This laser product complies with performance standards of United States Code of Federal Regulations, Title 21, Chapter 1 – Food and Drug Administration, Department of Health and Human Services, Subchapter J – Parts 1040.10 or 1040.11, as applicable.
This manual contains information you need in order to safely operate the Mai Tai™ HP high-performance laser system.

The “Unpacking and Inspection” section contains information on how to unpack your Mai Tai HP system and lists the items you should have received. It also lists any options you may have purchased. Please read this short, but important, section before you begin to unpack the rest of your unit. Please note that only personnel authorized and trained by Spectra-Physics may install the Mai Tai HP system.

The “Introduction” contains a brief description of the Mai Tai HP laser, its power supply and the control devices.

Following the Introduction is an important chapter on safety. The Mai Tai HP is a Class IV laser and, as such, emits laser radiation that can permanently damage eyes and skin. This section contains information about these hazards and offers suggestions on how to safeguard against them, as well as installation procedures and maintenance you must perform in order to keep your system in compliance with CDRH regulations.

To ensure your system is installed according to CDRH regulations and to minimize the risk of injury or expensive repairs, be sure to read this chapter on Laser Safety—then follow these instructions.

“Laser Description” contains a brief exposition on solid-state CW pumping and Ti:Sapphire laser theory. This is followed by a more detailed description of the Mai Tai HP laser system. The chapter concludes with system specifications and outline drawings.

Chapter 4 describes the Mai Tai HP controls and is followed by a chapter that describes how to install the laser head, power supply, chiller and control software (included with the system).

Chapter 6 contains procedures for operating the laser and includes descriptions of (a) the Windows-based GUI interface provided with the system and (b) the command/query structure required for writing your own control program.

Should you experience any problems with any equipment purchased from Spectra-Physics, or you are in need of technical information or support, please contact Spectra-Physics as described in “Customer Service.” This chapter contains a list of world-wide Spectra-Physics Service Centers you can call if you need help.

Appendix A provides information on short pulse formation in the mode-locked Mai Tai HP laser, while Appendix B provides general information.
on pulse width measurement. Appendix C lists the status and error codes that might be generated by the system, and Appendix D explains how to replace the purge pump filter cartridge.

This product has been tested and found to conform to the provisions of Directive 73/23/EEC governing product safety and the provisions of Directive 89/336/EEC governing electromagnetic compatibility. Refer to the “CE Declaration of Conformity” in Chapter 2, “Laser Safety,” for a complete of directives to which this system has been tested and found in compliance.

This product conforms to the requirements of 21 CFR 1040.10 CDRH and is compliant to Underwriters Laboratory UL1950 and is listed as ULR for recognized components. This equipment has been designed and tested to comply with the limits for a Class A digital device pursuant to Part 15 of the FCC Rules.

Every effort has been made to ensure that the information in this manual is accurate. All information in this document is subject to change without notice. Spectra-Physics makes no representation or warranty, either express or implied, with respect to this document. In no event will Spectra-Physics be liable for any direct, indirect, special, incidental or consequential damages resulting from any defects in this documentation.

If you encounter any difficulty with the content or style of this manual, please let us know. The last page is a form to aid in bringing such problems to our attention.

Thank you for your purchase of Spectra-Physics instruments.
Environmental Specifications

CE Electrical Equipment Requirements

For information regarding the equipment needed to provide the electrical service listed under “Service Requirements” at the end of Chapter 3, please refer to specification EN-309, “Plug, Outlet and Socket Couplers for Industrial Uses,” listed in the official Journal of the European Communities.

Environmental Specifications

The environmental conditions under which the laser system will function are listed below:

**Indoor use**
- Altitude: up to 2000 m
- Temperatures: 10° C to 40° C
- Maximum relative humidity: 80% non-condensing for temperatures up to 31° C.
- Mains supply voltage: do not exceed ±10% of the nominal voltage
- Insulation category: II
- Pollution degree: 2

FCC Regulations

This equipment has been tested and found to comply with the limits for a Class A digital device pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Modifications to the laser system not expressly approved by Spectra-Physics could void your right to operate the equipment.

CDRH and UL Regulations

This product conforms to the requirements of 21 CFR 1040.10 CDRH. It is designed to meet Underwriters Laboratory UL1950 and uses a power supply that is a UL recognized (ULR) component.
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Warning Conventions

The following warnings are used throughout this manual to draw your attention to situations or procedures that require extra attention. They warn of hazards to your health, damage to equipment, sensitive procedures, and exceptional circumstances. All messages are set apart by a thin line above and below the text as shown here.

- **Laser radiation is present.**
- **Condition or action may present a hazard to personal safety.**
- **Condition or action may present an electrical hazard to personal safety.**
- **Condition or action may cause damage to equipment.**
- **Action may cause electrostatic discharge and cause damage to equipment.**
- **Condition or action may cause poor performance or error.**
- **Text describes exceptional circumstances or makes a special reference.**
- **Do not touch.**
- **Appropriate laser safety eyewear should be worn during this operation.**
- **Refer to the manual before operating or using this device.**
The following units, abbreviations, and prefixes are used in this Spectra-Physics manual:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>length</td>
<td>meter</td>
<td>m</td>
</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>frequency</td>
<td>hertz</td>
<td>Hz</td>
</tr>
<tr>
<td>force</td>
<td>newton</td>
<td>N</td>
</tr>
<tr>
<td>energy</td>
<td>joule</td>
<td>J</td>
</tr>
<tr>
<td>power</td>
<td>watt</td>
<td>W</td>
</tr>
<tr>
<td>electric current</td>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>electric charge</td>
<td>coulomb</td>
<td>C</td>
</tr>
<tr>
<td>electric potential</td>
<td>volt</td>
<td>V</td>
</tr>
<tr>
<td>resistance</td>
<td>ohm</td>
<td>Ω</td>
</tr>
<tr>
<td>inductance</td>
<td>henry</td>
<td>H</td>
</tr>
<tr>
<td>magnetic flux</td>
<td>weber</td>
<td>Wb</td>
</tr>
<tr>
<td>magnetic flux density</td>
<td>tesla</td>
<td>T</td>
</tr>
<tr>
<td>luminous intensity</td>
<td>candela</td>
<td>cd</td>
</tr>
<tr>
<td>temperature</td>
<td>celcius</td>
<td>C</td>
</tr>
<tr>
<td>pressure</td>
<td>pascal</td>
<td>Pa</td>
</tr>
<tr>
<td>capacitance</td>
<td>farad</td>
<td>F</td>
</tr>
<tr>
<td>angle</td>
<td>radian</td>
<td>rad</td>
</tr>
</tbody>
</table>

**Prefixes**

| Prefixes |  |  |  |  |  |
|----------|  |  |  |  |  |
| tera     | (10^{12})  | T | deci | (10^{-1})  | d | nano | (10^{-9})  | n |
| giga     | (10^{9})   | G | centi | (10^{-2})  | c | pico | (10^{-12}) | p |
| mega     | (10^{6})   | M | mill  | (10^{-3})  | m | femto | (10^{-15}) | f |
| kilo     | (10^{3})   | k | micro | (10^{-6})  | µ | atto | (10^{-18}) | a |
Abbreviations

The following is a list of abbreviations used in this manual:

- ac: alternating current
- AOM: acousto-optic modulator
- APM: active pulse mode locking
- AR: antireflection
- bi-fi: birefringent filter
- CDRH: Center of Devices and Radiological Health
- CPM: colliding pulse mode locking
- CW: continuous wave
- dc: direct current
- E/O: electro-optic
- fs: femtosecond or $10^{-15}$ second
- GTI: Gires-Touitnois Interferometer
- GVD: group velocity dispersion
- HR: high reflector
- IR: infrared
- OC: output coupler
- ps: picosecond or $10^{-12}$ second
- PZT: piezo-electric transducer
- RF: radio frequency
- SCFH: standard cubic feet per hour
- SPM: self phase modulation
- TEM: transverse electromagnetic mode
- Ti:sapphire: Titanium-doped Sapphire
- UV: ultraviolet
- $\lambda$: wavelength
Unpacking and Inspection

Unpacking Your Laser

Your Mai Tai™ HP high-performance laser was packed with great care, and its container was inspected prior to shipment—it left Spectra-Physics in good condition. Upon receiving your system, immediately inspect the outside of the shipping containers. If there is any major damage (holes in the containers, crushing, etc.), insist that a representative of the carrier be present when you unpack the contents.

Once uncrated, carefully inspect your laser system as you unpack it. If any damage is evident, such as dents or scratches on the covers or broken parts, etc., immediately notify the carrier and your Spectra-Physics sales representative.

Keep the shipping containers. If you file a damage claim, you may need them to demonstrate that the damage occurred as a result of shipping. If you need to return the system for service at a later date, the specially designed container assures adequate protection.

Warning! Spectra-Physics considers itself responsible for the safety, reliability and performance of the Mai Tai HP laser only under the following conditions:

- All field installable options, modifications or repairs are performed by persons trained and authorized by Spectra-Physics.
- The equipment is used in accordance with the instructions provided in this manual.

System Components

- Mai Tai HP laser head
- Model J80 power supply
- A chiller with tubing and fittings and its own user’s manual
- A 19 in. rack with hardware for completing its assembly and mounting the chiller and Model J80 power supply
- An accessory kit (see below)
Accessory Kit

Included with the laser system is this manual, a test summary, a packing slip listing all the components shipped with this order, and an accessory kit containing the following items:

- Hardware for mounting the Mai Tai HP laser head to a horizontal base plate
- RS-232 serial cable
- Interface control software on a CD-ROM
- Retail version cover (for scientific orders only)
- Protective caps for the fiber-optics
- Model J80 10 A fuses (2)
- D-sub jumper plugs (for the REMOTE and ANALOG ports, which are not used on this system)
- Specification summary form
The Mai Tai HP Laser System

A Mai Tai™ HP high-performance laser system comprises four main elements:

- The Mai Tai HP modelocked laser head (scientific or OEM version)
- The Model J80 power supply
- A rack-mountable chiller
- Windows®-based LabWindows™ control software for installation on your own personal computer or the optional notebook computer.
- Optional notebook personal computer with control software installed.

Figure 1-1 shows a typical Mai Tai HP laser system.

![Mai Tai HP Laser System](image)

Figure 1-1: The scientific version of the Mai Tai HP Ti:sapphire modelocked laser system (chiller not shown).

The Mai Tai HP comprises two lasers, a CW diode-pumped laser and a mode-locked Ti:sapphire pulsed laser. Each is substantially reduced in size and squeezed into a single small enclosure. The CW pump laser is designed after the popular Spectra-Physics Millennia® diode-pumped laser. The mode-locked Ti:sapphire laser design is based on that of the field-proven Spectra-Physics Tsunami® femtosecond (fs) pulsed laser.

Windows is a registered trademark of Microsoft Corporation.
LabWindows is a trademark of National Instruments Corporation.
The laser head has two chambers, a CW pump chamber and a pulsed output chamber. The CW pump chamber contains a diode-pumped, intracavity, frequency-doubled, solid-state Millennia-type 532 nm laser. The pulsed output chamber contains a mode-locked Ti:sapphire cavity. Because of Ti:sapphire broad absorption band in the blue and green, the 532 nm output of the CW laser is an ideal pump source for the Ti:sapphire laser.

The Mai Tai HP delivers continuously tunable output over a range of near infrared (IR) wavelengths, from 700 to 1020 nm at <100 fs.

For performance stability, a chiller is used to water-cool and control the temperature of the CW pump laser Nd:YVO₄ crystal, the pulsed chamber Ti:sapphire rod and the base of the laser head. (The chiller is fully described in its own manual shipped with the system.)

The Mai Tai HP laser head is sealed to prevent dust and water vapor from entering it. An umbilical connects the laser head to the power supply.

**Warning!**

There are no user-serviceable parts inside the Mai Tai HP laser head. Opening the laser head and compromising the seal will void the Mai Tai HP warranty.

### The CW Pump Chamber

The pump chamber contains a high power, visible CW Millennia laser that provides greater than 10 W of green 532 nm pump output from a standard 110 or 220 Vac, single-phase outlet. Optical noise is less than 0.04% rms (10 Hz to 2 GHz). This performance is possible through the integration of our patented, high-efficiency FCharr™ diode-pumping and QMAD intracavity doubling technologies.

Fiber-coupling enables the astigmatic light from a diode laser module to be transformed into a round beam that is suitable for an efficient end-pumping geometry. It also allows the diode laser module to be located in the power supply, thereby removing their heat load from the laser head and facilitating their replacement without the need for realigning the cavity.

Because the pump chamber is sealed, performance and stability are further improved, thus providing long-term operation without requiring cleaning or adjustment.

### The Pulsed Output Chamber

This chamber contains the mode-locked Ti:sapphire cavity and includes the Ti:sapphire rod, the rod focusing mirrors, cavity fold and end mirrors, an acousto-optic modulator for regenerative mode locking, prism dispersion control elements and a tuning element.

This chamber is sealed and there are no user controls. Chapter 6, “Operation,” describes the LabWindows control software and the on-screen controls for monitoring Mai Tai HP output power and controlling the shutter (all units) and for selecting the wavelength of the unit.
Patents

The Mai Tai HP laser system contains technology that is unique among Ti:sapphire lasers and is covered by the following United States patents:

**Mai Tai HP laser head, pump section and power supply**

- 4,653,056 4,761,785 4,942,582
- 4,656,635 4,785,459 5,080,706
- 4,665,529 4,837,771 5,127,068
- 4,701,929 4,872,177 5,410,559
- 4,723,257 4,894,839 5,412,683
- 4,739,507 4,908,632 5,436,990
- 4,756,003 4,913,533 5,446,749

**Mai Tai HP laser head, pulsed section**

- 4,894,831 5,056,103 5,185,750
- 4,977,566 5,175,736 5,212,698
- 5,020,073
Mai Tai HP High-Performance, Mode-Locked, Ti:sapphire Laser
The *Mai Tai™ HP* is a Class IV—High-Power Laser, whose beam is, by definition, a safety and fire hazard. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as specular reflections cause severe skin or eye damage.

Because the *Mai Tai HP* laser emits 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-High 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, Lasers and Optronics,* and *Photonics Spectra* buyer’s guides. Consult the ANSI or ACGIH standards listed at the end of this section for guidance.

- Maintain a high ambient light level in the laser operation area. This keeps the eye’s pupil constricted, thus reducing the possibility of eye damage.

- Avoid looking at the output beam; even diffuse reflections are hazardous.

- Avoid wearing jewelry or other objects that may reflect or scatter the beam while using the laser.

- Use an infrared detector or energy detector (IR viewer) to verify that the laser beam is off before working in front of the laser.

- Operate the laser at the lowest beam intensity possible, given the requirements of the application.

- Expand the beam whenever possible to reduce beam power density.

- Avoid blocking the output beam or its reflection with any part of your body.
• Establish a controlled access area for laser operation. Limit access to those trained in the principles of laser safety.
• Post prominent warning signs near the laser operation area (Figure 2-1).
• Set up the laser so the beam is either above or below eye level.
• Provide enclosures for beam paths whenever possible.
• Set up shields to prevent specular reflections.
• Set up an energy absorbing target to capture the laser beam, preventing unnecessary reflections or scattering (Figure 2-2).

Figure 2-1: These standard safety warning labels are appropriate for use as entry warning signs (EN 60825-1, ANSI Z136.1, Section 4.7).

Figure 2-2: Folded Metal Beam Target

The use of controls or adjustments, or the performance of procedures other than those specified herein may result in hazardous radiation

Follow the instructions contained in this manual for safe operation of your laser. At all times during operation, maintenance, or service of your laser, avoid unnecessary exposure to laser or collateral radiation* that exceeds the accessible emission limits listed in “Performance Standards for Laser Products,” United States Code of Federal Regulations, 21CFR1040 10(d).

* Any electronic product radiation, except laser radiation, emitted by a laser product as a result of, or necessary for, the operation of a laser incorporated into that product.
Safety Devices

Emission Indicators

Figure 2-3 and Figure 2-5 show the locations of the emission indicators.

Figure 2-3: Laser Head Emission Indicator

The EMISSION connector on the back of the Model J80 (see Figure 2-4 and Figure 2-5) can be used to turn on and off a user-installed emission indicator. When the laser is off (i.e., there is no emission), there is closure between pins 3 and 1 and an open between pins 3 and 2. The opposite is true when the laser is on, i.e., there is emission or emission is imminent. There is no power supplied by these terminals. The circuit is rated for 30 Vac at 1 A. These indicators turn on 3 seconds before actual emission occurs.

Figure 2-4: The EMISSION Connector Schematic
The internal shutter is electromechanical and is controlled via the controller or by software via the RS-232 interface. Its interlock fault and fail-safe mode is the closed position.

**Cover Safety Interlocks**

Neither the laser head nor power supply contain user-serviceable parts and are not to be opened by the user. Therefore, no cover interlocks are required in the laser head or the power supply. Only someone trained by Spectra-Physics should be allowed to service the system. A non-interlocked warning label is attached to the laser head as shown in Figure 2-7.
Operating the laser with the cover off may expose people to high voltages and high levels of radiation. It also increases the rate of optical surface contamination. There are no user-serviceable parts inside the Mai Tai HP laser head or the Model J80 power supply. Therefore, operating the laser or power supply with the aluminum cover off is prohibited and will void your warranty.

**Interlock Keyswitch**

The key switch on the front panel of the power supply (Figure 2-5) is used as the key-actuated interlock control. The key must be inserted turned to the “on” position in order to close the interlock and allow the diode to be energized if the POWER switch is also on. The key can only be removed when it is turned to the “off” position. Removing the key prevents unauthorized system use.

**POWER Switch**

The POWER switch provides ac power to the control circuits.

**POWER Indicator**

When on, this green LED indicates that ac power is applied to the system control circuits.

**Remote Interlock Connector**

The 2-pin INTERLOCK connector on the power supply connector panel (Figure 2-5) can be wired to an external interlock switch. Remove the jumper plug (supplied, see Figure 2-6), and either rewire it or use a similar connector to wire to a perimeter safety switch that is attached to an access door or to other auxiliary safety equipment. Wire the switch as “normally closed” so that when the door or safety device opens and the switch opens, the power supply will immediately turn off the diode lasers as a safety precaution to prevent unaware personnel from getting hurt.

**Figure 2-6: Interlock Jumper Plug**

The two contacts of the INTERLOCK connector must either be wired to a safety switch or be shorted together using the jumper plug provided in order of the power supply to turn on.
CDRH Requirements for Operating the Mai Tai HP Laser System

The *Mai Tai HP* laser head and the *Model J80* power supply comply with all CDRH safety standards. However, if either is embedded into another system where an emission indicator is not readily visible or the power supply interlock key is not accessible, these functions must be provided by the user to satisfy CDRH regulations:

- **an emission indicator**—that indicates laser energy is present or can be accessed. It can be a “power-on” lamp, a computer display that flashes a statement to this effect, or an indicator on the control equipment for this purpose. It need not be marked as an emission indicator so long as its function is obvious. *Its presence is required on any control panel that affects laser output, including the computer display panel.*

- **a safety key**—when the power supply interlock key is not accessible, you must provide a safety key to prevent unauthorized use. The password feature of your personal computer (in the CMOS Setup program) or the Windows® operating system meets this requirement.

