the correct beam height above the component mounting surface. To aid in changing mirror sets you should place the fixture in the TM[->]FM leg of the cavity, positioning the aperture to allow laser operation. (Early systems did not include the fixture; please call SEO if you would like to obtain one.) As an alternative, you can use an index card with a hole placed at the correct height as a temporary aperture.
- 5.4.2 As a further aid to changing mirror sets, you can establish a diagnostic for the Titan-CW laser that is very sensitive to the alignment of the output beam (e.g., a fiber-coupled detector, wavemeter, and/or optical spectrum analyzer).
- 5.4.3 Tune the BRF to operate in the center of the overlap region.
- 5.4.4 Prior to changing mirrors, place white index cards behind the OM and FM and observe the patterns resulting from imaging of the Ti:sapphire fluorescence by the cavity optics. Although you can see faint fluorescence patterns directly, you will get a much better indication of the patterns if you use an IR viewer or phosphor card. Place a color filter (such as the plastic filter supplied in the toolkit) behind the FM to block the transmitted pump light, and reduce the pump power below threshold to eliminate the strong Titan-CW laser output beam. By alternately placing and removing another index card in front of the OM and observing the pattern behind the FM, you can distinguish between fluorescence coming directly from reflection off the FM and that retroflected back from the OC. An equivalent procedure can be used in observing fluorescence patterns behind the OC.

Important note!

A small and relatively intense spot will appear behind both the FM and OM, and is the result of a reflection

from the back, AR-coated surface of the TM and PM, respectively. The spot should not be confused with the more diffuse patterns resulting from reflections off the front surfaces of the TM and PM.

- 5.4.5 Mark an outline of the fluorescence patterns on the index cards behind the OM and FM.
- 5.4.6 Block the pump beam and remove the present PM, by carefully unfastening the two screws and then removing the flange holding the mirror and the mirror itself from the angular-adjustment mount. Put the new PM in the flange, seat the assembly in the mount and fasten the two screws back in.
- 5.4.7 Unblock the pump beam, increase the pump power well over the threshold level and restore laser action by adjusting the azimuth and elevation angles of the PM mount to bring the fluorescence images on top of the marked spots, while also centering the round-trip fluorescence on the temporary aperture. Angular adjustments are made by rotating the fine-pitch screws on the mount with the small Allen-head driver supplied as part of the Titan-CW toolkit. The PM is the only one of the four mirrors that may be difficult to realign because it can introduce a small deviation to the pump beam. If necessary, iterate adjustment of the pump alignment with that of the PM to achieve laser action and then minimize threshold. (Minimum threshold should coincide with optimum coupling to alignment-sensitive diagnostics, if you are using them.)
- 5.4.8 Block the pump beam, change and realign the TM, using the same basic procedure used for the PM.
- 5.4.9 Block the pump beam and change the FM. You perform this change by first unscrewing the mirror-holder assembly from the front of the gimbal mount (picture?). In removing the assembly, you will observe an O-ring that applies pressure against the back surface of the mirror; the O-ring may either be stuck to the mirror or remain in the back plate of the gimbal mount. In screwing back the assembly into the gimbal mount you should make sure that the O-ring is positioned correctly. The mirror is held in the assembly by a wire clip which presses against the side of the mirror; once the assembly has been unscrewed the clip can be released to remove the old mirror and replace it with a new one.
- 5.4.10 Unblock the pump and adjust the gimbal mount holding the FM to restore laser operation. You can use the temporary aperture and the fluorescence mark behind the OM to facilitate realignment.
- 5.4.11 Block the pump beam and change the OM, using the same procedure as for the FM.

- 5.4.12 Unblock the pump and adjust the OM mount to restore laser action. (Note that changing the output coupler may result in some deviation of the output beam, due to variations among mirror sets in the substrate wedge angle, so that the minimum-threshold adjustment may not result in good coupling to alignment-sensitive diagnostics.)
- 5.4.13 Tune the BRF to the wavelength of minimum threshold within the band of the mirror set. Minimize threshold by adjusting the OM and FM.

6.0 SPECIAL OPERATIONS

6.1
Swinging the
laser:
Standing-wave to
ring

You can change the Titan-CW laser from a standing-wave to ring-laser configuration by following the steps in this Section. You first change the laser cavity from standing-wave to bidirectional ring and then, with the addition of an optical diode (supplied either as part of the original system or obtained later from SEO), change to a unidirectional ring. Please review Section * for a discussion of the component parts of the optical diode. Also, if you have not been involved in the original installation of the system or have not changed mirror sets, please read over Section 4 and 5, to familiarize yourself with some of the alignment concepts and techniques employed below. While the fluorescence discussed in the procedures can be seen directly, you will find alignment easier if you use either an infrared viewer or an infrared-sensitive phosphor card.

