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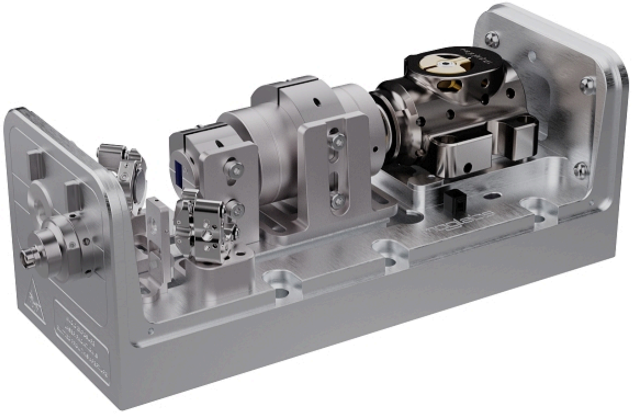
Cateye Laser

CEL, CEX and CEF



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Serial numbers A323xxxxx and higher

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Preface

Diode lasers can be wonderful things: they are efficient, compact, low cost, high power, low noise, tunable, and cover a large range of wavelengths. They can also be obstreperous, sensitive, and temperamental, particularly external cavity diode lasers (ECDLs). In combination with advanced electronics such as the MOGLabs dDLC external cavity diode laser controller, the “cateye” laser described here provides a robust, stable, acoustically inert, low linewidth and highly tunable laser system.

We hope that the MOGLabs cateye laser works well for your application. Please let us know if you have any suggestions for improvement in the laser or in this document, so that we can make life in the laser lab easier for all, and check our website from time to time for updated information.

MOGLabs, Melbourne, Australia
www.moglabs.com

Safety Precautions

Safe and effective use of this product is very important. Please read the following laser safety information before attempting to operate the laser. Also please note several specific and unusual cautionary notes before using MOGLabs lasers, in addition to the safety precautions that are standard for any electronic equipment or for laser-related instrumentation.

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 CEL/CEX/CEF 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 beam.
- Avoid looking directly into the beam.
- Note the safety labels (examples shown in figure below) and heed their warnings.
- When the laser is switched on, there will be a short delay of two seconds before the emission of laser radiation, mandated by European laser safety regulations (IEC 60825-1).
- The STANDBY/RUN keyswitch must be turned to RUN before the laser can be switched on. The laser will not operate if the keyswitch is in the STANDBY position. The key cannot be removed from the controller when it is in the clockwise (RUN) position.

- To completely shut off power to the unit, turn the keyswitch anti-clockwise (STANDBY position), switch the mains power switch at rear of unit to OFF, and unplug the unit.
- When the STANDBY/RUN keyswitch is on STANDBY, there cannot be power to the laser diode, but power is still being supplied to the laser head for temperature control.

WARNING The internal circuit board and piezoelectric transducers are at high voltage during operation. The unit should not be operated with covers removed.

WARNING The laser chassis should be in good electrical contact to the optical table or other surface, which in turn should be connected to the same mains power supply electrical ground as the controller.

WARNING If using water cooling, the water must be distilled (not de-ionised). The cooling channel is part of the 6061 aluminium chassis which will react with many cooling additives.

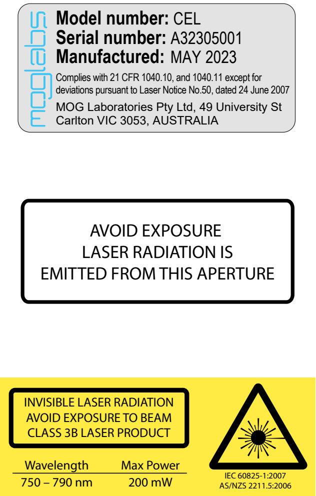
CAUTION Although the CEL/CEX/CEF is designed and priced with the expectation that the end-user can replace the diode and change the alignment, some components are fragile. In particular the filter, piezo actuator, and output coupler are very easily damaged. Please take care of these items when working inside the laser.

The filter and output coupler are hard-coated and can be cleaned but great care is needed as with any intracavity laser optics.

NOTE MOGLabs products are designed for use in scientific research laboratories. They should not be used for consumer or medical applications.

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



US FDA compliance

Aperture label engraving

Warning and advisory label
Class 3B

Figure 1: Warning advisory and US FDA compliance labels.

aperture where laser radiation is emitted. Figure 1 shows examples of these labels, and figures 2 and 3 show their location on the CEL laser and large-chassis CEX/CEF version.

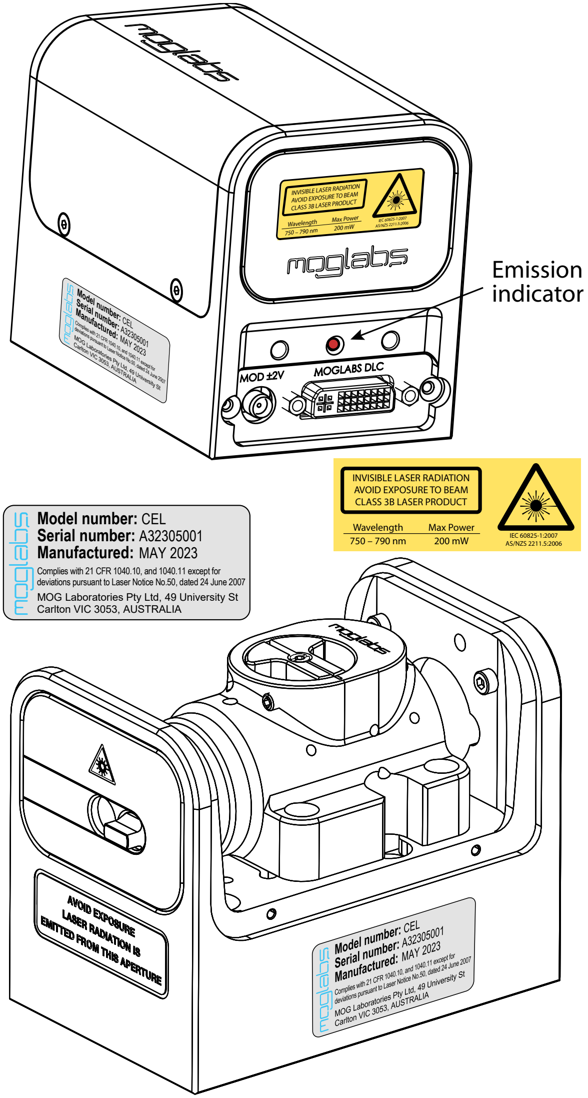


Figure 2: Schematic showing location of laser warning labels compliant with International Electrotechnical Commission standard IEC 60825-1:2007, and US FDA compliance label. Aperture label engraved on the front of the CEL laser near the exit aperture; warning advisory label on the rear and compliance label on side.

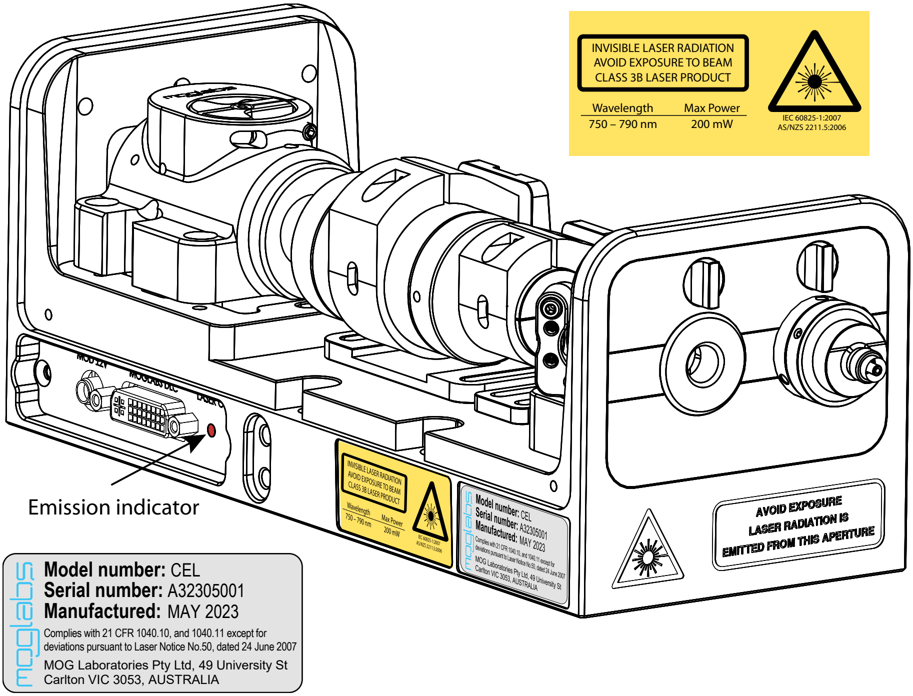


Figure 3: Schematic showing location of laser warning labels for the large-chassis CEX/CEF version of the cateye laser (CEF option shown).

Protection Features

MOGLabs lasers includes a number of features to protect you and your laser.

Protection relay	When the power is off, or if the laser is off, the laser diode is shorted via a normally-closed solid-state relay at the laser head board.
Emission indicator	The MOGLabs controller will illuminate the emission warning indicator LED immediately when the laser is switched on.
Interlock	It is assumed that the laser power supply is keyed and interlocked for safety. The laser head board also provides connection for an interlock (see appendix B), if used with a power supply which does not include such an interlock.

