

Mode-Locked Femtosecond Titanium:Sapphire Laser

MODEL Trestles-100-F4

MANUAL



DEL



MAR PHOTONICS

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TABLE OF CONTENTS

1. Introduction
2. Laser safety
3. Laser description
4. List of accessories
5. Installation
6. Alignment
7. Day-to-day operation
8. Possible problems

1. INTRODUCTION

Ti:Sapphire

Titanium-doped sapphire (Ti:Sapphire) is a solid state laser medium capable of tunable laser operation over broad range of near infrared (IR) wave lengths. Because of its broad absorption band in blue and green, energy for lasing process can be supplied by standard continuous wave (CW) argon ion laser or CW 532 nm, high-power, diode-pumped solid state laser as opposed to an electrical discharge or flash lamp that supplies broad band excitation.

Solid-state mode-locked lasers produce femtosecond light pulses using Kerr lens mode-locking (KLM) principle of operation and continuous wave pumping sources. KLM principle combines self-focusing nonlinear optical effect and aperture effect together to reach the shortest optical pulses. This Kerr self-focusing effect leads to slight changes in the spatial intensity profile of the resonator mode in laser oscillators. As a consequence, by introducing an intracavity aperture, a power-dependent loss can be created. Owing to the quasi-instantaneous response of nonresonant Kerr nonlinearities, the amplitude modulation induced by self-focusing is able to simulate ultrafast saturable-absorber action and support pulse formation down to the femtosecond regime in solid-state lasers that have long gain-relaxation times. The gain bandwidth of solid state laser materials such as Ti:Sapphire extends over >200nm and has the potential for supporting pulses of less than 10fs. The pulse duration from these lasers is determined by critical interplay between intracavity self-phase modulation in media, and negative group delay dispersion.

Trestles-100-F4 femtosecond laser head contains the Ti:Sapphire rod, the optics that form the resonator cavity, and CW 532 nm, high-power, diode-pumped solid state laser.

Del Mar Photonics guarantees that provided laser was tested and it is suitable for the Kerr lens mode-locked operation. On the one hand, the laser installation without the help of the manufacturer requires some experience of the user in laser physics. But on the other hand, by working with our laser you will gain experience in ultrafast laser technology.

2. LASER SAFETY

Trestles-100-F4 and its pump laser are Class IV –high-power lasers, whose beams are, by definition, safety and fire hazards. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as secular reflections cause severe skin or eye damage.



TRESTLES-100-F4 laser emits CW and pulsed infrared radiation, it is extremely dangerous to the eye. Infrared radiation passes easily through the cornea, which focuses it on the retina, where it can cause instantaneous permanent damage.

Precautions for the safe operation of Class IV Power lasers

- Wear protective eyewear at all times; selection depends on the wavelength and intensity of the radiation, the conditions of use, and the visual function required. Protective eyewear vendors are listed in the *Laser Focus World*, *Laser Optronics*, and *Photonics Spectra* buyer's guides. Please use safety instructions of your pump laser and follow their recommendations in your work.
- Maintain a high ambient light level in the laser operation area. This keeps the pupil constricted, thus reducing the possibility of eye damage
- Keep the protective cover on the laser at all times.
- Avoid looking at the output beam; even diffuse reflections are hazardous. Keep all beams below eye level always. Never look in the plane of propagation of the beams.
- Avoid wearing jewelry or other objects that may reflect or scatter the beam while using the laser.
- Use an infrared detector or energy detector to verify that the laser beam is off before working in front of the laser.
- Operate the laser at lowest beam intensity possible, given the requirements of the application.
- Expand the beam whenever possible to reduce beam power density.
- Avoid blocking the output beams or its reflection with any part of the body.
- Establish a controlled access area for laser operation. Limit to those trained in the principles of laser safety.

- Post prominent warning signs near the laser operation area (Fig.1).



Fig.1. Standard safety warning sign

- Provide enclosures for beam paths whenever possible.
- Set up shields for secular reflections.
- Set up an energy absorbing target to capture the laser beam, preventing unnecessary reflections or scattering.

Be very careful while executing any step of the alignment. Avoid any exposure to the direct and reflected laser beams. Direct and reflected laser radiation from pump laser and Ti:Sapphire laser can cause serious eye damage. Remember that Ti:Sapphire radiation is invisible or looks like as red radiation of small intensity. However, it is dangerous even at lowest intensity. Intense incoherent luminescence is emitted from the Ti:sapphire rod also.

We recommend using protective boxes covering all elements outside of the Ti:Sapphire laser.

Follow the instructions listed in this manual for safe operation of your laser.

3. Laser description

General overview

The TRESTLES-100-F4 laser head contains the Ti:Sapphire rod, optics that form the resonator cavity and CW 532 nm, high-power, diode-pumped solid state laser. Elements include pump beam mirrors, laser rod, focusing lens and mirrors, an output coupler (OC), high reflector (HR), beam folding mirrors, prisms as dispersion control elements and slit as spectral turning element.