Maintenance Necessary to Keep this Laser Product in Compliance with Center for Devices and Radiological Health (CDRH) Regulations

This laser product complies with Title 21 of the *United States Code of Federal Regulations*, Chapter 1, subchapter J, parts 1040.10 and 1040.11, as applicable. To maintain compliance with these regulations, once a year, or whenever the product has been subjected to adverse environmental conditions (e.g., fire, flood, mechanical shock, spilled solvent, etc.), check to see that all features of the product identified on the CE/CDRH Radiation Control Drawing (found later in this chapter) function properly. Also, make sure that all warning labels remain firmly attached.

1. Verify removing the auxiliary interlock (INTERLOCK) connector on the power supply prevents laser operation. Figure 2-5 on page 2-4 shows the interlock with the jumpered plug in place.

2. Verify the laser can only be turned on when the key switch is in the on position and that the key can only be removed when the switch is in the off position.

3. Verify the emission indicator provides a visible signal when the laser emits accessible laser radiation that exceeds the accessible emission limits for Class I.**

4. Verify the time delay between turn-on of the emission indicator and starting of the laser; it must give enough warning to allow action to avoid exposure to laser radiation.

5. Verify the beam attenuator (shutter) operates properly when commanded from the personal computer/controller and that it closes when the control device is disconnected or the key switch is turned off. Verify it actually blocks access to laser radiation.

* Windows is a registered trademark of the Microsoft corporation.
** 0.39 µW for continuous-wave operation where output is limited to the 400 to 1400 nm range.
Figure 2-7: CE/CDRH Radiation Control Drawing, OEM Version (labels shown on page 2-10)
Figure 2-8: CE/CDRH Radiation Control Drawing, Scientific Version (labels shown on page 2-10)
Figure 2-9: CE/CDRH Radiation Control Drawing, *Model J80 Power Supply* (labels shown on page 2-10)
CE/CDRH Warning Labels

- CE Danger Label
- RF Caution Label
- CDRH Aperture Label
- CE Caution Label
- Warning—Pressure Label
- Caution—Noninterlocked Housing Label
- Patent Label
- Patent Label
- Voltage Input/Fuse Label
- CE Warning Label Interlock Defeated
- CE Warning Label
- Model/Serial Identification Label
- Model/Serial Identification Label
- Identification/Certification Label
- Distilled Water Label
- Chiller Label
- Clock Labels
- WEEE Label

Figure 2-10: CE/CDRH Warning Labels
**Label Translations**

For safety, the following translations are provided for non-English speaking personnel. The number in parenthesis in the first column corresponds to the label number listed on the previous page.

<table>
<thead>
<tr>
<th>Label</th>
<th>French</th>
<th>German</th>
<th>Spanish</th>
<th>Dutch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture Label (3)</td>
<td>Un rayonnement visible et/ou invisible est émis par cette ouverture. Ouverture Laser.</td>
<td>Austritt von sichtbarer und unsichtbarer Laserstrahlung! Bestrahung vermeiden!</td>
<td>Por esta abertura se emite radiación láser visible e invisible; evite la exposición.</td>
<td>Vanuit dit apertuur wordt zichtbare en onzichtbare laserstraling geemitteerd! Vermijd blootstelling!</td>
</tr>
<tr>
<td>Pressure Warning Label (6)</td>
<td>Attention: Ajuster la pression du refroidisseur a plus de 40 PSI (2,6 bar) peut provoquer de sévères dommages et annulera la garantie.</td>
<td>Betrieb des Kühlgerätes bei mehr als 40 PSI (2,6 bar) führt zu Beschädigungen und zum Erlöschen der Garantie.</td>
<td>Peligro. Si ajusta la presión del refrigerador de agua arriba de 40 PSI (Libras por pulgada Cuadrada) puede causar daños catastróficos y se eliminará la garantía.</td>
<td>Waarschuwing. Instellen van een chiller-druk hoger dan 40 PSI (2,6 bar) kan leiden tot catastrofale schade en beëindigt de garantie dekking.</td>
</tr>
<tr>
<td>Patent Label (8, 9, 10)</td>
<td>Ce produit est fabriqué sous l’un ou plusieurs des brevets suivants.</td>
<td>Dieses Produkt wurde unter Verwendung einer oder mehrerer der folgenden US-Patente hergestellt.</td>
<td>Este producto esta fabricado con una o más de las siguientes patentes de los Estados Unidos.</td>
<td>Dit product is gefabriceerd met een of meer van de volgende USA patenten.</td>
</tr>
</tbody>
</table>
To Our Customers in the European Union:

As the volume of electronics goods placed into commerce continues to grow, the European Union is taking measures to regulate the disposal of waste from electrical and electronic equipment. Toward that end, the European Parliament has issued a directive instructing European Union member states to adopt legislation concerning the reduction, recovery, re-use and recycling of waste electrical and electronic equipment (WEEE).

In accordance with this directive, the accompanying product has been marked with the WEEE symbol. See label 25 on page 2-10.

The main purpose of the symbol is to designate that at the end of its useful life, the accompanying product should not be disposed of as normal municipal waste, but should instead be transported to a collection facility that will ensure the proper recovery and recycling of the product's components. The symbol also signifies that this product was placed on the market after 13 August 2005. At this time, regulations for the disposal of waste electrical and electronic equipment vary within the member states of the European Union. Please contact a Newport / Spectra-Physics representative for information concerning the proper disposal of this product.
CE Declaration of Conformity

We,
Spectra-Physics
1330 Terra Bella Avenue
Mountain View, CA. 94043
United States of America

declare under sole responsibility that the:

Mai Tai diode-pumped, mode-locked Ti:sapphire laser system with
Model J80 power supply, user-supplied or compliant pc-based
controller, and rack-mountable chiller

manufactured after August 2004

meets the intent of EMC Directive 89/336/EEC (2004/C 98/05) for electromagnetic compatibility and 73/23/EEC (1973) for low-voltage directives. Compliance was demonstrated to the following specifications as listed in the official Journal of the European Communities:

EN 55011: 1998 + A1 + A2: Industrial, scientific and medical (ISM) radio-frequency equipment radio disturbance characteristics.
EN 61000-3-2: 2000: Limits for harmonic current emissions (equipment input up to and including 16A per phase).
EN 61000-4-6: 1996 + A1: Part 4-6: Testing and measurement techniques—immunity to conducted disturbances induced by radio-frequency fields.
EN 61000-4-8: 1993: Testing and measurement techniques—power frequency magnetic field immunity test.


I, the undersigned, hereby declare that the equipment specified above conforms to the above Directives and Standards.

Don Mills
Vice-President Operational Excellence
Newport Corporation & Spectra-Physics
September 15, 2004
Sources for Additional Information

Laser Safety Standards

Safe Use of Lasers (Z136.1)
American National Standards Institute (ANSI)
11 West 42nd Street
New York, NY 10036
Tel: (212) 642-4900

Occupational Safety and Health Administration (Publication 8.1-7)
U. S. Department of Labor
200 Constitution Avenue N. W., Room N3647
Washington, DC 20210
Tel: (202) 693-1999
Internet: http://www.osha.gov

American Conference of Governmental and Industrial Hygienists (ACGIH)
1330 Kemper Meadow Drive
Cincinnati, OH 45240
Tel: (513) 742-2020
Internet: http://www.acgih.org/home.htm

Laser Institute of America
13501 Ingenuity Drive, Suite 128
Orlando, FL 32826
Tel: (800) 345-2737
Internet: http://www.laserinstitute.org

Compliance Engineering
Canon Communications LLC
11444 W. Olympic Boulevard
Los Angeles, CA 90064
Tel: (310) 445-4200

International Electrotechnical Commission
Journal of the European Communities
EN 60825-1 Safety of Laser Products — Part 1: Equipment classification, requirements and user’s guide
Tel: +41 22-919-0211 Fax: +41 22-919-0300
Internet: http://www.iec.ch

Cenelec
35, Rue de Stassartstraat
B-1050 Brussels, Belgium
Tel: +32 2 519 68 71
Internet: http://www.cenelec.org

Document Center, Inc.
111 Industrial Road, Suite 9
Belmont, CA 94002
Tel: (650) 591-7600
Internet: http://www.document-center.com
Equipment and Training

Laser Safety Guide
Laser Institute of America
13501 Ingenuity Drive, Suite 128
Orlando, FL 32826
Tel: (800) 34LASER
Internet: http://www.laserinstitute.org

Laser Focus World Buyer's Guide
Laser Focus World
Pennwell Publishing
98 Spit Rock Road
Nashua, NH 03062
Tel: (603) 891-0123
Internet: http://lfw.pennnet.com/home.cfm

Photonics Spectra Buyer's Guide
Photonics Spectra
Laurin Publications
Berkshire Common
PO Box 4949
Pittsfield, MA 01202-4949
Tel: (413) 499-0514
Internet: http://www.photonics.com
Chapter 3  Laser Description

A Brief Review of Laser Theory

Emission and Absorption of Light

Laser is an acronym derived from Light Amplification by Stimulated Emission of Radiation. Thermal radiators, such as the sun, emit light in all directions, the individual photons having no definite relationship with one another. But because the laser is an oscillating amplifier of light, and because its output comprises photons that are identical in phase and direction, it is unique among light sources. Its output beam is singularly directional, monochromatic, and coherent.

Radiant emission and absorption take place within the atomic or molecular structure of materials. The contemporary model of atomic structure describes an electrically neutral system composed of a nucleus with one or more electrons bound to it. Each electron occupies a distinct orbital that represents the probability of finding the electron at a given position relative to the nucleus. Each orbital has a characteristic shape that is defined by the radial and angular dependence of that probability, e.g., all $s$ orbitals are spherically symmetrical, and each of three all $p$ orbitals lie parallel to the x, y or z axis in a double-lobed configuration with a characteristic node at the nucleus (Figure 3-1). The energy of an electron is determined by the orbital that it occupies, and the overall energy of an atom—its energy level—depends on the distribution of its electrons throughout the available orbitals. Each atom has an array of energy levels: the level with the lowest possible energy is called the ground state, and higher energy levels are called excited states. If an atom is in its ground state, it will stay there until it is excited by external forces.

Movement from one energy level to another—a transition—happens when the atom either absorbs or emits energy. Upward transitions can be caused by collision with a free electron or an excited atom, and transitions in both directions can occur as a result of interaction with a photon of light. Consider a transition from a lower level whose energy content is $E_1$ to a higher one with energy $E_2$. It will only occur if the energy of the incident photon matches the energy difference between levels, i.e.,

$$h\nu = E_2 - E_1$$  \[1\]

where $h$ is Planck’s constant, and $\nu$ is the frequency of the photon.

“Light” will be used to describe the portion of the electromagnetic spectrum from far infrared to ultraviolet.
Likewise, when an atom excited to $E_2$ decays to $E_1$, it loses energy equal to $E_2 - E_1$. The atom may decay spontaneously, emitting a photon with energy $h\nu$ and frequency

$$\nu = \frac{E_2 - E_1}{h}$$  \[2\]

Spontaneous decay can also occur without emission of a photon, the lost energy taking another form, e.g., transfer of kinetic energy by collision with another atom. An atom excited to $E_2$ can also be stimulated to decay to $E_1$ by interacting with a photon of frequency $\nu$, emitting energy in the form of a pair of photons that are identical to the incident one in phase, frequency, and direction. This is known as stimulated emission. By contrast, spontaneous emission produces photons that have no directional or phase relationship with one another.

A laser is designed to take advantage of absorption, and both spontaneous and stimulated emission phenomena, using them to create conditions favorable to light amplification. The following paragraphs describe these conditions.

**Population Inversion**

The net absorption at a given frequency is the difference between the rates of emission and absorption at that frequency. It can be shown that the rate of excitation from $E_1$ to $E_2$ is proportional to both the number of atoms in the lower level ($N_1$) and the transition probability. Similarly, the rate of stimulated emission is proportional to the population of the upper level ($N_2$) and the transition probability. Moreover, the transition probability depends on the flux of the incident wave and a characteristic of the transition called its “cross section.” The absorption coefficient depends only on the difference between the populations involved, $N_1$ and $N_2$, and the flux of the incident wave.
When a material is at thermal equilibrium, there exists a Boltzmann distribution of its atoms over the array of available energy levels with most atoms in the ground state. Since the rate of absorption of all frequencies exceeds that of emission, the absorption coefficient at any frequency is positive.

If enough light of frequency $\nu$ is supplied, the populations can be shifted until $N_f = N_i$. Under these conditions the rates of absorption and stimulated emission are equal, and the absorption coefficient at frequency $\nu$ is zero. If the transition scheme is limited to two energy levels, it is impossible to drive the populations involved beyond equality; that is, $N_2$ can never exceed $N_f$ because every upward transition is matched by one in the opposite direction.

However, if three or more energy levels are employed, and if their relationship satisfies certain requirements described below, additional excitation can create a population inversion where the population of the intermediate state, $N_3$, exceeds $N_f$. This population scheme favors stimulated emission for the $N_f-N_i$ transition.

A model four-level laser transition scheme is depicted in Figure 3-2. A photon of frequency $\nu_1$ excites—or “pumps”—an atom from $E_1$ to $E_4$. If the $E_4$ to $E_3$ transition probability is greater than that of $E_4$ to $E_1$, and if the lifetime of an atom at $E_4$ is short, the atom will decay almost immediately to $E_3$. If $E_3$ is metastable, i.e., atoms that occupy it have a relatively long lifetime, the population will grow rapidly as excited atoms cascade from above. The $E_3$ atom will eventually decay to $E_2$, emitting a photon of frequency $\nu_2$. Finally, if $E_2$ is unstable, its atoms will rapidly return to the ground state, $E_1$, keeping the population of $E_3$ small and reducing the rate of absorption of $\nu_2$.

In this way the population of $E_3$ is kept large and that of $E_2$ remains low, thus establishing a population inversion between $E_3$ and $E_2$. Under these conditions, the absorption coefficient at $\nu_2$ becomes negative. Light is amplified as it passes through the material, which is now called an “active medium.” The greater the population inversion, the greater the gain.

Figure 3-2: A Typical Four-level Transition Scheme

A four-level scheme has a distinct advantage over three-level systems, where $E_i$ is both the origin of the pumping transition and the terminus of the lasing transition. Also, the first atom that is pumped contributes to the population inversion in the four-level arrangement, while over half of the atoms must be pumped from $E_f$ before an inversion is established in the three-level system.
**Resonant Optical Cavity**

To sustain lasing action, the gain medium must be placed in a resonant optical cavity. The latter can be defined by two mirrors which provide feedback to the active medium, i.e., photons emitted parallel to the cavity axis are reflected back into the cavity to interact with other excited states. Stimulated emission produces two photons of equal energy, phase, and direction from each interaction. The two photons become four, four become eight, and the numbers continue to increase geometrically until an equilibrium between excitation and emission is reached.

Both cavity mirrors are coated to reflect the wavelength, or wavelengths, of interest while transmitting all others. One of the mirrors, the output coupler, transmits a fraction of the energy stored within the cavity, and the escaping radiation becomes the output beam of the laser.

The laser oscillates within a narrow range of frequencies around the transition frequency. The width of the frequency distribution, the “linewidth,” and its amplitude depend on the gain medium, its temperature, and the magnitude of the population inversion.

Linewidth is determined by plotting gain as a function of frequency and measuring the width of the curve where the gain has fallen to one half maximum (“full width at half maximum”, or FWHM, Figure 3-3).

![Figure 3-3: Frequency Distribution of Longitudinal Modes for a Single Line](image)

The output of the laser is discontinuous within this line profile. A standing wave propagates within the optical cavity, and any frequency that satisfies the resonance condition

$$\nu_m = \frac{mc}{2L}$$  \[3\]

will oscillate, where \(\nu_m\) is the frequency, \(c\) is the speed of light, \(L\) is the optical cavity length, and \(m\) is an integer. Thus, the output of a given line is a set of discrete frequencies, called “longitudinal modes,” that are spaced such that

$$\Delta\nu = \frac{c}{2L}$$  \[4\]
Nd$^{3+}$ as a Laser Medium

The source of excitation energy for the gain medium in a laser is usually optical or electrical. The output of one laser is often used to pump another, e.g., a diode laser can be used to pump a solid state laser. The Mai Tai™ HP pump laser (the Millennia) uses the output from diode laser modules in the Model J80 power supply to pump Nd$^{3+}$ ions doped in a yttrium vanadate crystalline matrix (Nd:YVO$_4$).

The properties of neodymium-doped crystals are the most widely studied and best understood of all solid-state laser media. The four-level Nd$^{3+}$ ion scheme is shown in Figure 3-4. The active medium is triply ionized neodymium which has principle absorption bands in the red and near infrared. Excited electrons quickly drop to the $^4F_{3/2}$ level, the upper level of the lasing transition, where they remain for a relatively long time (about 60 µs for Nd:YVO$_4$).

![Figure 3-4: Energy Level Scheme for the Nd$^{3+}$ Ion.](image)

The most probable lasing transition is to the $^4I_{15/2}$ state where a photon at 1064 nm is emitted. Because electrons in that state quickly relax to the ground state, its population remains low. Hence, it is easy to build a population inversion. At room temperature the emission cross section of this transition is high, so its lasing threshold is low. While there are competing transitions from the same upper state, most notably at 1319, 1338, and 946 nm, all have lower gain and a higher threshold than the 1064 nm transition. In normal operation, these factors and wavelength-selective optics limit oscillation to 1064 nm.
**Diode-pumped Laser Design**

Diode lasers combine very high brightness, high efficiency, monochromaticity and compact size in a near-ideal source for pumping solid-state lasers. Figure 3-5 shows the monochromaticity of the emission spectra of a diode laser compared to a black body source and compares that with the absorption spectra of the Nd$^{3+}$ ion. The near-perfect overlap of the diode laser output with the Nd$^{3+}$ absorption band ensures that the pump light is efficiently coupled into the laser medium. It also reduces thermal loading since any pump light not coupled into the medium is ultimately removed as heat.

![Figure 3-5: Nd$^{3+}$ absorption spectra compared to emission spectra of (a) a Black Body Source and (b) a Diode Pump Laser.](image)

One of the key elements in optimizing the efficiency of a solid-state laser is maximizing the overlap of the regions of the active medium excited by the pumping source and the active medium occupied by the laser mode. The maximization of this overlap is often called mode matching, and in most applications, TEM$_{00}$ is the laser mode that is most desired. A longitudinal pumping geometry provides this sort of optimal mode-match.

