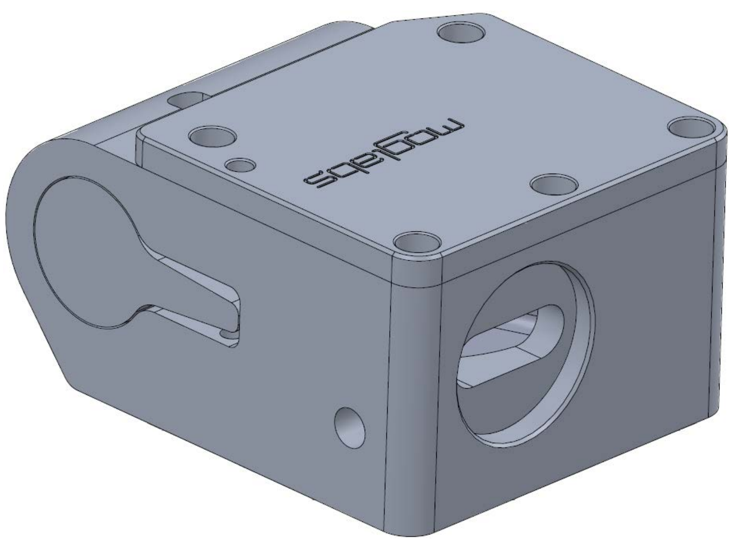
moglabs

External Cavity Diode Laser

LDL Littrow



Revision 1.02

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Preface

Semiconductor laser diodes can provide an energy-efficient, compact, low cost, high power, low noise, tunable source of coherent light over a large range of wavelengths. With wavelength-dependent feedback from an external cavity, they can be very narrow in linewidth, but also very sensitive to vibration and frequency drift caused by environmental changes. The MOGLabs LDL Littrow design offers very high passive stability with low sensitivity to vibration by avoiding common ECDL weaknesses, in particular springs and flexures.

We hope that you enjoy using the MOGLabs LDL ECDL. 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 LDL 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.

CAUTION Although the LDL is designed and priced with the expectation that the end-user will tweak the alignment, some components are fragile. In particular the piezo actuator behind the grating, and the grating itself, are very easily damaged. Please take care of these items when working inside the laser.

Do not attempt to clean the diffraction grating. Finger prints and blemishes do not usually impact the laser performance.

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 aperture where laser radiation is emitted. Figures 1 and 2 shows examples of these labels and their location on the LDL laser.

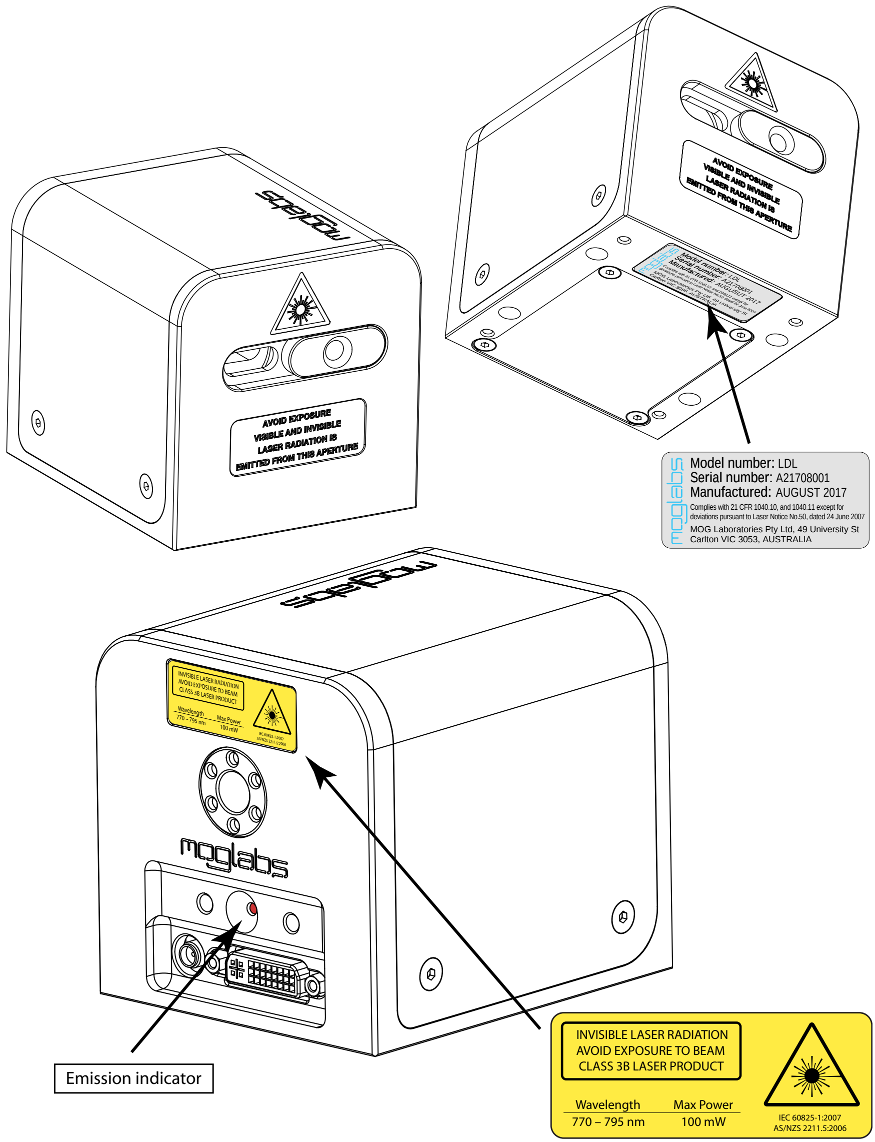

Figure 1: Schematic showing location of laser warning labels compliant with International Electrotechnical Commission standard IEC 60825-1:2007, and US FDA compliance label. Aperture label engraved on the front of the laser near the exit aperture; warning advisory label on the rear and compliance label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