Connections to the cover box include cooling water, power and control from “Electronics Module” (optionally).

Option:

The Electronics module enclosed with the laser consists of the pulse detection circuit and driver circuits for electromechanical starter. All indicators and controls are located on the front and upper panel. One cable connects it to cover box of laser, the other is power cable. BNC cable may be connected to customer's oscilloscope.

Pumping optimization

For continuous-wave (CW) pumping, there is one basic requirement for lasing action: the unsaturated round-trip CW gain must exceed the round trip loss from all sources. The CW gain is obtained by having a high inversion density and an adequate length of Ti:Sapphire material. The high inversion density comes from having a high pump intensity and high Ti³⁺ ion concentration. Losses in the Ti:Sapphire laser come from losses in mirror coatings and polished surfaces, and what is more important, the residual loss in the Ti:Sapphire material itself. This loss is proportional to the rod length and varies with the Ti³⁺ concentration, generally increasing as the Ti³⁺ concentration increases.

Unlike a dye laser, the pump illumination in Ti:Sapphire laser must be collinear with the cavity mode over a relatively long length of laser rod. Continuous, high inversion density over the entire volume of a rod several millimeters in diameter is difficult to achieve. To circumvent this problem, the pump light is focused to a narrow line within the rod and the oscillating laser mode is similarly focused and overlapped within the same volume – a technique known as longitudinal pumping. The output beam is then collimated and expanded to normal size. The residual pump beam is dumped through the second cavity focus mirror.

TRESTLES-100-F4 laser description

Pump laser

Due to broad absorption band in blue and green, energy for lasing process can be supplied by standard continuous wave (CW) argon ion laser or CW 532 nm, high-power, diode-pumped solid state lasers. It is very important to note that pump laser should work in TEM₀₀ mode.

For pumping TRESTLES-100-F4 laser a pump laser operating in TEM₀₀ transverse mode regime with output power 3 - 5 Watts should be used. CW 532 nm, high-power, diode-pumped solid state laser from Laser Quantum is used in TRESTLES-100-F4.

This laser generates a near-diffraction limited, highly stable beam at 532nm. Capable of delivering >3W of power, this laser is the most compact laser in its class. It has highly sophisticated digital electronics.

Specifications	
Power	> 4 W
Wavelength	532 nm
Beam size	2.5 mm
Transverse mode	TEM ₀₀
Divergence	< 0.4 mrad
M2	< 1.1
Power stability (rms)	< 1.0 %
Noise (1Hz-6MHz - rms)	< 0.5 %
Polarisation ratio	100:1

The folded cavity

Del Mar Photonics modeled, analyzed and optimized the cavity design for optimum performance in minimal space. The result was a 10 mirror folded cavity (Fig.2). This scheme incorporates 10-mirror cavity (M1, M2, M3, M4, M5, M6, M7, M8, M9, OC), Ti:Sapphire crystal (TiS), lens for focusing of pump radiation (L), two prisms (P1 and P2) and slit (S).

