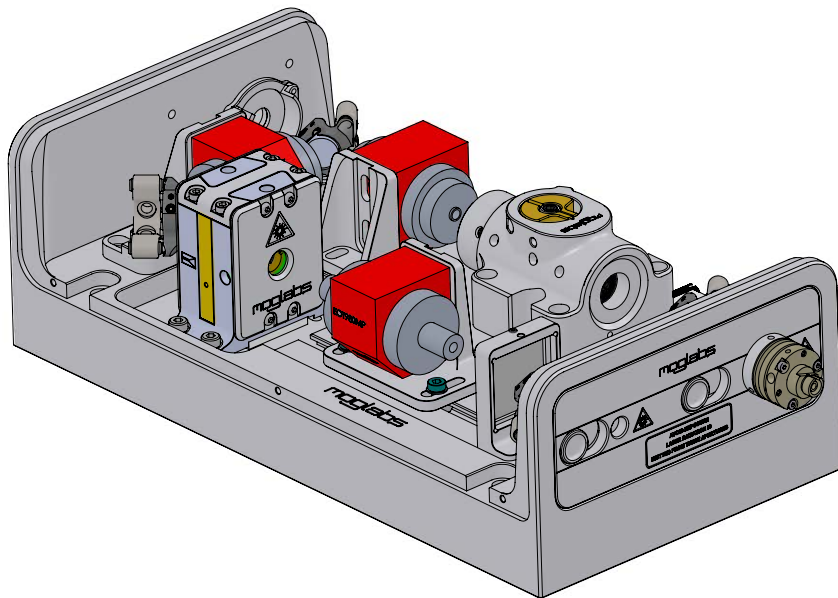




# Amplified laser system

*Model MOA/MSA*



Revision 1.05

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## Contact

For further information, please contact:

MOG Laboratories P/L 49 University St Carlton VIC 3053 AUSTRALIA +61 3 9939 0677 info@moglabs.com www.moglabs.com	MOGLabs USA LLC 419 14th St Huntingdon PA 16652 USA +1 814 251 4363 info@moglabsusa.com www.moglabsusa.com	MOGLabs Europe Goethepark 9 10627 Berlin GERMANY +49 30 21 960 959 info@moglabs.eu www.moglabs.eu
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# Preface

The MOGLabs MSA amplified laser system provides up to 4W of tunable highly coherent optical radiation for atomic cooling, Bose-Einstein condensation, ion trapping, and other spectroscopic applications. It reproduces the optical spectrum of the input seed laser, maintaining the linewidth while increasing the output power by up to 400 times (+26 dB). It can be configured as amplifier only (MOA) or with cateye seed laser (MSA). Options include fibre coupling, and input and output Faraday isolators. The MOGLabs DLC and LDD drivers are ideally suited for operating the seed and amplifier components of the MSA.

We hope that you enjoy using the MSA, and please let us know if you have any suggestions for improvement of the MSA or this document, so that we can make life in the lab better for all.

MOGLabs, Melbourne, Australia  
[www.moglabs.com](http://www.moglabs.com)



# Safety Precautions

Your safety and the safety of your colleagues depends on careful attention to proper operation of this product. Please read the following safety information before attempting to operate. Also please note several specific and unusual cautionary notes before using the MOGLabs MSA and MOA, in addition to the safety precautions that are standard for any electronic equipment. The directions here apply to both MSA and MOA (amplifier-only) configurations except where explicitly stated otherwise.

## ***WARNING***

Do not operate the amplifier without input seed laser. The input seed power must be at least 10 mW, and properly mode-matched to the tapered amplifier diode. Operation without appropriate seed can destroy the tapered amplifier diode.

## **CAUTION**

**USE OF CONTROLS OR ADJUSTMENTS OR  
PERFORMANCE OF PROCEDURES OTHER THAN THOSE  
SPECIFIED HEREIN  
MAY RESULT IN HAZARDOUS RADIATION EXPOSURE**

Laser output from the MSA and MOA can be dangerous. Please ensure that you implement the appropriate hazard minimisations for your environment, such as laser safety goggles, beam blocks, and door interlocks. MOGLabs takes no responsibility for safe configuration and use of the laser. Please:

- Avoid direct exposure to the output beams, both from the injection seed input aperture and the amplified output aperture.
- Avoid looking directly into either beam.

- Note the safety labels (examples shown in figure below) and heed their warnings.
- The MSA or MOA must be operated with a controller with keyswitch interlock. The MSA must not be powered unless the keyswitch is inserted and switched on. It should not be possible to remove the keyswitch without turning off the power to the MSA or MOA.
- When the seed laser and amplifier are switched on, there should be a delay of two seconds before the emission of laser radiation, mandated by European laser safety regulations (IEC 60825-1).

**WARNING** Do not operate the amplifier without input seed laser. Then input seed power must be at least 10 mW, and properly mode-matched to the tapered amplifier diode. Operation without appropriate seed can destroy the tapered amplifier diode.

**WARNING** Do not couple more than 10 mW of seed light into the amplifier diode with less than 100 mA injection current.

**NOTE** The MOGLabs MSA and MOA are designed for use in scientific research laboratories. They should not be used for consumer or medical applications.

## Protection Features

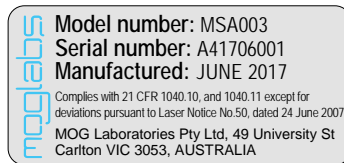
The MOGLabs MSA and MOA include a number of features to protect you and the device. They should be used with a power supply that provides additional safety features such as key lock operation, current limit, temperature limit, cable continuity and short-circuit detection, soft-start and turn-on delay.

*Protection relay* When the power is off, or the temperature controller is off, the amplifier diode is shorted via a normally-closed relay.

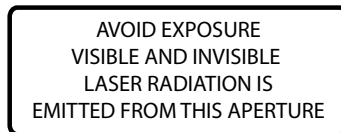
*LEDs* Separate LED indicators illuminate when the seed laser and amplifier diode current supplies are enabled.

## Label identification

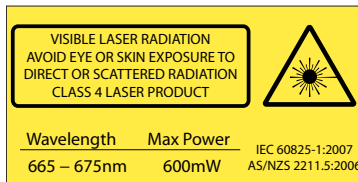
The International Electrotechnical Commission laser safety standard IEC 60825-1:2007 mandates warning labels that provide information on the wavelength and power of emitted laser radiation, and which show the aperture where laser radiation is emitted. Figures 1 and 2 show examples of these labels and their location on the MSA and MOA.



US FDA compliance

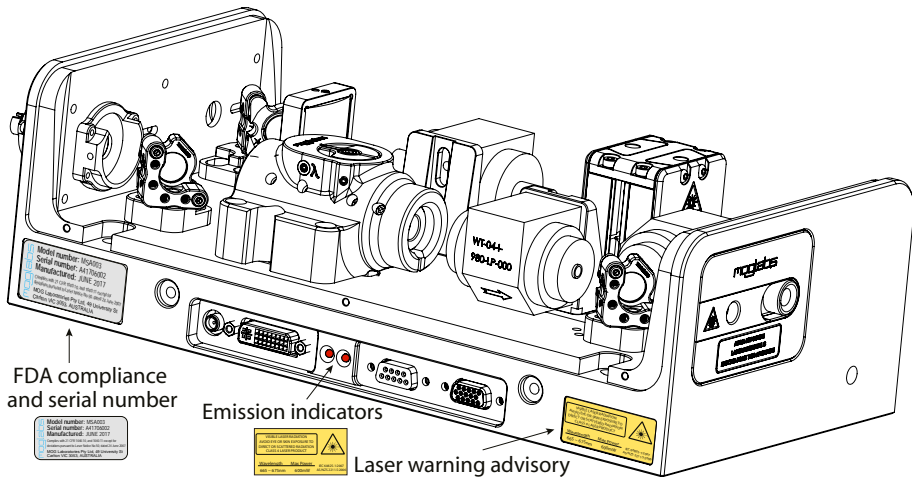


Aperture label engraving



Warning and advisory label  
 Class 4

Figure 1: Warning advisory and US FDA compliance labels.