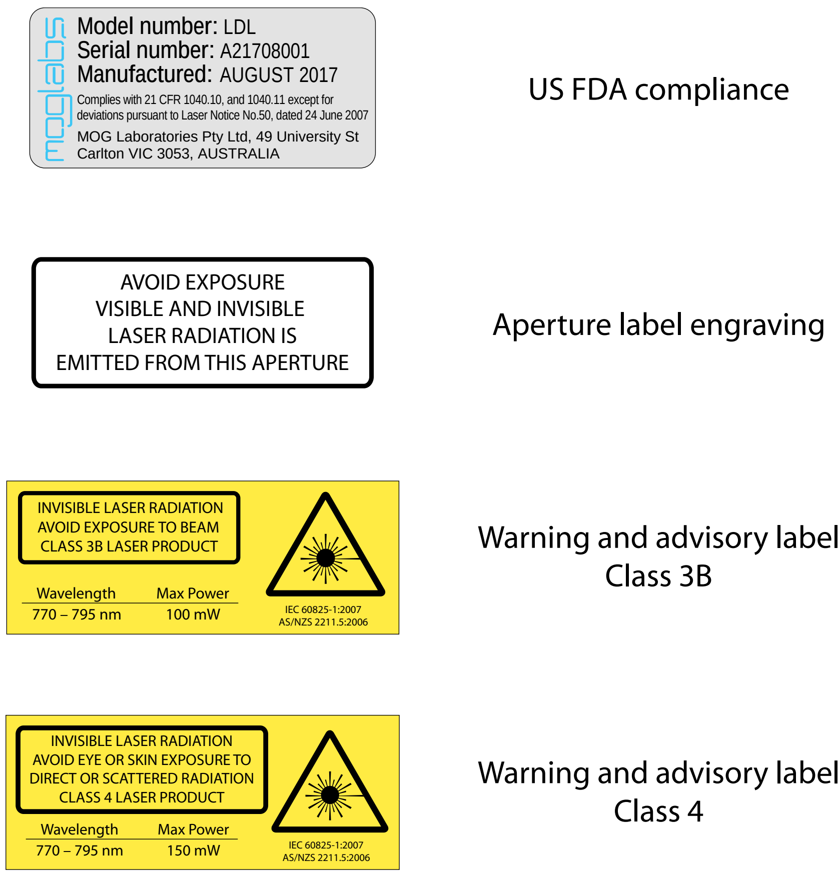

Figure 2: Warning advisory and US FDA compliance labels.

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. There will then be a delay of at least 2 seconds before actual laser emission.

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.

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 LDL (see Fig. 1.1) is machined from a solid aluminium block, so that the laser is stable, robust, and insensitive to vibration. The cavity is hermetically sealed for additional suppression of environmental fluctuations and drift.

The MOGLabs LDL is a Littrow design (see Fig. 1.2) in which an external cavity is formed between the rear reflecting surface of the semiconductor diode, and a diffraction grating at several centimetres from the diode. Many references describe designs and design considerations [1, 2, 3, 4, 5, 6].

The output beam from a laser diode is collimated with a high numerical aperture (NA) lens and incident on a diffraction grating. The grating is

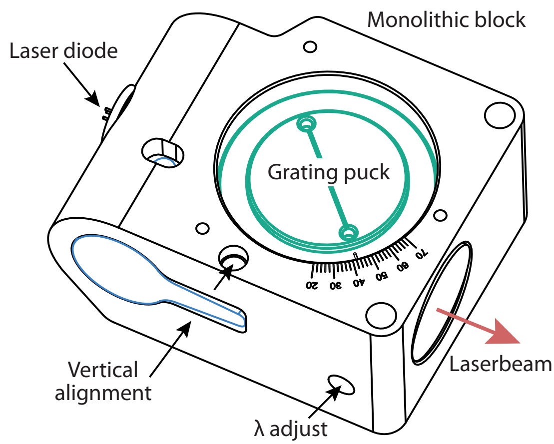

Figure 1.1: Sketch of the MOGLabs LDL monolithic block external cavity diode laser.

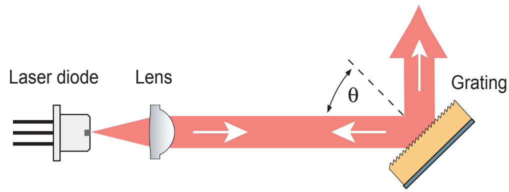

Figure 1.2: Schematic of a Littrow configuration external cavity diode laser (ECDL). The external cavity, formed by the rear facet of the laser diode and the grating, determines the laser wavelength. One longitudinal cavity mode is selected by dispersive feedback from the grating.

angled such that the first order reflection is directed back into the laser diode. This feedback has a wavelength centered around $\lambda = 2d \sin\theta$ where d is the grating line spacing and θ is the angle with respect to the the grating normal.

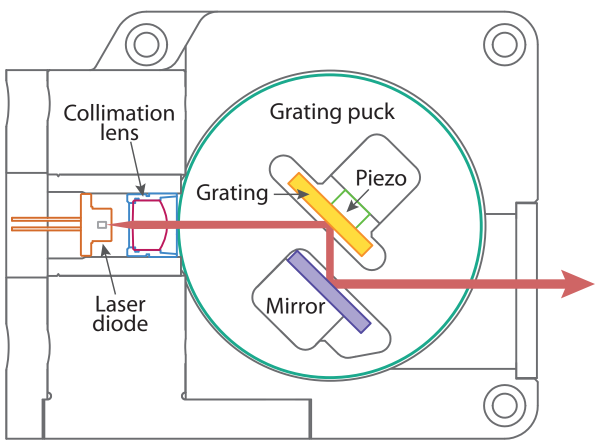

Figure 1.3: Cross-section of MOGLabsLDL Littrow laser, showing arrangement of laser diode, collimation lens, grating, piezoelectric transducer and fold mirror. The grating angle and hence wavelength is adjusted by rotating the central cylinder (the grating puck) which forms a rigid mount for grating and mirror.

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 diffraction grating and the diode rear facet, and because the feedback from the grating is generally greater than that of the front facet, the external cavity determines the lasing wavelength. The external cavity is typically around 20 mm long, with cavity mode spacing (FSR) of $c/2L = 7.5\,\text{GHz}$.

The laser diode and collimating lens are held rigidly in a focusing tube. The grating (usually sinusoidal holographic) is fixed to a precision mechanical mount which can be adjusted to optimise feedback of the first order diffraction back into the laser diode, and the zeroth order (direct reflection) becomes the laser output beam. An optional fold mirror cancels angular deviation of the output beam as the laser wavelength is tuned [3]. Variation of the grating angle is used for coarse selection of the wavelength, within the gain bandwidth of the laser diode.

1.2 Mode competition

As the wavelength is varied, competition between the frequency determined by the internal and external cavities, and the dispersion of the grating diffraction, leads to *mode hops*. From figures 1.4 and 4.2, the net gain (combined product of semiconductor gain, diffraction dispersion, internal and external cavity interference) can be very similar at adjacent external cavity modes. A small change in the internal cavity mode, or the grating 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. [1] for a detailed discussion.