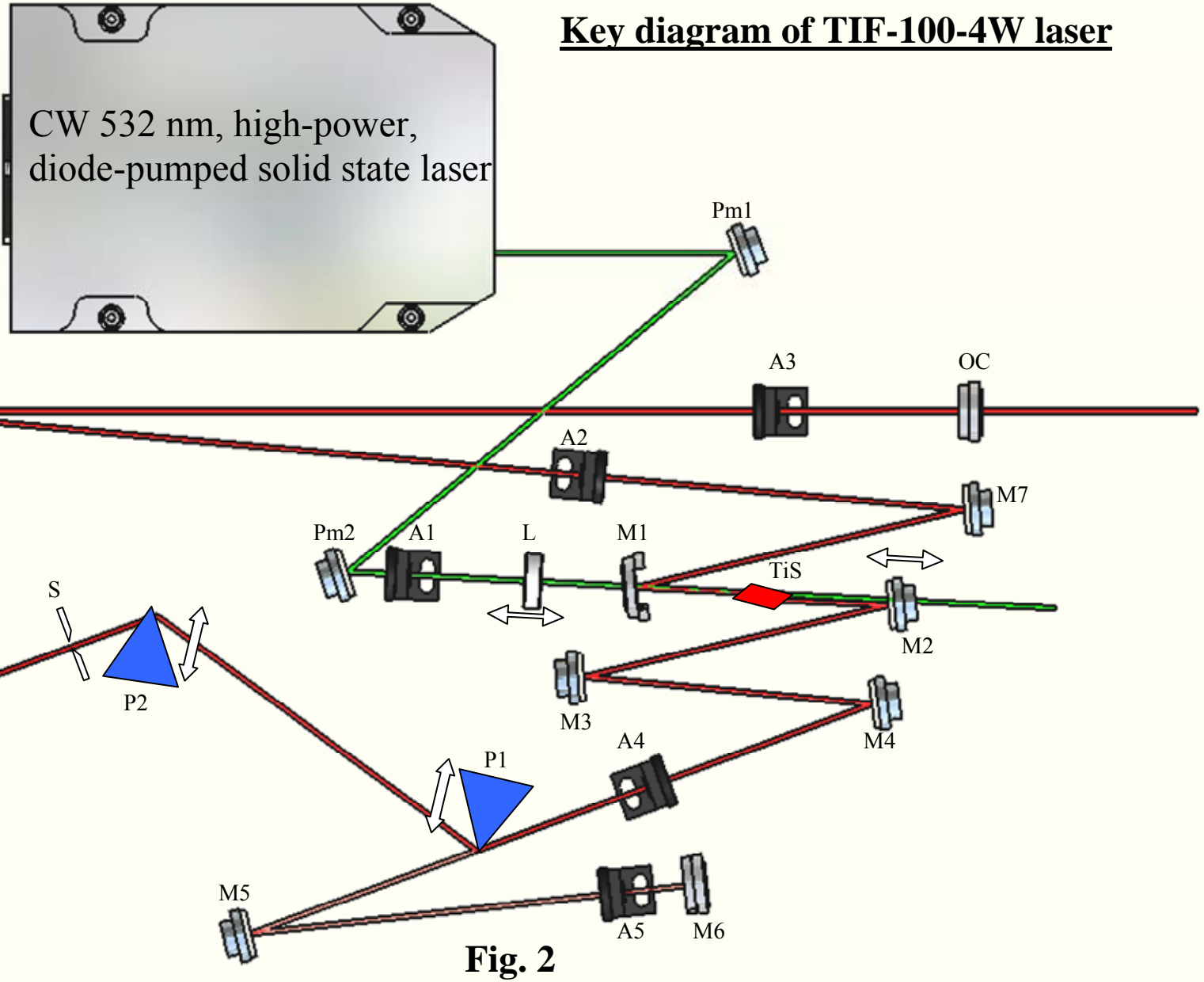
In folded cavities where astigmatism is not eliminated, output beams are elliptical and hard to focus. But by carefully choosing the angles of the cavity focus mirrors and rod length, astigmatism in TRESTLES-100-F4 output beam is virtually eliminated.

Wavelength turning characteristics

Because the Ti:Sapphire rod is birefringent, uninterrupted turning is achieved when the c – axis of the rods is aligned coplanar with the polarization of electric field within the cavity. Since the Ti:Sapphire rod and prism surfaces represent a total of six Brewster's angle surfaces, the polarization within the cavity is largely determined by the orientation of these surfaces. Furthermore, cavity losses are minimized and tuning is optimized when all these surfaces are accurately aligned at Brewster's angle. The laser uses a proprietary Ti:Sapphire rod holder that orients the rod surfaces at Brewster's angle and allows the “ c ” axis of the rod to be aligned coplanar to the electric field vector. This technique compensates for unavoidable errors in rod orientation that occur when the rod is cut and polished. Wavelength tuning range of the TRESTLES-100-F4 laser is 730 nm to 860 nm with 10-25 nm FWHM.

Wavelength selection

The femtosecond laser TRESTLES-100-F4 is wavelength turned using a prism sequence and the slit. This prism sequence provides a region in cavity where the wavelengths are spatially spread. A variable slit is located in this dispersed beam. The output wavelength is turned by changing the position of the slit in horizontal plane. The width of the slit can also be changed so that the bandwidth (and, hence, the temporal width) of the output pulse can be varied. This simple, straight-forward method covers the entire Ti:Sapphire range for ultrashort pulses.



Scheme of laser head.