RoHS Certification of Conformance

MOG Laboratories Pty Ltd certifies that the MOGLabs External Cavity Diode Laser does not fall under the scope defined in *RoHS Directive 2002/95/EC*, and is not subject to compliance, in accordance with *DIRECTIVE 2002/95/EC Out of Scope; Electronics related; Intended application is for Monitoring and Control or Medical Instrumentation*.

MOG Laboratories Pty Ltd makes no claims or inferences of the compliance status of its products if used other than for their intended purpose.

Extending laser diode and piezo lifetime

At night, switch to standby:

1. If using the laser to seed an amplifier, first turn off the amplifier.
2. Switch the laser diode current off.

   If using a MOGLabs DLC or dDLC controller, don't adjust the current, just switch the toggle up (off).
3. Switch from RUN to STANDBY.

For a MOGLabs DLC or dDLC controller in standby mode, the temperature controller will continue to operate, so the laser is ready for quick startup the next day. But the laser diode current and piezo voltage will be zero, extending their operating life.

In the morning, switch back on:

1. Switch from STANDBY to RUN.
2. Switch the laser diode toggle down (on).

   You don't need to adjust the current, just wait a few minutes for the diode temperature to equilibrate.

You should switch your MOGLabs DLC or dDLC into STANDBY mode at nights and weekends and whenever the laser is not being used for more than a few hours. Most lasers need to operate only 40 hours during a 168 hour week; thus switching to standby mode can extend the diode and piezo lifetime by a factor of four.

Contents

1. Introduction

Semiconductor laser diodes are compact, efficient and low-cost, but usually have poor wavelength control, linewidth and stability. The addition of an external frequency-selective cavity allows control of the operating wavelength over a few nm range, with sub-MHz linewidth and stability. The MOGLabs cateye laser (see figure 1.1) is machined from a solid aluminium block, so that the laser is stable, robust, and insensitive to acoustic disturbances. The cavity is hermetically sealed for additional suppression of environmental fluctuations and drift. The cateye laser block is mounted on a standard chassis (CEL) or an extended chassis (CEX) which can optionally include a fibre output (CEF).

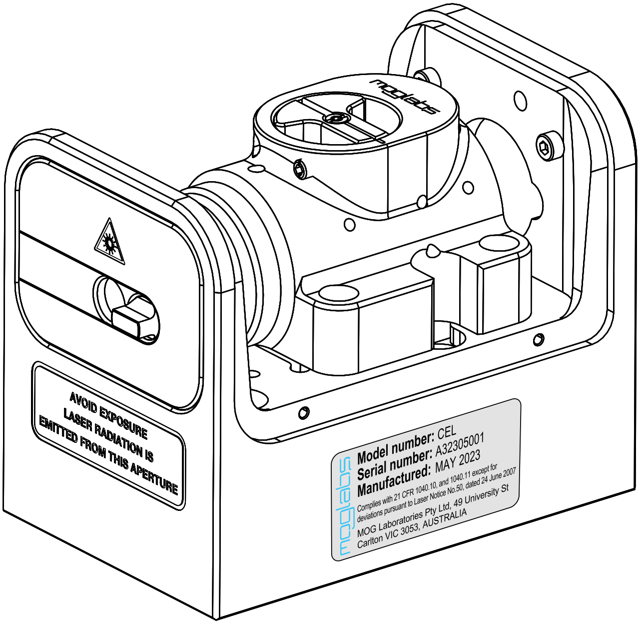


Figure 1.1: The MOGLabs CEL cateye laser. Mechanical version from 2023 shown (serial A323xxxxx and above).

The MOGLabs CEL/CEX/CEF is a "cat-eye" design (see figure 1.2), in which an external cavity is formed between the rear reflecting surface of the semiconductor diode, and a cat-eye reflector at several centimetres from the diode [1–3]. Rather than the customary diffraction grating of Littrow-configuration ECDLs, a high efficiency ultranarrow filter is used to select a single external cavity mode. Without the need for illuminating a large area of a grating for feedback, a cat-eye retroreflector and partially transmitting output coupler (OC) can be used to form the external cavity. The cateye reflector is inherently self-aligning, so that the laser is extremely insensitive to mechanical disturbance, and also ensures high feedback coupling efficiency and consequently narrow linewidth.

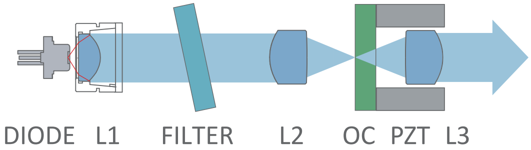


Figure 1.2: Schematic of a cateye external cavity diode laser (ECDL). The external cavity, formed by the rear facet of the laser diode and the output coupler (OC), determines the laser frequency. One longitudinal cavity mode is selected by an ultranarrow intracavity bandpass filter. A cateye reflector is formed by the output coupler and intracavity lens L2.

The output beam from a laser diode is collimated with a high numerical aperture (NA) lens L1 and then incident on the filter. The filter transmission wavelength depends on the rotation angle. Transmitted light is back-reflected by the cateye lens/output-coupler combination which efficiently couples light back into the laser diode. Lens L2 focuses light on the OC and lens L3 re-collimates the laser beam. More details can be found in references [1–3].

1.1 External cavity

Semiconductor laser diodes normally have a high reflectivity rear facet and a front facet with reflectivity of only a few percent. The diode cavity is called the intrinsic or internal cavity. The *external* cavity is formed by the OC and the diode rear facet, and when the external feedback is greater than that of the front facet, the external cavity determines the lasing wavelength. The effective external cavity is 20 to 40 mm long with cavity mode spacing (FSR) of $c/2nL = 3.5$ to 7 GHz.

1.1.1 Filter

The filter selects one longitudinal cavity mode, and rotation of the filter allows selection of which mode, within the gain bandwidth of the laser diode (see figure 1.3). Filter adjustments can achieve wavelength changes better than 0.1 nm precision at 780 nm.

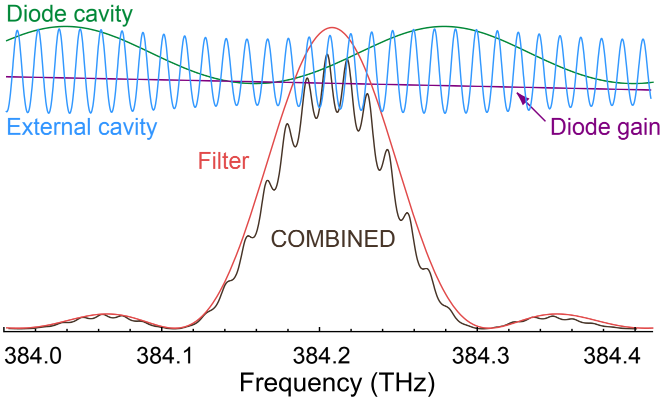


Figure 1.3: Schematic representation for the various frequency-dependent factors of an ECDL, adapted from Ref. [4], for wavelength $\lambda = 780$ nm and external cavity length $L_{\text{ext}} = 15$ mm.

1.2 Piezo-electric frequency control

Small changes to the laser frequency are achieved by controlling the external cavity length with a piezo electric actuator. For the MOGLabs cateye laser, the frequency change is about 20-25 GHz over the 150 V range of the piezo.

1.3 Temperature and current

The laser frequency is also dependent on temperature and injection current; the sensitivities are typically 3 MHz/μA and 30 GHz/K [5]. Thus, low-noise stable electronics, such as the MOGLabs DLC, dDLC or mLC external cavity diode laser controllers, are essential [6] to achieve sub-MHz linewidth and stability.

An important aspect of an ECDL is temperature control of the cavity, since the laser frequency depends on the cavity length and hence on the thermal expansion coefficient of the cavity material [4]. The cavity can be machined from materials with low thermal expansion coefficient but even then the passive stability is inadequate for research applications. Active feedback of the cavity temperature and piezo cavity length provide flexible and stable control. The MOGLabs cateye laser uses a negative temperature coefficient (NTC) thermistor to sense the cavity temperature and Peltier thermoelectric cooler (TEC) to heat and cool the cavity material.

2. First light

Mount your laser to an optical table using the screws provided. Your laser has been carefully tuned to the specifications given in your laser test report. Please make sure as you continue with this manual, that the diode injection current, temperature and piezo offset (FREQUENCY) match those of the test report.

The laser chassis should be in good electrical contact to the optical table or other surface, which in turn should be connected to the same mains power supply electrical ground as the controller.

It is assumed that a MOGLabs diode laser controller has been provided with your laser. If a third party controller is used, please set a current limit according to the maximum safe operating current stipulated in your test report.

For longer wavelength lasers, an IR upconversion card or video camera without IR filter can be very helpful. Common low-cost security cameras, computer USB cameras, and home movie or still cameras are also good options, although they often have IR filters which may need to be removed.

2.1 Standby/Run

In the case of a MOGLabs DLC, please first check that the correct mains supply voltage has been set by inspecting the red voltage selector above the rear panel IEC power inlet. Check that the DLC internal DIP switches match the laser test report specification. Make sure that the laser diode current supply (CURRENT knob) is turned fully anti-clockwise, and that the OFF/MOD, SLOW and FAST lock switches are off (up).