**Figure 2:** Schematic showing location of warning labels compliant with International Electrotechnical Commission standard IEC 60825-1:2007, and US FDA compliance label. Emission indicator for seed laser (left) and amplifier (right). Aperture label engraved on front and rear apertures; warning advisory label on right hand side, compliance label left hand side near exit aperture.



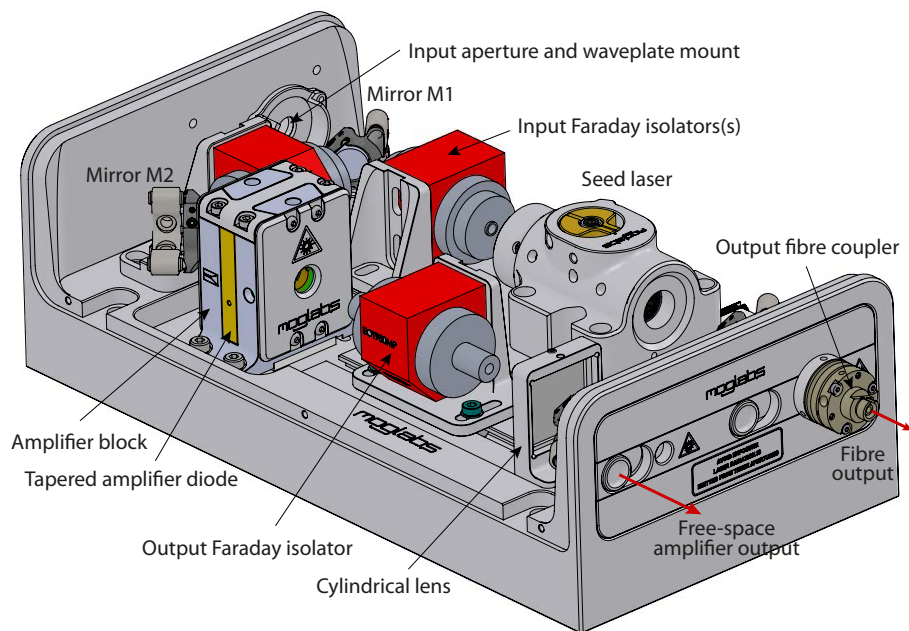
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# 1. Introduction

The MOGLabs MSA is a semiconductor laser amplifier with injection seed laser. The MOA is an amplifier-only configuration of the MSA, without seed laser. The amplifier block (see figure 1.1) consists of the core semiconductor tapered amplifier diode and aspheric input and output collimation lenses in flexure  $xy$  translation stages. A cylindrical lens at the output provides astigmatism compensation and Faraday isolators protect the amplifier diode and prevent the amplifier output from disturbing the seed laser. Fibre coupling options are available for the output and also for MOA input with an external seed laser.



**Figure 1.1:** Schematic diagram of major components in the MSA, including tapered amplifier diode, cylindrical lens astigmatism compensator, Faraday isolators and seed laser.

The tapered amplifier diode is user-replaceable (see chapter 7). Two flexure stages control the transverse position of the input and output collimation lenses, providing precise alignment with mechanical stability. Finely threaded tubes control the focus of the lenses.

In normal operation, the seed laser produces a collimated beam with power of 10 to 30 mW. The beam propagates through the first isolator, is deflected by mirror M1 through a second isolator, deflected by mirror M2 into the amplifier. If using an external seed laser, the seed beam will enter through the input aperture in free-space or via a fibre coupler, then deflect from M1. A 95:5 beamsplitter option can be used in place of mirror M1 to allow free-space output of a fraction of the seed beam, for example to use for locking to a frequency reference.

The seed laser beam must be mode-matched to the TA amplifier diode. Mode matching can be checked by ensuring that the “tracer beam” output from the ridge waveguide (input) of the TA back towards M2 and M1 is overlapped with the seed beam propagating forwards. The seed and tracer beams should have similar beam size along their paths, and should have the same polarisation. See chapters 3 and 4 for more details.

The output from the TA diode propagates through a high-power Faraday isolator and a cylindrical lens. The output from a TA diode is highly astigmatic, expanding rapidly in one direction (the fast axis) and slowly along the orthogonal (slow) axis. The aspheric lens on the output of the amplifier is adjusted to collimate the fast axis, and thus over-focuses along the slow axis. The cylindrical lens then collimates along the slow axis only, producing a beam collimated in both transverse directions. The focal length of the cylindrical lens is chosen to produce a beam as close as possible to 1:1 aspect ratio; i.e. circular.

The output can then exit through the free-space output port, or be reflected by mirrors M3, M4 to a fibre coupler. See chapter 6 for details on fibre coupling.

For background information on tapered amplifiers, please see Refs. [1, 2].

# 2. First light

## 2.1 Basic setup

Initial installation of the device is typically a matter of mounting it to an optical table and connecting to MOGLabs DLC and LDD controllers. Mounting holes can be accessed by removing the cover, and M6 x 16 socket head cap screws can then fix the device to the optical table. The hole spacing also allows direct mounting to imperial tables for non-metric countries (Burma, Liberia and the USA).

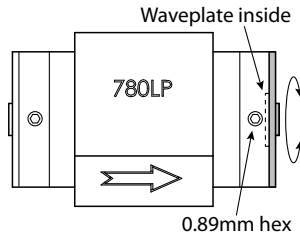
The MSA/MOA includes a water cooling channel for operation at unusually high or low temperatures, or in laboratories with high or unstable air temperature. Quick-fit connections are provided for connection to 6 mm OD tubing, but for most applications, water cooling is not required; dissipation to the air and/or optical table is sufficient.

1. The MSA or MOA should be firmly mounted to an optical table or other stable surface, using the through-holes which have spacings suitable for both metric and imperial tables.
2. The exit aperture should be directed towards a suitable power meter or beam block.
3. Connect to MOGLabs DLC and LDD controllers, or to alternatives using the connector pinout description in appendix B.
4. Enable the temperature controllers for seed and amplifier and check that the temperatures are approaching their set points. Detailed instructions for the controllers are provided in their associated user manuals.
5. Check seed operation and alignment to the amplifier, as described below and in the following chapters.

## 2.2 Polarisation control

The polarisation of the seed and output beams can be controlled with half-wave retarders. The seed polarisation must match the TA diode and control of the output polarisation can be useful for matching to polarisation-maintaining (PM) singlemode fibre (see chapter 6).

For input polarisation control, a waveplate can be internal to the final Faraday isolator (fig. 2.1) or to a waveplate holder mounted to the inside of the chassis as shown in figure 1.1. On the output beam, a polarisation rotator can again be an integral part of the final isolator for low-power (< 500 mW) devices. High power isolators do not have a suitable aperture for mounting a waveplate, and instead the rotator should be attached to the chassis just before the fibre coupler. The test report provided with your laser system will specify if waveplates have been added; please contact MOGLabs if more information is required.