1.3 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 LDL, the grating is mounted to a multilayer piezoelectric “stack”. The cavity length

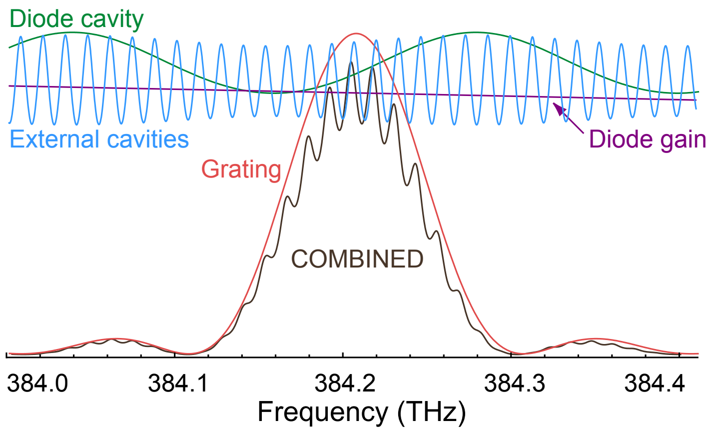

Figure 1.4: Schematic representation for the various frequency-dependent factors of an ECDL, adapted from Ref. [1], for wavelength $\lambda = 780$ nm and external cavity length $L_{\text{ext}} = 15$ mm.

variation is about 10 nm per volt, producing a frequency shift of 250 MHz/V with a range of 25 GHz for 100 V drive voltage. The bandwidth is limited by mechanical resonances, typically at a few kHz.

1.4 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 [7]. Thus, low-noise stable electronics, such as the MOGLabs DLC external cavity diode laser controller, are essential [2] to achieve sub-MHz linewidth and stability.

A critical 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 [1]. 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 combined with cavity length control provide a flexible and stable approach. The MOGLabs LDL 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

Initial installation of the laser is typically a matter of mounting it to an optical table and connecting to a MOGLabs controller. Mounting holes can be accessed by removing the cover, so that the M6x16 socket head cap screws provided can attach the laser to the optical table. The hole spacing also allows direct mounting to imperial tables for non-metric countries (Burma, Liberia and the USA).

The laser includes a water cooling channel for laser operation at unusually high or low temperatures, or in laboratories with high or unstable air temperature. For most applications, water cooling is not required; dissipation to the air and/or optical table is sufficient.

The performance of an external cavity diode laser is strongly dependent on the external environment, and in particular acoustic vibrations. Very small changes in the external cavity length have a large effect on the laser frequency, typically 25 MHz per nanometre length change. The monolithic block construction of the MOGLabs LDL reduces the influence of vibrations on the cavity length, but some elasticity remains. The LDL is hermetically sealed to substantially reduce the effects of acoustic disturbances in the cavity air gap.

Active feedback to the laser frequency, via piezo translation and current modulation, reduces external influences, but some simple measures to minimise coupling to environmental variations and vibration sources may be warranted. For example, a surrounding box to reduce air movement and accidental bumping of the laser; mounting the laser to a heavy support, and isolation from the optical table with an intermediary breadboard which is separated from the main optical table with viscoelastic polymer (e.g. Sorbothane™).

Once the laser is mounted appropriately, the laser can be powered on. Please refer to the supplied test data for nominal temperature and current settings, and in particular be aware of the maximum current limit.

It is assumed that a MOGLabs DLC controller will be used to drive the laser. If an alternative supply is used, note that +5 V must be provided on pin 15 of the headboard connector to open the protective relay. See section B for connection details. Also please refer to the laser test data for the maximum safe operating current.

2.1 Temperature

The preferred diode temperature will depend on the diode, the required wavelength, and the ambient room temperature. For example, typical AlGaAs diodes used for data storage applications (CD-R burners) have a nominal wavelength of $\lambda = 784\,\text{nm}$ at 25°C, with a $d\lambda/dT$ slope of $-0.3\,\text{nm}/°\text{C}$, implying an optimum temperature of about 12°. Depending on the humidity, low temperatures may induce condensation on the diode and collimation lens. The grating feedback will determine the final wavelength, and the feedback is generally sufficient to "pull" the wavelength by $\pm 5\,\text{nm}$, and thus in this example a sensible set temperature would be about 17 to 18°C.

2.2 Current

The output of semiconductor laser diodes follow a nominally linear power *vs.* current (PI relationship, once the current is above a device-specific threshold (see Fig. 2.1). Initially the current should be set above threshold, but well below the nominal maximum operating current, until the laser is fully aligned.

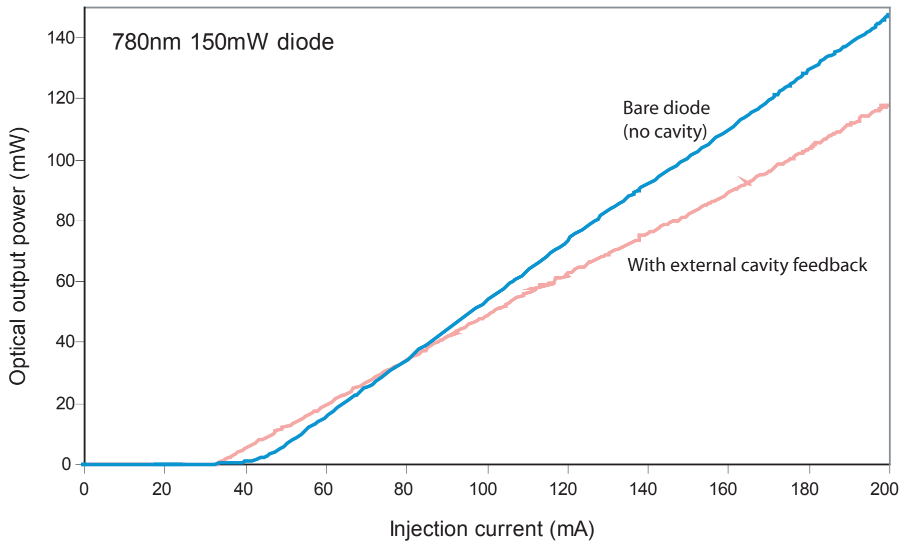

Figure 2.1: Sample laser diode power-current *PI* characteristic curves, with and without an external cavity. The external cavity feedback reduces the threshold current, and also the apparent power/current slope because the measured power with feedback is not the raw power from the diode, but the output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

3. Alignment

Laser diodes have a finite lifetime, and are sensitive to electrostatic discharge and COD (catastrophic optical damage, caused by surface defects). Replacement is tedious but not difficult.