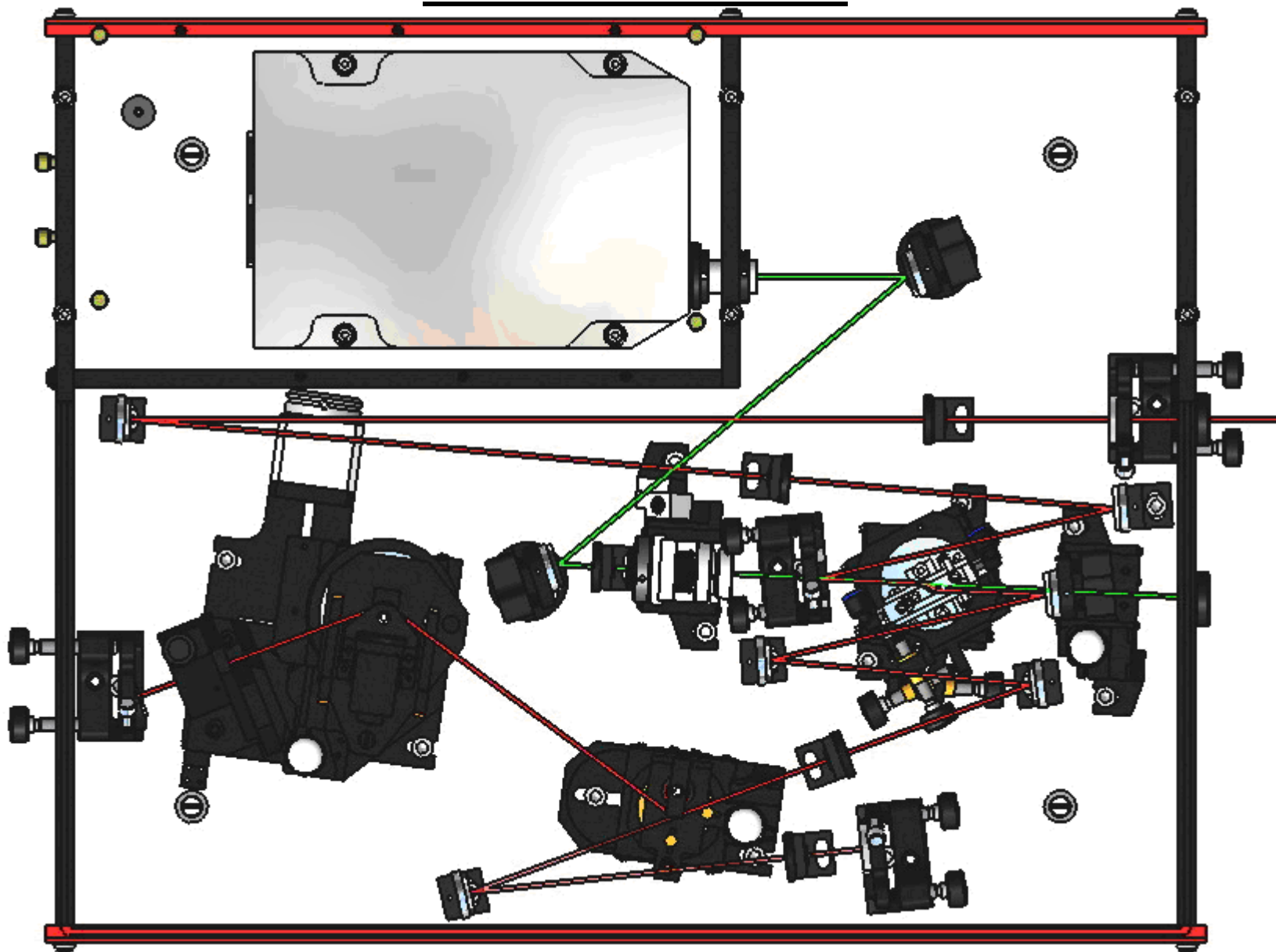


Fig.3

Pulse width selection

The pulse width turning characteristics of the Ti:Sapphire laser are influenced by two factors: those inherent in the Ti:Sapphire material itself and those from cavity parameters. While we cannot readily modify the Ti:Sapphire material to change pulse width, we can modify the net group velocity dispersion (GVD). The optical components in the laser cavity introduce positive GVD and cause pulse spreading. Further pulse spreading causes self-Phase modulation (SPM) in the Ti:Sapphire rod, which results from the interaction of the short optical pulse with the nonlinear refractive index. In order to obtain stable short output pulses, these effects must be compensated with negative GVD. Prism pairs are used to produce a net negative intracavity GVD in fs system. This allows the system to produce sub 50 fs near transform limited pulses over most of wave length regime.

The scheme of laser depicted on the Fig.2. Laser consists of the following optical elements for the basic configuration:

1. 1.5 mm long Ti-doped sapphire crystal (TiS);
2. Dielectric mirrors M1, M2, M3, M4, M5, M6 M7, M8, M9 with high reflection (>99,5%). M1, M2 – have high reflection for working wavelength and transparent for laser pumping radiation, radius of curvature is 100 mm;
M3, M4, M5, M6, M7, M8, M9- high reflectors for working wavelength, flat mirrors;
OC - output coupler;
Pm1, Pm2 – pump routing flat mirror.
3. L - lens for focusing of pumping radiation, focal length is F=80 mm.
4. P1, P2 - Brewster angle prisms at 800 nm
5. A1, A2, A3, A4, A5 – aligning apertures.