- 6.1.1 Set the BRF to the wavelength region corresponding to the minimum threshold pump power for the mirror set in place. If the pump laser is on, turn off the pump or block the pump beam before it reaches the Titan-CW laser.
- 6.1.2 Unscrew and remove the bolts holding the etalon mount, the OM and the FM gimbal mounts to the laser base. To protect the fine threads of the gimbal-mount differential adjustments from being damaged during this procedure, we strongly recommend that, prior to unscrewing the bolts, you rotate those adjustments counterclockwise so the threads are fully retracted. Place the etalon amount aside for the moment.
- 6.1.3 Rotate the entire FM gimbal mount clockwise to align its mounting holes with the alternate set of threaded holes on the base plate, and bolt the unit down. Follow the same procedure for the OM mount, except rotate the unit counter-clockwise to mate with the alternate holes. (If you have retracted the threads on the gimbal mounts, reset the gimbal-mount differential adjustments back to a normal position.)
- 6.1.4 The following applies only to the breadboard configuration. The OM and FM gimbal mounts bolt on to movable base plates, which must be repositioned when the Titan-CW laser is changed between standing-wave and ring configurations. Turn on or unblock the pump beam and set the pump laser for minimal power. Loosen the screws holding the FM gimbal-mount base plate to the breadboard, slide the plate along (approximately 1 cm) in its slots in a direction away from the Ti:sapphire

crystal so that the reflected pump beam is centered on the FM and tighten down the base-plate screws. You should then slide the OM base plate over the same amount, bring the pump power up to a level well over the threshold value for the ring configuration and proceed to *.

- 6.1.5 Turn on or unblock the pump beam and bring the pump power up to a level well over the threshold value for the ring configuration of the Titan-CW system.
- 6.1.6 Adjust the gimbal-mount controls on the OM so that, on the surface of the FM, the fluorescence reflected from the OM intersects the fluorescence reflected directly from the TM. Similarly adjust the FM gimbal mount for overlap of the reflected and direct fluorescence at the OM.
- 6.1.7 Iterate between adjustments of the OM and FM gimbal mounts to achieve bidirectional laser action and continue these adjustments (while lowering the pump power) to minimize threshold.
- 6.1.8 Except for early units, Titan-CW lasers are shipped with an index plate for the optical diode, and in some cases the plate may be fastened to the laser base. The plate is designed to accurately locate the optical diode in the laser cavity, and minimize the amount of time required to shift between standing-wave and ring configurations. (Please call SEO if you would like to obtain an index plate.) If you don't have an index plate, or if it is not fastened to the laser base, proceed to 6.1.9. Otherwise, you should position the base of the optical diode assembly in the plate so that the diode magnet is closest to the FM and then bolt down the diode to the laser base. Next, adjust the FM so that the reflected fluorescence is centered on the entrance aperture of the magnet, and proceed to (6.1.12).
- 6.1.9 Block the cavity by placing a white card in the OM gimbal mount between the OM and the front of the mount, as close to the OM surface as is possible. Mark on the card the position of the pump beam reflected from the FM.
- 6.1.10 Place the optical diode in the beam path between the OM and FM, just to the side of the BRF and toward the FM, as shown in Figure 3; do not bolt the diode assembly to the laser baseplate at this point. The diode magnet should be closest to the FM. You should then adjust the position and angle of the diode so that the reflected pump beam from the FM passes through the optical diode and is visible on the card in front of the OM.
- 6.1.11 Iteratively adjust the horizontal control of the FM along with the position and angle of the diode until the pump beam reflected from the FM passes through the diode

and hits the marked spot on the card. When optimally aligned, varying the azimuth control of the FM will cause the transmitted pump beam to walk horizontally across the marked spot. At this point, bolt the optical diode to the laser base and remove the card in front of the OM.

6.1.12 Observe fluorescence reflected by the OM on the entrance aperture of the optical-rotator section of the optical diode. With the pump power at several times the threshold value for the installed mirror set, restore laser action by adjusting the azimuth and elevation controls of the OM gimbal mount so that reflected fluorescence from the OM is centered on this aperture. If laser action is not obtained, you should carry out a mirror "walking" procedure between the OM and FM mounts, as described in Section * for the pump mirrors, to search for laser operation. Use the "walking" technique to minimize the Titan-CW threshold power.