Alignment of the laser will be needed after diode replacement, and at other times for example initially after shipping if the laser has been mishandled, or after making significant changes to the laser wavelength or cavity configuration. The process is straightforward and normally takes only a few minutes.

For long-wavelength lasers, an infra-red upconversion card or video camera 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 infra red filters which may need to be removed.

Diodes are very sensitive to electrostatic discharge. Please make sure you are electrically grounded, ideally with a wrist ground strap. If you do not have a proper wrist ground strap, at least be sure you are not wearing woolen clothingx, and touch something grounded from time to time (e.g. a soldering iron tip, the earth of a power supply, the MOGLabs DLC controller).

3.1 Pre-alignment of lens tube and diode

1. Insert the laser diode into the lens tube (see fig. 3.1). If using a lens tube with alignment screws, ensure that the V-notch in the base flange of the diode can is *not* aligned with one of the alignment screws.

2. Add the retaining threaded ring, and tighten gently, enough such that the diode does not move but not so much that it cannot move.

3. If using a lens tube with alignment adjustment screws, use the 5.6 mm retaining ring even for 9 mm diodes.

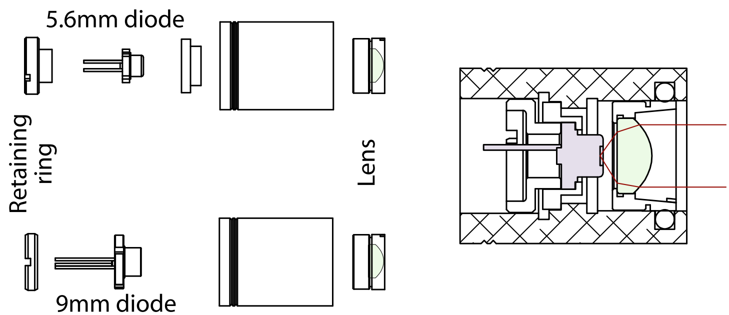

Figure 3.1: Lens tube assembly, showing diode, lens, and mounting hardware. The same tube can be used for 5.6 mm and 9 mm diodes. Note that your lens tube may have alignment adjustment screws.

Figure 3.2: Image showing collimation tubes with alignment adjustment screws.

4. Approximately centre the diode using the alignment adjustment screws and two 0.9 mm hex keys.
5. Insert the collimation lens, taking care to ensure that the lens does not contact the diode. Also ensure the lens is tight; if not, use PTFE tape on the lens threads. Two layers of thick tape (90 μm as used for gas plumbing) is usually sufficient.
6. Mount the lens tube in a holder or mount that allows rotation of the entire assembly around the long axis.
7. Apply power to the diode, above threshold but well below the maximum permissible current.

8. Approximately focus at several metres distance. It may be helpful to reflect it from a mirror and back so that you can adjust the alignment and see the effect nearby. You should adjust focus until you see a clean symmetric ellipse at this distance.

9. Rotate the collimation assembly and adjust the alignment screws until the beam remains reasonably well on-axis.

10. Adjust the alignment to optimise the laser beam spatial profile even at the expense of maintaining concentric alignment. The profile should be a symmetric ellipse with Gaussian profile along each axis.

11. Tighten the retaining ring (hard) and re-check that the beam profile remains uniform and symmetric.

12. Focus the collimation lens such that the laser focuses to a spot at some significant distance, more than 4 m. The laser stability and modehop free range can be better if the laser output is weakly converging [2].

3.2 Initial diode test

1. Inspect the beam profile for diffraction fringes. If the lens has been screwed in too far and made contact with the diode (particularly for 5.6 mm diodes), the lens can become scratched or stressed, leading to poor performance. Fringes can be an indication of such scratches (or an indication of a poor diode).

2. On the MOGLabs DLC controller, make sure DIP switch 4 (Bias) is OFF, the span is set to zero (fully anti-clockwise), and the frequency knob is at zero (middle of range; set the display selector to Frequency and adjust to zero volts).

3. Measure the power/current (*PI*) curve for the bare collimated diode. This provides a useful benchmark for comparison when optimising the threshold lowering with feedback.

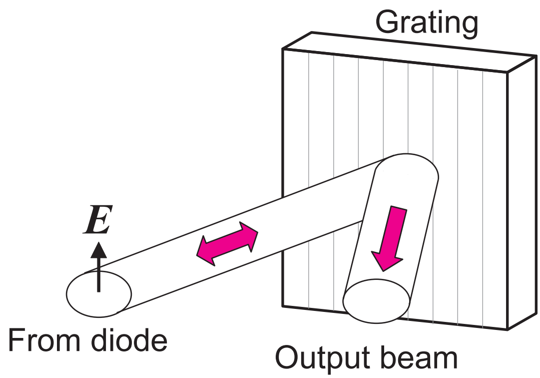

Figure 3.3: Orientation of the diode laser beam ellipse with respect to the diffraction grating.

3.3 Orientation and polarisation of the output beam

The output from the diode is a widely diverging *elliptical* beam. The grating dispersion (i.e. frequency selectivity) increases with the number of rulings illuminated by the light: $\Delta\lambda/\lambda \propto 1/N$ where N is the number of grating lines illuminated. The ellipse is therefore typically oriented with the major axis perpendicular to the grating rulings. For the MOGLabs ECDL, the grating rulings are vertical and so the elliptical beam should have the major axis horizontal (see Fig. 3.3), for most laser diodes which operate in TE mode.

The diode laser polarisation is *usually* parallel to the *short* (minor) axis of the ellipse. Thus, for the orientation described above, the polarisation is parallel to the grating rulings. However, the grating feedback efficiency is larger when the polarisation of the incident light is *perpendicular* to the grating rulings, so for the arrangement shown, the diffraction efficiency is small (typically around 15%). While low efficiency might seem undesirable, 15% is usually sufficient for single-mode operation of the laser, and the high percentage of non-diffracted light is directly reflected to provide the maximum possible power in the output laser beam.

3.4 Alignment

The horizontal and vertical angles of the grating, and the lens focus, must be adjusted so that the diffracted beam propagates back into the exit facet of the diode, so that the external cavity dominates the optical feedback. When aligned, the external cavity feedback overrides the feedback from the front facet of the diode itself, so that the laser frequency is determined by the external cavity. The feedback alignment is optimised by setting the diode current just below threshold, and then adjusting the vertical alignment until the output suddenly flashes brightly, indicating effective feedback which tends to lower the overall ECDL gain threshold.