Longitudinal pumping allows the diode laser output to be focused on a volume in the active medium that best matches the radius of the TEM$_{00}$ mode. In general, the TEM$_{00}$ mode radius is chosen to be as small as possible to minimize the solid-state laser threshold. Figure 3-6 shows a schematic of a mode-matching design of this type.
For higher output power levels, a larger diode laser having a larger emission region is necessary. The diameter of the TEM\(_{00}\) mode volume must also be expanded to effectively mode-match the volume of the extended diode laser emission region. However, increasing the TEM\(_{00}\) mode volume raises the solid-state laser threshold. This is undesirable when attempting to create an efficient diode laser design.

At Spectra-Physics, we use diode laser modules made from a single monolithic piece of semiconductor material which typically contains ten to twenty diode lasers. The modules are ideal as high power pump sources. These devices have the same high efficiency as the discrete diode lasers, yet they allow for the manufacture of a much simpler and more reliable high-power pump laser design than is possible in a design incorporating an equal number of discrete devices (for the same output power level).

The active emission area for these devices is increased from the 200 µm range found in low power diode lasers, to 1 cm: a “ribbon of light.” The use of these modules has, therefore, been limited due to the difficulty of mode matching their outputs.

A number of attempts have been made by some manufacturers to couple the output of a diode laser module into a multimode optical fiber. The results have been discouraging, with coupling efficiencies on the order of 60–70% with a numerical aperture of 0.4. This makes for an expensive, inefficient pump source.

At Spectra-Physics, we have developed and patented a vastly more efficient method of fiber coupling the output of the diode laser module. It is called FCbar™. With this method, it is possible to achieve coupling efficiencies in excess of 90% with a numerical aperture of 0.1. With such high coupling efficiency and brightness, high power diode-pumped laser designs are readily achieved.
Frequency Doubling

In the *Mai Tai HP* pump laser (*Millenia*), the high output power from the diode lasers is used to end-pump the Nd:YVO₄, or vanadate, lasing medium. The resulting 1064 nm output is converted to the visible through frequency doubling or second harmonic generation in a nonlinear crystal. The *Mai Tai HP* pump laser uses a 90°, noncritically phase-matched, temperature-tuned lithium triborate (LBO) nonlinear crystal as its doubling medium.

Although LBO has a lower nonlinear coefficient than other materials, it offers several advantages: (a) noncritical phase matching means collinear fundamental and second harmonic beams which facilitates alignment, (b) there is no spatial “walk-off” of the fundamental and second harmonic beams, which preserves the high spatial mode quality and favors a long interaction length for higher gain, and (c) the crystal can be easily optimized for maximum conversion efficiency by simply changing its temperature (with no realignment of the laser cavity).

In frequency doubling, the second harmonic power ($P_{2\omega}$) is given by:

$$P_{2\omega} \propto \frac{d_{\text{eff}}^2 P_{\omega}^2 l^2 [\phi]}{A}$$  \[5\]

where $d_{\text{eff}}$ is the effective nonlinear coefficient, $P_{\omega}$ is the fundamental input power, $l$ is the effective crystal length, $[\phi]$ is a phase-matching factor, and $A$ is the cross-sectional area of the beam in the crystal.

Since the second harmonic output is dependent upon the square of the fundamental peak power, very high conversion efficiencies can be achieved by enhancing the intensity of the fundamental wave through intracavity frequency doubling or through the use of an external-cavity resonant-doubler. The former is used in the *Mai Tai HP* pump laser.

Historically, free-running intracavity-doubled diode-pumped solid state lasers have typically yielded chaotic output with large amplitude fluctuations that render the laser output useless for most scientific applications. This was first identified at Spectra-Physics over ten years ago in a short cavity diode-pumped Nd:YAG laser with a KTP intracavity doubler; it has since become known as the “green problem.”

Part of the cause of the instability arises from nonlinear coupling of axial modes via sum-frequency mixing in the laser cavity. The problem can be circumvented by forcing oscillation on a single longitudinal mode. However, this adds considerable complexity to the laser, since it requires an actively stabilized ring cavity (and it may also have power limitations). The *Mai Tai HP* pump laser overcomes this chaotic noise problem with the simple, patented, QMAD (quiet multiaxial mode doubling) solution, which makes use of many axial modes (see Figure 3-7).

Figure 3-7: The quiet multiaxial mode-doubling (QMAD) solution to the “green problem.” (a) The “green problem.” Intracavity frequency doubling in a laser with a few axial modes produces large amplitude fluctuations in the second harmonic output resulting from nonlinear coupling of the modes through sum-frequency mixing. (b) The single-frequency solution forces oscillation on a single axial mode to eliminate mode coupling. (c) The QMAD solution produces oscillation on many axial modes, effectively averaging the nonlinear coupling terms to provide highly stable second-harmonic output.

In the Mai Tai HP pump laser, the laser cavity allows oscillation of over 100 longitudinal modes. This facilitates quiet intracavity doubling by reducing the relative power in each axial mode so that no one mode reaches sufficient peak power to induce high nonlinear loss. Effectively, there is an averaging of the nonlinear coupling terms and the resultant frequency-doubled output exhibits extremely low amplitude noise (about an order of magnitude lower than that of an ion laser).
**Ti:Sapphire as a Laser Medium**

The output of the frequency-doubled *Millennia* pump laser is used to pump the Ti:sapphire rod, which in turn produces the *Mai Tai HP* laser output. The Ti$^{3+}$ titanium ion is responsible for the laser action of Ti:sapphire. Ti:sapphire is a crystalline material produced by introducing Ti$_2$O$_3$ into a melt of Al$_2$O$_3$. A boule of material is grown from this melt where Ti$^{3+}$ ions are substituted for a small percentage of the Al$^{3+}$ ions. The electronic ground state of the Ti$^{3+}$ ion is split into a pair of vibrationally broadened levels as shown in Figure 3-8.

**Figure 3-8: Energy Level Structure of Ti$^{3+}$ in Sapphire**

Absorption transitions occur over a broad range of wavelengths from 400 to 600 nm, only one of which is shown in Figure 3-8. Fluorescence transitions occur from the lower vibrational levels of the excited state to the upper vibrational levels of the ground state. The resulting emission and absorption spectra are shown in Figure 3-9.

Although the fluorescence band extends from wavelengths as short as 600 nm to wavelengths greater than 1000 nm, the lasing action is only possible at wavelengths longer than 670 nm because the long wavelength side of the absorption band overlaps the short wavelength end of the fluorescence spectrum.

The tuning range is further reduced by an additional weak absorption band that overlaps the fluorescence spectrum. This band has been traced to the presence of Ti$^{4+}$ ions, but it is also dependent on material growth techniques and Ti$^{3+}$ concentration. Additionally, the tuning range is affected by mirror coatings, tuning element losses, pump power, atmospheric absorption (both oxygen and water vapor) and pump mode quality.
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. A high inversion density comes from having a high pump intensity and a high Ti$^{3+}$ ion concentration.

Losses in the Ti:sapphire laser come from losses in mirror coatings and polished surfaces, and more importantly, the residual loss in the Ti:sapphire material itself. This loss is proportional to the rod length and varies with the Ti$^{3+}$ concentration, generally increasing as the Ti$^{3+}$ concentration increases.

The pump illumination in a Ti:sapphire laser must be collinear with the cavity mode over a relatively long length of the laser rod. A 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 a second cavity focus mirror.
The Mai Tai HP CW Pump Chamber

General

The output from two high-power, fiber-coupled diode laser modules (FCbar™) is used to end-pump the vanadate laser gain medium in the Mai Tai HP pump laser (similar to the Spectra-Physics Millennia laser). The FCbar design allows the diode laser modules to be placed in the power supply, which removes their heat load from the laser head. It also facilitates their field replacement without requiring a realignment of the Mai Tai HP pump laser.

The non-critically phase-matched LBO crystal in the cavity converts the intracavity light to the green 532 nm wavelength. The patented Quiet Multi-Axial Mode Doubling (QMAD) technique provides exceptionally low-noise performance. It uses a very large number of axial modes and balances gain, nonlinear conversion, and excited-state lifetime to provide high power and extremely stable amplitude.

Virtually all the doubled light passes through the dichroic output coupler where the beam is then directed out of the laser. A beam splitter and photodiode sample the output and provide feedback to the pump diode laser drivers to provide a constant output in power mode operation.

The laser head is designed for maximum reliability with minimum complexity. The inherent operation is so stable and the output so quiet that no adjustments are needed. Control of the entire system is provided via a simple Windows®-based program running on a laptop pc.

The vanadate laser crystal is the “driving engine” of the Mai Tai HP pump laser. The crystal is end-pumped by two fiber-coupled diode laser (FCbar) modules, and it provides a very high CW, small-signal gain. It is capable of producing over 10 W of near diffraction-limited, 1064 nm infrared power with a conversion efficiency greater than 50%.

The outputs from the two pump diode laser modules in the power supply are fiber-coupled into the laser head and focused into each end of the vanadate crystal. The diode laser pump light is absorbed by the crystal and emitted as 1064 nm output, which resonates in the Mai Tai HP pump laser cavity and is amplified through stimulated emission.

Frequency Doubling

Frequency-doubling converts the 1064 nm light from the laser crystal to green 532 nm laser output.

For maximum intracavity frequency doubling conversion efficiency, a non-critically phase-matched, temperature-tuned LBO crystal is used. It offers a large acceptance angle, which makes it insensitive to any slight misalignment of the Mai Tai HP pump laser cavity. A compact, low-power, temperature-regulating oven is used to maintain the crystal at the appropriate phase-matching temperature to keep the 532 nm output power optimized.

Windows is a registered trademark of Microsoft Corporation.
QMAD technology (patent number 5,446,749) allows the *Mai Tai HP* pump laser to provide greater than 5 watts of exceptionally stable, low-noise, frequency-doubled light. It provides a stable balance of:

- a very large number of axial modes (typically hundreds),
- small signal gain,
- gain saturation,
- nonlinear conversion,
- long excited state lifetime, and
- long cavity lifetime.

This allows the *Mai Tai HP* pump laser to use intracavity doubling within a simple, linear, X-Cavity design. The result is a high-power, multiaxial-mode pump laser that exhibits extremely low noise performance with very high reliability and a doubled beam that has a smooth intensity distribution and is near diffraction limited.

**Beam Delivery**

A dichroic output coupler allows the 532 nm light to exit the cavity while reflecting the 1064 nm light back into the cavity.

Unlike other systems that require multiple feedback loops to maintain stable output, the *Mai Tai HP* pump laser is inherently stable within its operating range. It requires only one simple feedback loop to maintain its exceptional performance and maintain constant output power. The light pick-off is an integral part of the system.

**The Mai Tai HP Pulsed Output Chamber**

**The Folded Cavity**

Because the second stage of the *Mai Tai HP* is a mode-locked laser, a cavity longer than that in a CW laser is required in order to allow it to run at convenient repetition frequencies near 80 MHz. Spectra-Physics modeled, analyzed, and optimized this cavity design for optimum performance in minimal space.

While folding the cavity optimizes space utilization, it makes pumping more complex. A focusing mirror used at an angle other than normal incidence creates astigmatism in the beam unless corrected by some other element, e.g., a Brewster-angle rod. In folded cavities where this astigmatism is not eliminated, output beams are elliptical and hard to focus. But by carefully choosing the angles of the cavity focus mirrors and the rod length, astigmatism in the pulse laser output beam is virtually eliminated.

However, astigmatism still exists within the laser rod. Therefore, the pump beam must also be astigmatic for efficient coupling between the pump and intracavity beam. A concave focusing mirror used at the proper angle induces astigmatism in the pump beam that matches that of the pulse laser cavity mode. The result is a laser with high conversion efficiency and good beam quality.
Mode Locking Device

The Mai Tai HP uses an acousto-optic modulator (AOM) to ensure reliable mode-locked operation when the laser starts up and to provide smooth wavelength tuning. It also allows the laser to operate for extended periods without dropouts or shut-downs associated with pure Kerr lens mode locking. The AOM is driven by a regeneratively derived RF signal. To reduce system complexity, the mode-locker heater and RF driver circuits are located in the laser head.

Wavelength Tuning Characteristics

Because the Ti:sapphire rod is birefringent, uninterrupted tuning is achieved when the c-axis of the rod is aligned coplanar with the polarization of the electric field within the cavity.

The pulse 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.

The wavelength tuning range for the Mai Tai HP is 690 to 1020 nm. A typical tuning curve for this range is shown in Figure 3-10 on page 3-17. The drivers and control circuits for wavelength selection are located in the laser head.

Wavelength Selection and Pulse Width

The femtosecond (fs) pulse laser is wavelength tuned by means of a sequence of prisms and a slit. The prism sequence creates a region in the cavity where the wavelength components of the pulse are spatially dispersed and the slit is placed in this dispersed beam. Changing the position of the slit in the dispersed beam tunes the output wavelength.

The pulse width characteristics of a Ti:sapphire laser are influenced by three factors: the characteristics inherent in the Ti:sapphire material itself, the cavity parameters, and, to a degree, the wavelength that is selected. While we cannot readily modify the Ti:sapphire material to change pulse width, we can modify the net group velocity dispersion (GVD) of the cavity.

The optical components in the laser cavity introduce positive GVD and cause pulse spreading. Further pulse spreading is caused by self-phase modulation (SPM) in the Ti:sapphire rod that 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 for with negative GVD. Because positive GVD in the cavity changes with wavelength, the amount of compensating negative GVD must be varied with wavelength.

Prism pairs are used in the Mai Tai HP to produce negative intracavity GVD. This compensation scheme is fully automated and results in an optimized pulse at any chosen wavelength within the tuning range. For a full review of GVD and compensation, refer to Appendix A, “Mode Locking: Group Velocity Dispersion.”
The Model J80 Power Supply

The Model J80 power supply contains two diode laser modules, a TEC cooler to maintain the temperature of these modules, a multi-output dc power supply that provides low voltage to all the control circuits and the two high-current supplies for the diode lasers, and an air-cooling system. The front panel provides boot information and system status and error codes. Chapter 4 provides information for connecting the system together and Chapter 6 provides system operation information and explains the software commands.

The FCbar System

The two diode laser modules in the power supply are each capable of producing 40 W of optical power. Each “fiber-coupled bar,” or FCbar, is coupled to an optical bundle that transports the diode laser output to one end of the pump laser, where it is focused into one end of the laser crystal. FCbar technology enables the high power levels available from the laser diode modules to efficiently end-pump the vanadate laser crystal. The output of the lasers is collimated with a cylindrical microlens of high numerical aperture that is bonded to the diode laser module and reduces the fast-axis divergence of the diode laser beam. The highly asymmetric light is coupled into a fiber bundle that, in turn, delivers exceptional brightness to the crystal. To stabilize the output wavelength of the diode lasers, the modules are mounted directly on a temperature regulated cold plate.

Because the coupling technology is so efficient, the 40 W diode laser modules are typically derated to 75% of their rated output to increase their operating lifetime. Typically, 85 to 90 percent of the diode light is transmitted by the multimode optical fiber; thus, up to 26 W is available from each derated laser diode module at the output of the fiber bundle.

The FCbar modules mate with the fiber bundle through precision connections that are assembled and aligned at the factory. The bundles are then terminated at the laser head with industry standard fiber-optic connectors. This scheme provides a precise and repeatable attachment of the bundle to the laser head and allows the FCbar modules to be replaced in the field, if necessary, without requiring an alignment of the cavity.

The Control Software

A special version of LabWindows™ software is provided by Spectra-Physics for controlling the Mai Tai HP system. It comes installed on the notebook computer optionally sold with the system, or it can be installed on your own Windows-based personal computer. Minimum requirements for the computer are listed in Chapter 5, “Installation.”

The Mai Tai HP can also be automatically controlled using your own software program. A command line interface allows this control through the RS-232 serial connection. The Mai Tai HP command language is described in Chapter 6, “Operation,” as is the operation of the laser using such a program.
Specifications

The Table 3-1 lists the optical performance specifications for the Mai Tai HP laser system. Table 3-2 lists the mechanical specifications. Table 3-3 on the next page lists the environmental specifications.

Table 3-1: Mai Tai HP Optical Specifications

<table>
<thead>
<tr>
<th>Output Characteristics¹</th>
<th>690 nm</th>
<th>700 nm</th>
<th>800 nm</th>
<th>920 nm</th>
<th>1020 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Power²</td>
<td>&gt;500 mW</td>
<td>&gt;1 W</td>
<td>&gt;2.5 W</td>
<td>&gt;1.35 W</td>
<td>&gt;400 mW</td>
</tr>
<tr>
<td>Peak Power²</td>
<td>&gt;60 kW</td>
<td>&gt;120 kW</td>
<td>&gt;310 kW</td>
<td>&gt;165 kW</td>
<td>&gt;50 kW</td>
</tr>
<tr>
<td>Pulse Width³</td>
<td>100 fs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuning Range⁴</td>
<td>690 – 1020 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repetition Rate⁵</td>
<td>80 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise⁶</td>
<td>&lt; 0.15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability⁷</td>
<td>&lt; ±1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pointing Stability</td>
<td>&lt; 50 µrad/100 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Mode</td>
<td>TEM₀₀₀</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Roundness</td>
<td>0.9 – 1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astigmatism</td>
<td>&lt;10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Diameter at ¹/e² points</td>
<td>&lt; 1.2 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Divergence, full angle</td>
<td>&lt; 1 mrad</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polarization</td>
<td>&gt; 500:1 horizontal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Due to our continuous product improvement program, specifications may change without notice.
² Specifications apply to operation at the wavelength noted.
³ A sech² pulse shape (0.65 deconvolution factor) is used to determine the pulse width as measured with a Spectra-Physics PulseScout autocorrelator.
⁴ The Mai Tai HP is also available with a fixed factory preset wavelength within the wavelength ranges noted.
⁵ Laser operation is specified at a nominal repetition rate of 80 MHz.
⁶ Specification represents rms measured in a 10 Hz to 10 MHz bandwidth.
⁷ Percent power drift in any 2-hour period with less than ±1°C temperature change after a 1-hour warm-up.