**Figure 2.1:** Faraday isolator showing exit aperture with half-wave rotator mounted inside. The small set screw should be released (0.89 mm hex key) to allow rotation of the waveplate.

## 2.3 First light

### **WARNING**

Do not operate the amplifier above the maximum unseeded current specification without input seed. The input seed power must be at least 10 mW, and properly mode-matched to the tapered amplifier diode. Operation without appropriate seed will destroy the tapered amplifier diode.

For MOA with external seed laser, please proceed to the following chapter (chap. 3). If you have an MSA, your seed and amplifier have been aligned in the factory and only very minor adjustments should be required. However, you should first check that the seed is operating correctly and that seed and amplifier are at least approximately aligned.

1. Power on the seed laser and adjust for a few mW of output power. Instructions on operation of the seed laser are provided separately in the MOGLabs CEL cateye laser user manual. Please refer to the supplied test report for nominal temperature and current settings, and in particular be aware of the maximum current limit.
2. Measure the seed power before and after each isolator, and verify that the beam is centred on the input to the amplifier block. It may be necessary to use a video camera (e.g. webcam with IR filter removed), or an infrared upconversion card, to see the seed beam.
3. Power on the amplifier diode and adjust the diode injection current until a weak alignment (tracer) beam can be detected exiting from the *input* side of the amplifier block. Do not exceed the maximum unseeded current specified in the test data for your device (300 to 700 mA). Again, it may be necessary to use a video camera (e.g. webcam with IR filter removed), or an infrared upconversion card, to see the alignment beam.
4. Ensure that the tracer and seed beams overlap between isolator and amplifier (the tracer beam should not propagate backwards through the isolator). Both beams should have the same polarisation which can be checked using a sheet polariser (for example, a linear polarising filter from a photographic store). The beams should have similar cross-sections.

If there is any concern that the system alignment has been disturbed in shipping, please contact MOGLabs before proceeding to full seed alignment described in chapters 3, 4.

5. If the alignment is good, arrange a power meter and recording device

(computer) to monitor and record the output power of the amplifier for the following stages.

6. Increase the seed power to 15 mW measured at the input to the TA. You should observe an increase of at least 50% in the amplifier output power as the seed power increases from 1 mW to 15 mW.
7. Adjust mirrors M1, M2 to optimise the output power. Only very small adjustments should be needed.
8. At the maximum unseeded injection current of the TA diode (see your test report), ensure the TA is amplifying the seed by comparing the output power seeded and unseeded. Compare also to the output power to the test results provided with your system. If the output power is notably lower than expected, adjust the focus of the amplifier input collimation lens and adjust mirrors M1, M2 to optimise the output power. If unable to achieve power comparable to that of the factory test report, please contact MOGLabs for advice.
9. If the output power is similar to factory results, then you can increase the TA injection current while monitoring the output, until normal operating conditions are achieved.
10. Please record a PI curve as a reference for comparison when system performance changes. See section 4.2.



# 3. MSA: internal seed alignment

**WARNING**

Do not operate the amplifier above the maximum unseeded current specification without input seed. The input seed power must be at least 10 mW, and properly mode-matched to the tapered amplifier diode. Operation without appropriate seed will destroy the tapered amplifier diode.

## 3.1 Seed laser alignment

For the MSA, your seed and amplifier have been aligned in the factory and only very minor adjustments should be required. Please *do not* proceed with the alignment steps below unless there has been substantial misalignment, or the TA chip has been replaced. Refer to section 2.3 for instructions on initial operation.

The following instructions apply if there has been major disruption to the alignment, for example due to mishandling during shipping, or when changing the TA diode.

## 3.2 Seed laser

Proper operation of the seed laser should be established prior to attempting operation of the amplifier. Instructions on operation of the seed laser are provided separately in the MOGLabs CEL cateye laser user manual.

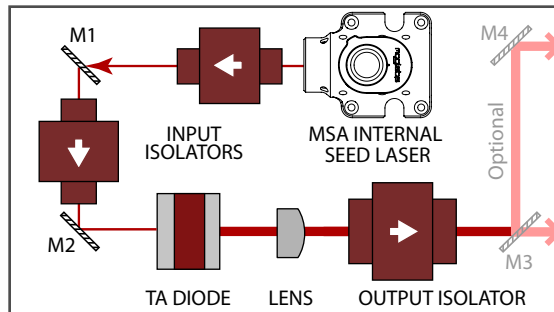
The seed laser beam can be accessed by insertion of a mirror directly after the seed laser or first isolator, or if substantial adjustments are needed, by removing the first mirror (M1) and opening the shutter on the MSA/MOA input aperture. The seed laser should be stable, not near a mode-hop. The beam profile should be similar to that of the output from the input (ridge waveguide) side of the tapered amplifier (TA) diode, typically about  $1 \times 3$  mm ( $1/e^2$  full widths) and at least 10 mW power. The polarisation of the seed laser beam must match that of the TA chip; a  $\lambda/2$  waveplate will

have been inserted into the final isolator if needed (see your test report). Please contact MOGLabs if further information is required.

### 3.3 Seed alignment

If the tapered amplifier (TA) diode is operated without injection seed, all of the electrical input energy is lost as heat, and at high current there is significant risk of damaging the diode. At currents over 300 to 700 mA (device dependent), it is important that an injection seed laser beam is coupled into the TA diode so that some of the input energy is converted to optical output rather than heat. Follow these steps to align the seed into the TA.

1. Insert a mirror after the seed laser to deflect the beam outside the chassis, or remove mirror M1 to allow the seed laser beam to propagate through the input aperture. Adjust the seed laser collimation so that the beam is well collimated, or weakly focusing at a distance of at least 4 m from the the seed laser. Replace mirror M1.

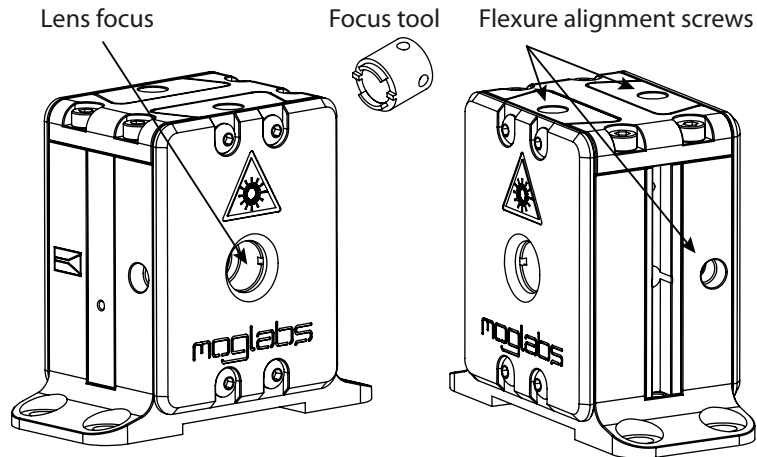


**Figure 3.1:** Configuration of MSA with internal seed laser, two isolators, amplifier, and output isolator.

2. Remove both input isolators between seed and amplifier. Ensure the isolator inputs and outputs are covered to protect against items being magnetically attracted into the isolator optics.
3. Adjust the TA diode injection current until a weak alignment beam can

be detected exiting from the *input* side of the TA diode. Do not exceed the maximum unseeded current specified in the test data for your device (300 to 700 mA). It may be necessary to use a video camera (e.g. webcam with IR filter removed), or an infrared upconversion card, to see the alignment beam.