For both DLC and dDLC, turn the mains power switch on, then (after a brief power up period for the dDLC) turn the keyswitch from STANDBY to RUN. The LED status indicator should initially be yellow indicating that the thermistor and TEC elements are connected, then change to green when set to RUN.

2.2 Current

Turn the laser diode CURRENT adjust to zero (fully anti-clockwise for the DLC). Note that for normal daily operation, it is not recommended to turn the current to zero when turning off the laser as the soft-start function of the DLC and dDLC ensures that the current is ramped up slowly and safely to the required current. However, when first aligning the laser to your experiment, it is important to set the laser output power to a low value for safety.

Enable the current (push-button for dDLC, toggle switch for DLC), adjust the diode current to 5 – 10 mA and check that the diode voltage (VOLTAGE selection on the DLC 8-way display encoder) is within the range specified in the laser test report (typically around 2 V for a red/IR diode or 3–5 V for a UV/blue diode). If in doubt, please contact MOGLabs before continuing.

The laser threshold current is defined as the current at which the output is 1 mW. Adjust CURRENT to achieve 1 mW output, and if the threshold differs from that in the test report by more than 10 mA please refer to § 4.3.

Above threshold, the laser power *vs.* injection current is well approximated by a linear curve function (see Fig. 2.1). Initially the current should be set above threshold, but well below the maximum operating current, until the laser is fully aligned with your experiment.

2.3 Temperature

The optimum temperature has been set by MOGLabs and should not require adjustment. Once the diode current is set, allow 5 minutes for the temperature to reach equilibrium. When the laser is not needed for extended periods, for example overnight, turn the laser diode off and the keyswitch to STANDBY. In standby mode, the temperature controller remains active, so that stable operation can be achieved more quickly than when the controller is powered off. It is not necessary to change the CURRENT setting when turning the laser diode on and off.

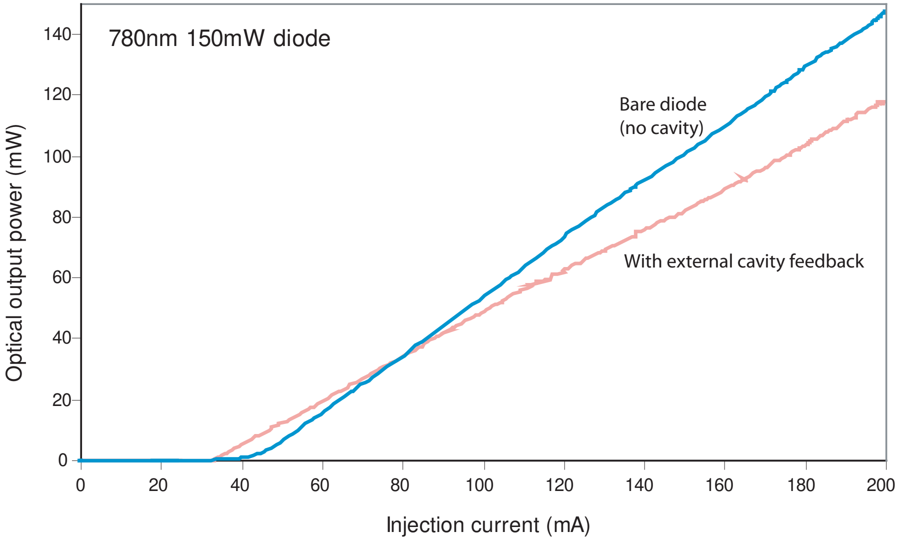


Figure 2.1: Sample laser diode power-current *PI* characteristic curves, with and without an external cavity. The external cavity feedback reduces the threshold current, and also the apparent power/current slope because the measured power with feedback is not the power from the bare diode, but the output beam reflected from the grating. The slope with feedback in this example is 75% of the bare diode output slope, consistent with the grating direct reflectivity.

3. Operation

Your laser has been carefully tuned to the specifications provided in the laser test report. In most cases, the laser will perform as expected once the current, temperature and piezo settings are adjusted to those in the test report.

3.1 Power

Adjust CURRENT and compare the output power from the laser power *vs.* injection current curve provided in the first few pages of your laser test report. If possible, use an integrating sphere sensor to avoid the saturation typically observed when using Si photodiode sensors with small spot sizes. The threshold current and slope above threshold should be similar; if not, refer to § 4.3.

3.2 Wavelength

Once the power is comparable with the test report, the wavelength can be adjusted with reference to a wavemeter or spectrometer. Increase CURRENT to the value recorded in the laser test report. If the measured wavelength is within 0.1 nm of the desired wavelength, the current and piezo (FREQUENCY) can be used to make small changes. If the precise wavelength cannot be reached with current and piezo adjustments, then the wavelength should be adjusted using the λ adjustment screw (see figure 3.1). Ensure that the spring plunger is not locked against the arm of the filter spindle. For larger wavelength changes, release the spindle-clamp lock screw, insert the correctly sized hex driver into the top of the spindle, then rotate the filter spindle and re-clamp the lock screw (see also § 4.2).

Do not attempt to control wavelength by adjusting the temperature.

Note that the cateye lens focus is wavelength dependent, so whenever the laser wavelength is changed substantially (more than say 5–10 nm), we recommend also optimising the current threshold (see § 4.3).

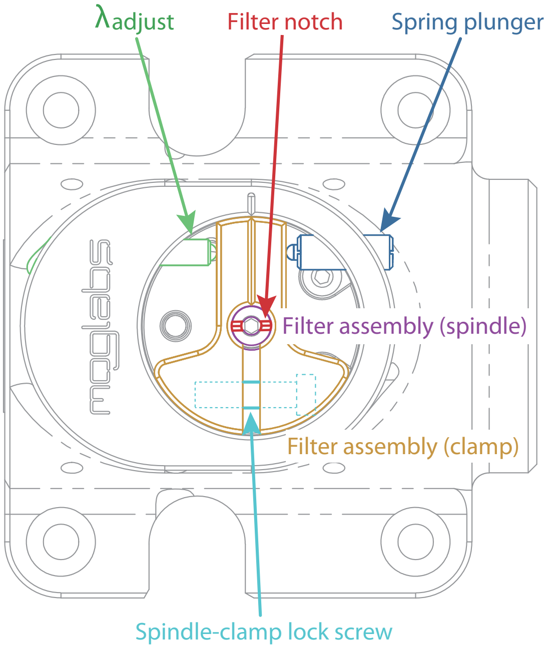


Figure 3.1: Filter angle adjustment, showing the primary wavelength adjustment screw and counter-acting spring plunger. Mechanical version from 2023 shown (serial A323xxxxx and above).

After the target wavelength has been achieved, SPAN can be adjusted to increase the width of the piezo scan. Adjustments of the SPAN knob should be gradual, and careful adjustments of the diode current may be required in order to maintain single-mode operation. Confirm that your laser is capable of reaching the mode-hop free scan range (MHFR) specified in the laser test report. If the MHFR is less than specified, proceed to § 3.3 and 4.1.

3.3 Mode-hops

Mode-hops are a frequent occurrence with external cavity diode lasers. A mode-hop is a discontinuity when tuning or scanning the laser wavelength. As the laser wavelength is varied, usually by changing the cavity length with a piezo, competition between the wavelength determined by the different wavelength-dependent cavity elements can lead to a *mode hop*: a jump in laser wavelength to a different external cavity mode. Wavelength-dependent elements include the external cavity, the laser diode internal cavity between the rear and front facets of the diode, the filter, and the gain bandwidth of the laser diode.

The different wavelength-dependent characteristics are shown schematically in figure 3.2. The net gain is the product of semiconductor gain, filter response, and internal and external cavity interference. The net gain can be very similar at adjacent external cavity modes. A small change in the laser cavity optical path length, the diode internal cavity mode frequency, or the filter angle, can lead to the overall gain being greater at a mode adjacent to the mode in which the laser is oscillating, and the laser then hops to that higher-gain mode. See Ref. [4] for a detailed discussion.

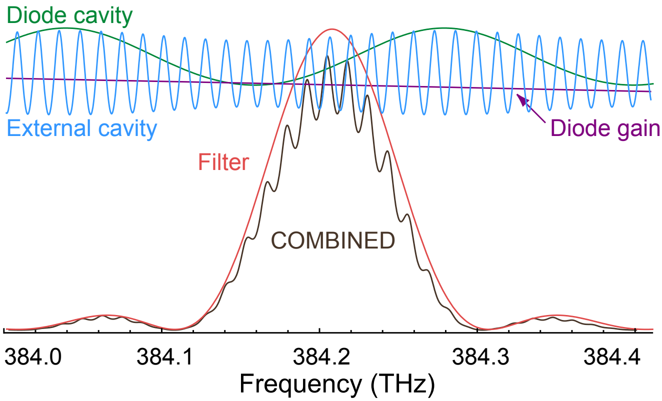


Figure 3.2: Schematic representation for the various frequency-dependent factors of an ECDL, adapted from Ref. [4], for wavelength $\lambda = 780\,\text{nm}$ and external cavity length $L_{\text{ext}} = 15\,\text{mm}$.