6.1.13 Reattach the etalon to the laser base so that the etalon is in the beam path between the FM and OM, in a location on the laser base between the diode and the FM. The etalon should be mounted so that the etalon surfaces are exactly perpendicular to the beam direction when the etalon mount angular adjustment is at one extreme or the other. This can be accomplished by observing the reflection of residual pump light back toward the FM.

6.2 Swinging the laser: Ring to standing-wave

You can change the laser from a ring to a standing-wave configuration by following the steps described below. If you have not been involved in the original installation of the system or have not changed mirror sets, please read over Sections 4 and 5 first, to familiarize yourself with some of the alignment concepts and techniques employed below. While the fluorescence discussed in the procedures can be seen directly, you will find alignment easier if you use either an infrared viewer or an infrared-sensitive phosphor card.

6.2.1 Set the BRF to the wavelength region corresponding to the minimum threshold pump power for the mirror set in place. If the pump laser is on, turn off the pump or block the pump beam before it reaches the Titan-CW laser.

6.2.2 Unscrew and remove the bolts holding the etalon mount, the OM and the FM gimbal mounts to the laser base. To protect the fine threads of the gimbal-mount differential adjustments from being damaged during this procedure, we strongly recommend that, prior to unscrewing the bolts, you rotate those adjustments counterclockwise so the threads are fully retracted. Place the etalon mount aside for the moment.

6.2.3 Rotate the entire FM gimbal mount counter-clockwise to align its mounting holes with the alternate set of

threaded holes on the base plate, and bolt the unit down. Follow the same procedure for the OM mount, except rotate the unit clockwise to mate with the alternate holes. (If you have retracted the threads on the gimbal mounts, reset the gimbal-mount differential adjustments back to a normal position.)

- 6.2.4 The following applies only to the breadboard configuration. The OM and FM gimbal mounts bolt on to movable base plates, which must be repositioned when the Titan-CW laser is changed between ring and standing-wave configurations. Turn on or unblock the pump beam and set the pump laser for minimal power. Loosen the screws holding the FM gimbal-mount base plate to the breadboard, slide the plate along (approximately 1 cm) in its slots in a direction toward the Ti:sapphire crystal so that the reflected pump beam is centered on the FM and tighten down the base-plate screws. You should then slide the OM base plate over the same amount, bring the pump power up to a level well over the threshold value for the standing-wave configuration and proceed to *.
- 6.2.5 Turn on or unblock the pump beam and bring the pump power up to a level well over the threshold value for the standing-wave configuration of the Titan-CW system.
- 6.2.6 Adjust the gimbal-mount controls on the OM so that, on the surface of the FM, the fluorescence retro-reflected from the OM intersects the fluorescence reflected directly from the TM. Similarly adjust the FM gimbal mount for overlap of the reflected and direct fluorescence at the OM.
- 6.2.7 Iterate between adjustments of the OM and FM gimbal mounts to achieve laser action and continue these adjustments (while lowering the pump power) to minimize threshold.
- 6.2.8 Reattach the etalon to the laser base so that the etalon is in the beam path between the FM and TM. The etalon should be mounted so that the etalon surfaces are exactly perpendicular to the beam direction when the etalon mount angular adjustment is at one extreme or the other. This can be accomplished by observing the reflection of residual pump light back toward the TM.

7.0 MAINTENANCE

7.1 Cleaning the laser optics

"A clean laser is a happy laser." This is especially true for relatively low-gain systems such as the Titan-CW laser. Dust, oil and other contaminants on the surfaces of the optical components of the laser can increase threshold, decrease laser efficiency and increase surface scatter. The latter effect can be particularly problematic in a ring laser because it can destabilize the unidirectional nature of the cavity, by providing feedback into the unwanted direction of oscillation.

On the other hand, every time a piece of optics is cleaned there is a risk that the optics may be damaged through improper handling or cleaning techniques, or that residue from the cleaning process may worsen, rather than improve the condition of the optics.

The best preventive maintenance for the Titan-CW laser is to assure that the optics in the laser never get dirty. In the best case, the Titan-CW laser should operate in an environment where contamination of the optics is unlikely to occur, i.e. where the air quality is high. Operating time with the cover off the laser should be minimized.

Low output from the Titan-CW laser will result if the pump laser beam quality has reduced. This often may happen with argon-ion pump lasers if the Brewster-angle windows on the plasma tube become dirty. Before suspecting a problem with the Ti:sapphire laser, check the pump laser first!