Table 3-2: Mai Tai HP Mechanical Specifications

<table>
<thead>
<tr>
<th>Size (L x W x H)</th>
<th>Laser Head, Scientific</th>
<th>Laser Head, OEM</th>
<th>Model J80 Power Supply</th>
<th>Umbilical Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23.4 x 13.8 x 5.8 in.</td>
<td>19.50 x 13.25 x 5.48 in.</td>
<td>17.9 x 19.0 x 6.9 in.</td>
<td>10 ft</td>
</tr>
<tr>
<td></td>
<td>59.5 x 35.0 x 14.7 cm</td>
<td>49.5 x 33.7 x 13.9 cm</td>
<td>45.5 x 48.3 x 17.5 cm</td>
<td>3 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight</th>
<th>Laser Head, Scientific</th>
<th>Laser Head, OEM</th>
<th>Model J80 Power Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70 lb</td>
<td>65 lb</td>
<td>49.5 lb</td>
</tr>
<tr>
<td></td>
<td>32 kg</td>
<td>29.5 kg</td>
<td>22.5 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Requirements</th>
<th>Model J80 Power Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110 Vac ±10%, &lt;10 A, 60 Hz / 220 Vac ±10%, &lt;6 A, 50 Hz</td>
</tr>
</tbody>
</table>
### Table 3-3: Environmental Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Specification Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>Up to 2000 m</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>10 – 40°C</td>
</tr>
<tr>
<td>Maximum relative humidity</td>
<td>80% non-condensing for temperature up to 31°C</td>
</tr>
<tr>
<td>Mains supply voltage</td>
<td>See Specification Table on preceding page</td>
</tr>
<tr>
<td>Insulation category</td>
<td>II</td>
</tr>
<tr>
<td>Pollution degree</td>
<td>2</td>
</tr>
</tbody>
</table>

**Typical Tuning Curve**

![Typical Tuning Curve](image_url)

Figure 3-10: *Mai Tai HP* Tuning Curve
Outline Drawings

Figure 3-11: Outline Drawing, OEM and Scientific Mai Tai HP Laser Heads
Figure 3-12: Outline Drawing, *Mai Tai HP* Power Supply (*Model J80*)

![Control Panel Diagram](image)

Figure 3-13: Outline Drawing, Rack

![Side View Diagram](image)

**Note**

Refer to the chiller manual for chiller drawings.
Mai Tai HP High-Performance, Mode-Locked, Ti:sapphire Laser
Chapter 4  Controls, Indicators and Connections

Introduction

This section defines the user controls, indicators and connections of the Mai Tai™ HP laser system. It is divided into three sections: the Mai Tai HP laser head, the Model J80 power supply and the laptop pc controller. Information on the chiller can be found in the chiller user's manual.

The Mai Tai HP Laser Head

Controls

There are none.

Indicators

Emission indicator light—warns of present or imminent laser radiation. This white-light CDRH indicator is located on top of the laser near the output bezel. A built-in delay between the turn on of the lamp and actual emission allows for evasive action in the event the system was started by mistake and the shutter is open.

Connections

Figure 4-1: The umbilical attachment panel showing the 40 MHz and 80 MHz BNC connectors.

Umbilical attachment panel—(part of which is shown in Figure 4-1) anchors the umbilical to the rear of the laser head. The umbilical provides cooling water from the chiller and output from the diode lasers. This umbilical is permanently attached: do not try to remove it. To move the laser system, disconnect the chiller supply lines at the chiller and drain the lines,
then set the power supply on top of a wheeled cart and the laser head on top of the power supply and roll the system to its new location. Make sure the cooling lines are reconnected and tightly fastened before you restart the laser after moving it.

**40 MHz connector (BNC)**—connects to a 1 MΩ oscilloscope trigger input for viewing the photodiode signal available from the 80 MHz connector. A typical waveform is shown in Figure 4-2. This ac-coupled signal can also drive other Spectra-Physics products, such as the Model 3985 pulse selector. This is a negative signal. The signal amplitude shown is approximate and depends on operating wavelength, power and photodiode response.

![Figure 4-2: Sample waveform supplied by the 40 MHz connector into a 1 MΩ oscilloscope trigger input.](image)

**80 MHz connector (BNC)**—connects to a frequency counter or to a 50 Ω oscilloscope input for monitoring the laser head photodiode signal. A typical waveform is shown in Figure 4-3. Use the ac-coupled output to trigger the oscilloscope. The signal amplitude shown is approximate and depends on operating wavelength, power and photodiode response.

![Figure 4-3: Sample waveform from the 80 MHz connector into a 50 Ω oscilloscope input.](image)
The Model J80 Power Supply

This power supply is air-cooled and has two fiber outputs on the rear panel that provide diode laser pump power to the *Mai Tai HP* laser head.

This section defines the user controls, indicators and connections of the *Model J80* power supply. The control SERIAL port is fully described below. However, instructions for controlling the system via this port are located in Chapter 7, “Operation.” The front and rear panels are described below from left to right, top to bottom, starting with the front panel.

Provide at least 6 inches of room on the front and back of the *Model J80* power supply to allow cool air to enter the front and for the heated exhaust air to exit the rear panel. Inadequate cooling will cause the system to overheat and shut down. Damage to components caused by insufficient cooling is not covered by your warranty.

**Front Panel**

![Image of the front panel of the Model J80 Power Supply]

**Figure 4-4: The Model J80 Power Supply Front Panel**

**LCD display**—displays the status of the power supply during normal operation and any status codes generated by the power supply. During start up, this panel displays the status of the self-diagnostics program. If problems ever occur, monitor this panel to see where it occurs. All warnings, including errors generated by the system and indications related to proper system operation, are displayed on the control device as well.

**LASER ENABLE interlock keyswitch**—provides interlock safety to prevent unauthorized personnel from using the *Mai Tai HP* laser system when the key is turned to the “off” position and the key is removed. Turning the key to the “on” position allows the diode lasers to be energized if the ac power switch is also on.

**POWER indicator (green)**—when on, it indicates ac power is applied to the system.
LASER EMISSION indicator (red)—when on, it shows that power is supplied to the diode lasers and that diode laser emission is present or imminent.

Air intake—allows cooling air to be drawn into the power supply. The heated exhaust air is then vented from the rear panel.

REMOTE connector (15-pin D-sub)—is used for controlling the laser locally with the control module (provided).

AC power on/off switch—provides ac power to the Model J80 when the LASER ENABLE interlock keyswich is also on.

Rear Panel

Air exhaust—these two grills allow heated air to be expelled from the power supply.

Diode laser fiber-optic cables—are permanently attached to the modules inside the power supply and must be replaced along with the diode laser modules. The clamping device on the panel provides strain relief for the cable and must be loosened to unclamp the cable prior to removing the modules from the system. The fiber cable provides 809 ±1 nm pump power.

Figure 4-5: The Model J80 Power Supply Rear Panel

ANALOG connector (25-pin, D-sub)—is jumpered as it comes from the factory. This connector is not used on the Mai Tai HP laser system. The jumper plug (Figure 4-6) must always be attached to the connector or the pump laser (the Millennia) will not turn on.

Figure 4-6: The ANALOG Jumper Plug
Controls, Indicators and Connections

**SERIAL COM connector (9-pin, D-sub)**—is used as a computer control port. Connect your computer to this connector. Refer to the pin descriptions in Table 4-1 at the end of this chapter and to the section on “Using the Serial Interface” in Chapter 7, “Operation.” When the system is controlled in this manner, RS-232 ENABLED is shown on the controller Main menu.

**EMISSION connector (3-pin)**—provides access to a relay that can be used to turn on and off a remote emission indicator on an OEM system (Figure 4-8). When the laser is off (i.e., when there is no emission), there is closure between pins 3 and 1 and an open between pins 3 and 2. The opposite is true when the laser is on or emission is imminent. There is no power supplied by these terminals. This circuit is rated for 30 Vac at 1 A.

This connector mates to AMP shell no. 350766-1 using pins no. 350218-1.

**INTERLOCK connector (2-pin)**—provides attachment for a safety switch. These two contacts must be shorted together before the laser will operate. A defeating jumper plug is installed at the factory to permit operation without a safety switch. This plug can be replaced with a similar, non-shorting plug that is wired to auxiliary safety equipment (such as a door switch) to shut off the laser when actuated (opened). Such a switch must be designed for a low-voltage, low-current digital signal.

The mating connector is an AMP 350777-1 using AMP pins 350536-1.

**LASER HEAD connector (27-pin, D-sub)**—provides attachment for the control cable to the Mai Tai HP laser head.

**AC POWER connector**—provides connection for an IEC power cable to provide ac power to the Model J80 power supply.

### Connector Interface Descriptions

**SERIAL COM Port Connector**

The Mai Tai HP system uses 4 of the 9 pins available on the Serial COM port: 2 pins for the transmit and receive signals in a switched configuration, and 2 pins for ground. The pin usage is described in Table 4-1 below.

![Figure 4-7: The 9-Pin SERIAL COM Port](image)

**Table 4-1: The SERIAL COM Port Connections**

<table>
<thead>
<tr>
<th>Signal Name</th>
<th>Computer or Terminal PIN No.</th>
<th>Model J80 Pin No.</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit Data</td>
<td>TXD 2</td>
<td>3</td>
<td>RXD</td>
</tr>
<tr>
<td>Receive Data</td>
<td>RXD 3</td>
<td>2</td>
<td>TXD</td>
</tr>
<tr>
<td>Signal Ground</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Protective Ground</td>
<td>1 SHELL</td>
<td>SHELL</td>
<td></td>
</tr>
</tbody>
</table>
**EMISSION Connector**

This connection can be used to turn on and off an external EMISSION light. It consists of a relay-driven, single-pole, double-throw relay that closes pins 3 and 2 when emission occurs or is imminent. This circuit is rated for 30 Vac at 1 A.

<table>
<thead>
<tr>
<th>Pin #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Wiper</td>
</tr>
<tr>
<td>2</td>
<td>Normally Open</td>
</tr>
<tr>
<td>1</td>
<td>Normally Closed</td>
</tr>
</tbody>
</table>

![Figure 4-8: Model J80 Emission Connector Circuit](image)

**Safety INTERLOCK Connector**

This is a system interlock that must be *closed* for operation. It is provided for safety to shut the diode laser current *off* if the connection is opened.

<table>
<thead>
<tr>
<th>Pin #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System Interlock</td>
</tr>
<tr>
<td>2</td>
<td>System Interlock Return</td>
</tr>
</tbody>
</table>

**The Chiller**

Refer to the user’s manual supplied for your chiller for description of the chiller controls and operation.
Chapter 5

Installation

There are no controls to adjust or optics to change in the Mai Tai™ HP laser, which makes it very easy to set up and operate.

When you received your laser, it was packed with the laser head and power supply already connected via an umbilical. **Do not disconnect the umbilical cables from either end!**

---

**Warning!**

The following installation procedure is provided for reference only and is not intended as a guide to the initial installation and setup of your laser. Please call your Spectra-Physics service representative to arrange an installation appointment in accord with the purchase agreement. Allow only personnel qualified and authorized by Spectra-Physics to install and set up your laser. You will be charged for repair of any damage incurred if you attempt to install the laser yourself, and such action will void your warranty.

---

**Moving the Laser System**

Remove the laser head, power supply and, if present, the optional laptop computer from the shipping crate and inspect for damage. Refer to the “Unpacking and Inspection” notes at the front of this manual.

To move the laser system, set the power supply onto a cart, then place the laser head on top of the power supply. Roll both units to the desired location.

---

**Warning!**

The power supply weighs about 22 kg (50 lb), the laser head approximately 32 kg (70 lb). Ask for help when moving these units; **do not attempt it by yourself.**
Installing the Mai Tai HP Laser Head

The tools and equipment you need to set up the *Mai Tai HP* laser are in the accessory kit.

---

**Warning!**

Be careful when moving the laser head that any bend in the umbilical does not exceed the 6 inch (15 cm) minimum bend radius. Exceeding this limit can fracture and/or break the fiber bundle inside. Also, be careful not to snag any of the various cables extending from the power supply. Such damage is not covered by your warranty.

1. Place the *Mai Tai HP* laser head on the table with the power supply nearby, and orient the laser head toward the target.

---

**Warning!**

Be careful when you set the laser head on the table that the attached umbilical does not pull the laser head off the table. Before moving the power supply, be sure to clamp the laser head to the table using the clamps provided.

2. Use the two slots located on the front and rear panels to clamp the laser head onto an optical table. Position the laser head so that these slots coincide with the hole pattern in the table. Then use standard $\frac{1}{4}-20$ screws and the clamps provided to fasten the laser head to the table.

This completes the installation of the laser head.

Installing the Chiller and the Power Supply into the Rack

The following instructions are for assembling the 19 in. standard rack and installing the chiller and *Model J80* power supply into it. The rack is shipped with the system in a separate box containing two parts: the rack base with 4 lockable casters pre-installed, and a vertical rack.

The following instructions allow you to easily install the laser head, chiller and power supply. Because of their weight, be sure to use two people to safely support and install the power supply and chiller.

1. Remove the bubble pack from both rack components. Take care not to scratch the coated surfaces.

2. Place the rack base onto the floor. Note the end of the base that has a notch in each corner (Figure 5-1).
3. Set the chiller onto the base so that its front panel faces the notched end (Figure 5-2).

4. Place the power supply on top of the chiller and align their front panels (Figure 5-3). The chiller must be on the bottom to prevent any damage to the power supply caused by leaks or condensation from the chiller if it is set on top of the power supply.

**Warning!** Ensure that the electrical and fiber-optic cables are safely routed and not under any strain or compression. Use caution when moving the power supply to prevent fiber damage. Avoid conditions where the cables can be stepped on by personnel or rolled over by mobile units.
5. Attach the vertical rack to the notched end of the base.
   a. Loosen the T-shaped locking bolt and its nut (Figure 5-4) on each end of the rack (loosen the nut all the way to the end of the threads).

   b. Orient the locking bolts to the slots in the base (Figure 5-1), then drop the rack into place so that the locking bolts engage the slots. There has to be enough free play for the bolt to extend completely down into the slot and turn 90 degrees.
   c. Align the rack to the base so that it is straight.
   d. Tighten the locking nuts to 18 lb./in.
      The locking nut automatically turns the locking bolt 90 degrees inside the slot to its locking position, then pulls the rack tight to the base. Loosening the nut does just the opposite and realigns the bolt with the slot for easy removal.
Figure 5-5 shows the fully assembled unit before the chiller and power supply panels are secured to the rack.

6. Using the 8 mounting screws from the system accessory kit, secure the front panel of the chiller and power supply to the rack.

To uninstall the laser system or disassemble the rack, reverse these steps.

Allow 6 inches of clearance to the front and back panels of the Model J80 power supply for proper cooling air flow. Be certain that heated air exhausted from the back panel from returning to the intakes on the front panel. Failure to do so will cause over-heating.

This completes the installation procedure for the chiller and power supply.

Figure 5-5: The Power Supply and Chiller in the Rack
Connecting the Chiller

1. Screw both hoses onto the chiller and tighten.
   Coolant in the red hose flow into the chiller; coolant in the black hose flows to the laser head. Finger tight is enough: do not overtighten.
2. Fill the chiller reservoir with filtered tap water or distilled water; do not use deionized water.
3. Turn on the chiller and verify water is flowing. Inspect for leaks at the hose connections.
   Refer to the chiller manual for instructions.
4. Adjust the chiller temperature for 21°C.
5. Turn off the chiller.

---

Warning!

The chiller must always be on when the Model J80 power supply is on, even if the diode laser arrays are not switched on!

Please note: it takes the chiller about 15 minutes to stabilize the temperature of the laser head cold plate and, thus, the output of the laser. Leaving the chiller on between periods of laser use will eliminate this stabilization period. For general use, the chiller should always be left on. Only if the laser is used infrequently should the chiller be turned off. If this is the case, turn off the Model J80 power supply first.

This completes the chiller connections.

Connecting the Mai Tai HP System

Refer to interconnect drawing Figure 5-6.

---

Figure 5-6: The Model J80 Interconnect Drawing

1. Set the computer in a convenient location.
Front Panel

2. Verify the jumper plug is in place on the REMOTE connector (see Figure 5-7). This connection is not used on the Mai Tai HP laser system and must be jumpered to enable the system to turn on.

3. Verify the jumper plug is in place on the ANALOG interface on the back panel (Figure 5-8). This connection, too, is not used on the Mai Tai HP laser system and must be jumpered to enable the system to turn on.

Figure 5-7: The REMOTE Connector on the Power Supply Front Panel

Back Panel

4. Connect a serial cable of ample length between the serial port on the computer and the SERIAL COM connector on the back of the power supply. Refer to Table 4-1 at the end of Chapter 4 for pin descriptions.

5. If emission indicators other than the one on top of the laser head and the red LED on the front panel of the Model J80 is required, use the EMISSION relay connector on the power supply rear panel as a switch to turn a lamp on and off (Figure 5-9). To use the relay, attach a wire to pins 3 and 2 of the connector. When the laser is off, there is closure between pins 3 and 1 and an open between pins 3 and 2. The opposite is true when there is emission or emission is imminent. There is no power supplied by these terminals. This circuit is rated for 30 Vac at 1 A.
6. Verify the INTERLOCK jumper plug is in place or, if a safety interlock is desired, remove the plug and rewire it (or a similar non-jumpered connector plug) to a safety switch. The switch must be wired so that when the device is actuated (e.g., a door is opened), the switch opens. This will turn off the laser.

7. Attach the provided IEC power cord to the power connector on the power supply and fasten it to the receptacle using the retaining screws provided so that it does not pull out. Plug the other end into a facility power outlet. The outlet must supply 100 to 240 Vac, 15 A single-phase power.

This completes the wiring connection for the power supply.
Installing the Control Software

To control *Mai Tai HP*, you can either install the supplied LabWindows™ control software on the optional notebook computer or on your own personal computer, or you can control the *Mai Tai HP* remotely using a software program written by you, based on the *Mai Tai HP* command language. Refer to Chapter 6, “Operating the System Using the LabWindows Software” and “Commands and Queries Used by the Mai Tai” for information on controlling the system using the SERIAL COM interface.

If you are using your own computer to control the system, verify your unit meets these minimum requirements.

- 486 (or higher) processor, 66 MHz or higher
- 16 MB RAM or more, (32 MB RAM recommended)
- 3 MB available disk space for installation
- a Windows®*-compatible pointing device, such as a mouse
- a video display with 800 x 600 (SVGA) or higher resolution
- an available RS-232 serial port
- Microsoft Windows 98, ME, 2000 or XP operating system

If your computer meets these requirements, or if you are going to operate the laser remotely using your own software, continue:

1. If you have not already done so, attach the 9-pin serial cable (supplied with the *Mai Tai HP*) between the serial port (COM port) of the control device and the 9-pin SERIAL COM connector on the rear of the power supply.
2. Use the fastening screws on the cable to secure it at each end, otherwise the cable will very likely disengage and the laser will shut off.

*Installing the LabWindows Control Software*

A special version of LabWindows software is provided by Spectra-Physics on CD-ROM. To install the software, place the disk in the drive, then double-click “My Computer” > “CD-ROM” or “CD-RW” > “Setup.exe” and follow the prompts. The software will create and install itself into the “c:\Program Files\Spectra-Physics\Mai Tai Rev. #” directory on a drive of your choice (default drive is C). It will also install LabWindows run-time components into the “windows/system” directory on drive C.

Please note: an uninstall program is also placed in the “Mai Tai Program” directory. Run this program if you wish to remove these components from your system (e.g., when you wish to change or upgrade your personal computer).