4. Arrange a power meter and recording device (computer) to monitor and record the *output* power of the amplifier for the following stages.
5. The TA alignment beam will have an elliptical beam profile. If necessary, you can rotate the TA diode by  $90^\circ$  to best match these elliptical beam profile of the seed laser beam.
6. The beams into and out of the TA chip are focused with aspheric lenses mounted to wire-cut flexures. Using the flexure alignment screws (see fig. 3.2), adjust the input collimation lens position so that the weak alignment beam exits (from the input side of the MSA) parallel to and aligned with the MSA. Adjust the input focus by rotation of the lens mount using the focus tool provided with your amplifier (see fig. 3.2).



**Figure 3.2:** TA power block, showing location of flexure screws for adjusting alignment of input and output lenses.

7. Install the first isolator and optimise transmission to the TA. The polarisation will not match the TA diode, and therefore a waveplate rotator will be required between the isolator and TA. Typically the second isolator will have a waveplate mounted inside the exit aperture (see fig. 2.1) which can be temporarily installed in the first isolator.
8. Turn on your seed laser and ensure about 15 mW of power will be available at the amplifier input. Record the seed laser power.
9. Using mirrors M1 and M2 between the seed laser and TA, align your seed laser beam with the amplifier alignment beam. Both beams should be colinear and collimated. To optimise the alignment, use a 'walking' procedure as follows.
  - (a) For the horizontal axis first, find the maximum output power by adjusting the mirror closest to the amplifier (furthest from the seed), mirror M2.
  - (b) Take note of the output power.
  - (c) Adjust the horizontal axis of the mirror furthest from the amplifier (closest to the seed, mirror M1) clockwise such that the output power drops by no more than 25%. Take note of roughly how many degrees rotation were required.
  - (d) Adjust the horizontal axis of mirror M2 and maximise for amplifier output power. Compare the new maximum amplifier output power you have obtained to the output power photocurrent you obtained at step (b).
  - (e) If your new power is greater, repeat steps (c) and (d). If your new power is lower, adjust the horizontal axis of mirror M1 anti-clockwise to return it to its original angle (as you noted at the end of step (c)), then optimise the horizontal axis of mirror M2 to regain the output power you noted in step (b). If your first horizontal clockwise adjustment of both mirrors (steps (b) and (c)) resulted in a decrease in output power, repeat steps (c) and (d) using an anti-clockwise adjustment instead.

- (f) Once horizontal alignment is optimized, repeat steps (c) through (e) for the vertical alignment.
  - (g) Iterate the horizontal and vertical alignment procedure until you can no longer increase the output power. You may need to drop the output power by less than 25% as your alignment improves, e.g. 10% or 5%.
  - (h) Record the maximum amplifier output power and the seed power and injection current. Temporarily block the seed beam and record the unseeded amplifier output power.
10. You should observe an increase of at least 50% in the amplifier output power as the seed alignment improves. The focus of the amplifier input collimation lens may require small adjustment to mode-match the seed and amplifier.
11. Adjust the seed polarisation to match the amplifier polarisation, preferably using a half-waveplate in a rotation mount. The amplifier polarisation can be horizontal or vertical, depending on TA diode. Please refer to your datasheet; use a half-wave rotator on the input if required, to match the polarisation. You should observe that the output power maximises when the seed polarisation matches the amplifier polarisation.
12. (Optional) The TA diode will act as a photodiode which can be used to optimise the alignment of the seed laser. This step is optional and alignment can instead be optimised by monitoring the amplifier output power (see below). To use the TA diode as a photodiode:
  - (a) Disconnect the TA cathode, directly at the diode or on the circuit board on the underside of the amplifier.
  - (b) Connect the TA cathode to a nano-ammeter.
  - (c) Adjust the seed alignment by walking the seed beam with the mirror pair, and the focus, to optimise the photocurrent from the TA.

For more detail on this procedure, please refer to [http://www.eagleyard.com/fileadmin/downloads/documents/eyP\\_AppNote\\_TPA\\_2-0.pdf](http://www.eagleyard.com/fileadmin/downloads/documents/eyP_AppNote_TPA_2-0.pdf).

13. Verify optimum seed alignment by optimising the amplifier output power, again walking the beam with the mirror pair and adjusting focus.
14. Reinstall and align the second isolator to maximise the amplifier output power. You will need to adjust height, translation, and (to a very small degree) tilt of the isolators. You will also need to ensure the seed polarisation is matched to the amplifier polarisation, as the isolator rotates the polarisation by  $45^\circ$ . It may be necessary to adjust the rotation of the isolator about the optical axis to match the isolator and seed beam polarisations, and the final waveplate on the isolator (if installed) to match to the TA diode.
15. Repeat step 13 walking the mirrors.
16. At the maximum unseeded injection current of the TA diode, ensure the TA is amplifying the seed by comparing the output power seeded and unseeded. You should observe at least a 50% increase in output power when the seed is aligned correctly. Compare also to the MOGLabs MOA/MSA test data.

### 3.4 Measure PI curve

It is important to verify proper seed injection by measuring the output power ( $P$ ) against input current ( $I$ ) and comparing to the PI curve measured at MOGLabs.

1. Reconnect the TA power supply if necessary.
2. With TA current of 0.3 A (500 mW devices), 0.5 A (1000 mW devices) or 0.7 A (2000 mW devices), increase the seed power and verify significant output from the TA (see figure 3.3). The TA output is predominantly ASE (amplified spontaneous emission) until the seed power is increased to several milliwatts. The TA output will normally saturate with seed power of 10 mW to 50 mW depending on the specific TA diode and the efficiency of coupling of seed into the amplifier.

- Carefully optimise the seed alignment and focus at the recommended initial TA current. Note that both will depend on the TA current due to thermal lensing.
- Repeat alignment at a current above the initial low injection current, for example at 1 A for 1000 mW devices, to ensure optimum alignment under near-normal operating conditions.
- Measure the PI curve (see figure 3.4). Make sure that the output power is comparable to the factory test results. Do not increase the TA current significantly if the threshold current (i.e. the current at which the TA output power is more than a few milliwatts) and the slope are not comparable to the factory test results. Further optimisation of the seed alignment and focus may be necessary.

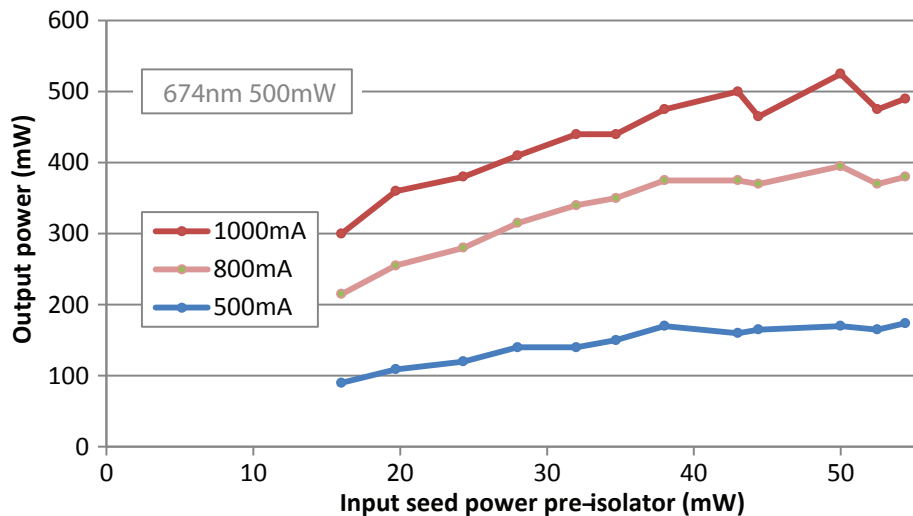


Figure 3.3: TA output against seed power, for several injection current values.