3.4 Scanning

The external cavity length is controlled by a piezo actuator moving the external cavity mirror.The cavity length changes with piezo voltage, and for a large change, the laser will usually hop to a neighbouring cavity mode. Figure 3.3 is a schematic of the net gain variation with laser frequency, showing two adjacent modes of very similar gain. Figure 3.4 is a measurement of the frequency of a laser scanning properly, and with a mode-hop at one edge of the scan.

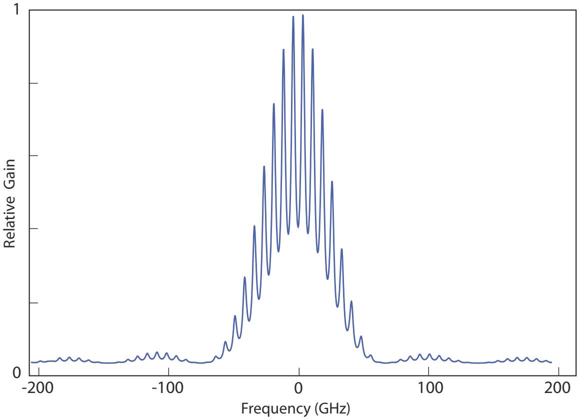


Figure 3.3: Combined gain for an external cavity diode laser, including the internal and external modes, the diode laser gain, and the filter response. The broad feature is the frequency selectivity of the filter, and the smaller peaks are the external cavity modes (see figure 3.2). The laser will easily hop between the two highest external modes with similar net gain.

The mode-hop-free range (MHFR) can be optimised by careful adjustment of the injection current, which affects the optical path length of the diode and hence the frequency of the cavity mode.

3.5 Faraday isolator

The laser can be supplied in a very compact form, or with optional extended chassis (option CEX or CEF) which allows internal mounting of Faraday

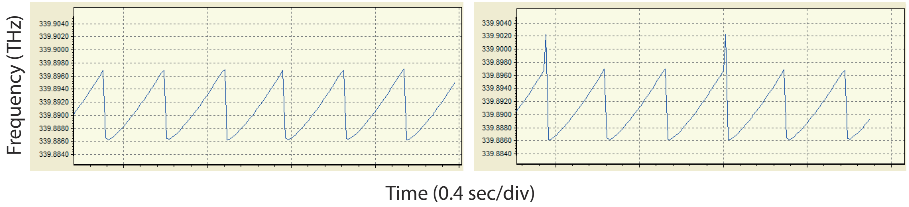


Figure 3.4: Laser frequency vs. time for a laser with a 4Hz piezo ramp rate, giving about 10 GHz of cavity frequency change when scanning mode-hop-free properly (left) and with a mode-hop at one edge (right).

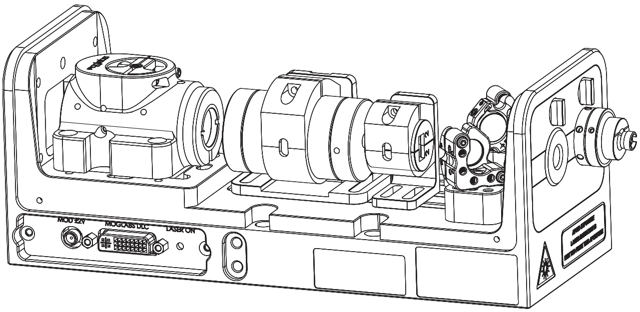


Figure 3.5: Extended chassis CEF option, which adds two coupling mirrors and fibre output to the extended chassis option CEX. The chasiss mounted Faraday isolator and beam shaping are available with either CEF or CEX option.

isolators, and also the addition of coupling mirrors and a fibre coupler (option CEF, see figure 3.5).

3.5.1 Faraday isolator alignment

Faraday isolators are critical to the stability of an external cavity diode laser: even very weak reflections from external optics can have a significant effect on the laser frequency. At least 30 dB of isolation is needed; that is, the optical feedback into the ECDL should be less than 0.1% of the output power. Double-stage isolators provide 60 dB or more of isolation which is necessary if locking to a high-finesse optical cavity.

The extended chassis version of a MOGLabs laser allows internal mounting of a Faraday isolator (see figure 3.6). Alignment is straightforward: the isolator should be concentric with the laser beam, and rotated axially so that the first polariser is parallel to the polarisation of the input laser beam. Depending on wavelength, the transmission varies from about 70% to 98%, with 90 to 95% typical at 780 nm.

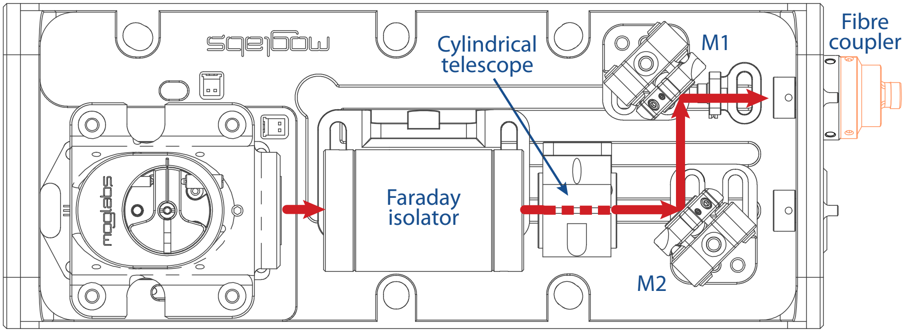


Figure 3.6: Schematic of the extended chassis laser showing Faraday isolator, and two mirrors used for aligning the beam to a single-mode fibre.

The isolator typically has a half-wave retardation waveplate on the output, for controlling the angle of polarisation of the beam. The waveplate is typically mounted inside the end-cap of the isolator (see figure 3.7) or alternatively in a freestanding rotation mount fixed to the chassis.

The waveplate angle in the plane orthogonal to the optical axis may need adjustment, for example to vary the power ratio for the two beams exiting a PBS, to align the polarisation to a more convenient horizontal or vertical axis for experiments, or to align to a polarisation preserving fibre. To adjust the waveplate angle, loosen the radial set screw holding the waveplate, rotate, and restore set screw tension. Some isolators use a 0.035″ or 0.9 mm hex key while others require a 1.5 mm hex key (see figure 3.7).

On lasers with fibre-coupled output, a second waveplate may be mounted directly before the exit face of the laser, either in a freestanding mount or a mount directly attached to the chassis end face. The waveplate allows separate polarisation control for the beam reflected from M1 to match the

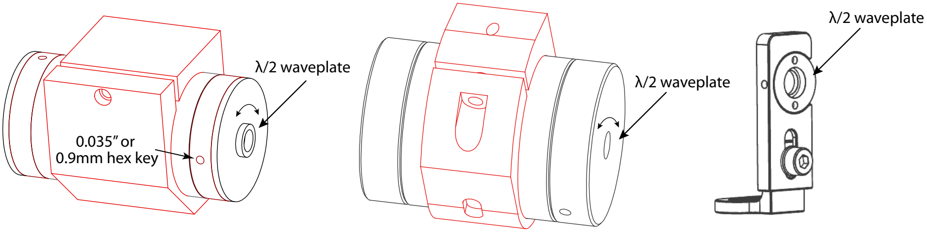


Figure 3.7: Two types of single-stage Faraday isolator (left, centre) can each be supplied with a $\lambda/2$ waveplate inside the exit end-cap. A freestanding waveplate mount (right) is also available. The waveplate in all cases can be adjusted to rotate the plane of polarisation of the exit beam, for example to optimise coupling into polarisation maintaining fibre, or to adjust the ratio of exit beams for lasers fitted with a polarising beamsplitter instead of mirror M2.

fibre polarisation axis.

4. Troubleshooting

4.1 Scanning adjustment

Achieving a wide continuous mode-hop free wavelength scan requires careful optimisation of the control parameters, including laser diode current, piezo offset, and feed-forward current bias (see § 4.1.1). The laser has been carefully tuned to the wavelength and scan range specified in the laser test report. The instructions below describe how to achieve the maximum mode-hop free range (MHFR).

The first step is to confirm that the laser is indeed scanning, for example with a wavemeter such as the MOGLabs Fizeau wavemeter (FZW), MOGLabs economical wavemeter (MWM), or a Fabry-Perot cavity.

1. If using a MOGLabs DLC or dDLC, ensure the fast and slow locks are both not engaged. For the DLC, also ensure DIP switches 9 and 13 are off (internal sweep, stack). Then slowly increase SPAN while monitoring the frequency change with a wavemeter.

2. If there is no change in scan range, then disable feed-forward current bias (using DIP switch 4 in the DLC; opening laser settings and setting bias current to 0 mA for the dDLC). If there is no evidence that the laser is scanning with bias disabled, then the piezo has failed; please contact MOGLabs for assistance.

3. If the laser succcessfully scans with bias disabled, now enable feed-forward current bias (using DIP switch 4 in the DLC). Slowly increase SPAN, and use small adjustments of CURRENT and piezo offset FREQUENCY to suppress any mode-hops observed.