This completes the installation of the computer and software.

*LabWindows is a trademark of National Instruments Corporation.
Windows is a registered trademark of Microsoft Corporation.*
Chapter 6  Operation

The Mai Tai™ HP is a Class IV—High Power Laser, whose beam is, by definition, a safety and fire hazard. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as specular reflections cause severe skin or eye damage.

Because the Mai Tai HP 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.

The Mai Tai HP laser can either be controlled locally using the supplied LabWindows™ control software or it can be controlled remotely using your own software program running on a computer or terminal. If you did not purchase the optional laptop pc controller with the LabWindows control software already installed, install the software on your own personal computer.

Chapter 5 explains how to connect the various components of your system and install the LabWindows control software. This chapter assumes this has already been done.

The first part of this chapter describes laser operation using the LabWindows software; the latter part describes the command/query language that can be used to write a program for controlling the system remotely.

**Using the Chiller**

Refer to the chiller manual for information on how to operate that unit. In general, the reservoir should always be full before turning on the unit and the chiller should be set to 21°C whenever the laser is running.

Please note: it takes the chiller about 15 minutes to stabilize the temperature of the laser head cold plate and, thus, the output of the laser. Leaving the chiller on between periods of laser use will eliminate this stabilization period. In general, if the laser is used often, leave the chiller on between laser usage; if it is used infrequently, turn off the power supply, then turn off the chiller.

*LabWindows is a trademark of National Instruments Corporation.*
Turning the System On and Off

The LabWindows control menus are described in “Operating the System Using the LabWindows Software” on page 6-4. This section provides a simple scenario for turning on and off the system.

Turning On the System

1. Verify all connectors are plugged into the power supply (they should never be disconnected—if they were, refer to Chapters 4 and 5 for information on reconnecting them).
2. Verify the chiller reservoir is full.
3. Turn on the chiller and verify it is set to 21°C.
   
   It takes the chiller about 15 minutes to stabilize the temperature of the laser head cold plate and, thus, the output of the laser. To eliminate this stabilization period, leave the chiller on between periods of laser use. As a rule, if the laser is used often, leave the chiller on; if it is used infrequently, turn off the Model J80 power supply, then turn off the chiller. Refer to the chiller user’s manual for more detailed instructions.
4. Turn on the power supply power switch.
5. Turn on the power supply key switch.

As the system starts up, the following message sequence is displayed on the power supply LCD screen:

   “Spectra-Physics,” followed by the software version number.

Then self tests 1 through 12 will complete, and end with:

   “Success. Boot test passed.”

Wait approximately 40 minutes for the power supply LCD screen to indicate “100% warmup,” which indicates it is ready for use. The LCD screen then displays status messages.

6. Turn on the control computer, then start the control program. The Com Port Setup menu will appear (Figure 6-1).

Warning! The chiller must always be on when the Mai Tai HP power supply is on, even if the diode lasers are not switched on!
7. Verify the com port setting is correct for your system, then press OK. The system will look for the Mai Tai HP and, when found, will display the Main menu (Figure 6-2).

8. Wait until the status warning on the control screen says “Ready to turn on,” then turn on the laser.
   Click on and hold down the ON button for about 3 seconds until the EMISSION light turns on (the emission light on the laser will also turn on). Although the EMISSION light is on and the diodes are on, no light is emitted until the shutter is opened in Step 11.
   Laser power will climb gradually and the system will enter PULSING (modelocked) operation.

9. Set the desired wavelength from the Main menu.

10. The PULSING indicator on the Main menu turns green when pulses are present.

11. Open the shutter.
   Click on and hold down the SHUTTER button for about 3 seconds until the SHUTTER light turns red. The shutter will open and emission will be present.

12. Output power should reach maximum output within 30 minutes.

13. To temporarily turn off laser emission without turning off the laser, click on the SHUTTER button. Emission will stop immediately and the SHUTTER light will turn gray. However, the EMISSION light will remain on to warn of possible emission (the diodes are still on). To open the shutter again, simply click on the SHUTTER button again.

<Referrer: Turning Off the System>

1. Press the OFF button to shut off the system.
   The system will turn off immediately, as will the EMISSION light.

2. Press the SHUTTER button to close the shutter.

3. If you are done for the day and wish to turn off the computer, press the QUIT button to exit the control program, then turn off the computer as you would normally.

4. Turn the key switch on the power supply to OFF and remove the key to prevent unauthorized use. To minimize start-up stabilizing time, leave the power switch on the power supply in the “on” position and keep the chiller on.
   This is the preferred “off” mode for day-to-day operation. If the laser is not to be used for an extended period of time, turn off the power supply completely, then turn off the chiller.

---

**Warning!**

The chiller must always be on when the Mai Tai HP power supply is on, even if the diode lasers are not switched on!

This completes the turn on/off sequence.
Operating the System Using the LabWindows Software

Operating the *Mai Tai HP* is easy using the supplied LabWindows control software running on a Windows®-based personal computer (pc). The Main menu allows the operator to monitor the laser, turn it on and off, set the operation wavelength and open and close the shutter. It monitors pulsed laser output power, and it shows the system status, including whether or not the laser is pulsing (mode-locked), the shutter is open, and that the computer is successfully communicating with the laser system (*RS232 ACTIVE*).

From this menu the operator can access three other sub-menus: Setup, Info and Scan. These menus and their functions are described on the next several pages.

**The Main Menu**

![Figure 6-2: The Main menu showing the optional sub-menu buttons.](image)

The Main menu (Figure 6-2) appears when the software starts, following the Com Port Setup menu. Large and easily seen from a distance, it serves as both monitor and input screen.

The five control features include:

- Emission on/off control
- Shutter open/close
- Wavelength select/monitor
- IR power monitor
- Sub-menu selection

*Windows is a registered trademark of Microsoft Corporation.*
These menu functions are described below as they appear on the screen from left to right, top to bottom. The sub-menus are accessible through View on the command bar. If preferred, these buttons can be displayed permanently on the Main menu by checking the “show buttons” selection.

**Submenu Selection**—allows the operator to select Quit, the Setup menu, the Info menu and the Scan menu.

- **QUIT**—exits the program. Press this button prior to powering down the computer.
- **SETUP**—brings up the Setup menu.
- **INFO**—brings up the Info menu.
- **SCAN**—brings up the Scan menu.

**EMISSION indicator**—when on, shows that laser output is imminent or available, i.e., the diodes are on (but the shutter must be open for actual emission); when off (“emission” is not displayed), it indicates the laser diodes are turned off. For safety, this indicator turns on at least 3 seconds before laser output is possible.

**PULSING indicator**—when green, indicates the output beam is pulsing (mode-locked); when gray, either there is no output (the laser is off) or the output beam is not pulsing (i.e., the laser is running CW).

**SET WAVELENGTH controls and indicators**—allows selection of an operation wavelength from 690 to 1020 nm.

There are several ways to set the wavelength: by using the up/down arrows to the left of the SET WAVELENGTH window, by typing in a number in the window itself, by dragging the bar in the upper bar graph to the desired location (wavelength numbers corresponding to its position will display in the window), and by using the left and right arrows on the bar graph to move the bar.

**ACTUAL WAVELENGTH indicator**—indicates the output wavelength value in the lower bar graph.

When the system is active, the arrow in the lower bar graph indicates the present output wavelength. When the operator changes the requested wavelength in the “Set Wavelength” window, the arrow will move toward that same value as the unit automatically compensates. When the desired value and actual value are equal, the arrow will stop and will be in line with the upper bar, and the ACTUAL WAVELENGTH value will match the “Set” value.

**IR POWER indicator**—displays IR output power (in Watts) as a relative value via a mark on a bar graph, and as an absolute value in the lower window.

The system automatically optimizes output power at each wavelength. Thus, there is no power setting control.

**SHUTTER button**—opens and closes the internal shutter.

To open the shutter, click and hold down the SHUTTER button about 3 seconds (safety delay) until the shutter light over the button turns red.
Actual emission will occur only when the laser is turned on via the ON button (see below). To close the shutter, click on the SHUTTER button again. The shutter closes immediately, blocking the laser beam.

**ON button**—turns on the laser diodes.

To turn on the laser diodes, click and hold down the ON button about 3 seconds until the EMISSION light over the wavelength display turns on. Actual emission will occur only when the shutter is open (see above).

**OFF button**—turns off the laser diodes.

To turn off the laser diodes, click on the OFF button. The laser turns off immediately.

**SYSTEM STATUS monitor**—provides system status information.

**RS-232 ACTIVE indicator**—turns green when the serial link between the computer and *Mai Tai HP* is capable of transmitting data.

---

**The Setup Menu**

The Setup menu (Figure 6-3) is for use by Spectra-Physics service personnel only. The information shown on this display is not required for routine operation of the system. Therefore, these controls are not described here, but in the service manual.

![Setup Menu Image](image)

**Figure 6-3: The Setup Menu**

---

**Caution!**

The parameters shown in Figure 6-3 are set at the factory for optimum system performance. Do not use this menu to modify any parameters. In particular, do not change the pump power setting. *Increasing pump power may actually decrease output performance!* These controls are for diagnostic purposes only and are to be used only by someone trained by Spectra-Physics.

**OK button**—returns to the Main menu.
The Info Menu

The Info menu (Figure 6-4) provides information on a number of important system parameters and is for informational purposes only.

![Figure 6-4: The Info Menu](image)

**OK button**—returns to the Main menu.

**PUMP POWER indicator**—shows internal pump laser output power (in Watts). Different wavelengths require different power settings and this value is dependant on the wavelength selected.

**CURRENT (AMPS) indicators**—show the current (in amperes) of each diode laser module. Pump laser output power is related to diode current, and the current required to maintain a given output power increases as the diode lasers age. This is normal, and the system is designed accordingly.

**TEMPERATURE (DEG C) indicators**—show the temperature of each diode laser module.

**SHG STATUS monitor**—indicates when the SHG crystal is at operating temperature. Stable output is only possible when this crystal is “settled.”

**P2 and M3 readings**—show the status of feedback-controlled elements in the Mai Tai HP optical train that are used for power and wavelength stability.

**ERROR CODE indicator**—displays the last error code generated by the system. Although typically used by persons operating the system remotely as a feedback source for branching operations, it can be used for local diagnostic purposes as well.

**HISTORY BUFFER list**—shows the last 16 operations performed by the system. Although typically used when the system is operated remotely, this list can be used for diagnostic purposes or to simply see the most recent sequence of events.
FAST PHOTODIODE indicator—displays a relative value of the fast photodiode signal used in the regenerative modelocking system.

PULSING PHOTODIODE indicator—displays a relative value of pulse energy from the two-photon detector.

TOWER TEMP indicator—shows the temperature (in degrees C) of the Millennia pump laser cavity inside the Mai Tai HP laser head.

BODY TEMP indicator—shows the general temperature (in degrees C) of the pump laser (Millennia) body.

CTRL PCB TEMP indicator—shows the temperature (in degrees C) of the Control pc board in the Mai Tai HP laser head.

RF PCB TEMP indicator—shows the temperature (in degrees C) of the RF pc board in the Mai Tai HP laser head.

HUMIDITY indicator—shows the relative humidity (in percent) inside the Ti:sapphire laser cavity.

MAI TAI SOFTWARE REV statement—shows the revision level of the current software interface.

CONTROL SOFTWARE REV statement—shows the revision level of the control firmware.

The Scan Menu

The Scan menu (Figure 6-5) provides a means to scan from a beginning wavelength to an end wavelength in pre-settable steps, to stop at each step for a preset period of time, and to turn the scan function on and off.

![Scan Controls](image.png)

Figure 6-5: The Scan Menu

OK button—returns to the Main menu regardless of the WAVELENGTH SCAN switch setting.

START WAVELENGTH control—sets the wavelength at which to begin a scan.

STOP WAVELENGTH control—sets the wavelength at which to end a scan.
**Operation**

**nm/STEP control**—sets the interval (in nanometers) between the stops to be made during a scan. When set to “0,” stepping is defeated and the system will scan continuously between the “begin” and “end” wavelengths; the SECONDS PER STEP function is ignored.

**SECONDS PER STEP control**—sets the stop duration (in tens of milliseconds) during a scan.

**WAVELENGTH SCAN ON/OFF switch**—enables/disables the scan function. The system will continue to scan even if you press the OK button and return to the Main menu. This switch must be set to off to stop the scan.

**The RS-232 Serial Port**

**Pinout/Wiring**

The Model J80 power supply RS-232 serial port accepts a standard 9-pin D-sub male/female extension cable for hookup. Only three of the pins are actually used:

<table>
<thead>
<tr>
<th>Pin Numbers</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>transmit data (Mai Tai out)</td>
</tr>
<tr>
<td>3</td>
<td>receive data (Mai Tai in)</td>
</tr>
<tr>
<td>5</td>
<td>signal ground</td>
</tr>
</tbody>
</table>

**Communications Parameters**

Communications must be set to 8 data bits, no parity, one stop bit, using the XON/XOFF protocol (do not use the hardware RTS/CTS setting in your communications software). The baud rate is set to 9600 at power up.

**Command/Query/Response Format**

In the interest of standardization, the RS-232 commands and queries used on the Mai Tai HP follow the SCPI protocol (Standardized Commands for Programmable Instruments). This protocol was developed with the user in mind, thus all commands are easily readable by the user. The following rules apply:

- All commands and responses are in ASCII format.
- Commands to the Mai Tai HP system are terminated by an ASCII carriage return, line feed, or both.
  
  In this document, a carriage return is indicated by `<CR>` and a line feed by `<LF>`.
- All responses from the Mai Tai HP system are terminated by an ASCII line feed character.
- All queries end with a question mark (?). If a query has no command associated with it, it is preceded with READ.
- The Mai Tai HP system will not generate any signals on the RS-232 unless a query command is received first.
Parameters are separated from commands by spaces.

Commands have both a “short” and “long” form.

The long form is the completely written command. The short form is derived from the long form by dropping every character after the fourth character. If the fourth character is a vowel, a three-letter form is used. The only exceptions to this pattern are “OFF” and “ON”.

Example:

Long form: SHUTTER 1
Short form: SHUT 1

In the examples in this document, the long form of the command is used with the short form portion of it written in capital letters (e.g., SHUTTER 1) and, when contained within text, the entire command is in lower case.

Several commands have variations or sub-commands which are separated by semicolons (;). Short and long forms of the various commands and sub-commands may be freely mixed. For example, all of the following are equivalent:

READ:PLAS:DIOD1:CURR?
READ:PLASER:DIODE1:CURRENT?
READ:PLAS:DIODE1:CURR?

However, for consistency and readability, it is best to choose one form and stay with it throughout.

**Typical Command Usage**

The control flow of a Mai Tai HP program might look like this:

1. Turn on the system, then wait approximately 15 seconds for the computers to initialize.
2. Begin issuing a series of READ:PCTWarmedup? queries and wait for it to return 100 to indicate the system is fully warmed up (i.e., 100% warm).
3. Set the output wavelength to 800 nm by issuing the WAVelength 800 command.
4. Turn on the laser by issuing the ON command.
5. Open the shutter by issuing the SHUTter 1 command.
Commands and Queries Used by the Mai Tai HP

Quick Reference

The following is a list of the commands and queries used by the Mai Tai HP and are provided as a reference guide. A list with explanations follows in the next section.

ON
OFF
CONTrol:MLENable
CONTrol:MLENable?
CONTrol:PHAse
CONTrol:PHAse?
MODE
MODE?
PLASer:AHISTory?
PLASer:ERRCode?
PLASer:PCURrent
PLASer:PCURrent?
PLASer:POWer
PLASer:POWer?
READ:AHISTory?
READ: HUM?
READ:PCTWarmedup?
READ:PLASer:DIODe(n):CURRent?
READ:PLASer:DIODe(n):TEMPerature?
READ:PLASer:PCURrent?
READ:PLASer:POWer?
READ:PLASer:SHGS?
READ:POWer?
READ:WAVelength?
SAVE
SHUTter (n)
SHUTter?
SYStem:COMMunications:SERial:BAUD (nnn)
SYStem:ERR?
TIMer:WATCHdog (n)
WAVelength (nnn)
WAVelength?
WAVelength:MIN?
WAVelength:MAX?
*IDN?
*STB?
**Full Description**

This sections explains the commands and queries in detail. The form of the command is followed by the form of the associated query, which is followed by an explanation of each.

**ON**

Turns on the pump laser (the *Millennia*). Unless overridden by the MODE and/or PLASer:POWER commands, the laser will turn on in power mode at the power level set by the factory.

The shutter is not automatically opened when the ON command is issued.

The response to this command depends on whether or not the system is warmed up. Use the READ:PCTWarmedup? query to determine the progress of the warm-up cycle. When the response to the READ:PCTWarmedup? query reaches 100, the laser can be started. Do not issue an ON command while the response to READ:PCTWarmedup? query is 1 to 99.

<table>
<thead>
<tr>
<th>If the response to</th>
<th>The response to ON is...</th>
</tr>
</thead>
<tbody>
<tr>
<td>READ:PCTWarmedup? is...</td>
<td>to begin diode laser temperature stabilization. (approximately 2 minutes)</td>
</tr>
<tr>
<td>0</td>
<td>an execution error. (The EXE_ERR bit in the status byte is set.)</td>
</tr>
<tr>
<td>1 to 99</td>
<td>the diode lasers turn on, and the system output ramps to the most recently set power/current.</td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**OFF**

Turns off the pump diode lasers, but the SHG crystal oven temperature is maintained for a quick warm-up time.

The shutter is not automatically closed.

**CONTrol:MLENable n (1, 0)**

**CONTrol:MLENable?**

Turns the mode locker RF drive signal on (1) or off (0). The query returns a 1 or 0. You should not have to use this control. The modulator RF is disabled whenever the pump laser (the *Millennia*) is off and enabled when the pump laser is turned on (unless overridden by this command).

**CONTrol:PHAse nn.nn**

**CONTrol:PHAse?**

Sets/reads the RF phase control. You should not have to use this control. Phase is reset to the factory setting every time the wavelength command is used.
MODE nnnn (PPOWer/PCURrent)

The system defaults to power mode and output power is set at the factory for optimum system performance. Do not set the unit to current mode or change the power setting. Increasing power may actually decrease output performance! This control is for diagnostic purposes only and is to be used only by someone trained on this laser by Spectra-Physics.

MODE?

The legal parameters are PPOWer for “pump laser power” and PCURrent for “pump laser percent current.” The system always turns on in PPOWer mode by default.

The query returns PPOWer or PCURrent.

PLASer:AHISTORY?

Returns the contents of the history buffer for the status and error codes that relate to pump laser operation, that is, the status of the diode laser modules and the Millennia. The history buffer contains the most recent status codes listed first. This query only returns codes which are generated by the Model J80 power supply (to read the status codes related to the Mai Tai HP laser head, use READ:AHIS?). The list of status and error codes is given in Appendix C.