4. LIST OF ACCESSORIES

You need for assembling, testing and operation of femtosecond Ti:Sapphire laser:

1. Optical table. Ti:Sapphire laser itself requires about 0.530 m x 0,430 m area of the optical table.
2. A photodiode with $>10 \text{ mm}^2$ sensitive area or low-inertial power meter for fast control of relative output power in the process of alignment.
3. A power meter for control of output power value.
4. If you didn't order the electronics module you need fast photodiode with 400 MHz oscilloscope to display the temporal structure of output radiation.
5. Two polarizers, we recommend polarization cubs or Glan - laser prisms (PC1, PC2).
6. Interferometric autocorrelator for the measurement of pulse duration. Time resolution should be better than 10 fs. (We recommend using Del Mar's Reef femtosecond autocorrelator that is completely compatible with Del Mar Photonics lasers.)
7. Spectrometer or diffractive grating operating near 800 nm for spectrum control.
8. Infrared sensor card for observation of weak IR luminescence.
9. We recommend using chiller to keep the Ti:Sapphire rod and the pumping laser at a constant temperature for performance stability.

5. INSTALLATION

Unpacking your laser

Your laser was packed with great care and all containers were inspected prior to shipment: the laser left Del Mar Photonics in good condition. Upon receipt of your laser, immediately inspect the outside of the shipping containers. If there is any major damage, such as holes in the box or cracked wooden frame members, insists on that a representative of the carrier should be present when you unpack the contents.

Carefully inspect your laser as you unpack it. If you notice any damage, such as dents, scratches or broken knobs immediately notify the carrier and your Del Mar Photonics Sales representative.

Open the cover of laser head and remove the bags which covering the elements of laser and fixing elements which are used for transport. Do it very carefully, try not to misalign the laser, and damage mirrors during this procedure.

Placement of TRESTLES-100-F4 laser head.

1. Hook up the water hoses to the laser head.
2. Secure the laser head to the table with provided four foot clamps.
The clamps slide over the lower portion of each foot.
3. Verify the height adjust locking nuts on the fit are tight.
4. *Connect the slit control buttons to the laser head. Tap power supply into power line (options).*
5. Connect Starter button or connect the Electronic module (optionally) to the laser head. Tap power supply in to power line
6. Verify the output of the pump laser meets specifications for power and mode quality. (For pumping TRESTLES-100-F4 laser should be used pump laser operating in TEM₀₀ transverse mode regime with output power >3 Watts).
7. Reduce pump laser power to the minimum.

6. ALIGNMENT

This part of our instructions describes installation and alignment procedure. Researchers use slightly different approaches to constructing a mode-locking Ti:Sapphire laser (see review paper, references). If you have good experience in laser technology, you can use your own approach to the alignment of our femtosecond laser. Nevertheless, we hope that our instructions will help you in your work.

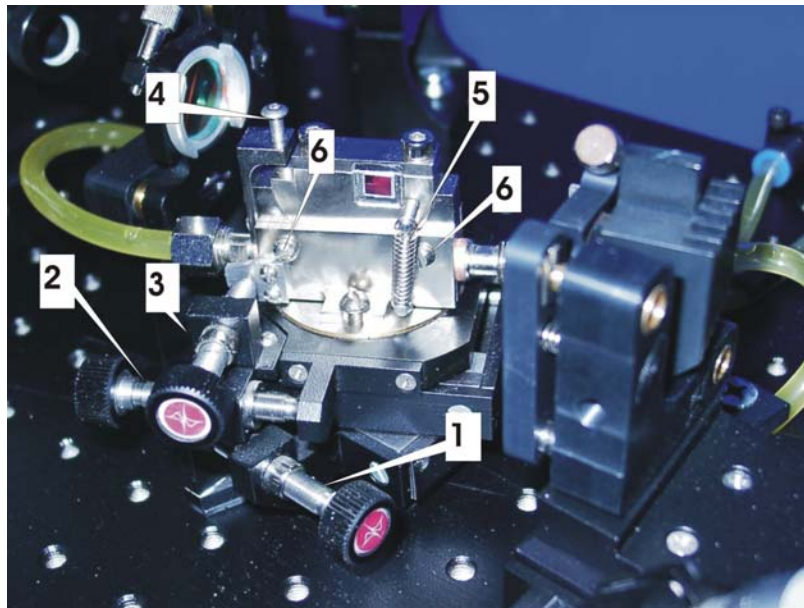
Alignment of Ti:Sapphire laser.

Reduce pump laser power to the minimum.

1. Wrench in the input aperture A1.
2. Using routing mirrors Pm1, Pm2 direct the pump beam to pass through the input aperture A1 and passes through the apertures A4 inside the TRESTLES-100-F4 laser. Verify that beam pass through the centers of all 2 apertures.
3. Switch on cooling water (moderate water flow ≥ 0.5 liter/min).

It is not necessary to follow the italicized instructions for the first alignment. You should only carry out these procedures in case of complete laser misalignment under severe transportation conditions. Please, follow the bold-typed instructions.

4. Close the shutter of the pump laser.
5. Remove M1 and M2 mirrors with holders from their mounts.
6. Remove focusing lens L with the draw-tube from mount.