4. Increase SPAN to the maximum before mode-hops are evident and compare DLC CHAN A Freq and CHAN B Current, or dDLC sweep settings and bias current, to the values listed in the MOGLabs laser test report provided with your laser. If the peak-to-peak voltage

differences are more than about 10%, then BIAS adjustment is recommended.

4.1.1 BIAS optimisation

Ideally the frequencies of the external cavity mode and the intrinsic laser diode mode are synchronised as the laser frequency is varied (see figure 3.2). The external mode frequency is controlled by the piezo. The intrinsic diode mode frequency can be controlled by adjusting the laser diode current.

The “feed-forward” or current bias “automatically” adjusts the diode injection current as the piezo voltage is changed. Feed-forward current bias adjustment is a feature of MOGLabs diode laser controllers. Each laser requires a different change in diode current for a given change in piezo voltage, and the ratio (and sign) can be adjusted with the BIAS trimpot on the DLC controller, or directly in the dDLC GUI under the laser settings.

Optimisation is straightforward. With the laser frequency scanning, the BIAS control is adjusted until the maximum mode-hop-free scan range is observed. Small changes to the injection current optimise the scan range near the nominal centre frequency. A fast Fizeau wavemeter, an atomic absorption spectroscopy signal, or a Fabry-Perot cavity can be used to monitor the laser frequency while varying the different control parameters.

1. For the DLC, ensure that BIAS is enabled (DIP switch **4**).
2. Adjust SPAN while monitoring CHAN A Freq and CHAN B Current on a dual-channel oscilloscope, or using the dDLC built-in oscilloscope funtionality to monitor piezo voltage and current. Two sawtooth signals should be apparent. First set CHAN A Freq (piezo voltage) to match the peak-to-peak voltage value (and sign) specified in the laser test report, then confirm that the peak-to-peak voltage (and sign) on CHAN B Current matches the laser test report. Adjust the BIAS trimpot until CHAN B Current matches if necessary.
3. Reduce SPAN to zero. Adjust the laser diode CURRENT to find the

required laser wavelength and approximate output power.

4. If the wavelength is close but not quite correct, small adjustments of either CURRENT or FREQUENCY may be required to find a better lasing mode. If more significant wavelength adjustment is required, mechanically rotate the filter (see § 4.2).

5. If the wavelength is within a few picometres (GHz) of the target, increase SPAN while observing the wavelength scan as shown in figure 3.4.

6. Increase SPAN until a mode-hop is evident. If using absorption spectroscopy to monitor the laser wavelength, it is helpful to observe the derivative, for example the demodulated error signal (CHAN B Error on a MOGLabs DLC).

   The mode hop should be at one edge of the scan; if so, adjust FREQUENCY so that the scan no longer 'clips' this mode hop (i.e. the scan is free of mode hops), and continue adjusting in the same direction until a mode hop is observed on the other edge of the scan.

7. Adjust FREQUENCY to the mid-point between these two extremes.

8. Increase SPAN and adjust FREQUENCY until mode hops are evident at one or both edges of the scan.

9. Adjust diode CURRENT by small amounts to suppress the mode hops. Increase SPAN and adjust CURRENT and FREQUENCY until the mode hops cannot be suppressed.

10. Adjust the BIAS trimpot to suppress the mode hops. Repeat the steps above: increase SPAN, adjust CURRENT, FREQUENCY and BIAS, and repeat until no further improvements can be made.

11. If the MHFR is substantially less than expected (refer to the factory test report), it may be helpful to change to a different intrinsic diode mode by increasing or decreasing CURRENT. Alternately rotate the filter slightly to alter the net gain so that one cavity mode has higher gain than those adjacent.

4.2 Filter adjustment

This section contains mechanical details that apply only to serial numbers A323xxxxx and above. For older cateye lasers, refer to the appropriate manual prior to version 2.01.

The primary control of wavelength is the filter rotation angle, which can be adjusted while the laser is operational. A MOGLabs Fizeau wavemeter or high-resolution spectrometer is almost essential, though with patience it is possible to find an atomic resonance by carefully adjusting the filter angle while scanning the laser.

WARNING: If the diode is powered on, ensure that the filter is never perpendicular to the laser axis (i.e. filter angle 0°, when filter notch on spindle is parallel to optical axis in figure 3.1). The filter is a highly reflective mirror that will back-reflect light into the diode, which can cause catastrophic damage.

To change the wavelength:

1. Set the laser current so that the output power is sufficient, taking care to ensure the current is below the maximum bare diode current specified in the laser test report (to avoid damaging the diode when operating at high current without sufficient feedback).

For adjustments of greater than 1nm:

2. Unlock the filter so that it can rotate, by turning the spindle-clamp lock screw anti-clockwise, for example one full turn.
3. Rotate the filter assembly spindle using an allen key or hex ball driver in the hex socket in the centre of the shaft, making sure that the notch does not align at 0° to the optical axis.
4. Lock the spindle-clamp.
5. Optionally adjust the fine diode focus to optimise the lasing threshold, and subsequently make corrections to the output collimation lens as necessary to recollimate the output (see § 4.3).

For adjustments of less than 1 nm:

6. Check that the spring-plunger is engaged but not locked against the brass arm of the spindle clamp. That is, the pin should be visibly protruding from the spring-plunger screw, and touching the brass arm.

7. Adjust the filter angle using the fine thread λ adjust screw, acting against the spring-loaded plunger opposite to the λ adjust screw.

8. The laser will hop between external cavity modes as the wavelength is adjusted, through cycles of dim and bright output.

9. It may be necessary to adjust the spring plunger, so that pressure is maintained on the brass arm of the spindle clamp, without locking completely.

10. Once the laser is operating near the desired wavelength, adjust the diode current and the piezo voltage to achieve the exact wavelength required. If the CURRENT adjustment has shifted the wavelength to a mode further away from the desired wavelength, use the fine screw adjustment method to correct the wavelength.

The filter transmission wavelength variation with angle is approximately

$$\lambda(\theta) = \lambda_0 \sqrt{1 - \left(\frac{\sin(\theta)}{n_{\mathrm{eff}}}\right)^2} \tag{4.2.1}$$

where θ is the angle of incidence, λ_0 is the filter wavelength at normal incidence and $n_{\mathrm{eff}} \approx 1.7$ is an effective refractive index. The sensitivity to rotation of the fine tangential wavelength adjustment screw is about 0.5 nm to 1 nm per turn.

4.3 Threshold optimisation

This section contains mechanical details that apply only to serial numbers A323xxxxx and above. For older cateye lasers, refer to the appropriate manual prior to version 2.01.

The lasing threshold, at which the overall gain exceeds losses, should be as low as possible to maximise the output power and also the scan range and frequency stability. The lowest threshold is achieved by optimising the focus of the laser diode collimation lens (see figure 4.1). The lens focus is wavelength dependent, so whenever the laser wavelength is changed substantially, we recommend also optimising the threshold.

Small changes to the focus adjustment can be achieved by rotation of the diode fine-focus ring on the rear of the CEL barrel. Such adjustments (no more than one tenth of a turn) are suitable when threshold optimisation due only to a wavelength shift is required. Larger changes of focus should not be required; please contact MOGLabs if you feel that small adjustments are insufficient.

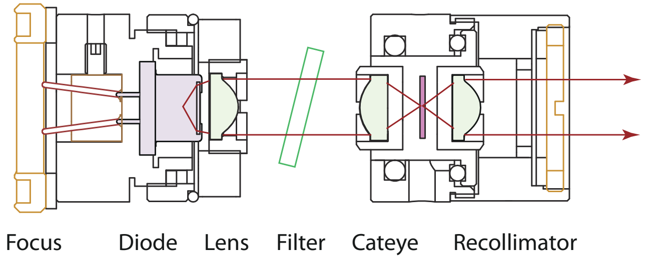


Figure 4.1: Arrangement of lens tube and cateye reflector.

The sequence is as follows:

1. Turn the DLC on and adjust CURRENT to 5 – 10 mA above the threshold specified in the laser test report. You should have at least 1 mW of output power, otherwise increase the current further, but do not exceed the maximum safe current specified in the laser test report.
2. Monitor the laser output power using a power meter as close to the cateye assembly as possible, before the isolator and with the power sensor angled slightly from orthogonal to the optical axis to protect the laser from back reflections from the sensor surface.
3. Adjust the focus by rotating the focus adjust ring at the rear of the

laser barrel, using the focus adjust tool provided with your laser (see figure 4.2) or a small screwdriver, until the power increases to a peak.

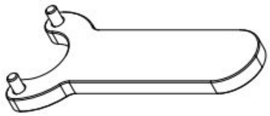


Figure 4.2: Adjustment tool for fine-focus adjust of diode tube position.

4. Reduce the injection current to obtain 1 mW, followed by adjusting the diode fine-focus adjust, and iterate until the minimum current threshold is achieved.
5. Increase the laser diode current to the desired operating current, then do a final optimisation of the CEL output power at this wavelength by adjusting the diode fine-focus adjust.

4.4 Fibre coupling

Lasers with extended chassis (CEF or LEF), amplifier systems (MSA or MOA) or harmonic doubling cavities (MSL) can be fitted with a fibre connector to allow coupling the free-space laser beam into a single-mode optical fibre. Two mirrors on kinematic mounts allow precise alignment of the position and angle of the laser beam into the fibre coupler: a common and familiar arrangement for optical scientists (see figure 3.6). The arrangement can also be configured to allow splitting the output into two beams, using a PBS as the first reflector.