The feedback is optimised by aligning the beam from the laser diode, to the grating and back to the diode. The vertical angle of the beam is adjusted to minimise the lasing threshold current.

The laser diode tube is mounted into a rotatable cylindrical mount (see fig. 3.4). The cylindrical mount can be rotated using a fine adjustment

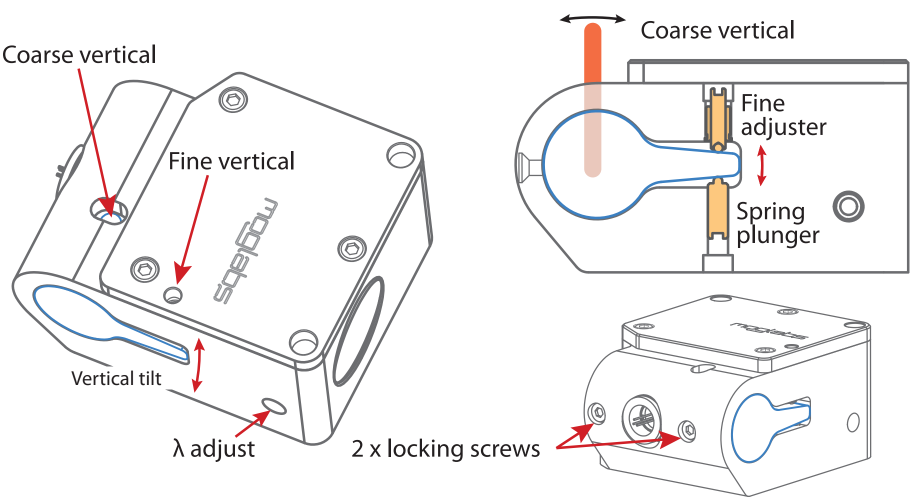

Figure 3.4: Sketch showing location of vertical alignment adjustments: a fine adjustment screw, and for coarse adjustment, a 5 mm diameter hole in which a screwdriver can be inserted.

screw acting against a lever arm and a spring plunger that pushes back against the fine adjustment screw, or a screwdriver or ball driver can be insderted into a 5 mm diameter hole in the top of the cylinder for coarse adjustment. Two locking screws at the rear of the laser clamp the cylinder; these can be released slightly to make adjustments, and tightened when satisfactory alignment is achieved.

The sequence is as follows:

1. Insert the lens tube into the laser cavity.
2. Project the output beam onto a piece of black card at a distance of about 30 cm from the laser. Monitor this beam spot using a video camera such as a webcam.
3. Rotate the lens tube so that the elliptical profile of the output beam is horizontal (for TE polarised laser diodes).
4. Adjust the diode current well above threshold, and search for a secondary output beam caused by the diffracted light propagating back into the diode and then reflecting from the rear of the diode back to the screen. Try adjusting the vertical alignment to see a spot moving up and down “faster” than the main output beam.
5. Align the reflection of the return beam so that the two spots are centred horizontally, but displaced vertically.
6. Adjust the vertical alignment until the secondary beam is colinear with the primary. The laser should significantly brighten or “flash” when the grating feedback is aligned back into the diode.
7. Adjust the injection current to just below threshold.
8. Adjust the vertical alignment and grating angle (wavelength) until flash (i.e. lasing).
9. Iterate reduction of the injection current, following by alignment until lasing occurs, until the minimum threshold is achieved.

The grating wavelength (horizontal angle) should then match the diode free-running wavelength.

10. If the threshold is not significantly lower (at least a few mA), remove the lens tube and adjust the focus of the collimation lens, being careful not to touch the surface of the lens. Usually the lens should be moved slightly closer to the diode, clockwise when viewed from the lens side, if the lens was previously set to focus some distance from the laser.

11. Iterate until threshold lowering is significant.

    Note that there is a compromise here. At minimum threshold, feedback is optimised giving the narrowest linewidth. However, then the overlap of the back-reflected beam with the laser output facet is quite critical, which can reduce the mode-hop-free scan range and make the laser more sensitive to acoustic vibrations. It is generally easier to have a weakly focusing beam.

12. Increase the current to well above threshold, check the laser wavelength, and adjust the grating angle if required. The wavelength adjustment is about 8 nm per full turn, i.e. 0.1 turns per nm, and clockwise is to increase wavelength.

    Note that if the wavelength of maximum gain is far from the desired wavelength, it may be a good idea to change the operating temperature to reduce that gap, before proceeding.

13. Adjust the vertical alignment to minimise the threshold.

14. If possible, scan the laser through an atomic resonance and view the absorption on an oscilloscope. With current bias disabled (DIP 4 on a MOGLabs controller) and full span, the pattern should repeat several times as the laser scans over a short range and then mode-hops. A Fabry-Perot etalon or a fast high-resolution wavemeter (e.g. MOGLabs MWM002, FWM001) can also be used to optimise the mode-hop-free range.

15. Adjust the alignment and grating angle, and the injection current, to optimise the scans so that you see the maximum number of repeats and the deepest signals.

16. Check that there is only one significant output beam (i.e. that the laser is running single-mode).

17. Check that the saturated absorption traces are clean. Noisy spectra indicate multi-mode operation, or high linewidth, which may be due to weak feedback. The feedback depends on the collimation lens focus. The lasing threshold is a good diagnostic: lower threshold indicates better feedback and consequently lower linewidth, at the expense of sensitivity. A noisy spectrum can also be due to extreme sensitivity to acoustic disturbance, or to external feedback.

    A scanning Fabry-Perot is a very useful diagnostic tool to check for single-mode operation.

18. Measure the laser output power as a function of diode injection current, and plot the power/current response as in Fig. 2.1.

19. Switch the current bias (DIP switch 4) back on, and adjust the bias to optimise the mode-hop-free scan range.

The laser should now be operating with grating controlled feedback near the desired wavelength of the diode. The threshold current should be significantly lower than without feedback (2 to 5 mA for standard 780 nm diodes). Record the output power and threshold characteristics for subsequent reference.

4. Operation

Figure 4.1 is a schematic of the monolithic laser cavity. Normal operation of the laser is usually a matter of selecting the correct wavelength, and adjusting the parameters to achieve the maximum possible mode-hop free scan.