1. Screw for aligning crystal position on optical axis.
2. Screw for transverse aligning.
3. Screw for aligning Brewster angle.
4. Screw for aligning crystallographic axis orientation.
5. Spring
6. Fixing screw

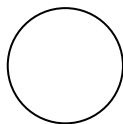
Fig.4

7. Remove the crystal with the crystal holder (fig. 4).
 - Remove two vertical springs from the holder using a metallic hook (metallic hook may be easily made from paper clip) or thin-flat-nose pliers.
 - Loose but not remove four clamping screws, two on each side of the crystal mount.
 - Remove the crystal with crystal holder.
8. Open pump shutter.
9. As you can see there is a scratch passing under the elements from Pm2 to M2 direction. Move the AA (AA-additional aperture) so the mark on lower part aperture coincides with scratch on the table top.
10. Direct the pump beam parallel to the scratch passing through the center of AA and A1 aperture, using mirrors Pm1, Pm2.

11. Install the focusing lens with a draw-tube back to the lens mount.
12. Place AA near M2 so the mark on the aperture holder coincides with scratch on the table top.
13. Verify that the center of the beam spot on AA is still on the center of AA
 - If the centers do not coincide in vertical plane then use the vertical lens adjusting screw to align the lens. (Some laser systems have lens holders without vertical aligning screw. If so, then loose, but don't remove, fixing screws. Align the position of the lens and then fix the screws.)
 - If the centers are not coinciding in horizontal plane then loose the screws that clamp the lens holding stage to the translation stage and move the lens holding stage in perpendicular to pump beam direction to align the lens and then fix the screws.
14. Close the pump beam shutter.
15. Install the M1 mirror with the holder to its mount.
16. Remove a beam stopper beyond M2
17. Insert the PC2 in the pump beam beyond the M2 mirror mount. Place the target (piece of paper) beyond the PC2. Align the PC2 for a "dark field".
18. Install and align the crystal
 - Close pump shutter.
 - Mount the crystal holder to its mount.
 - Tighten two vertical springs.
 - Open pump shutter.
 - Verify that the beam is passing through the center of the crystal.
 - Set up approximately Brewster angle by the angle control of crystal, observing green beam reflected from the Ti: sapphire crystal entrance surface. Find position of crystal with minimum reflection.
 - Align the crystal for a dark field on the target, rotating the crystal holder around the optical axis using the Screw for aligning crystallographic axis orientation 4 Fig. 4.
 - Close pump shutter.
 - Tighten four fixing screws, two on each side of the mount.
 - Set up distance between M2 surface and entrance surface of the crystal by the longitudinal control screw of laser crystal stage equal to 48 mm.
19. Remove PC2 with it mount

20. Install M2 mirror with the holder to its mount. Set up the distance between M1 and M2 surfaces approximately to 104-106 mm.
21. Place a beam stopper beyond M2.
22. Wrench off A5
23. Using adjusting screw of the P1 prism move the prism from the beam path.
24. *Open the pump shutter. Using insertion adjusting screw of the P1 prism, remove the prism from the beam path. Aligning M2 mirror, direct the residual part of pump beam to the center of the M3, M4 mirror, to the center of A4, and to the center of the mirrors M5 and M6 (verify that the beam is parallel to the scratch on the table top, if not make it parallel to the scratch). Verify the height of the beam*
25. *Aligning M6 direct beam back to the M5, M4, M3 mirrors and through the aperture A4.*
26. Wrench off all A1, A2, A3, A4, A5.
27. Increase pump power up to 3-4 W. Use protective goggles for pump laser radiation.
28. *Aligning the positioning of the lens. Use protective goggles for pump laser radiation during this procedure. Remove beam blocker, beyond M2. Translating the lens find the position when round shape of the pump beam will abruptly change to the oval shape. Place back the beam blocker.*
29. Use IR card to see the luminescence near OC mirror.

+ reflection of M2-M3-M4-M5-M6-M5-M4-M3
M2- M1-M7- M8



reflection of M1, M7, M8 only

30. Aligning M1 mirror, direct luminescence reflected only from the M1 – M7 – M8 to the center of the OC.
31. *Verify the height of the beam with help of AA*
32. Position of (+) spot is adjusted by M6 controls. The spot should be approximately on the center of spot reflected from M1, M7, M8 only.
33. Align OC mirror so the reflected beam return back to the center of M8-M7 and M1.
34. If a correct alignment has been done, laser radiation should appear after small adjustments of M6 and OC. If not then place the additional photodiode with large aperture beyond the OC mirror. The luminescence spot should be in the

active area of photodiode. Adjust M6, OC and position of M2 mirrors for a maximum signal until generation will appear. Remove the photodiode.

35. Place the power meter in the beam.

36. Adjust the M6 and OC for maximum output power. For optimization of Ti:sapphire output power adjust OC and M5 by horizontal controls together and vertical controls together also. Output power should be close to the maximum when the spots on M1 look like on the picture:

green  red

37. By small steps move M2 along the optical axis, try to find maximum output power. Make additional small adjustments using OC and M6 controls after each step.