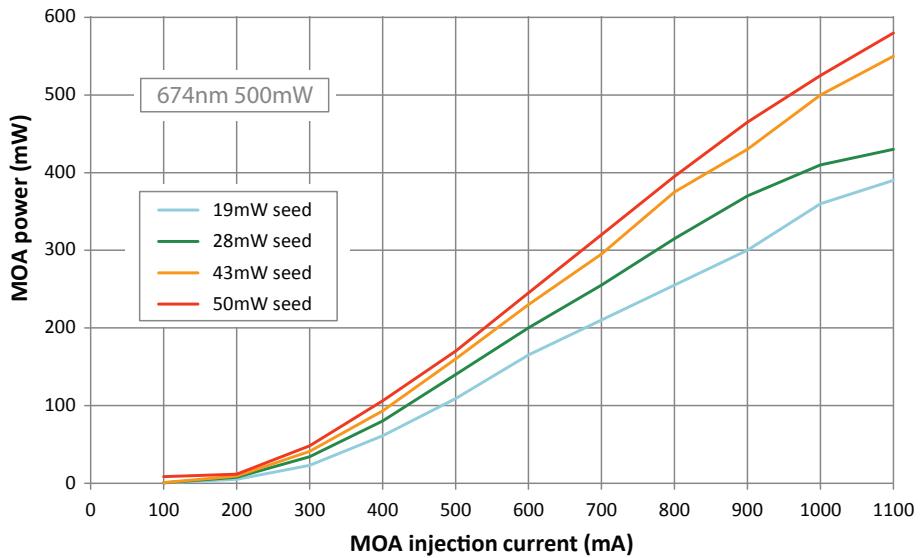


Figure 3.4: TA output against diode current, for several different injection seed laser powers (measured pre-isolator).



# 4. MOA: external seed alignment

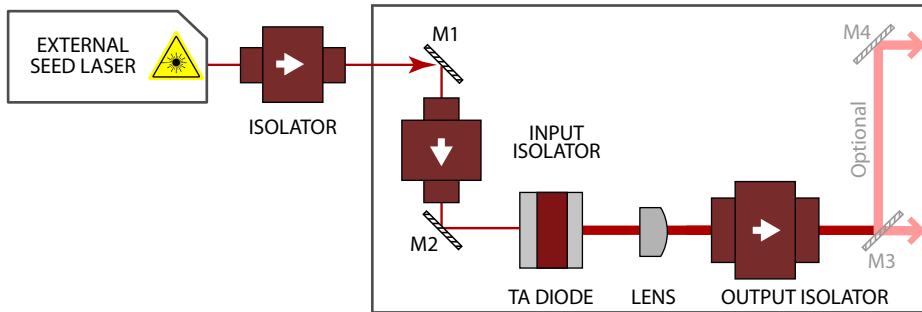
## **WARNING**

Do not operate the amplifier above the maximum unseeded current specification without input seed. The input seed power must be at least 10 mW, and properly mode-matched to the tapered amplifier diode. Operation without appropriate seed will destroy the tapered amplifier diode.

### 4.1 Seed alignment

If you have an MOA with external seed laser, then you must carefully align your seed laser beam to the amplifier. If the tapered amplifier (TA) diode is operated without injection seed, all of the electrical input energy is lost as heat, and at high current there is significant risk of damaging the diode. At currents over 300 to 700 mA (device dependent), it is important that an injection seed laser beam is coupled into the TA diode so that some of the input energy is converted to optical output rather than heat. Follow these steps to align the seed into the TA.

1. Adjust the seed laser collimation so that the beam is well collimated, or weakly focusing at a distance of at least 4 m from the seed laser.
2. When using an MOA with external seed laser, the seed should be directed through the input aperture, deflected by mirror M1 through the internal isolator and then by M2 into the TA chip (see figure 4.1).
3. There should be two stages of isolation between seed and amplifier, typically one inside the seed (or close to the seed) and one internal to the MOA. Remove the isolator in the MOA. Ensure the isolator inputs and outputs are covered to protect against items being magnetically attracted into the isolator optics.
4. Adjust the TA diode injection current until a weak alignment beam can be detected exiting from the *input* side of the TA diode. Do not exceed



**Figure 4.1:** Configuration of MSA with internal seed laser, or MOA with external seed laser. For MSA, there are two internal input isolators between seed and amplifier. For MOA, there is usually one internal input isolator and one external.

the maximum unseeded current specified in the test data for your device (300 to 700 mA). It may be necessary to use a video camera (e.g. webcam with IR filter removed), or an infrared upconversion card, to see the alignment beam.

5. The TA alignment beam will have an elliptical beam profile. If necessary, you can rotate the TA diode by  $90^\circ$  to best match these elliptical beam profile of the seed laser beam.
6. The beams into and out of the TA chip are focused with aspheric lenses mounted to wire-cut flexures. Using the flexure alignment screws (see fig. 3.2), adjust the input collimation lens position so that the weak alignment beam exits (from the input side of the MSA) parallel to and aligned with the MSA. Adjust the input focus by rotation of the lens mount using the focus tool provided with your amplifier (see fig. 3.2).
7. It can be helpful to align a pair of iris apertures around the weak alignment beam. The irises should be separated by at least 150 mm and be almost closed, with aperture diameter of 2 or 3 mm.
8. Arrange a power meter and recording device (computer) to monitor and record the *output* power of the amplifier for the following stages.

9. Turn on your seed laser and ensure about 15 mW of power will be available at the amplifier input. Record the seed laser power.
10. Using mirrors M1 and M2 between the seed laser and TA, align your seed laser beam with the amplifier alignment beam. Both beams should be colinear and collimated.
  - (a) For the horizontal axis first, find the maximum output power by adjusting the mirror closest to the amplifier (furthest from the seed), mirror M2.
  - (b) Take note of the output power.
  - (c) Adjust the horizontal axis of the mirror furthest from the amplifier (closest to the seed, mirror M1) clockwise such that the output power drops by no more than 25%. Take note of roughly how many degrees rotation were required.
  - (d) Adjust the horizontal axis of mirror M2 and maximise for amplifier output power. Compare the new maximum amplifier output power you have obtained to the output power photocurrent you obtained at step (b).
  - (e) If your new power is greater, repeat steps (c) and (d). If your new power is lower, adjust the horizontal axis of mirror M1 anti-clockwise to return it to its original angle (as you noted at the end of step (c)), then optimise the horizontal axis of mirror M2 to regain the output power you noted in step (b). If your first horizontal clockwise adjustment of both mirrors (steps (b) and (c)) resulted in a decrease in output power, repeat steps (c) and (d) using an anti-clockwise adjustment instead.
  - (f) Once horizontal alignment is optimized, repeat steps (c) through (e) for the vertical alignment.
  - (g) Iterate the horizontal and vertical alignment procedure until you can no longer increase the output power. You may need to drop the output power by less than 25% as your alignment improves, e.g. 10% or 5%.