Given the 8% Fresnel loss from entrance and exit facets of the fibre, the maximum theoretical efficiency for single-mode fibre coupling is 92%. The stainless steel kinematic mirror mounts are stable and easy to use. Different coupling efficiencies will be realised dependent on the input beam quality. For example coupling efficiency of over 70% is easily attained at 780 nm with a direct diode laser, whilst achieving over 60% is typically difficult for a blue laser. Tapered amplifiers typically have poor beam quality and some astigmatism and fibre coupling efficiencies above 55% can be difficult to achieve, whilst the harmonic output of a doubling cavity typically has very good beam quality and greater than 70% coupling is readily achieved, even in the blue.

Alignment requires first adjusting the mirrors so that the beam exits the laser chassis in the centre of the fibre coupling port, and parallel to the long axis of the chassis. The fibre coupler can then be installed, without fibre, and the mirrors adjusted so that the beam is clearly transmitted by the coupler (see below for detailed instructions).

An eccentric key tool, hexagonal shaped spanner or C-shaped pin-spanner is provided for adjusting the coupling lens focus, depending on which fibre coupler implementation is installed in the laser system. Please contact MOGLabs if you have attempted the below adjustments and your fibre coupling efficiency is much lower than stated in your laser test report.

4.4.1 Cleaning fibre optic connectors

A common cause of low fibre coupling efficiency is a contaminated fibre optic connector (which can easily lead to a permanently damaged end if not attended to). Visual inspection can only be conducted using a fibre optic microscope to be sure of a clean end - **do not inspect a fibre patchcord with a laser connected to the other end**. It is not unreasonable to assume your fibre optic connector has been contaminated whenever it is mated to a connector or a dust cap is removed/attached. Prior to insertion into your MOGLabs laser fibre port, clean both ends of your fibre patchcord using the wet-to-dry cleaning technique (described for example at `https://www.chemtronics.com/fiber-optic-cleaning-guidelines`).

4.4.2 Reverse beam: using a visual fault locator

A *visual fault locator* is a very useful device for quickly achieving initial coupling of the laser beam to the fibre. A visual fault locator (see figure 4.3) is a low-power red laser that can be used to inject a counterpropagating beam into the *exit* end of the fibre patchcord, thus providing a visible alignment beam along the laser beam path. These devices are very low in cost (search on eBay for *visual fault locator*; they are typically less than $20).

Figure 4.3: Fibre laser pen, or visual fault locator. Injects visible laser beam into fibre, which allows basic alignment and mode matching.

Aligning the MOGLabs laser beam to the fibre is then simply a matter of adjusting the mirrors so that the MOGLabs laser beam and the visual fault locator beam maximally overlap inside the laser along the entire optical path.

4.4.3 Mirror adjustment

To maximise the fibre coupling efficiency, the incident angle and location of the laser beam at the fibre coupler must be optimised by walking the mirrors.

Let M1 be the mirror closest to the fibre coupler, and M2 be closest to the laser (see figure 3.6).

1. Adjust the laser current so that the output power is around 5 to 10 mW.
2. With a clean fibre patchcord installed, attach a power sensor to the output. If some power is detected exiting from the fibre (no power difference with the beam blocked/unblocked), skip to step 7 below.
3. Otherwise, if no power is detected, remove the fibre patchcord and adjust the mirrors M1, M2 so that the beam exits from the fibre coupler cleanly. The beam should be approximately orthogonal upon reflection from each mirror. You should be able to observe a bright beam centred in the circle of a shadow at the fibre coupler output.

4. Measure the power just before the fibre coupler using a slim or compact sensor, and record the power meter reading.

5. Reinstall the fibre patchcord (consider recleaning the end as recommended in § 4.4.1).

6. If a visual fault locator is available, use that to inject a backwards-propagating beam, and adjust the mirrors so that the MOGLabs laser and visual fault locator beams are maximally coincident along their paths[1]. The visual fault locator can then be removed: a measurable transmitted beam should now be at the fibre patchcord output.

7. Using a power meter sensor, monitor the output power exiting from the fibre patchcord. Ensure that the reading is not affected by background light. We strongly recommend using integrating sphere sensors to avoid errors, as sensors using silicon photodiodes can easily saturate below their maximum rated power and thus give false readings, particularly when the entire sensor surface is not evenly illuminated as for a small beam.

8. Find the maximum output power by adjusting mirror M1 (closest to the fibre), both horizontally and vertically.

9. Record the output power. Adjust first the horizontal axis of mirror M2 (furthest from the fibre) clockwise such that the output power drops by no more than 25%. If the efficiency is over 50%, drop the power by only 5 to 10% or less. Take note of roughly how much rotation was required, so you can easily return to the original position.

10. Adjust the horizontal axis of mirror M1 and maximise for output power. Compare the new maximum output power to the output power recorded at the start of step 9.

11. If the power has increased, repeat steps 9 to 11. If the power has instead decreased, repeat steps 9 to 11 but change the adjustment

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[1] Note that the divergence of the input laser and the fault finder may be different, due to the chromatic focal shift of the fibre coupling lens.

direction to anti-clockwise instead of clockwise. If no improvement can be made through iteration in that axis, proceed to the next step.

12. Once horizontal alignment is optimised, repeat the procedure but using vertical adjustments. Iterate steps 9 to 11 alternately for horizontal and vertical alignment until coupling efficiency is fully optimised (after fully optimising one axis, then the other, the first axis can be further optimised). As optimum coupling is approached (greater than 50%), the magnitude of adjustments should be reduced at each step.

13. If the coupling efficiency is less than expected, adjusting the fibre coupler focus lens may be required. Focus adjustment is not normally needed unless severe shock has moved the lens, or if a new diode has been installed in the laser, leading to change in beam waist location. If your laser has been configured with a Schäfter-Kirchhoff fibre coupler please see instructions for using the 60EX-4 and 60EX-5 eccentric focus adjust tools at `https://www.sukhamburg.com/`. Most lasers instead use a C-shaped pin-spanner provided by MOGLabs (fig. 4.4). The focus has approximately a half turn of adjustment. If screwed too far in (too much clockwise adjustment, viewed from the fibre side) it will reach an built-in mechanical stop, preventing damage. If screwed too far out (anti-clockwise) the focus ring will disengage and further adjustment will not change the lens position.

    If focus adjustment is necessary and the focus is far from the initial position set by MOGLabs, approximate collimation can be achieved by fully screwing in (clockwise) the focus adjustment ring until it stops, then backing out by a tenth of a turn.

14. Once optimised, record the input power to the fibre coupler, maximum output power, and the laser current.

15. Increase the laser current to the desired operating current and re-optimise if needed (steps 9 to 11).

16. Use the factory test results for your laser as reference. Degradation may indicate facet damage on the fibre patchcord. Reversing or

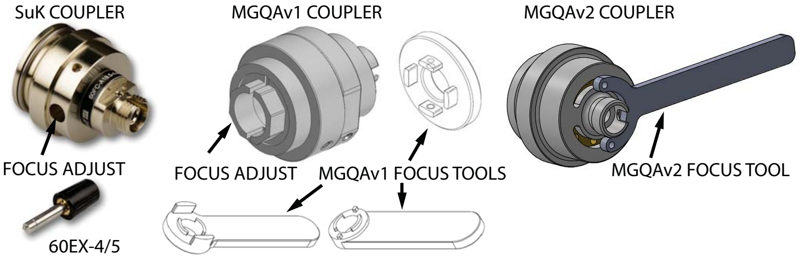

Figure 4.4: Fibre couplers showing access to fibre collimation lens adjustment. There is a slot in the SuK coupler mount for the eccentric focus tool 60EX-4/5 off-centre pin to mate with. The MGQAv1 coupler will come with one of three MGQAv1 focus tools indicated to adjust the internal nut acting on the collimation lens. The MGQAv2 coupler will come with the C-shaped pin-spanner focus tool indicated.

replacing the fibre patchcord may be helpful.