PLASer:ERRCode?

Returns the pump laser error code. See Table 6-1 and Table 6-2.

PLASer:PCURrent nn.n (0 to 20.0)

Sets the pump laser percentage of available current. This is only useful when the mode is set to MODE:PCURrent.

The query returns the last commanded pump laser current percentage.

Do not change the power setting. Increasing power may actually decrease output performance! This control is for diagnostic purposes only and is to be used only by someone trained on this laser by Spectra-Physics.

PLASer:POWer n.nn (0 to 10.0)

Sets the pump laser output power. This is useful only when the mode is set to MODE:POWer. It is overridden whenever the WAVelength command is issued.

The query returns the last commanded pump laser power in Watts. Use the query READ:PLASer:POWer? if you want to get the actual output power.

Do not change the power setting. Increasing power may actually decrease output performance! This control is for diagnostic purposes only and is to be used only by someone trained on this laser by Spectra-Physics.
READ:AHISTORY?

Returns the contents of the history buffer for the status and error codes that relate to the Mai Tai HP laser head. The history buffer contains the most recent status codes listed first. This query only returns codes which are generated by the Mai Tai HP laser head (to read the status codes related to the pump laser and Model J80 power supply, use PLAS:AHIS?). The list of status and error codes is given in Appendix C.

READ:HUM?

Reads and returns the relative humidity (in percent) of the Mai Tai HP Ti:sapphire laser cavity.

READ:PCTWarmedup?

Reads the status of the system warm-up time as a percent of the predicted total time (see the table below). The system responds with a value similar to “050%<LF>.” When the response is “100%<LF>,” the laser can be turned on.

READ:PLASer:DIODE1:CURRENT?
READ:PLASer:DIODE2:CURRENT?

Reads and returns the current of the specified pump diode laser (diode laser 1 or 2). The value is equal to the actual operating percentage of maximum diode laser current. A typical response might be “75.1%<LF>”.

READ:PLASer:DIODE1:TEMPerature?
READ:PLASer:DIODE2:TEMPerature?

Reads and returns the current temperature, in degrees C, of diode pump laser 1 or 2. A typical response might be “20.5<LF>”.

READ:PLASer:PCURrent?

Reads and returns the percentage of full operating current for the pump laser.

READ:PLASer:POWer?

Reads and returns the output power of the pump laser (0 to 10.5 W).

READ:PLASer:SHGS?

Reads and returns the pump laser SHG status. The system responds “3S<LF>” if the temperature is settling, “1S<LF>” if the oven is heating, and “2S<LF>” if it is cooling. Values less than zero indicate an error (such as a broken wire or loose cable).

READ:POWer?

Reads and returns Mai Tai HP output power, from 0 to 2.00 W.

READ:WAVelength?

Reads and returns the Mai Tai HP operating wavelength. The returned value may not match the commanded wavelength until the system has finished moving to the newly commanded wavelength.

SAVE

Saves the Mai Tai HP status. Use this command before turning off the ac power to return to this mode the next time the unit is turned on.
SHUTter n (1, 0)
SHUTter?

SHUTter 1 opens the shutter.
SHUTter 0 closes the shutter.

SHUTter? Reads and returns the shutter status. It is normal for SHUTter? to return a “0” for approximately 1 second after issuing the SHUTter 1 command or a “1” after issuing the SHUTter 0 command.

SYSTem:COMmunications:SERial:BAUD nnnn

Sets the baud rate to 300, 600, 1200, 4800, 19200, 38400, or 57600 baud. The system always powers up at 9600 baud. (The demonstration program uses 38400 baud.) Note: the XON/XOFF protocol is used regardless of baud rate. Hardware handshaking is not used.

SYSTem:ERR

Returns a numerical error and a text message (Table 6-1 and Table 6-2). These errors/messages are contained in a buffer which is gradually emptied as this command is used. These errors/messages are not the same as the ones you can obtain with READ:HIStory? SYSTem:ERR primarily indicates whether or not a command was properly received and executed.

TIMEr:WATChdog n

Sets the number of seconds for the software watchdog timer. A value of zero disables the software watchdog timer. If the Mai Tai HP does not receive a valid command (or Query) every n seconds, the pump laser is turned off.

WAVelength nnn (in nm)
WAVelength?

Sets the Mai Tai HP wavelength between 690 and 1020 nm. It will also set the modulator RF phase and the pump laser output power to the factory calibrated values appropriate to the wavelength.

The query reads and returns the most recent value of the WAVelength command. Use it to verify the command was properly received.

WAVelength:MAX?
WAVelength:MIN?

These queries return the maximum and minimum values for the WAVelength command.

*IDN?

Returns a system identification string that contains 4 fields separated by commas such as:

“Spectra-Physics,MaiTai,xxx,0454-8270T/6.00/0456-9100A.”

The first field indicates the laser was made by Spectra-Physics; the second is the model name; the third is reserved for the serial number of the Mai Tai HP/Millennia/J-series power supply; the fourth is the software revision, in this case, the Mai Tai HP software number and revision reserved for the EPROM for the Model J80 power supply (the default is –6.00) and the power supply number and software revision.
"STB?"

Returns the product status byte. This is a number between 0 and 255 and consists of the sum of the following weighted values:

1  Emission is possible (this bit follow the emission indicator light on the product). Note that the shutter may still be closed, even if this bit is set.
2  The Mai Tai HP is modelocked.
4  Reserved
8  Reserved
16  Reserved
32  Reserved
64  Reserved
128  Reserved

This completes the RS-232 command descriptions.

Table 6-1: Query Errors for PLAS:ERRC

<table>
<thead>
<tr>
<th>Binary Digit</th>
<th>Decimal Value</th>
<th>Name</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>CMD_ERR (CE)</td>
<td>Command error. Something was wrong with the command format, the command was not understood</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>EXE_ERR (EE)</td>
<td>Execution Error. A command was properly formatted, but could not be executed. For example, a power command of “P:0&lt;CR&gt;” was sent, when the minimum allowed power is 0.2 watts.</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>(reserved)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>(reserved)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>(reserved)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>SYS_ERR (SE)</td>
<td>Any “system” error. (An open interlock, or an internal diagnostic)</td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>LASER_ON (LO)</td>
<td>Indicates that laser emission is possible.</td>
</tr>
<tr>
<td>7</td>
<td>128</td>
<td>ANY_ERR (AE)</td>
<td>Any of the error bits are set.</td>
</tr>
</tbody>
</table>
Table 6-2: Error Return List for PLAS:ERRC

<table>
<thead>
<tr>
<th>Binary DigitS</th>
<th>Decimal Value</th>
<th>Errors Returned</th>
</tr>
</thead>
<tbody>
<tr>
<td>0100 0000</td>
<td>64</td>
<td>LO</td>
</tr>
<tr>
<td>1000 0001</td>
<td>129</td>
<td>CE + AE</td>
</tr>
<tr>
<td>1000 0010</td>
<td>130</td>
<td>EE + AE</td>
</tr>
<tr>
<td>1000 0011</td>
<td>131</td>
<td>CE + EE + AE</td>
</tr>
<tr>
<td>1010 0000</td>
<td>160</td>
<td>SE + AE</td>
</tr>
<tr>
<td>1010 0001</td>
<td>161</td>
<td>CE + SE + AE</td>
</tr>
<tr>
<td>1010 0010</td>
<td>162</td>
<td>EE + SE + AE</td>
</tr>
<tr>
<td>1010 0011</td>
<td>163</td>
<td>CE + SE + EE + AE</td>
</tr>
<tr>
<td>1100 0001</td>
<td>193</td>
<td>CE + LO + AE</td>
</tr>
<tr>
<td>1100 0010</td>
<td>194</td>
<td>EE + LO + AE</td>
</tr>
<tr>
<td>1100 0011</td>
<td>195</td>
<td>CE + EE + LO + AE</td>
</tr>
<tr>
<td>1110 0010</td>
<td>226</td>
<td>EE + SE + LO + AE</td>
</tr>
<tr>
<td>1110 0011</td>
<td>227</td>
<td>CE + EE + SE + LO + AE</td>
</tr>
</tbody>
</table>
Chapter 7  

Troubleshooting

Note

The chiller and power supply must both be either on or off. Condensation will occur in the Mai Tai if the chiller is on but the power supply is off, and the Mai Tai might misalign if the power supply is on but the chiller is off.

Preliminary Verification

1. Verify chiller temperature is set to 21°C.
2. Verify chiller pressure is at 26 < PSI < 40.
3. Verify the Tower, Body, Control pc board and RF pc board temperatures are within the range shown here:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower Temp (°C)</td>
<td>23 – 26</td>
</tr>
<tr>
<td>Body Temp (°C)</td>
<td>38 – 42</td>
</tr>
<tr>
<td>Ctrl PCB Temp (°C)</td>
<td>30 – 34</td>
</tr>
<tr>
<td>RF PCB Temp (°C)</td>
<td>27 – 29</td>
</tr>
</tbody>
</table>

4. Close and reopen the shutter by holding the shutter button down for 5 seconds.
5. Verify the system is set to the proper operating mode: Green Mode or IR Power Mode (system dependent).

Error Messages

**Could not find Mai Tai**

Verify the RS-232 cable is properly connected.
Verify there is no other software already talking to the Mai Tai, such as HyperTerminal or custom-made software.
Try other COM ports. COM port selection is based on computer type and the communications devices attached.

**High Temperature Warning**

Inspect and replace the chiller filter.
If an in-line flow meter is available, verify chiller flow is >15 GPH. Reverse flush if necessary. Flush chiller and refill it with steam distilled water. **Never use tap or deionized water** (see the chiller manual for details).
Servo Loops Out of Range

PZT Related

The P₂ PZT mirror maximizes output IR power by servoing the pump beam in the intracavity IR beam.
The M₃ PZT mirror keeps the IR beam centered on the quadcell (before it leaves the Mai Tai housing), thereby minimizing beam-pointing changes due to ambient temperature variations or wavelength changes. Follow the instructions under the “PZT Related” section below.

IR Power Loop Related (GrnAdj)

Follow the instructions under the “IR Power Loop Related (GrnAdj) if Applicable” section below.

PZT Related

1. Verify the status of the P₂ PZT by viewing the x,y values in the Info menu.
   a. “P2”—means the P₂ PZT mirror is enabled and active.
   b. “p2”—means the P₂ PZT mirror is enabled but inactive because of low Green pump or IR power. Refer to Step 2 under the “IR Power Loop Related (GrnAdj) if Applicable” section below.
   c. “X,Y”—the X-axis and Y-axis values should be between 10% and 90%. If not, go to Step 3 of this section.

2. Verify the status of the M₃ PZT by viewing the x,y values in the Info menu.
   a. “M3”—means the M₃ PZT mirror is enabled and active.
   b. “m3”—means the M₃ PZT mirror is enabled but inactive due to the absence of IR power, or IR output is not modelocked. If the system is operating in the water absorption region (refer to Figure 7-1 on page 7-3), verify humidity is all right according to Appendix D. Otherwise, note the current phase setting. Then, from the Setup menu, change the phase setting 1 count at a time until pulsing is restored. Watch for either the spreading of the spectrum from the spectrometer, or an increase in the pulsing photodiode signal as indicated on the RF Controls menu. Search ± 5 counts from the original setting.
   c. “X,Y”—the X-axis and Y-axis values should be between 10% and 90%. If not, go to Step 3.

3. Call your Spectra-Physics service representative.

IR Power Loop Related (GrnAdj) if Applicable

Skip to Step 2 if the system is not equipped with IR Power mode. The LED will light up next to the IR Power mode indicator on systems that include IR Power mode. The IR Power loop servos pump power to maintain a fixed factory-set IR output target value (wavelength dependent).

1. Verify the Green Correction (GrnAdj) value is correct on the Info menu. The “GrnAdj” value changes from black to red when it is less than 10% or greater than 90%.
2. Verify the Green Power setpoint value (shown in the display next to the Green Power Mode selector in the Setup menu) is the same as the actual Green Power value shown at the upper left side of the Info menu. If it is, go to Step 3. Otherwise, follow the procedure below to correct the crystal temperature for proper phase matching.
   a. From the Setup menu, change the operating mode to Current % mode.
   b. Set the Current % value to 100.
   c. Record the SHG Fine setting.
   d. Lower the SHG Fine value by 5 counts, then wait 1 minute to see if actual Green Power increases. If it does, repeat for another 5 counts. Otherwise, raise the value by 5 counts instead.
   e. Once Green Power has reached a maximum value, lower the SHG Fine setting by 5 to 10 counts. Verify the Actual Green Power value is 14.0 Watts. If it is, continue. If not, go to Step 3.
   f. Switch the operating mode to Green Power mode. Change the set-point to the maximum Green Power value (14.0 Watts) and let it run at this value for approximately 2 minutes. The Current % value will readjust itself to 100% when it detects stable output power over this time period.
   g. Change the operating mode to IR mode. Toggle the wavelength from the main menu to return to the factory-set pump power value.
3. Call your Spectra-Physics service representative.
At Spectra-Physics, we take pride in the durability of our products. We place considerable emphasis on controlled manufacturing methods and quality control throughout the manufacturing process. Nevertheless, even the finest precision instruments will need occasional service. We feel our instruments have favorable service records compared to competitive products, and we hope to demonstrate, in the long run, that we provide excellent service to our customers in two ways. First, by providing the best equipment for the money, and second, by offering service facilities that restore your instrument to working condition as soon as possible.

Spectra-Physics maintains major service centers in the United States, Europe, and Japan. Additionally, there are field service offices in major United States cities. When calling for service inside the United States, dial our toll-free number: 1 (800) 456-2552. To phone for service in other countries, refer to the Service Centers listing located at the end of this section.

Order replacement parts directly from Spectra-Physics. For ordering or shipping instructions, or for assistance of any kind, contact your nearest sales office or service center. You will need your instrument model and serial numbers available when you call. Service data or shipping instructions will be promptly supplied.

To order optional items or other system components, or for general sales assistance, dial 1 (800) SPL-LASER in the United States, or 1 (650) 961-2550 from anywhere else.

**Warranty**

This warranty supplements the warranty contained in the specific sales order. In the event of a conflict between documents, the terms and conditions of the sales order shall prevail.

The *Mai Tai™ HP* high-performance laser system is protected by a 12-month warranty. All mechanical, electronic, optical parts and assemblies are unconditionally warranted to be free of defects in workmanship and material for the warranty period.

Liability under this warranty is limited to repairing, replacing, or giving credit for the purchase price of any equipment that proves defective during the warranty period, provided prior authorization for such return has been given by an authorized representative of Spectra-Physics.
Warranty repairs or replacement equipment is warranted only for the remaining unexpired portion of the original warranty period applicable to the repaired or replaced equipment.

This warranty does not apply to any instrument or component not manufactured by Spectra-Physics. When products manufactured by others are included in Spectra-Physics equipment, the original manufacturer's warranty is extended to Spectra-Physics customers. When products manufactured by others are used in conjunction with Spectra-Physics equipment, this warranty is extended only to the equipment manufactured by Spectra-Physics.

Spectra-Physics will provide at its expense all parts and labor and one way return shipping of the defective part or instrument (if required).

This warranty does not apply to equipment or components that, upon inspection by Spectra-Physics, discloses to be defective or unworkable due to abuse, mishandling, misuse, alteration, negligence, improper installation, unauthorized modification, damage in transit, or other causes beyond Spectra-Physics’ control.

The above warranty is valid for units purchased and used in the United States only. Products with foreign destinations are subject to a warranty surcharge.

**Return of the Instrument for Repair**

Contact your nearest Spectra-Physics field sales office, service center, or local distributor for shipping instructions or an on-site service appointment. You are responsible for one-way shipment of the defective part or instrument to Spectra-Physics.

We encourage you to use the original packing boxes to secure instruments during shipment. If shipping boxes have been lost or destroyed, we recommend you order new ones. Spectra-Physics will only return instruments in Spectra-Physics containers.

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**Warning!**

Always drain the cooling water from the laser head before shipping. Water expands as it freezes and will damage the laser. Even during warm spells or summer months, freezing may occur at high altitudes or in the cargo hold of aircraft. Such damage is excluded from warranty coverage.
Service Centers

Belgium
Telephone: 0800 11257
Fax: 0800 11302

France
Telephone: 0810 007 615
Fax: 0810 062 611

Germany and Export Countries*
Spectra-Physics GmbH
Guerickeweg 7
D-64291 Darmstadt
Telephone: (49) 06151 708-0
Fax: (49) 06151 79102

Japan (East)
Spectra-Physics KK
East Regional Office
Daiwa-Nakameguro Building
4-6-1 Nakameguro
Meguro-ku, Tokyo 153-0061
Telephone: (81) 3-3794-5511
Fax: (81) 3-3794-5510

Japan (West)
Spectra-Physics KK
West Regional Office
Nishi-honmachi Solar Building
3-1-43 Nishi-honmachi
Nishi-ku, Osaka 550-0005
Telephone: (81) 6-4390-6770
Fax: (81) 6-4390-2760

The Netherlands
Telephone: 0900 555 5678
Fax: 0900 555 5679

People’s Republic of China
Spectra-Physics China
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Beijing 100080
P. R. China
Telephone: (86) 10-6254-7746
Fax: (86) 10-6255-6373

*And all European and Middle Eastern countries not included on this list.
Switzerland
Telephone: 0842 202 203
Fax: 0842 202 204

Taiwan R.O.C.
Newport Taiwan
2F, No. 188, Nanjing E. Road
Sec. 5 Taipei 105
Taiwan, R.O.C.
Telephone: (886) 2-2769-9796
Fax: (886) 2-2769-9638

United Kingdom
Telephone: (44) 1442-258100

United States and Export Countries*
Spectra-Physics
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Mountain View, CA 94043
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(800) SPL-LASER (Sales) or
(800) 775-5273 (Sales) or
(650) 961-2550 (Operator)
Fax: (650) 964-3584
e-mail: service@spectra-physics.com
sales@spectra-physics.com
Internet: www.spectra-physics.com

*And all non-European or Middle Eastern countries not included on this list.
Appendix A  Modelocking

This chapter provides a brief discussion of modelocking and the regenerative modelocking technique employed in the Mai Tai™ HP Ti:sapphire laser cavity. Also included is a description of the group velocity dispersion (GVD) found within the cavity, and the role of nonlinear effects (due to intense pulses passing through the gain medium) is considered. Finally, GVD compensation techniques employed within the Mai Tai HP are discussed since they ultimately determine the output pulse width.