You may have to clean the system optics in the case where the power output of your Titan-CW laser system has fallen but the pump laser is operating properly and re-alignment of the laser optics does not restore the power level. The most crucial optical surfaces in terms of the Titan-CW laser performance are those of the Ti:sapphire crystal, and should be cleaned first. You can determine the condition of other surfaces in the system by observing the level of light scattered from them, either by direct viewing for surfaces the pump laser interacts with, or with the use of an infrared viewer for surfaces where only strong Ti:sapphire wavelengths are present. We have found that the two outer surfaces of the BRF and, in the case of ring lasers, the surfaces of the optical rotator section of the optical diode tend to pick up dust, perhaps due the presence of surface charges on the crystalline quartz. The cleanliness of surfaces outside of the Titan-CW laser cavity, such as those of the focussing lens, waveplate or beam-directing mirrors, is less likely to

have a major effect on laser performance except for cases where the contamination level is very high. Nevertheless, they should be checked and cleaned if necessary to avoid the possibility of surface damage due to the heating of contaminants by the pump laser. We recommend the following procedures, in order of increasing level of cleaning:

7.1.1
Gas cleaning

In cases where dust is a likely cause of optics contamination, you may be able to effectively clean the optics by simply blowing the dust off. Use a clean, dry gas; nitrogen is recommended. The use of compressed air or Freon spray cans is not recommended. There is too great a possibility that contaminants in these propellants may settle on the optics.

7.1.2
Solvent cleaning

All components can be cleaned with soft tissue and reagent-grade acetone or methanol. The solvent should be stored in a closed container to minimize contamination by water.

Mirrors, BRF,
lens, waveplate

The mirrors, BRF, focussing lens and waveplate are best cleaned by removing the elements from their holders. Only one element at a time should be taken out, in order to simplify the re-alignment of the Titan-CW system that will likely be needed when the elements put back in position. You should use optical gloves or finger cots when handling the mirrors, lens and waveplate. Removal of the BRF assembly can be accomplished by undoing the set screw that attaches the assembly to the rotating mount. Optical elements should be set down only on clean lens tissue, clean nylon or dacron wipes to minimize contamination and scratches. For the cavity mirrors both reflecting and AR surfaces should be cleaned, except for the FM, which only requires a clean reflecting surface. The solvent cleaning process should proceed as follows:

1. Make sure that all loose particles have been removed from surface to be cleaned by thoroughly blowing off the surface with a dry gas such as nitrogen.
2. Apply a few drops of solvent onto a folded piece of lens tissue.
3. Gently and carefully wipe, in one direction only, the optical surface being cleaned with the solvent-moistened tissue. Make one pass only and discard the tissue.
4. Inspect surface and if observable residues remain, repeat Steps 2, 3 and 4. Inspection is best carried out with the aid of an bright light source, such as a microscope lamp.

Crystal

To clean the crystal, first reduce the pump power to the minimum visible level. Remove the orange cover plate and observe the pump spot scattered at the input surface of the $\text{Ti:Al}_2\text{O}_3$ crystal. Wipe the input surface with a folded tissue soaked in the solvent and held in a hemostat. Apply a smooth, even pressure. (The crystal is bonded to the copper block by a space-qualified RTV. This material is soluble and thus excess solvent should be avoided.) When clean, the scattered light should be minimal. Clean the second surface of the crystal in a similar fashion. When clean, scattered pump light should be barely visible on the TM side of the crystal. Replace the orange cover plate.

Optical diode (ring lasers only)

To clean the two surfaces of the Faraday rhomb, first remove the magnet. It is held on by the two bolts along the centerline of the magnet. Clean the surfaces with a folded tissue soaked in solvent and held in a hemostat. It is often helpful to cut off the excess tissue before cleaning. Observe the scattered intracavity light on the exposed rhomb surfaces with an IR viewer to determine when the surface is clean. Repeat cleaning until minimal scatter is observed on both surfaces and then replace magnet.

To clean the optical rotator, first remove the single bolt that holds the cover plate. As the rotator crystal is quite thin, you should not to apply excess force when cleaning it. Use the technique described above for the Faraday rhomb to clean both surfaces of the plate, if necessary. Smooth, even pressure applied in a single downward motion will yield the best results.

8.0 SERVICE

WARNING!

Section 3 of this manual (Safety) should be read carefully and reviewed periodically by anyone attempting to service this laser. In any case, before any attempt is made to service this equipment, an SEO service person should be contacted directly to aid in problem diagnosis and to review service procedures.