A. Specifications

Parameter	Specification
Wavelength/frequency	
368 – 1620 nm	Diode dependent. Please contact MOGLabs for availability.
Linewidth	Typically < 100 kHz
Filter	0.2 to 0.4 nm bandpass
Tuning range	Diode dependent; 5 nm to 50 nm
Sweep/scan	
Scan range	20 to 30 GHz
Mode-hop free	5 to 30 GHz
Piezo	$5 - 9$ μm @ 150 V, 200–350 nF (typical) or 2.6 μm @ 150 V, 550 nF (typical)
Cavity length	22 mm
Optical	
Beam	3 mm × 1.2 mm (1/e^2) typical
Polarisation	Vertical linear 100:1 typical

Parameter	Specification
Thermal	
TEC	±14.5 V 3.3 A $Q = 23$ W standard
Sensor	NTC thermistor 10 kΩ, $\beta = 3988$, standard AD590, 592 optional
Stability at base	±1 mK (controller dependent)
Cooling	M5x0.8 thread for 4 mm diam quick-fit connections (e.g. SMC KQ2S06-M5A). ***NOTE:*** Use distilled water only (not deionised). The 6061 aluminium chassis will react with many cooling additives.
Electronics	
Protection	Diode short-circuit relay; cover interlock connection; reverse diode
Indicator	Laser ON/OFF (LED)
Connector	MOGLabs Diode Laser Controller single cable connect
Modulation input	Active (AC and DC coupled) or RF bias tee
Mechanical & power	
Dimensions	108 × 70 × 83 mm (L×W×H), 1 kg
Beam height	58 mm
Shipping	420 × 360 × 260 mm (L×W×H), 3.1 kg

A.1 CEL mechanical (Rev9+)

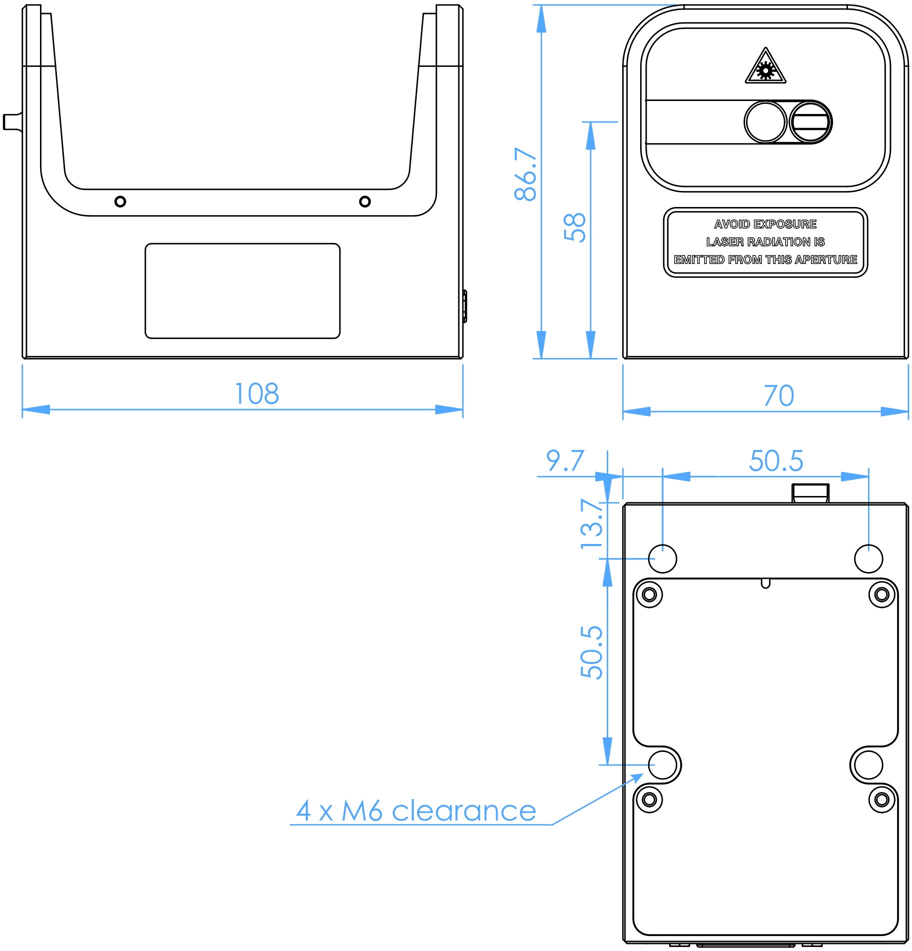

Figure A.1: Dimensions of CEL laser head (Rev9+).

A.2 CEX/CEF mechanical

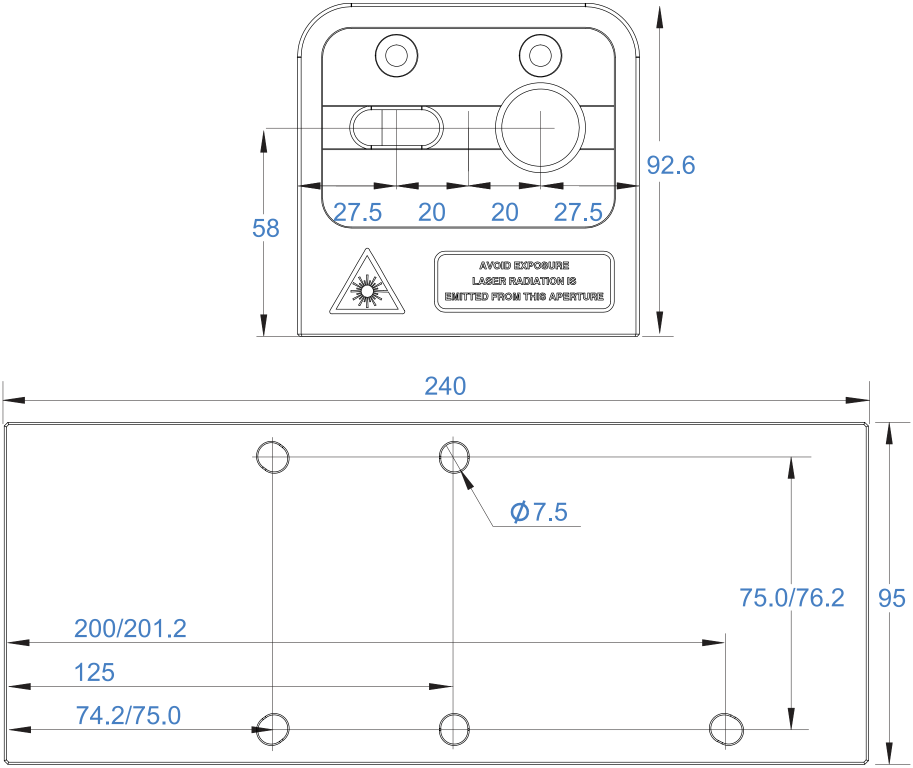

Figure A.2: Dimensions of CEX/CEF laser head.

B. Laser head board

The laser head interface board provides connection breakout to the laser diode, TEC, sensor, piezo actuators, and laser head interlock. It also includes a protection relay and passive protection filters, a laser-on LED indicator, and an SMA connection for direct diode current modulation.

Several versions of the laser headboard are available.

MOGLabs lasers are built with a T-shaped headboard, using Hirose DF59 “swing-lock” wire-to-board connectors (Digikey H11958-ND and H11957CT-ND plug and crimp pin). The B1047 headboard provides high bandwidth active current modulation for wide bandwidth frequency stabilisation and linewidth narrowing, for example using a high finesse optical cavity or polarisation spectroscopy. Higher bandwidth is provided by the B1240 headboard which further increases bandwidth and reduces phase delay, to allow sub-Hz linewidth narrowing. The B1240 is limited to low compliance voltage laser diodes (red and infrared); the B1047 must be used for blue diodes. B1045 and B1046 headboards provide RF modulation via an RF bias tee allowing modulation up to 2.5 GHz, for example to add sidebands for repumping, or to add noise for coherence control.

In all cases, there is no provision for the internal photodiode in many consumer-grade laser diodes.

B.1 B1045/1046 headboard

The B1045 and B1046 provide connection to one or two piezos (slow high-range multi-layer stack and fast disc), and either passive NTC thermistor or active AD590/592 active temperature sensor. Note only one temperature sensor should be connected, not both. They provide an SMA input for direct diode modulation via an RF bias tee (see B.1.1 below).

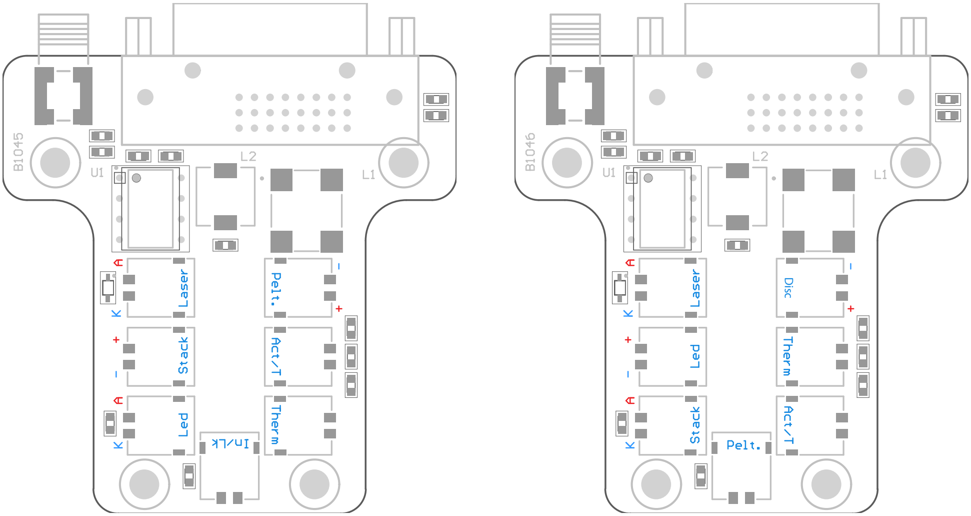

Figure B.1: MOGLabs B1045 and B1046 laser head boards showing connectors for laser diode, piezo actuator, temperature sensors, TEC and head enclosure interlock. Connectors are Hirose DF59.