38. Move Ti:sapphire crystal along the optical axis, try to find maximum output power. Make additional small adjustments using OC and M6 controls after each step.

39. Adjust Brewster angle using Ti:sapphire crystal angle control in small steps. Try to reach maximum output power. Make additional horizontal adjustments using OC and M6 controls after each step.

40. Adjust focusing lens position and Ti:sapphire crystal along the optical axis in small steps. Try to reach maximum output power. Make additional small adjustments using OC and M6 controls after each step.

41. Verify that Ti:sapphire output power is not less than 10% - 15% of pumping power. If not, repeat steps 36-41. Sometimes, you should repeat steps 34-39 several times during the first alignment of the CW Ti:Sapphire laser. It requires patience. And it may be necessary to clean the mirrors and crystal surface.

42. Wash all mirrors in the cavity.

- Close the pump shutter.
- Wash one mirror by alcohol or acetone.
- Open the pump shutter.
- Verify the output power the value should be bigger or the same.
- Make small adjustments of M6 and OC.
- Repeat this procedure for mirrors in the cavity M1, M2, M3, M4, M5, M6, M7, M8 OC, L, Pm1, Pm2 and crystal surfaces.

43. Write down maximum output power and position of M2 micrometric screw. Move M2 forward and back and find positions of micrometric screw where Ti:sapphire laser

oscillation disappeared. Write down these positions. This is a range of stability.

Note. There are two ranges of stability in the asymmetric cavity (see G.Cerulla et. al., Opt.Lett. 19 (1994) 807).

Alignment of mode-locked Ti:sapphire laser.

44. Flip the slit aside.
45. Using adjusting screw of the P1 prism insert prism in the beam path. Moving the prism you can find the position of prism when laser oscillation begin between mirrors M6 – OC and small fraction of this generation is deviated by P1 prism.
46. Verify the correct aligning of the prism
 - Loosen but don't remove the rotation fixation screw R (fig. 5).
 - Rotating the prism's base plate adjust prism for minimal deviation of the beam.
 - The heights should be also 70 mm above the laser head table top. If it is necessary use the adjusting screws to align the prism (see the figure №5).
47. Verify that beam strikes P2 prism. Verify the height of the beam near P2.
48. Using adjusting screw of the P2 prism insert prism in the beam path. Verify correct aligning of the prism in same manner as in 46.

Note. If your laser was provided with electro-mechanical starter, then P2 holder mounting is replaced by electro-mechanical starter.
49. Align M9 to return deviated by P1 prism part of beam back.
50. Insert P1 in the beam, by small adjustments of M9 mirror reach the generation through the prisms. **Block M6 mirror by blocker (aperture A5)**