- (h) Record the maximum amplifier output power and the seed power and injection current. Temporarily block the seed beam and record the unseeded amplifier output power.
11. You should observe an increase of at least 50% in the amplifier output power as the seed alignment improves. The focus of the amplifier input collimation lens may require small adjustment to mode-match the seed and amplifier.
  12. Adjust the seed polarisation to match the amplifier polarisation, for example using a half-waveplate in a rotation mount or a waveplate internal to the isolator (see fig. 2.1). Please refer to your datasheet to see if a half-wave rotator is included with your isolator. The amplifier polarisation can be horizontal or vertical, depending on TA diode. You should observe that the output power maximises when the seed polarisation matches the amplifier polarisation.
  13. (Optional) The TA diode will act as a photodiode which can be used to optimise the alignment of the seed laser. This step is optional and alignment can instead be optimised by monitoring the amplifier output power (see below). To use the TA diode as a photodiode:
    - (a) Disconnect the TA cathode, directly at the diode or on the circuit board on the underside of the amplifier.
    - (b) Connect the TA cathode to a nano-ammeter.
    - (c) Adjust the seed alignment by walking the seed beam with the mirror pair, and the focus, to optimise the photocurrent from the TA.

For more detail on this procedure, please refer to [http://www.eagleyard.com/fileadmin/downloads/documents/eyP\\_AppNote\\_TPA\\_2-0.pdf](http://www.eagleyard.com/fileadmin/downloads/documents/eyP_AppNote_TPA_2-0.pdf).

14. Verify optimum seed alignment by optimising the amplifier output power, again walking the beam with the mirror pair and adjusting focus.
15. Reinstall and align the input isolator to maximise the amplifier output power. You will need to adjust height, translation, and (to a

very small degree) tilt of the isolators. You will also need to ensure the seed polarisation is matched to the amplifier polarisation, noting that the isolator rotates the polarisation by  $45^\circ$ . It may be necessary to adjust the rotation of the isolator about the optical axis to match the isolator and seed beam polarisations, and the final waveplate on the isolator (if installed) to match to the TA diode.

16. Repeat step 14 walking the mirrors.
17. At the maximum unseeded injection current of the TA diode, ensure the TA is amplifying the seed by comparing the output power seeded and unseeded. You should observe at least a 50% increase in output power when the seed is aligned correctly. Compare also to the MOGLabs MOA/MSA test data.

## 4.2 Measure PI curve

It is important to verify proper seed injection by measuring the output power ( $P$ ) against input current ( $I$ ) and comparing to the PI curve measured at MOGLabs. Please follow the instructions in section 4.2.



# 5. Output beam optimisation

## **WARNING**

Do not operate the amplifier above the maximum unseeded current specification without input seed. The input seed power must be at least 10 mW, and properly mode-matched to the tapered amplifier diode. Operation without appropriate seed will destroy the tapered amplifier diode.

The beam profile of a tapered amplifier output beam generally looks awful. It is usually irregular, cross-shaped (like two orthogonal ellipses) and may have stripes. To some extent, appearances are deceiving because of the logarithmic response of human vision. For a better appreciation of the output beam, please use a beam profiler or imaging sensor (e.g. a weak reflection viewed on the CMOS sensor of a webcam).

Typically, the output will be fibre-coupled to produce a high-quality TEM<sub>00</sub> Gaussian beam. The simplest measure of the beam quality is known as the  $M^2$  parameter, which is loosely defined as the ratio of total beam power to that component in the TEM<sub>00</sub> mode. For example,  $M^2 = 1.7$  means that for a total beam power of  $P$ , after removing the higher-order modes which make the beam non-TEM<sub>00</sub>, the TEM<sub>00</sub> beam power will be  $P/1.7$ .

At MOGLabs, we believe that a more meaningful measure is how much of the total power can be extracted from a single-mode optical fibre, and hence we measure and optimise the fibre-coupled output as well as the total output.

Please follow these steps to optimise the output beam.

1. Operating at no more than 20% of full output power, align the output Faraday isolator to maximise transmission. Alignment includes translation, tilt, and rotation. Transmission is typically 80 to 90% but please refer to the factory test results for your amplifier.
2. View the output beam at a large propagation distance, for example by

reflecting from a mirror at several metres away, back to the MSA/MOA, with a beam profiler or imaging sensor.

3. Carefully adjust the exit collimator lens focus to collimate the exit beam. The beam size on exit from the MSA/MOA and after long propagation distance should be similar.
4. Some adjustment of the focus of the cylindrical astigmatism compensation lens may be needed so that the output is collimated along horizontal and vertical directions.
5. Increase to normal operating current. See section below in regards to optimising for changes in astigmatism.

See Chapter 6 for guidance on coupling to singlemode fibre.

## 5.1 Astigmatism

The emission of light from the TA diode can be modelled as coming from a point source slightly behind the exit facet of the diode. The location of that effective point source relative to the front facet of the diode is different for light along the fast and slow axes. The difference, called the astigmatism, can be very large; for example, 1.4 mm for a 780 nm 3 W TA diode. That compares to typical focal lengths used for the fast-axis collimation lens of about 3 mm. More importantly, the astigmatism varies dramatically with changes to the injection current.

To compensate for astigmatism, the collimation optics must be focused differently along slow and fast axes. Normally the fast-axis collimation lens (aspheric, short focal length) is focused to achieve beam collimation in the fast direction, and then the astigmatism compensating lens (cylindrical, long focal length) is used to focus for collimation along the slow axis.

### **NOTE**

Because the astigmatism varies with current, the final collimation adjustments, particularly the position the cylindrical lens, must be made after setting the TA operating to the final desired operating current.



## 6. Fibre coupling

The output beam profile of a TA diode can be highly irregular and highly astigmatic. Beam profile and astigmatism both vary with operating current. Fibre facets are easily damaged with high-power beams, and it is difficult to optimise at low power and then correct for astigmatism changes and photo-induced and thermal effects in the diode at higher power.

Nevertheless it is still possible to achieve good coupling into a singlemode fibre. Net coupling efficiency from power at the input of the fibre coupler, to power out of the exit facet of the fibre, is generally 50% or better, and 60% is not unusual, despite Fresnel losses at each facet (typically 4% each). Some instruments and tools will be helpful in quickly attaining optimum coupling:

1. Suitable fibre patchcord, e.g. Thorlabs P3-630A-FC-2 for 630 to 780 nm.
2. Fibre laser pen, fibre visual fault locator (see fig. 6.1).



**Figure 6.1:** Fibre laser pen, or visual fault locator. Injects visible laser beam into fibre, which allows basic alignment and mode matching.

3. OD3 neutral density filter.
4. Power meter and sensor, preferably with integrating sphere to avoid saturation.
5. Camera sensitive to the laser wavelength.

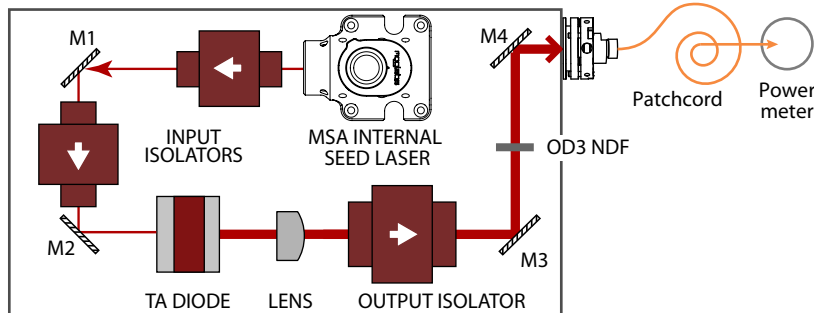
Note that power meters with sensors using silicon photodiodes can easily saturate and give false readings. Sensors based on integrating spheres work well.