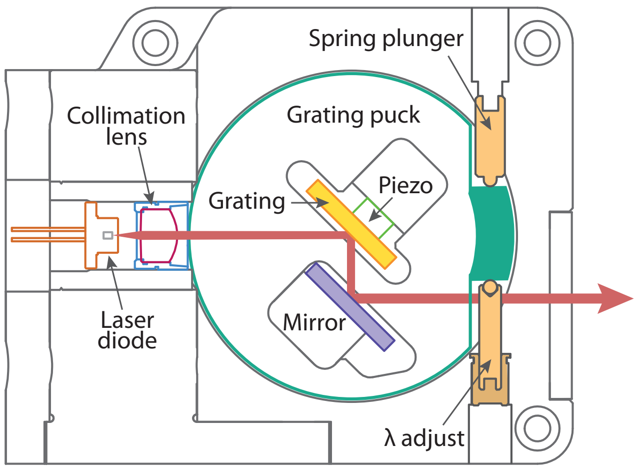

Figure 4.1: Cross-section sketch of the MOGLabs LDL, showing the cylindrical grating mount (puck), piezo-mounted grating, fold mirror, and wavelength adjustment. The grating mount can be rotated using the tangential λ fine adjustment screw. A counteracting spring-plunger should be released to allow rotation.

4.1 Wavelength

The primary control of wavelength is the grating angle, which can be adjusted while the laser is operational. A wavemeter [8], high-resolution spectrometer, or similar is almost essential, although with patience it is possible to find an atomic reference by carefully adjusting the grating angle while scanning the laser.

Note that the wavelength is quite sensitive to grating angle. For example, with the standard $\lambda = 780\,\text{nm}$, $1/d = 1800\,\text{l/mm}$ grating, the angular dependence is about 14 nm per degree of grating angle. With the LDL, that is 8 nm per full turn of the wavelength adjustment screw.

Set the laser current so that the output power is sufficient, taking care to ensure that the internal cavity power is below the maximum rated for the diode (see Fig. 2.1). Then change the grating angle to adjust the wavelength. The laser will hop between external cavity modes, as the wavelength is adjusted, through cycles of dim and bright output. Adjust the angle to one of the bright modes nearest the optimum wavelength, and then adjust the laser current and the piezo voltage to achieve the exact wavelength required.

It may then be necessary to adjust the vertical alignment slightly; follow the flash procedure outlined previously. That is, set the injection current just below threshold, and adjust the vertical alignment until the laser flashes, and repeat until the threshold current is minimised.

4.2 Scanning

With the MOGLabs LDL model, the piezo actuator translates the grating without significant rotation, thus controlling the cavity length alone. For a large frequency change, the laser will inevitably hop to a neighbouring cavity mode (see Fig. 4.2).

The continuous scan range (free of mode hops) can be optimised by careful adjustment of the injection current, which affects the refractive index of the diode semiconductor and hence the frequency of the cavity mode.

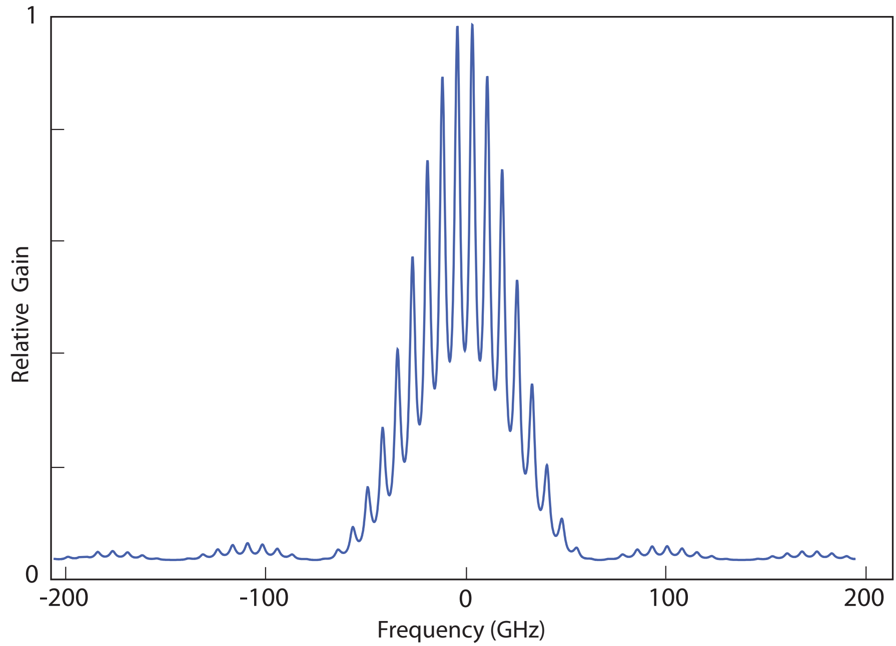

Figure 4.2: Combined gain for an external cavity diode laser, including the internal and external modes, the diode laser gain, and the diffraction grating dispersion, from Ref. [1]. The predominant feature is the frequency selectivity of the diffraction grating, and the smaller peaks are the external cavity modes (see Fig. 1.4). A small relative shift of the external cavity mode relative to the grating frequency will cause the laser to jump to another external cavity mode where the net gain is higher.

This shift of cavity mode frequency allows for compensation of the mismatch of tuning responses. The diode injection current can be "automatically" adjusted as the laser frequency is changed, using a "feed-forward" or current bias which changes as the piezo voltage is changed. Feed-forward current bias adjustment is a feature of MOGLabs DLC controllers. Adjustment is straightforward. The laser frequency is scanned with a ramp voltage to the piezo, and the current 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.

4.3 External modulation

The laser diode injection current can be modulated directly, or via the SMA RF input on the laser headboard (see section B.4). The combined modulation bandwidth extends from DC to about 2.5 GHz, provided the standard connection from headboard to diode is replaced with a suitable coaxial cable. Even higher frequencies can be used with addition of an appropriate microwave bias-tee such as the Minicircuits ZFBT-6G+, between the laser headboard and the diode.

Direct modulation is commonly used for frequency stabilisation, e.g. the frequency modulation sideband method [9, 10], Pound-Drever-Hall [11], and also for offset locking schemes [12, 13]. Microwave modulation is often used for two-frequency pumping of alkali atoms, for example to access both a laser cooling transition and a repump to prevent trapping in dark states [14, 15, 1].