General

In any laser system, the oscillating wavelengths (or frequencies) that are allowed are determined by two factors: the longitudinal modes, which are determined by the laser cavity (subject to threshold conditions), and the gain-bandwidth of the laser medium. In a laser cavity, the electric field of the oscillating optical frequencies must repeat itself after one round-trip; i.e., the oscillating wavelengths must satisfy a standing wave condition in the laser cavity, or an integral number of half-wavelengths must exactly fit between the end mirrors. Only a small group of frequencies that satisfy this condition make up the longitudinal modes of the laser. The gain-bandwidth of the laser medium is determined by its atomic or molecular energy levels. Atomic gas lasers tend to have relatively narrow bandwidth while molecular dye and solid state systems exhibit broader bandwidth.

In a CW or free-running laser, the longitudinal modes operate independently. Cavity perturbations cause some modes to stop oscillating and, when they re-start, they have a different phase. Thus, the laser output comprises various randomly phased mode frequencies. In a mode-locked laser, the longitudinal modes must be “locked” in phase in a way that they constructively interfere at some point in the cavity and destructively interfere elsewhere in order to create a single circulating pulse. Each time this intracavity pulse reaches the partially reflective output coupler, an output pulse is produced. The time between the output pulses is the time it takes for the cavity pulse to make one complete round trip. For the Mai Tai HP system, this corresponds to about 12.5 ns. The output pulse frequency, or repetition rate (rep rate), is about 80 MHz (refer to Figure A-1).
Modelocking Techniques

A variety of approaches have been used to obtain a train of mode-locked pulses from different laser systems including active modelocking, passive modelocking, additive pulse modelocking, and self modelocking.

Active modelocking is by far the most common approach used to obtain short optical pulses of ps duration from solid state or gas lasers. A loss modulation is applied to the laser cavity at the same frequency as the pulse rep rate. This is equivalent to introducing an optical shutter into the laser cavity—only light that arrives at the shutter at precisely the correct time passes through and is amplified in the gain media. Since the shutter is closed at all other times, a second pulse cannot be formed.

The most common active modelocking element is an acousto-optic modulator (AOM) which is placed inside the optical cavity close to one of the end mirrors. The modulator comprises a high quality optical material (such as quartz) with two highly polished surfaces that are parallel to the direction of light propagation. Attached to one of these surfaces is a piezoelectric transducer that is driven at an RF frequency to generate an acoustic wave within the modulator (Figure A-2). Using the reflection off the opposite surface, a standing acoustic wave is generated within the modulator. This induces a time-dependent refractive index grating along an axis perpendicular to the light propagation. As the light interacts with this grating, a portion of it is both diffracted and shifted in frequency by an amount equal to the acoustic frequency. After passing through the modulator, the diffracted and undiffracted rays are reflected back through the modulator where a portion of each beam is diffracted once again.

If the RF drive is at frequency $\omega_{mL}$, the acoustic grating generated by the standing wave will turn on and off at a rate of $2\omega_{mL}$. The value for $2\omega_{mL}$ is chosen to be the same as the laser repetition rate $\frac{c}{2L}$. The AOM diffracts light out of the cavity only when the acoustic grating is present and, thus, functions as a time-dependent loss. In the frequency domain, this loss imparts modulation sidebands when a wave passes through the modulator (Figure A-2). In this manner, the AOM “communicates” the phase between the longitudinal modes of the laser cavity. The final amplitude and frequency of the phase-locked longitudinal modes is shown in Figure A-3.
Figure A-2: Active modelocking using an AOM. Modulation sidebands are produced when a wave passes through an amplitude modulator.

Figure A-3: Amplitude and frequency of longitudinal modes in a mode-locked laser.

The modulation frequency $2\omega_{ml}$ must be precisely matched to the repetition rate of output pulses which is $c/2L$. The RF signal used to drive the AOM is, thus, usually generated by a temperature-stabilized crystal oscillator, and the cavity length of the laser is adjusted to obtain the appropriate frequency.

The duration of the mode-locked pulses depends on several factors including the gain bandwidth of the laser and the modulation depth of the AOM. Laser media with greater gain bandwidth have the capability of generating shorter pulses. Consequently, active modelocking a Nd:YAG laser produces pulse widths of 30 to 150 ps, while for an ion laser, durations are usually 120 to 200 ps.
In passively mode-locked systems, the pulse itself generates the periodic modulation. This can be accomplished with a saturable absorber dye that responds to the instantaneous light intensity in a nonlinear manner. At low light intensity the dye is opaque, but at higher intensities the dye is bleached and becomes transparent. The bleaching time of the dye is the effective time of the optical shutter. In the 1980's, a colliding pulse geometry was used with the passive modelocking technique to produce a colliding pulse mode-locked (CPM) dye laser. When intracavity GVD compensation (described later in this chapter) was used with a CPM laser, sub-100 fs pulses were generated for the first time.

Also, during the 1980's, several new developments in broad bandwidth, solid-state laser materials occurred. The most notable of these was titanium-doped sapphire, which allowed lasers to be tuned over a continuous range from < 700 to 1100 nm. In 1989, Spectra-Physics was the first company to offer a commercial CW Ti:sapphire laser.

The broad bandwidth and good thermal properties of this new material motivated several new modelocking approaches. Additive pulse modelocking (APM) used an interferometrically-coupled, external nonlinear fiber cavity to induce modelocking. In 1991, self-modelocking in Ti:sapphire was observed to be induced through the intensity-dependent, nonlinear refractive index of the laser medium. At Spectra-Physics, the Tsunami laser was developed. It was a commercial, mode-locked Ti:sapphire laser based upon a regeneratively initiated technique.

**Regenerative Modelocking**

Like active modelocking, regenerative modelocking in the *Mai Tai HP* laser employs an AOM within the cavity to generate a periodic loss. However, unlike active modelocking, the RF drive signal used to drive the AOM is derived directly from the laser cavity (Figure A-4). This removes one of the greatest drawbacks of active modelocking, i.e., the requirement that the cavity length match the external drive frequency. In the *Mai Tai HP*, if the laser cavity length changes slightly, the drive signal to the modulator changes accordingly.

When the *Mai Tai HP* is initially aligned, the laser is operating CW with oscillations from several longitudinal modes. These are partially phase-locked, and mode beating generates a modulation of the laser output at a frequency of $c/2L$. This mode beating is detected by a photodiode and then amplified. Since this signal is twice the required AOM modulation frequency ($\omega_{mL}$), it is divided by two, then the phase is adjusted such that the modulator is always at maximum transmission when the pulse is present. Finally, the signal is reamplified and fed to the AOM.

Most actively mode-locked systems run on resonance for maximum diffraction efficiency. The AOM in a *Mai Tai HP* is operated off-resonance with a diffraction efficiency of about 1%. The output pulse width is not controlled by the AOM diffraction efficiency. Rather, pulse broadening in the *Mai Tai HP* occurs through a combination of positive GVD and nonlinear effects (self phase modulation) in the Ti:sapphire rod. Ultimately, the output pulse width is controlled by adding net negative GVD to the cavity to balance these effects. (Refer to the following section on GVD.)
Group Velocity Dispersion

Fourier analysis (as a consequence of the Heisenberg uncertainty principle) imposes a restriction on the bandwidth of an ultrashort pulse. For a pulse of duration $\Delta t_p$ and bandwidth $\Delta \nu$, it is always true that $\Delta \nu \cdot \Delta t_p$ will be greater than a constant with a value of about 1. The exact nature of the constant depends on the exact shape of the pulse (examples are given in Appendix B). It is apparent that, the shorter the pulse, the larger the bandwidth and, thus, the greater the difference from the lowest to highest frequency within a pulse. Since the index of refraction of any material is frequency dependent, each frequency in a pulse experiences a slightly different index of refraction as it propagates. This index of refraction difference corresponds to a velocity difference, causing a time separation between the different frequencies of a pulse. GVD is defined as the variation in transit time as a function of wavelength. For positive GVD, the lower frequencies (red) travel faster than higher frequencies (blue). The effect is more pronounced for shorter pulses (because of their larger bandwidth).

Figure A-5 shows the refractive index $n$ versus wavelength $\lambda$ for a typical transparent optical material. For any given wavelength, the refractive index $n(\lambda)$ determines the phase velocity. The slope of the curve, $dn(\lambda)/d\lambda$, determines the group velocity (or the velocity of a short pulse with a center wavelength of $\lambda$).
Typical wavelength dependence of the refractive index of a material.

The second derivative of the curve, $d^2n(\lambda)/d\lambda^2$, determines the GVD, which is the rate at which the group velocity changes as a function of wavelength, i.e., it governs the rate at which the frequency components of a pulse change their relative time. GVD can change the temporal shape of the pulse by broadening it or narrowing it, depending on the “chirp” of the original pulse. A pulse is said to be positively chirped, i.e., it has experienced positive GVD, if the low frequencies lead the high (red is in front), and negatively chirped if the opposite is true. Pulses are typically positively chirped as they pass through normal materials at visible and near IR wavelengths.

**Nonlinear Effects**

In addition to GVD, the output pulse width and pulse shape from the *Mai Tai HP* are governed by the interaction of the pulse with the nonlinear index of the Ti:sapphire. The nonlinear index of refraction $n_2$ introduces an intensity-dependent index at high intensities:

$$n = n_0 + n_2I$$  \[1\]

where $n_0$ is the linear index of refraction and $I$ is the instantaneous pulse intensity. This results in self phase modulation (SPM) of the pulse. As the pulse propagates through the Ti:sapphire material, the leading edge experiences an increasing index of refraction. This causes a delay in the individual oscillations of the electric field and results in a “red-shifted” leading edge. Conversely, the trailing edge of the pulse is “blue-shifted.” SPM will, thus, broaden the spectrum of the pulse and provide a positive chirp.
In order to achieve near transform-limited output pulses, it is necessary to compensate for the pulse spreading caused by positive GVD and SPM. In the *Mai Tai HP*, this is accomplished with prism pairs that provide negative GVD linear over a large bandwidth.

**GVD Compensation**

The materials in the *Mai Tai HP* contribute positive GVD and, in combination with SPM in the Ti:sapphire rod, induce a positive chirp on the pulse. Consequently, the circulating pulse continues to broaden as it propagates through the cavity unless negative GVD is present to balance these effects.

As discussed earlier, a material exhibits GVD when the second derivative of its refraction index with respect to wavelength \( (d^2n/d\lambda^2) \) is non-zero. This is a special case that is only valid when all wavelengths follow the same path through a material. This can be extended to any optical system having a wavelength dependent path length \( (P) \). GVD is then governed by the second derivative of the optical path with respect to wavelength \( (d^2P/d\lambda^2) \).

For this reason, a prism pair can be used to produce negative GVD in the *Mai Tai HP*. This is generally the preferred intracavity compensation technique for ultrashort pulse lasers because (a) losses can be minimized by using the prisms at Brewster’s angle, and (b) the negative GVD is nearly linear over a large bandwidth. Ideally, for stable short-pulse formation, the round trip time in the cavity must be frequency independent, i.e., \( T_g(\omega) = \frac{d\phi}{d\omega} = \text{constant} \), where \( T_g(\omega) \) is the group delay time, \( \phi \) is the phase change, and \( \omega \) is the frequency. In reality, dispersion is not purely linear, and higher order dispersion terms become significant for shorter output pulse widths (larger bandwidths).

In the *Mai Tai HP* laser, a two-prism sequence configuration is used to provide negative GVD (for clarity, Figure A-6 shows a four-prism sequence to illustrate the point).

![Figure A-6: A four prism sequence used for dispersion compensation. An input pulse with a positive chirp (red frequencies at the leading edge of the pulse) experiences negative GVD (red frequencies have longer group delay time) in the prism sequence. The net effect is that the prism sequence compensates for the positive GVD and produces a pulse which has no chirp.](image-url)
The different spectral components of the pulse are spatially spread between prisms \( \text{Pr}_2 \) and \( \text{Pr}_3 \). This allows wavelength selection to be conveniently accomplished by moving a slit between these two prisms in the direction of the spectral spread.
Appendix B  Pulse Width Measurement

Introduction

This chapter provides information on how to measure pulses using an autocorrelator.

The Autocorrelation Technique

Measurement of Ultrashort Pulses

An autocorrelator is the most common instrument used for measuring an ultrafast femtosecond (fs) or picosecond (ps) optical pulse. By using the speed of light to convert optical path lengths into temporal differences, the pulse is used to measure itself.

The basic optical configuration is similar to that of a Michelson interferometer. An incoming pulse is split into two pulses of equal intensity and an adjustable optical delay is imparted to one. The two beams are then recombined within a nonlinear crystal for second harmonic generation. The efficiency of the second harmonic generation resulting from the interaction of the two beams is proportional to the degree of pulse overlap within the crystal. Monitoring the intensity of UV generation as a function of delay between the two pulses produces the autocorrelation function directly related to pulse width.

Two types of autocorrelation configurations are possible. The first type, known as interferometric and shown in Figure B-1, recombines the two beams in a collinear fashion. This configuration results in an autocorrelation signal on top of a constant dc background, since the second harmonic generated by each beam independently is added to the autocorrelation signal. Alternatively, if the two beams are displaced from a common optical axis and then recombined in a noncollinear fashion (Figure B-2), the background is eliminated because the UV from the individual beams is separated spatially from the autocorrelator signal. This configuration is called “background-free.”

The Spectra-Physics Model 409-08 scanning autocorrelator operates in a background-free configuration according to the principles of noncollinear autocorrelation. It allows the autocorrelator signal to be conveniently displayed on a high impedance oscilloscope, providing the user with instantaneous feedback of laser performance. The Model 409-08 uses a rotating block of fused silica for varying the relative path lengths of both beam paths, and the scanning time base is calibrated by moving a calibration eta-
lon of known thickness in and out of one of the beam paths. The Model 409-08 can be used over the wavelength range from 650 to 1600 nm and, by changing the rotating blocks, it can be used to measure pulse widths from 25 ps to < 80 fs.

Figure B-1: Interferometric (Collinear) Autocorrelation

Figure B-2: Background-free (Non-collinear) Autocorrelation
Signal Interpretation

In order to determine the actual pulse width from the displayed autocorrelation function, it is necessary to make an assumption about the pulse shape. Table B-1 shows the relationship between pulse width, $\Delta t_p$, and the autocorrelation function, $\Delta t_{ac}$, for several pulse shapes. It also shows the time-bandwidth product, $\Delta t_p \Delta n$, for transform-limited pulses.

Table B-1: Second-order Autocorrelation Functions and Time-Bandwidth Products for Various Pulse Shape Models

<table>
<thead>
<tr>
<th>Function</th>
<th>$l(t)$</th>
<th>$\Delta t_p/\Delta t_{ac}^{**}$</th>
<th>$\Delta t_p \Delta n^{***}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>$l(t) = \begin{cases} 1;</td>
<td>t</td>
<td>\leq t_p^2 \ 0;</td>
</tr>
<tr>
<td>Diffraction Function</td>
<td>$l(t) = \frac{\sin^2(t\Delta t_p)}{(t\Delta t_p)}$</td>
<td>0.751</td>
<td>0.886</td>
</tr>
<tr>
<td>Gaussian</td>
<td>$l(t) = \frac{\exp(-4(\ln 2)t^2)}{\Delta t_p^2}$</td>
<td>0.707</td>
<td>0.441</td>
</tr>
<tr>
<td>Hyperbolic Secant</td>
<td>$l(t) = \sech^2(1.76t)\Delta t_p$</td>
<td>0.648</td>
<td>0.315</td>
</tr>
<tr>
<td>Lorentzian</td>
<td>$l(t) = \frac{1}{1 + (4t^2\Delta t_p^2)}$</td>
<td>0.500</td>
<td>0.221</td>
</tr>
<tr>
<td>Symmetric two-sided exponential</td>
<td>$l(t) = \exp\left(\frac{-4(\ln 2)t}{\Delta t_p}\right)$</td>
<td>0.413</td>
<td>0.142</td>
</tr>
</tbody>
</table>

* $\Delta t_p$ (sec) is FWHM of intensity envelope of the pulse.
**$\Delta t_{ac}$ (sec) is FWHM of autocorrelator function of the pulse.
***$\Delta n$ (Hertz) is FWHM of the spectrum of the pulse.
GVD Compensation in Measurement of Ultrashort Pulses

Because the pulses produced by the Mai Tai™ HP laser are extremely short (<100 fs), the pulse broadening in optical materials from GVD makes measurement of its true pulse width difficult. Also, because the GVD of glass causes the pulse width to broaden, the pulse that reaches the target after traveling through beam splitters, lenses, etc., may not be the same pulse that is measured in the autocorrelator. It is thus important to ensure that the measurement technique and optical setup incorporate the same amount of glass and some GVD compensation if the shortest pulses are to be measured and delivered to the sample.

Even before the pulse leaves the laser, it travels through extra glass. For example, if we assume the pulse in a Mai Tai HP laser is at its shortest as it passes through the coating of the output coupler, it then travels through the output coupler substrate, the photodiode beam splitter and the output window. The total thickness of these optics is about 1.9 cm (0.75 in.). Thus, a pulse that is 60 fs at the output coupler coating becomes 66 fs by the time it exits the laser. Include the glass of the autocorrelator and that in any optical setup and the pulse can be broadened substantially.

Since most autocorrelators use beam splitters, a lens and often a spinning block (as in the Model 409-08), the pulse is also broadened before it is measured. This means the pulse out of the Mai Tai HP may be actually shorter than that indicated by direct measurement. Consequently, GVD must also be compensated for when using an autocorrelator.

Since the sign of GVD in material is generally positive for the wavelengths produced by the Mai Tai HP laser, introducing negative GVD into the beam path compensates for the broadening effect of the material. Negative GVD can be introduced into a system with prism pairs, grating pairs or a Gires-Tournois Interferometer (GTI). The prism pair provides the easiest, lowest loss means for compensating for the positive GVD of materials.

To compensate for pulse broadening from materials, a simple setup using two high index prisms (SF-10) is all that is necessary. Figure B-3 shows the layout (top and side views) for an easily built pre-compensation unit. The laser pulse travels through the first prism where different frequency components are spread in space. Then the broadened pulse travels through the second prism, strikes a high reflector and reflects back along its original path—with one exception. The high reflector is slightly tilted in the plane perpendicular to the spectral spreading and causes the pulse to travel back through the prisms at a slightly different vertical height. After the beam returns through the first prism it is reflected by another mirror to the autocorrelator and/or the experiment.

This setup allows the higher frequencies (blue) to catch up with the lower frequencies (red). This is not intuitively obvious since it appears that the higher frequencies actually travel a longer path length than the lower frequencies. However, it is the second derivative of the path with respect to wavelength, $d^2P/d\lambda^2$, that determines the sign of the GVD. In Table B-2 and Table B-3, dispersion values at 800 nm are provided for materials and grating prism pairs. Dispersion, $D_w$, is expressed in units fs$^2$/cm of path length.
Double passing the beams in the prisms maintains the spatial profile of the beam. If only one pass is used, the output is spatially chirped. While the spacing of the prisms provides negative dispersion, the prism material actually adds more positive dispersion to the system. This can be used to our advantage in the optimization of a prism pre-compensator.