## 6.1 Fibre alignment

The amplifier should first be operating well in free space as described in the previous chapter; in particular, the output should be well collimated both horizontally and vertically. In particular, the astigmatism compensation should be optimised for the desired operating current of the amplifier diode. The beam cross-section will in principle be approximately circular but limited focal lengths of cylindrical lens and variations in TA diode astigmatism can make it difficult to optimise aspect ratio.

Before attempting fibre alignment, please ensure the beam is well-collimated *at the desired operating current and power*. Please read section 5.1 in relation to changes in astigmatism.

1. Remove the fibre patchcord.
2. Place the NDF between the TA output and the fibre coupler (see fig. 6.2).



**Figure 6.2:** MSA showing addition of an OD3 neutral density filter between amplifier and fibre coupler to minimise risk of damage to fibre facet when operating at normal power and hence normal astigmatism and thermal lensing.

3. Operate with normal seed power (about 10 mW), and amplifier at 1 A current. Power after the NDF but before the fibre coupler should be 1 to 10 mW.
4. Walk the M3, M4 mirror pair to optimise power through fibre coupler. A camera sensitive to the laser wavelength, for example a webcam with IR filter removed, can be extremely helpful.
5. Once the beam is passing through the fibre coupler without obstruction, reconnect the fibre patchcord and monitor the output at the other end. Initially, a camera can be extremely effective at achieving some fibre output. Remove the lens from the camera and place the exit fibre tip very near the camera imaging sensor. A power meter will also work.
6. Walk the mirror pair to optimise output power. The efficiency should be 40% or greater. It may help to adjust the fibre coupler lens focus.
7. Adjust the cylindrical lens distance from the TA to see if that can help, for example 1 mm forward, then realign. If the coupling efficiency drops, try 1 mm backwards and continue until maximised.
8. Block the TA output and remove the NDF.
9. Unblock the TA output and check the coupling efficiency. A small amount of walking the mirror pair may be needed due to deflection introduced by the NDF. Be careful not to walk the beam too far as the high power MOA output walking across the fibre end-face will damage the fibre.
10. Coupling efficiency should be at least 40%. The TA output can be increased to the desired operational power. Make small adjustments of the mirror pair to optimise efficiency.
11. Adjust the seed alignment very small amounts using M2. Changes to seed alignment can affect the profile of the TA output and therefore the coupling efficiency.

Some examples of coupling efficiency are provided in the table below. They were obtained with the previous generation amplifier (MOA002). They are not in any sense heroic attempts, just tests to ensure reasonable operation.

Wavelength	Power	Fibre	Focal length	Efficiency
767 nm	2 W	Hi780	8.0 mm	57%, 63%
780 nm	2 W	SM600 (AR)	8.0 mm	60%
780 nm	2 W	SM600 (AR)	8.0 mm	52%
780 nm	3 W	SM600 (AR)	8.0 mm	57%
780 nm	3 W	780HP	8.0 mm	46%
808 nm	2 W	PM780HP	8.0 mm	64%
811 nm	2 W	SM800	8.0 mm	60%
813 nm	2 W	Hi780	6.2 mm	55%

**Figure 6.3:** Examples of fibre coupling efficiency. Power is the power from the TA chip, before losses from the Faraday isolator and the mirror pair. The coupling efficiency is the power at the fibre exit divided by the power into the fibre coupler.

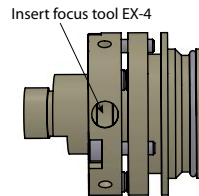
## 6.2 Fibre coupler collimation

It will not normally be necessary to adjust the focus of the fibre coupler. The procedure below should only be applied if it clear that there is a problem with focus, for example if recommended in discussion with MOGLabs.

1. Connect the fibre patchcord to the MSA or MOA fibre output connector.
2. Connect the exit of the fibre to the visual fault locator laser source.
3. Examine the red tracer beam emitted from the back of the MSA or MOA fibre coupler, back towards the tapered amplifier.
4. Using the EX-4 eccentric cam tool provided in your toolkit, adjust the lens collimation of the coupler (see fig. 6.4) such that the light exiting the coupler is well-collimated over at least 1 m distance. The

beam can be deflected outside the chassis using one of the internal alignment mirrors (M3 or M4), or the fibre coupler can be removed, to allow sufficient propagation distance.

5. Restore the fibre coupler if removed, and walk the M3, M4 mirror pair so that the tracer beam is directed onto the centre of the TA exit lens.



**Figure 6.4:** Fibre coupler showing access to collimation lens. There is a slot in the collimation lens mount. Eccentric focus tool EX-4 has an off-centre pin that should be inserted into the slot. Rotation of the tool then slides the collimation lens back and forth, away from or towards the fibre facet.

### 6.3 Polarisation control

The polarisation of the TA output can be aligned to that of a polarisation-maintaining (PM) singlemode fibre in two ways. The fibre coupler can be rotated around its axis by releasing the three radial mounting screws. A half-wave retarder can instead be mounted to the chassis, just before the fibre coupler, using an optional optic attachment available from MOGLabs.

### 6.4 Troubleshooting

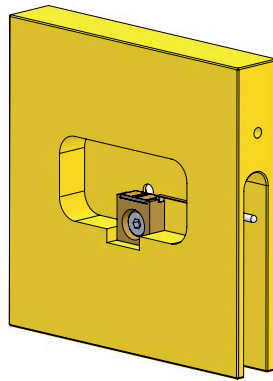
The most frequent cause of low coupling efficiency is damage to the fibre facet. Inspect the end facets using a fibre microscope inspection tool, and clean/polish if necessary. Also try reversing the fibre patchcord or just try a new patchcord. Note for 780/795 nm, we generally find that SM600 fibres achieve better efficiency and polarisation preservation.

Another frequent problem is the variation in astigmatism, and thus beam collimation, with injection current. Changing the operating current to vary the output power of the TA diode will affect the beam collimation and thus fibre coupling efficiency. To operate at a new current, it will be necessary to readjust the cylindrical lens position and then reiterate the fibre coupling optimisation.

Of course, damage to the TA chip is also possible. It is highly advisable to record the TA output beam profile regularly, so that progressive damage can be monitored.

# 7. Diode replacement

Replacement tapered amplifier diodes can be purchased from MOGLabs or directly from suppliers (e.g. Eagleyard Photonics or DILAS). The diode semiconductor chip is mounted to an industry-standard C-mount, which is then mounted to a proprietary MOGLabs MGM-068 mount (see fig. 7.1).



**Figure 7.1:** MGM-068 copper mount with C-mount TA diode seen from exit aperture side. Cathode pin, groove for cathode wire, and one registration pin hole are on right.

To replace the diode:

1. Disconnect the diode anode and cathode wires at the PCB (lever the connector up gently from the wire entry end of the connector) and pull the thermistor from the TA block. The cathode (black wire) may be press-fit or soldered to the pin on the MGM-068 mounted diode. The anode (red wire) is connected to the TA block with a small screw.
2. Rotate the lenses using the focus tool to pull the input and output collimation lenses away from the diode. Turn each anti-clockwise

until the lenses retract fully. It will be helpful to mark the focus knob and count the turns, so that the operation can be reversed when re-assembling.