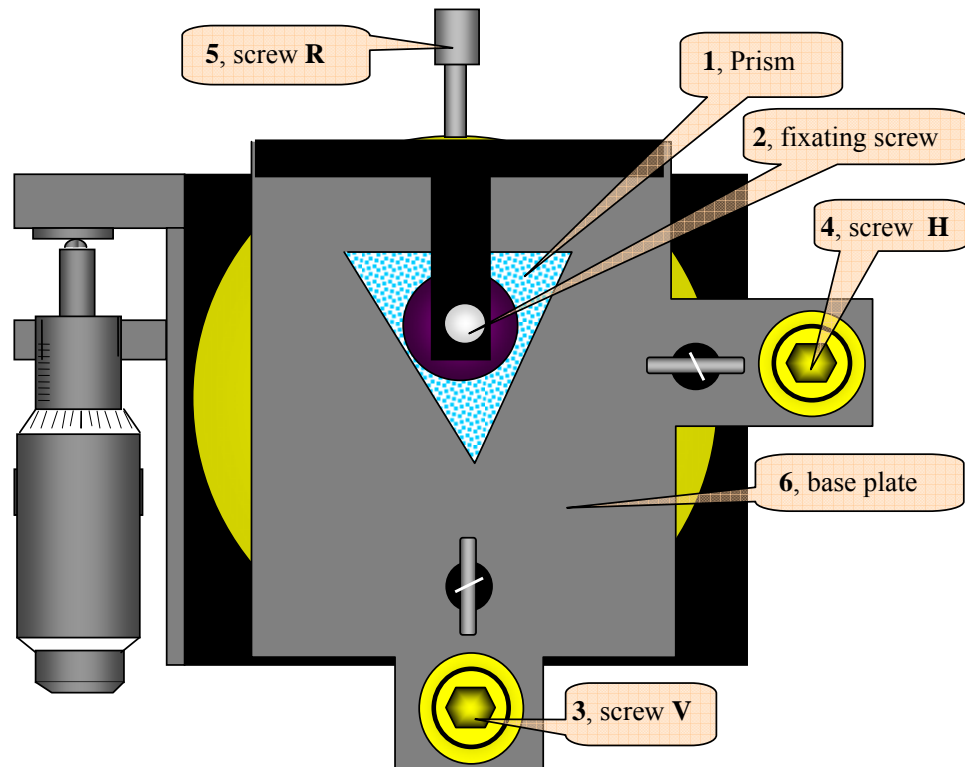


Fig.5. Schematic picture of prisms fixation and service

- 1 - prism
- 2 - fixating screw, ! don't tight it with force to prevent birefringence of prism !
- 3 - screw **V** to align deviated beam in vertical plane,
- 4 - screw **H** to align reflected beams in vertical plane,
- 5 - screw **R** to fix rotation of base plate **6**,
- 6 - prism's base plate rotating by hand.

51. Aligning OC and M9 find maximum output power in same manner as in CW operation.

52. Verify that output power decreases not more than 15-25 percent lower then output power without prisms. If not, repeat procedure from step 45. Sometimes, you should repeat it several times during the first alignment of the CW Ti:Sapphire laser. It requires patience.

Note. After finishing this procedures there are some check points:

1. The spot on the M1 mirror should be look like described in 35. If not align M9 and OC.
2. There are beams reflected from the apex of each prism. The beams should be almost parallel to each and must be in resonator plane (plane at 70 mm above table top of the laser head). If not then align the prisms and M9, OC .

53. Align P1 so that generation is passing almost through the apex of prism. But generation should not be lost.
54. Test the output beam using fast photodiode and oscilloscope.
55. Using the position aligning screw remove P2 from the pump beam. The generation will be lost.
56. Moving the P2 prism by your finger (thus you change the depth of insertion of the prism) look to the result on the oscilloscope. Then moving M2 by small steps find the place where the pulses appear. Femtosecond pulses should appear near the end of the region of stability. Continuous pulse train should be observed on the oscilloscope screen in femtosecond operation.

Note: We remind you that two regions of stability exist in asymmetric cavity. You are moving through the stability region having less distance between M1 and M2.

57. Manage to achieve the situation when pulses train is observed while you hold the prism in place. Then align the prism position screw to hold the prism in place.
58. The laser was aligned at pump power 3-4W and output coupler 10% transmission. For higher pump level use output couplers with higher transmission (options).
59. Measure the spectrum of Ti:Sapphire laser radiation with help of spectrometer or diffractive grating.
60. Measure the spectrum and try to find its optimum using control of P2 mount. You will obtain shorter pulses with broader spectrum. Spectral bandwidth should be not less than 10 nm at FWHM (full width half maximum) with central wave length 800 nm. It corresponds to 100 fs.
61. Femtosecond operation starts from moving of optical elements. Once started, femtosecond operation lasts in hours at good pump laser stability and in stable room conditions. When femtosecond operation disappears, start it again with mechanical movement of P2.
62. Measure pulse duration with autocorrelator.
63. To get a tuning of output wavelength and to control a spectral bandwidth, flip back the slit. Align the width and position of the slit so the pulses are easily appearing at the same spectral position where they appear without slit. Write down the position of the prism and the slit. Then watching the spectrum and "pulse train" move the slit to shift the pulse spectrum to the desired region. When you will see the noise in the train or CW portion in pulse spectrum move the prism in the same direction. Make movements in small steps.

Verify that laser easily starts at new position. Repeat this steps until you reach the desired central wave length.

Note. If your laser is modified model with combined prism + slit stage, then you can achieve spectral turning by wrenching only one prism position screw.

If you failed to achieve the lasing after several attempts, please repeat all the steps, including the italicized ones.

7 DAY-TO-DAY OPERATION

1. Switch on cooling water for Ti:Sapphire laser (moderate flow).
2. Switch on the pump laser (3-5 W output).
3. Ti:Sapphire will give proper characteristics after 40 minutes. Pump power should be stable from day to day.
4. Small adjustments of M9 and OC might be necessary in day-to-day operation
5. To turn off the system repeat the procedure in reverse order.

Note. Occasionally, it may be necessary to clean the optics and surfaces of the Ti:Sapphire rod. The best method is to clean surfaces is to first block the ion laser pump beam and then blow excess particles from the surface. Then fold a piece of lens tissue into a pad and clamp with a hemostat (usually provided with the ion laser). Soak this pad with spectroscopic grade acetone or methanol, and shake off the excess liquid. Then make one cleaning stroke only across the surface (particles on the surface can become imbedded in the tissue and act as an abrasive if a second stroke is made across the surface).

8 POSSIBLE PROBLEMS

1. Pump beam is not TEM₀₀ mode.
2. Stability of pump laser is not enough.
3. Optical surfaces of laser elements are dirty.
4. The laser was aligned at pump power 3-4W and output coupler 10% transmission. For higher pump level use output couplers with higher transmission (options).
5. You spend not enough time to reach good femtosecond pulses.