**Figure B-3:** Using two prisms to compensate for positive GVD.

**Table B-2: Positive Dispersion Values @ 800 nm**

<table>
<thead>
<tr>
<th>Material</th>
<th>$\Delta \omega$ (fs$^2$/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fused Silica</td>
<td>300</td>
</tr>
<tr>
<td>BK-7</td>
<td>450</td>
</tr>
<tr>
<td>Ti:sapphire</td>
<td>580</td>
</tr>
<tr>
<td>SF-10</td>
<td>1590</td>
</tr>
</tbody>
</table>
For an initial setup that includes your Mai Tai HP and a Model 409-08 autocorrelator, set the prisms approximately 30 cm apart at Brewster's angle to the beam with the high reflector a few centimeters from the second prism. With this spacing, the prism pair should start with excess negative GVD. By moving the prism tips into the beam, we can balance the GVD for minimum pulse width. To do this, place the first prism on a translation stage that moves the prism in the direction of the bisector of the apex. This way, more glass can be pushed into the beam path without displacing the beam or changing its angular direction. This allows the negative GVD of the prism system to balance the positive GVD created by all the glass. By moving the prism into the beam path and monitoring the output with the autocorrelator, the pulse should get narrower as the dispersion is balanced. If a minimum cannot be found, adjust the prism spacing and search for the minimum again.

### Calculating Pulse Broadening

Below are some simple formulae for calculating the effects of GVD and compensation. $B$ (broadening) is defined as the ratio of the output pulse width to the input pulse width where $B = \frac{t_{out}}{t_{in}}$. Consequently, knowing the input pulse width, $B$ can be calculated and $t_{out} = B \cdot t_{in}$.

A simple formula for calculating the broadening of a transform-limited Gaussian pulse by dispersive elements is:

$$B = \frac{t_{out}}{t_{in}} = \left\{ 1 + \left[7 \cdot 68 \cdot \left(\frac{D_w \cdot L}{t_{in}^2}\right)^2\right]^{\frac{1}{2}}\right\}^{\frac{1}{2}}$$  \[1\]

where $t_{in}$ is the input pulse width in femtoseconds, and $D_w$ is a dispersion value normalized for a given length and wavelength. Table B-2 gives values for different materials at 800 nm. Also given in Table B-3 are the values for some negative dispersion setups, prisms and grating pairs for compensation at 800 nm. Using these values, $B$ is calculated directly. We define $S$ as:

$$S = D_w \cdot \frac{L}{t_{in}^2}$$  \[2\]

Using Figure B-4, the value of $S$ is directly related to a value for broadening ($B$).
Pulse Width Measurement

Figure B-4: Broadening Curve

When using this equation and graph, it is important to remember that the values of \( D_w \) are wavelength sensitive. For example, for BK-7 material, the difference from 800 to 880 nm is 17%. Therefore, it is important to use the correct value of \( D_w \) for the operational wavelength. Also, if there are several materials present, the values for dispersion must be added before calculating \( B \). For example:

\[
\omega_{(\text{tot})}L_{\omega_{(\text{tot})}} = D_{\omega_{(1)}}L_{\omega_{(1)}} + D_{\omega_{(2)}}L_{\omega_{(2)}} + \ldots D_{\omega_{(n)}}L_{\omega_{(n)}}
\]  

[3]

This provides a simple means for calculating the spacing between prisms necessary for compensation.

**Example 1:** Calculating pulse width measured by a *Model 409-08* autocorrelator without pre-compensation.

Assume that an 800 nm pulse at the output coupler surface of a *Mai Tai HP* laser is 55 fs long and is transform limited. It passes through 1.9 cm of fused silica before exiting the *Mai Tai HP* and 0.25 cm of BK-7 glass and 0.26 cm of fused silica in the autocorrelator.

\[

\omega_{(\text{tot})}L_{\omega_{(\text{tot})}} = D_{\omega_{(1)}}L_{\omega_{(1)}} + D_{\omega_{(2)}}L_{\omega_{(2)}}
\]

[4]

\[
= 300@1.9 + 300@0.26 + 450@0.25 = 760\,\text{fs}^2
\]

Therefore \( S = 760(\text{fs}^2)/(55\,\text{fs})^2 = 0.251 \)

Then, looking at our normalized curve (Figure B-5) \( S = 0.251 \), and \( B = 1.22, t_{out} = 1.22 \times t_{in} = 67 \,\text{fs} \).

**Example 2:** Calculating the prism spacing necessary for pre-compensating the *Model 409-08* autocorrelator.

Since dispersion is additive, it is only necessary to make the total dispersion equal to zero to eliminate all broadening effects. This allows a direct calculation of the required prism spacing without finding the actual broadening.
Again, start with a 55 fs transform-limited, 800 nm pulse going through 2.16 cm of fused silica and 0.25 cm of BK-7. Also assume the use of an SF-10 prism-pair pre-compensator where the beam passes through a total of 2 mm of prism tip per pass, or 8 mm total. The GVD for all parts of the system and the length for everything but the prism spacing are known. The length can be calculated by setting total GVD = 0.

\[
\phi_{\text{tot}} L_{\phi_{\text{tot}}} = D_{\phi_{\text{tot}}} (1) L_{\phi_{\text{tot}}} (1) + D_{\phi_{\text{tot}}} (2) L_{\phi_{\text{tot}}} (2) + D_{\phi_{\text{tot}}} (3) L_{\phi_{\text{tot}}} (3) + D_{\phi_{\text{tot}}} (4) L_{\phi_{\text{tot}}} (4) = 0
\]

\[
= 300@2.16 + 450@0.25 + 0.8@1590 + L@(-80.2) = 0
\]

Therefore  \( L = 25.3 \) cm (10 in.).

Note: the spacing \( L \) is the distance between the two tips of a prism in a double-pass configuration, or the distance between the two tips in one leg of a four-prism sequence.

The calculated \( L \) is shorter than recommended above, but since the material dispersion value of SF-10 prisms is so high, sliding just a bit more glass in will add a large amount of positive GVD, thereby balancing out the prism spacing.
Appendix C

Status Codes

This Appendix lists the status codes and messages that might be produced by the Mai Tai™ HP laser system. Most are self-explanatory and many errors can be corrected by the user as shown in Table C-1 and Table C-2.

In the event the error cannot be corrected, or the action required to correct the error is not known, contact your Spectra-Physics service representative. First, however, write down the code and its description.

The PLAS:AHIS? RS-232 command reports the most recent 16 codes from the system, with the most recent listed first. These codes are also shown on the LCD display on the front panel of the Model J80 power supply, as indicated by the line numbers given in Table C-1.

Table C-1: Status Codes Reported by the PLAS:AHIS? RS-232 Command

<table>
<thead>
<tr>
<th>Status Code</th>
<th>LCD Displays</th>
<th>Description</th>
<th>Action Required (if blank, no action is required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Laser ON</td>
<td>Laser is in Power mode: diode laser currents will be auto-adjusted to regulate laser output power.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power Mode OK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Laser ON</td>
<td>Laser is in Current mode: diode laser currents are fixed, laser output power unregulated.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current Mode OK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Laser ON</td>
<td>A change in laser power is stabilizing.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power Mode Adjust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Laser ON</td>
<td>A change in diode laser current is stabilizing.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current Mode Adjust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Laser Diodes OFF Ready</td>
<td>Diode lasers are not emitting light or drawing current.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Sleep Mode OFF Ready</td>
<td>Laser is in Sleep Mode.</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>Watchdog expired</td>
<td>(A software time-out has occurred.)</td>
<td>Turn keyswitch OFF for 2 seconds, then turn it back ON. Check for loose/bad head cable.</td>
</tr>
<tr>
<td>58</td>
<td>Watchdog working normally</td>
<td>Watchdog recovery was successful.</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>Diode Therm Short</td>
<td>A diode laser thermistor short has been detected.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>89</td>
<td>Diode Therm Open</td>
<td>A diode laser thermistor open has been detected.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>90</td>
<td>Diode MaxT Exceed</td>
<td>Diode laser temperature ≥ 50°C. (shutdown condition)</td>
<td>Shut off power supply (diode laser damage is imminent). Contact Spectra-Physics</td>
</tr>
</tbody>
</table>
Table C-1: Status Codes Reported by the PLAS:AHIS? RS-232 Command

<table>
<thead>
<tr>
<th>Status Code (line 2)</th>
<th>LCD Displays (line 3 and line 4)</th>
<th>Description</th>
<th>Action Required (if blank, no action is required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>91</td>
<td>Diode Over Temp.</td>
<td>Diode laser temperature ≥45°C. (shutdown condition)</td>
<td>Shut off power supply. Contact Spectra-Physics</td>
</tr>
<tr>
<td>92</td>
<td>Diode Under Temp.</td>
<td>Diode laser temperature ≤5°C.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>100</td>
<td>Diode Temperature</td>
<td>Diode laser temperature cannot be properly stabilized.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>101</td>
<td>HSink Over Temp.</td>
<td>Heatsink has increased to ≥65°C.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>102</td>
<td>HSink Under Temp.</td>
<td>Heatsink has decreased to ≤5°C.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>103</td>
<td>HSink Therm Short</td>
<td>A short has been detected in the heatsink thermistor.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>104</td>
<td>HSink Therm Open</td>
<td>An open has been detected in the heatsink thermistor.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>105</td>
<td>HSink MaxT Exceed</td>
<td>Diode laser heatsink has increased to ≥75°C. (shutdown condition)</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>106</td>
<td>Tower temp</td>
<td>Tower temperature ≥40°C. (shutdown condition)</td>
<td>Error clears once tower temperature decreases to ≤38°C.</td>
</tr>
<tr>
<td>116</td>
<td>Interlocks Cleared</td>
<td>Open interlock condition has been cleared.</td>
<td></td>
</tr>
<tr>
<td>117</td>
<td>Fuse Interlock</td>
<td>Blown power supply fuse detected.</td>
<td>Replace appropriate fuse.</td>
</tr>
<tr>
<td>118</td>
<td>System Interlock</td>
<td>The two-pin interlock jumper is missing/open.</td>
<td>Replace/repair jumper.</td>
</tr>
<tr>
<td>119</td>
<td>User Interlock</td>
<td>The Analog port interlock jumper is missing/open.</td>
<td>Replace/repair jumper.</td>
</tr>
<tr>
<td>120</td>
<td>Key Switch ILK</td>
<td>Keyswitch is in OFF position.</td>
<td>Turn keyswitch ON.</td>
</tr>
<tr>
<td>121</td>
<td>Remote Interlock</td>
<td>Remote interlock jumper is missing/open.</td>
<td>Replace/repair jumper.</td>
</tr>
<tr>
<td>122</td>
<td>Head Interlock</td>
<td>Head cable is missing or loose.</td>
<td>Check for loose or damaged head cable.</td>
</tr>
<tr>
<td>123</td>
<td>Boot test Fail</td>
<td>One of the power supply boot tests has failed.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>131</td>
<td>Head overtemp check chiller</td>
<td>Tower temperature ≥27°C. (warning only, no shutdown)</td>
<td>Check chiller temperature and water level. Clears once temp ≤25°C.</td>
</tr>
<tr>
<td>201</td>
<td>Current Calib. Diode 1</td>
<td>Should only occur following a diode laser module replacement.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>202</td>
<td>Current Calib. Diode 2</td>
<td>Should only occur following a diode laser module replacement.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>205</td>
<td>Temp. Calib. Diode 1</td>
<td>Should only occur following a diode laser module replacement.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>206</td>
<td>Temp. Calib. Diode 2</td>
<td>Should only occur following a diode laser module replacement.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>209</td>
<td>SHG Temperature Setting</td>
<td>SHG setting is incorrect.</td>
<td>Contact Spectra-Physics</td>
</tr>
<tr>
<td>210</td>
<td>Tower Over Temperature</td>
<td>Tower temperature &gt;27.0°C. Millennia heater and LBO shutdown.</td>
<td>Verify chiller temperature and water level.</td>
</tr>
<tr>
<td>211</td>
<td>Tower temp dropped to &lt;25.5°C</td>
<td>Tower temperature &lt;25.5°C. Millennia heater and LBO recovering.</td>
<td>Turn off for &gt;10 sec., turn back to “On” to clear the error code.</td>
</tr>
</tbody>
</table>
In addition to the status codes available on the Model J80 display, the PLAS:AHIS? RS-232 command reports the most recent 16 codes produced by the Mai Tai HP laser head itself. These codes are given in Table C-2. These codes are primarily for diagnostic purposes by Spectra-Physics service technicians.

Table C-2: Mai Tai HP Status and Error Codes

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>System just finished boot</td>
</tr>
<tr>
<td>405</td>
<td>System ON</td>
</tr>
<tr>
<td>406</td>
<td>System OFF</td>
</tr>
<tr>
<td>407</td>
<td>command “MODE PCUR” received</td>
</tr>
<tr>
<td>408</td>
<td>command “MODE PPOW” received</td>
</tr>
<tr>
<td>409</td>
<td>command “MODE POW” received</td>
</tr>
<tr>
<td>421</td>
<td>communication error between Mai Tai &amp; Power Supply</td>
</tr>
<tr>
<td>430</td>
<td>motors are moving</td>
</tr>
<tr>
<td>431</td>
<td>wavelength is stable, all motors stopped</td>
</tr>
<tr>
<td>444</td>
<td>P₂ is between 10% and 90%</td>
</tr>
<tr>
<td>445</td>
<td>P₂ (X or Y) is between 1% and 10% or 90 and 99%</td>
</tr>
<tr>
<td>446</td>
<td>P₂ (X or Y) is lower then 1% or greater then 99%</td>
</tr>
<tr>
<td>450</td>
<td>M₃ is not available</td>
</tr>
<tr>
<td>451</td>
<td>M₃ is disabled</td>
</tr>
<tr>
<td>452</td>
<td>M₃ is inactive</td>
</tr>
<tr>
<td>453</td>
<td>M₃ is active</td>
</tr>
<tr>
<td>454</td>
<td>M₃ are between 10% and 90%</td>
</tr>
<tr>
<td>455</td>
<td>M₃ (X or Y) is between 1% and 10% or 90 and 99%</td>
</tr>
<tr>
<td>456</td>
<td>M₃ (X or Y) is lower then 1% or greater then 99%</td>
</tr>
<tr>
<td>460</td>
<td>IR loop is not available</td>
</tr>
<tr>
<td>462</td>
<td>IR loop is inactive</td>
</tr>
<tr>
<td>463</td>
<td>IR loop is active</td>
</tr>
<tr>
<td>470</td>
<td>Tower temperature is correct (between 18.0 and 24.9°C)</td>
</tr>
<tr>
<td>471</td>
<td>Tower temperature is warm (between 25.0 and 27.0°C)</td>
</tr>
<tr>
<td>472</td>
<td>Tower temperature is hot (higher than 27.0°C)</td>
</tr>
<tr>
<td>474</td>
<td>Tower temperature is cold (lower than 18.0°C)</td>
</tr>
</tbody>
</table>
Mai Tai HP High-Performance, Mode-Locked, Ti:sapphire Laser
Appendix D  Purge Filter Replacement

The *Mai Tai™ HP* laser system is equipped with a recirculating purge system to keep the relative humidity within the Ti:Sapphire cavity low. Doing so insures continuous modelocking when tuning through the water absorption region at wavelengths above 900 nm. The purge filter incorporates active filtering materials and a sub-micron filter mesh to not only reduce the relative humidity quickly and effectively within the IR laser cavity, but also to continuously filter the air recirculating through it.

The purge filter has an average lifetime of more than one year, depending on the relative humidity and the temperature of the operating environment. Refer to Table D-1.

**Table D-1: When to Change the Filter**

<table>
<thead>
<tr>
<th>Relative Humidity Level (%)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 10</td>
<td>Normal operating range.</td>
</tr>
<tr>
<td>10 – 15</td>
<td>High humidity level. Order purge filter PN 0135-1707</td>
</tr>
<tr>
<td>≥ 15</td>
<td>Replace purge filter. Refer to procedure below.</td>
</tr>
</tbody>
</table>

Note: Ignore the humidity warning when the system is initially turned on or immediately after the purge filter cartridge is replaced: the humidity level will drop to normal operating level (below 10%) within 24 hours after the power supply main switch is turned on.

**Changing the Filter Cartridge**

The following procedure describes how to remove an expired cartridge and install a new one. Remove and replace the cartridge when the Info panel HUMIDITY indicator shows the humidity inside the Ti:Sapphire laser cavity has reached 15% or more.

1. Remove the beauty cover.
   a. Loosen the four Phillips screws on both sides of the beauty cover.
   b. Gently lift the cover up until it clears the *Mai Tai HP* housing, then remove it and set it aside.
2. Locate the purge filter cartridge, PN 0135-1707, on the back of the *Mai Tai HP* (Figure D-1).

![Figure D-1: The Purge Filter Cartridge Assembly](image)

3. Disconnect the purge pump connector from the back of the *Mai Tai HP* (Figure D-2) by unscrewing the collar nut and pulling the connector straight out.

![Figure D-2: The Purge Pump Connector](image)
4. Disconnect the inlet fitting (Figure D-3) by pressing in on the release lever and pulling the elbow fitting straight out.

![Figure D-3: The Purge Filter Inlet Connection](image1)

5. Disconnect the outlet fitting (Figure D-4) by pressing in on the release lever while gently pulling the filter cartridge to the right out of the holding straps. As the filter slides out, the connector will disengage.

![Figure D-4: The Purge Filter Outlet Connection](image2)

6. Continue to slide the used cartridge out until it is free of the three holding straps.

7. Install the new filter cartridge in the reverse order by sliding the filter into the three straps and reconnecting the two connectors. Gently push the fittings together until a “click” sound is heard.
8. Reconnect the purge pump connector to the *Mai Tai HP* laser head and tighten the collar nut.

9. Install the cover on the *Mai Tai HP* housing using the 4 Phillips screws removed earlier.

   This completes this procedure.
Report Form for Problems and Solutions

We have provided this form to encourage you to tell us about any difficulties you have experienced in using your Spectra-Physics instrument or its manual—problems that did not require a formal call or letter to our service department, but that you feel should be remedied. We are always interested in improving our products and manuals, and we appreciate all suggestions. Thank you.

<table>
<thead>
<tr>
<th>From:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name:</td>
</tr>
<tr>
<td>Company or Institution:</td>
</tr>
<tr>
<td>Department:</td>
</tr>
<tr>
<td>Address:</td>
</tr>
</tbody>
</table>

Instrument Model Number: Serial Number:

Problem:

Suggested Solution(s):

Mail To:
Spectra-Physics, Inc.
SSL Quality Manager
1335 Terra Bella Avenue, M/S 15-50
Post Office Box 7013
Mountain View, CA 94039-7013
U.S.A.
E-mail: sales@spectra-physics.com
www.spectra-physics.com

FAX to:
Attention: Quality Manager
(650) 961-7101