B.1.1 RF coupling

For the B1045/1046 headboard, the SMA connector allows high-frequency current modulation via a bias-tee. The RF input is AC coupled, with low- and high- frequency limits of about 30 kHz and 2.5 GHz (see figure B.2). Capacitor C4, either 47 nF or 100 pF, can be changed to adjust the low-frequency cutoff. For higher bandwidths, use an external bias-tee such as the Mini-Circuits ZFBT-4R2GW-FT between the head board and the diode.

The input impedance is 10 kΩ. The sensitivity depends on the diode impedance but is typically around 1 mA/V.

WARNING: The RF input is a direct connection to the laser diode. Excessive power can destroy the diode, which is separated from the head board relay by an inductor. Thus the relay does *not* provide protection from high frequency signals.

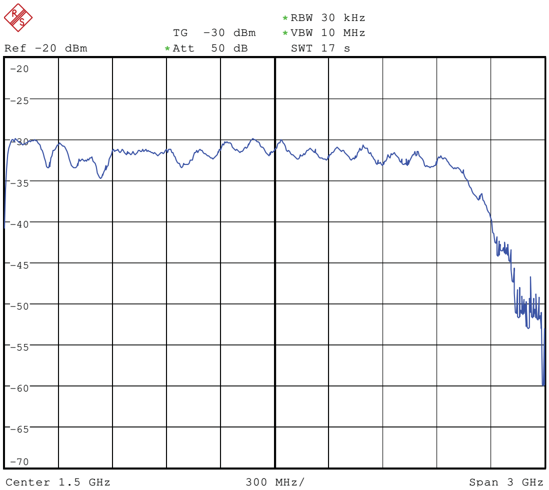

Figure B.2: RF response, SMA input on laser headboard to diode SMA output.

B.2 B1047/B1240 headboards

The B1047 and B1240 provide high-speed active modulation of the diode current. They use 500 MHz opamps and very low latency circuitry to reduce phase delay to around 12 ns for the B1240. The B1047 allows for closed-loop bandwidth of about 1.2 MHz while the B1240 can achieve about 4 MHz (in both cases, without phase advance), which is helpful in achieving sub-Hz linewidth reduction by locking to a high-finesse optical cavity. The B1240 also allows direct-ground connection or buffered; the latter is about 10% slower but reduces problems with ground-loop noise. The B1240 is not suitable for diodes with high compliance voltage, typically diodes with wavelength below 600 nm.

Note that connection to the SMA input will reduce the diode current, even if the control voltage is at zero.

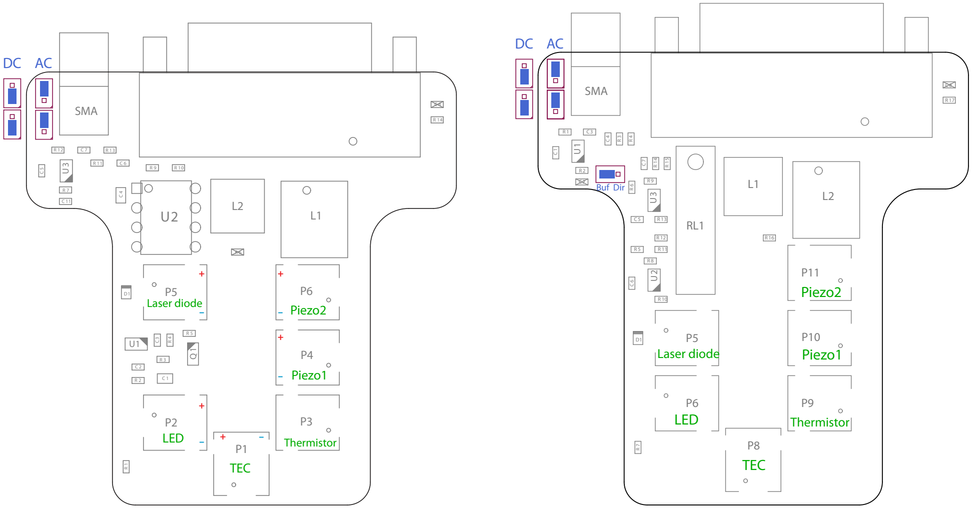

Figure B.3: B1047 (left) and B1240 (right) enhanced laser head boards. Jumpers at top left can be configured for AC or DC coupling. The B1240 has an additional jumper “Buf Dir” for buffered or direct input, shown connected for buffered; change to pins 1 and 2 for direct. Modulation input via SMA connector, sensitivity 2.5 mA/V. Connectors are Hirose DF59.

B.2.1 SMA input

The B1047/B1240 SMA input provides AC or DC coupling to an active modulation circuit. Note that connection to the SMA input will reduce the diode current by about 1.6 mA (B1047) to 2.5 mA (B1240), with zero input voltage.

	B1047	B1240
Input range	±2.0 V max	±2.0 V max
Input coupling	AC/DC	DC (direct) AC/DC (buffered)
AC time constant	15 μs (10 kHz)	15 μs (10 kHz)
Phase delay	40 ns	< 20 ns (direct) < 30 ns (buffered)
Gain bandwidth (−3 dB)	3 MHz	20 MHz
Input impedance	5 kΩ	AC buffered: 1 kΩ at 10 kHz DC buffered: 1 kΩ Direct: 1 kΩ
Current gain	1 mA/V	1 mA/V
Laser diode voltage	10 V max	2.5 V max

B.3 Headboard connection to controller

Note The MOGLabs laser cable is a digital DVI-D DL (***dual link***) cable. There is a bewildering assortment of apparently similar cables available. Most *computer display* DVI cables will ***not*** work because they are missing important pins; see diagram below. Only high quality digital ***dual-link*** DVI-D DL cables should be used.

Pin	Signal	Pin	Signal	Pin	Signal
1	TEC –	9	DIODE –	17	DISC +
2	TEC +	10	DIODE +	18	DISC –
3	Shield	11	Shield	19	Shield
4	TEC –	12	DIODE –	20	STACK +
5	TEC +	13	DIODE +	21	STACK –
6	T_{sense} –	14	Relay GND	22	
7	T_{sense} +	15	+5V in	23	NTC –
8		16	Interlock out	24	NTC +

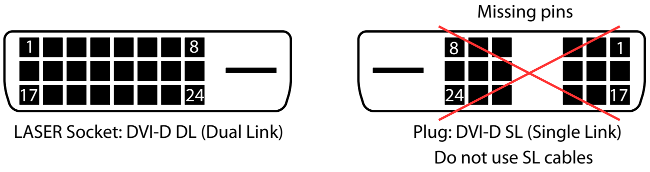

Figure B.4: Headboard connector. Note that the pinout is different to that of the matching connector on the rear of the DLC controller.

A 10 k thermistor (typically EPCOS B57861S0103F040, $\beta = 3988$) should be connected to NTC+ and NTC–, but an AD590 or AD592 temperature sensor can be instead be connected to T_{sense}. Pin 15 should be connected to a +5 V supply. To activate the laser diode, relay GND (pin 14) should be grounded to open the relay that otherwise short-circuits the diode current. +5 V (pin 15) is internally connected to pin 16 (Interlock), normally with a permanent connection but on some headboards (see above), a connector is provided to allow connection to a cover-activated microswitch to disable the laser when the cover is removed.

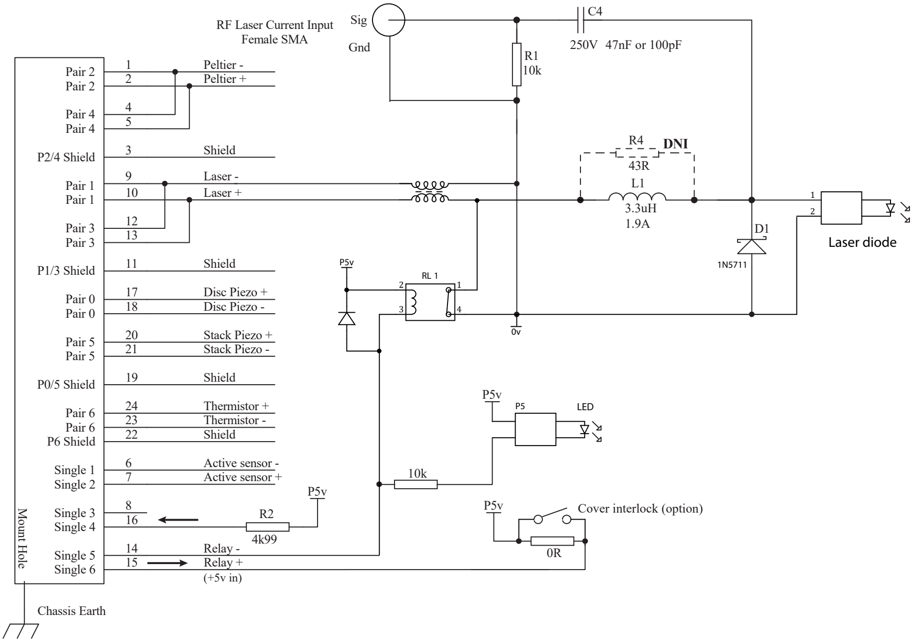

Figure B.5: MOGLabs DLC laser head board schematic (B1040/1045). The RF modulation low-pass cutoff frequency is determined by C4 and the diode impedance ($\sim 50\Omega$).

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