The modulation efficiency can be enhanced by matching the external cavity length to the modulation frequency. That is, set the cavity length $L = c/2\Omega$ where Ω is the modulation frequency. The cavity length can be adjusted slightly by sliding the collimation tube in the monolithic block. For example, to access the ^{87}Rb hyperfine ground states, separated by 6.8 GHz, the cavity length could be 2.2 cm and the modulation at 6.8 GHz, or 4.4 cm with modulation at 3.4 GHz so that the two sidebands are used and the carrier is off-resonant.

A. Specifications

Parameter	Specification
Wavelength/frequency	
370 – 1620 nm	Depending on diode. Up to 200 mW at 780 nm output power available. Please contact MOGLabs for availability.
Linewidth	Typically < 200 kHz FWHM
Grating	Standard: 1800 l/mm holographic Au
Tuning range	Up to 100 nm, depending on diode
Sweep/scan	
Scan range	40 GHz typical
Mode-hop free	> 10 GHz; up to 40 GHz (780 nm, uncoated diode)
Piezo stack	4.5 μm @ 150 V, 310 nF
Cavity length	25 – 30 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 10 kΩ standard; AD590, 592 optional
Stability at base	±1 mK (controller dependent)
Cooling	4 mm diam quick-fit water cooling connections
Electronics	
Protection	Diode short-circuit relay; cover interlock connection; reverse diode
Indicator	Laser ON/OFF (LED)
Modulation input	Active (AC and DC coupled) or RF bias tee
Connector	MOGLabs DLC Diode Laser Controller single cable connect
Mechanical & power	
Dimensions	110 × 90 × 90 mm (L×W×H), 1 kg
Shipping	420 × 360 × 260 mm (L×W×H), 3.1 kg

A.1 Mechanical

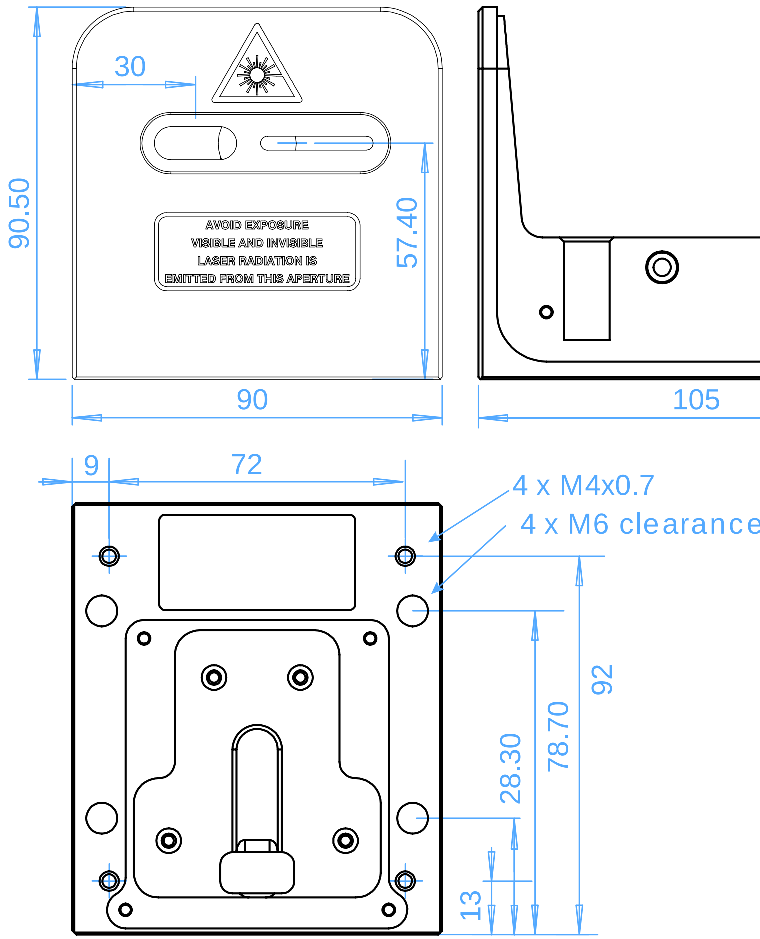

Figure A.1: Dimensions of LDL laser head.

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 solid-state protection relay and passive protection filters, a laser-on LED indicator, and an SMA connection for direct diode current modulation. The connections are made with Hirose DF59 "swing-lock" wire-to-board connectors.

Several versions of the laser headboard are available. Recent lasers have shipped with the B1047 headboard which 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 increases bandwidth and reduces phase delay, easily achieving sub-Hz linewidth narrowing. For RF modulation, a B1045 is available. The B1045 includes 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. For high bandwidth RF modulation the diode can be directly soldered to a special interconnect assembly available from MOGLabs.

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.4 below).

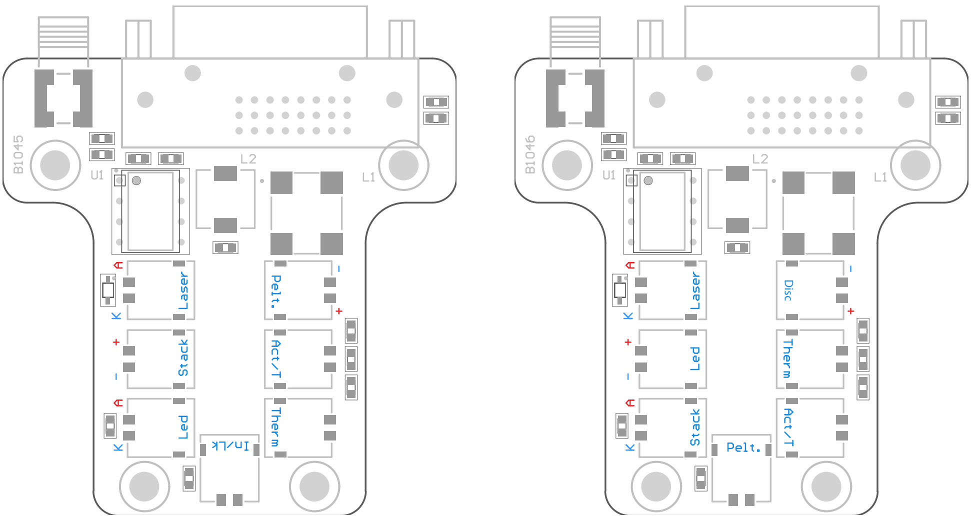

Figure B.1: MOGLabs B1045 and B1046 laser head boards showing connectors for laser diode, piezo actuator, temperature sensors, TEC and head enclosure interlock.

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). The latter makes it particularly easy to achieve 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.