8.1 Troubleshooting involves determining the cause(s) of low power and/or high threshold. When "low power" means "no power", realignment may be indicated. This section provides a checklist to help diagnose the problem(s). Often simple cleaning of one or more of the cavity components is all that is required to restore peak performance

Symptoms:

The laser runs but the output power is low and/or threshold is high ...

- [1] Is the water flowing? Is the water temperature too high (>30 C) or too low (below the dew point)?
- [2] Is the crystal dirty? Clean the crystal (see [5.1]) and verify the result by observing the pump light scattered by the input surface of the Ti:Al₂O₃ crystal with the cavity blocked. Looking to the right of the reflected pump spot, a uniform pink glow is good while blue-green speckle is bad.
- [3] Do optics need to be cleaned? With an IR viewer, look for unusually strong sources of intracavity scatter. Pay particular attention to the BRF, all surfaces of the optical diode (the Faraday rhomb can be observed by removing the magnet), and the exposed surfaces of the PMIR and lens. Clean surfaces as required (See Section 7.0)
- [4] Is the pump misaligned? Adjust the pump beam for minimum threshold.
- [5] Is the pump lens too close or too far from the Ti:Al₂O₃ crystal? Adjust the position of the pump lens to maximize output power at the desired operating point. This may require iterative adjustment of the pump beam to compensate for the deviation of the pump beam induced by the lens.
- [6] Is the HWP properly oriented? Rotate the HWP over 360° to determine the optimum orientation and set it there.
- [7] Is the pump laser less than ideal? Is it linearly polarized? Is it operating in a clean TEM₀₀ mode? Is it delivering as much power to the Titan-CW laser as you think? Avoid beam steering optics of poor optical quality and do not use transmitting optics such as prisms that may distort the pump beam.

- [8] Inspect components for damage. Although all optics are carefully inspected and tested prior to installation, occasionally an optical coating may fail. Pay particular attention to the HWP and PMIR. Failure may occur if the laser is operated for long periods of time at high power in excessive humidity.
- [9] Inspect the crystal for damage. The crystal can be damaged if the pump beam is focussed at the interface of the input surface of the $\text{Ti:Al}_2\text{O}_3$ crystal and the copper support block. A damaged crystal will exhibit strong scatter when illuminated by the pump. If damage is suspected, turn off the water, remove the copper support block, and inspect the crystal under magnification. A damaged crystal can be replaced with a new mounted crystal. Contact SEO for a replacement.

9.0 WARRANTY

LIMITED ONE (1) YEAR WARRANTY

SCHWARTZ ELECTRO-OPTICS, INC. (SEO) warrants for one (1) year from the date of shipment any SEO laser system according to the following terms.

Any part of the laser system manufactured or supplied by SEO and found in the reasonable judgement of SEO to be defective in material or workmanship will be repaired or replaced by SEO without charge for parts and labor.

The laser system, including any defective part, must be returned to SEO within the warranty period. All shipping expenses for warranty repair will be paid for by the buyer. SEO's responsibility in respect to warranty claims is limited to making the required repairs or replacements, and no claim of breach of warranty shall be cause for cancellation or rescision of the contract of sale of any laser system.

This warranty does not cover any laser system that has been subject to neglect, misuse, negligence or accident. This warranty does not apply to any damage to the laser system that is the result of improper installation or maintenance, or to any laser system that has been operated or maintained in any way contrary to the operating or maintenance instructions as specified in the SEO Instruction Manual. The warranty does not cover any laser system that has been altered or modified so as to change its intended use.

The warranty does not cover laser optics which may: (1) become damaged or pitted in the course of operation due to operation in an unclean environment (i.e. with dust on optics) (2) be scratched due to improper handling or cleaning.

In addition, the warranty does not extend to repairs made necessary by the use of parts, accessories, or laser coolant that are either incompatible with the unit or adversely affect its operation.

SEO reserves the right to change or improve the design of any laser system or accessory without assuming any obligation to modify any system previously manufactured.

The foregoing Express warranty is in lieu of all other warranties, expressed or implied.

SEO's OBLIGATION UNDER THIS WARRANTY IS STRICTLY AND EXCLUSIVELY LIMITED TO THE REPAIR OR REPLACEMENT OF DEFECTIVE PARTS.

SEO ASSUMES NO RESPONSIBILITY FOR INCIDENTAL, CONSEQUENTIAL OR OTHER DAMAGES INCLUDING BUT NOT LIMITED TO: LOSS OR DAMAGE TO PROPERTY, LOSS OF REVENUE, LOSS OF USE OF THE UNIT, LOSS OF TIME OR INCONVENIENCE.