3. The diode is held in place by the H-shaped clamp on top. Remove the H-clamp, and then the MGM-068 mount can slide upwards for removal. Note that registration dowel pins lock the MGM-068 into place laterally. Again, take care that the collimation lenses are retracted (see above) so that they do not obstruct the diode.
4. If replacing the C-mount TA diode rather than the MGM-068 assembly, remove the old TA by desoldering the cathode ribbon from the turret pin, then unscrew the M2 screw. Replace the indium foil and assemble with new TA diode. When soldering the cathode ribbon to the turret pin, use low-temperature silver solder. Do not resolder until the TA diode is firmly attached to the copper to act as a heatsink.
5. Re-assemble the amplifier with MGM-068 by following the steps in reverse, taking care to replace the dowel pins.
6. Don't forget to reconnect anode and cathode wires, and to re-insert the thermistor.
7. Restore the lens focus. This should be done while monitoring the two exit beams for collimation as described above.



# A. Troubleshooting

## No light or low output power

- Ensure input and output shutters are open.
- Check that the TA diode current and voltage drop are as expected (refer to factory test results).
- Is ASE apparent from input and output sides of TA? If not, the diode may be damaged. Remove and inspect under a microscope, or contact MOGLabs.
- Is the input seed beam mode-matched and polarisation-matched to the TA diode? Refer to alignment instructions.

## Output unstable

For example, output power varies substantially with small changes of input seed frequency.

- Check for sufficient optical isolation between seed and amplifier. Two Faraday isolators, or a double-stage isolator, may be required.
- Adjust angular alignment of the Faraday isolators very slightly to reduce direct back-reflection from first optical surface into the TA diode.

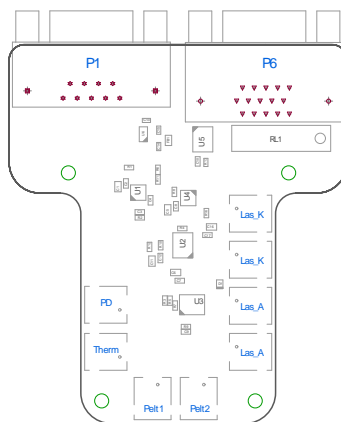


## B. Electrical connections

The MSA has two electronic circuit boards, one associated with the seed laser and one for the amplifier. For information on the seed laser, please read the seed laser user manual. The information below relates to the amplifier only.

### B.1 MOA amplifier headboard

The amplifier is connected via the B1048 headboard (fig. B.1) which includes connections to the TA diode, TEC, and a passive NTC thermistor temperature sensor. Connections from the board to the components use Hirose DF59 “swing-lock” wire-to-board connectors. There is also a photodiode amplifier which can be used to generate a signal for monitoring the laser input or output, but this is not used at present. The board includes a solid-state protection relay and passive protection filters, and a laser-on LED indicator.



**Figure B.1:** MOGLabs MOA B1048 laser head board showing connectors for tapered amplifier diode, temperature sensor, TEC and LEDs.

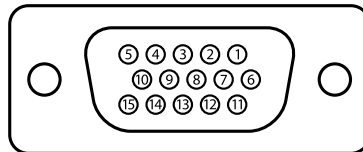
Name	Description
<b>P1</b>	DE9 female (TEMP)
<b>P6</b>	DE15 female (CURRENT)
<b>PD</b>	Photodiode
<b>Therm</b>	Thermistor
<b>Pelt1</b>	TEC connection 1
<b>Pelt2</b>	TEC connection 2
<b>Las A</b>	Laser anode
<b>Las K</b>	Laser cathode

**Figure B.2:** B1048 headboard connectors. The two TEC connections are in parallel to provide greater current-carrying capacity.

## B.2 Connector pinouts

### B.2.1 Current

Pin	Signal	Pin	Signal
1	Relay (–)	9	N/C
2	I2C SDA	10	Laser diode anode (+)
3	Photodiode status	11	+5V
4	Laser diode cathode (–)	12	I2C SCL
5	Laser diode anode (+)	13	Laser diode cathode (–)
6	0V (ground)	14	Laser diode cathode (–)
7	0V (ground)	15	Laser diode anode (+)
8	0V (ground)		



**Figure B.3:** DE15, female, current supply connector (P6) pinout. Relay (–) should be grounded to open the protection relay and enable operation.

### B.2.2 Temperature

Pin	Signal	Pin	Signal
1	Thermistor NTC 10 k $\Omega$ (+)	6	Thermistor NTC 10 k $\Omega$ (-)
2	0 V (ground)	7	Peltier TEC (-)
3	Peltier TEC (-)	8	Peltier TEC (-)
4	Peltier TEC (+)	9	Peltier TEC (+)
5	Peltier TEC (+)		

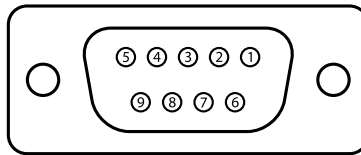
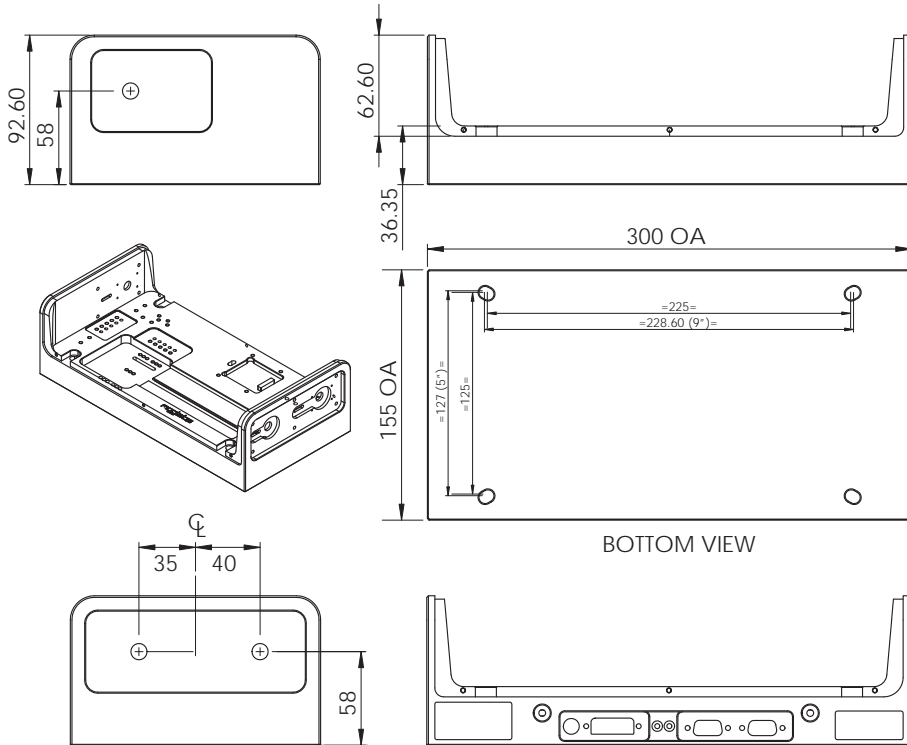


Figure B.4: DE9, female, temperature supply connector (P1) pinout.



# C. Chassis dimensions







# Bibliography

- [1] AC Wilson, JC Sharpe, CR McKenzie, PJ Manson and DM Warrington, Narrow-linewidth master-oscillator power amplifier based on a semiconductor tapered amplifier *Appl. Opt.* **37** 4871 (1998). 2
- [2] JCB Kangara, AJ Hachtel, MC Gillette, JT Barkeloo, ER Clements *et al.* Design and construction of cost-effective tapered amplifier systems for laser cooling and trapping experiments, *Am. J. Phys.* **82** 805 (2014) <http://doi.org/10.1119/1.4867376> 2