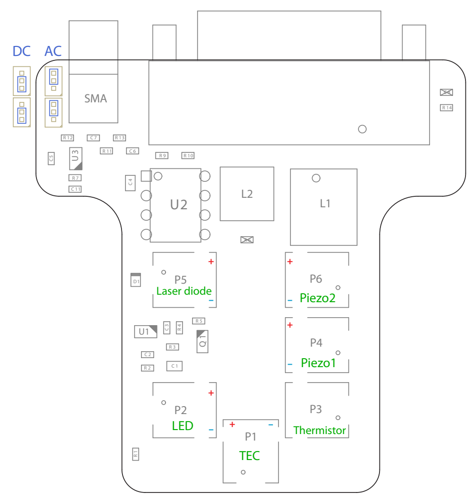

Figure B.2: B1047 enhanced laser head board. Jumpers at top left can be configured for AC or DC coupling. Modulation input via SMA connector, sensitivity 2.5 mA/V. The B1240 is almost identical but has an additional jumper for direct or differential ground coupling adjacent to U2.

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)
Phase delay	40 ns	$<$ 20 ns (direct) $<$ 30 ns (buffered)
Gain bandwidth (−3 dB)	3 MHz	20 MHz
Input impedance	5 k	1 k
Current gain	1 mA/V	1 mA/V
Laser diode voltage	10 V max	2.5 V max

B.3 Laser connection

The MOGLabs cable can be replaced with a standard digital DVI-D Dual cable. There is a bewildering assortment of apparently similar cables available; only high quality dual-link digital DVI-D cables should be used.

WARNING: The LASER connector is a standard DVI-D Dual Link socket as used for consumer digital display devices. It should only be connected to the corresponding MOGLabs DLC controller. It supplies the high-voltage signals to drive the laser piezoelectric actuators. The piezo drivers will be disabled if the cable is disconnected, but nevertheless considerable care should be taken to ensure that non-MOGLabs devices are not connected via this connector.

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	AD590/592 –	14	Relay GND	22	
7	AD590/592 +	15	Relay +5V	23	NTC –
8		16	Interlock +5V	24	NTC +

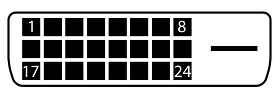

Figure B.3: LASER connector.

B.4 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 fig. B.4). 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 k. The sensitivity depends on the diode impedance but is now typically around 1 mA/V.

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

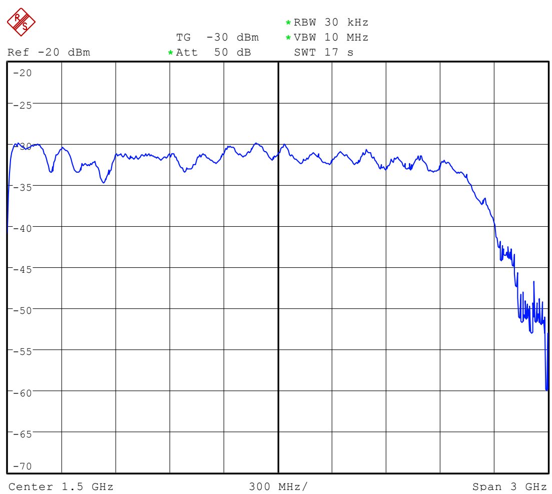

Figure B.4: RF response, SMA input on laser headboard to diode SMA output.

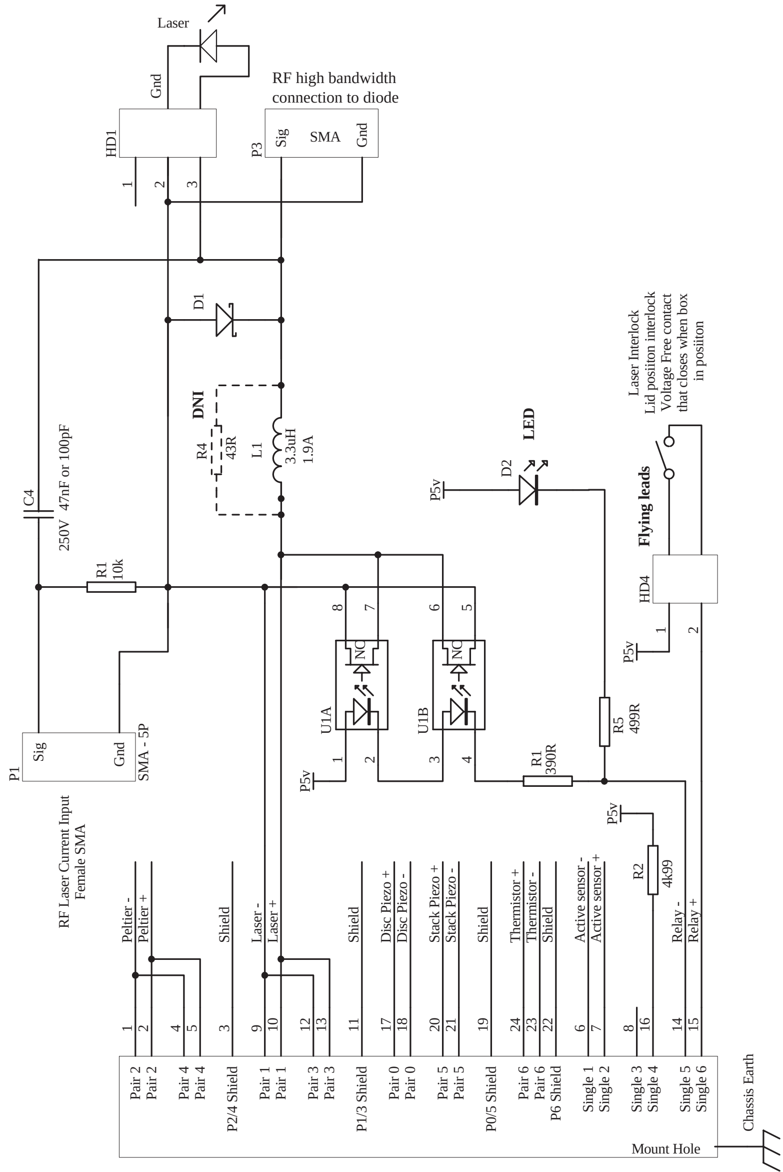

Figure B.5: MOGLabs DLC laser head board schematic (B1040/1045). The RF modulation low-pass cutoff frequency is determined by C4 and the diode impedance ($\sim 50\Omega$).

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