

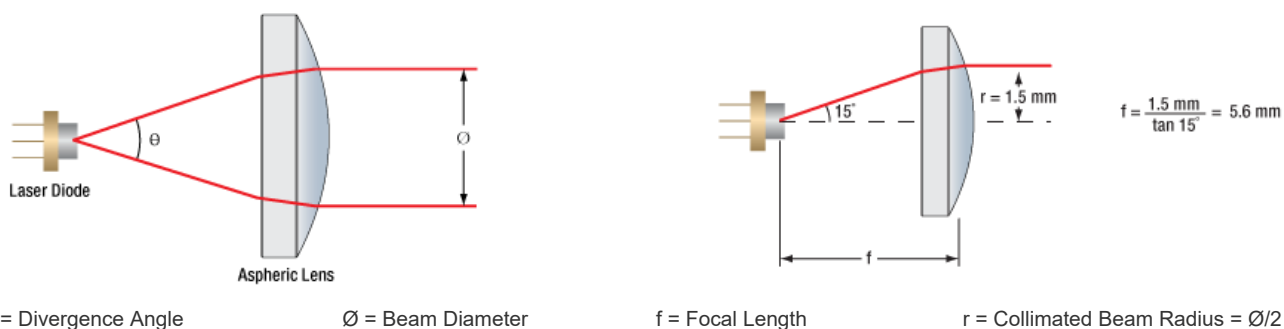
Since the output of a laser diode is highly divergent, collimating optics are necessary. Aspheric lenses do not introduce spherical aberration and are therefore commonly chosen when the collimated laser beam is to be between one and five millimeters. A simple example will illustrate the key specifications to consider when choosing the correct lens for a given application. The second example below is an extension of the procedure, which will show how to circularize an elliptical beam.

Example 1: Collimating a Diverging Beam

- Laser Diode to be Used: L780P010
- Desired Collimated Beam Diameter: Ø3 mm (Major Axis)

When choosing a collimation lens, it is essential to know the divergence angle of the source being used and the desired output diameter. The specifications for the L780P010 laser diode indicate that the typical parallel and perpendicular FWHM beam divergences are 8° and 30°, respectively. Therefore, as the light diverges, an elliptical beam will result. To collect as much light as possible during the collimation process, consider the larger of these two divergence angles in any calculations (i.e., in this case, use 30°). If you wish to convert your elliptical beam into a round one, we suggest using an anamorphic prism pair, which magnifies one axis of your beam; for details, see Example 2 below.

Assuming that the thickness of the lens is small compared to the radius of curvature, the thin lens approximation can be used to determine the appropriate focal length for the asphere. Assuming a divergence angle of 30° (FWHM) and desired beam diameter of 3 mm:



Note that the focal length is generally not equal to the needed distance between the light source and the lens.

With this information known, it is now time to choose the appropriate collimating lens. Thorlabs offers a large selection of aspheric lenses. For this application, the ideal lens is a molded glass aspheric lens with focal length near 5.6 mm and our -B antireflection coating, which covers 780 nm. The C171TMD-B (mounted) or 354171-B (unmounted) aspheric lenses have a focal length of 6.20 mm, which will result in a collimated beam diameter (major axis) of 3.3 mm. Next, check to see if the numerical aperture (NA) of the diode is smaller than the NA of the lens:

$$0.30 = \text{NA}_{\text{Lens}} > \text{NA}_{\text{Diode}} \approx \sin(15^\circ) = 0.26$$

Up to this point, we have been using the full-width at half maximum (FWHM) beam diameter to characterize the beam. However, a better practice is to use the $1/e^2$ beam diameter. For a Gaussian beam profile, the $1/e^2$ diameter is almost equal to 1.7X the FWHM diameter. The $1/e^2$ beam diameter therefore captures more of the laser diode's output light (for greater power delivery) and minimizes far-field diffraction (by clipping less of the incident light).

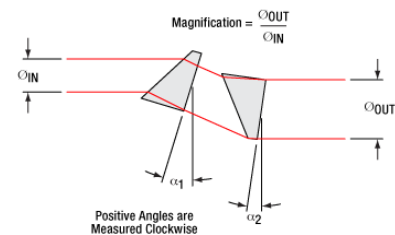
A good rule of thumb is to pick a lens with an NA twice that of the laser diode NA. For example, either the A390-B or the A390TM-B could be used as these lenses each have an NA of 0.53, which is more than twice the approximate NA of our laser diode (0.26). These lenses each have a focal length of 4.6 mm, resulting in an approximate major beam diameter of 2.5 mm. In general, using a collimating lens with a short focal length will result in a small collimated beam diameter and a large beam divergence, while a lens with a large focal length will result in a large collimated beam diameter and a small divergence.

Example 2: Circularizing an Elliptical Beam

Using the laser diode and aspheric lens chosen above, we can use an anamorphic prism pair to convert our collimated, elliptical beam into a circular beam.

Whereas earlier we considered only the larger divergence angle, we now look at the smaller beam divergence of 8°. From this, and using the effective focal length of the A390-B aspheric lens chosen in Example 1, we can determine the length of the semi-minor axis of the elliptical beam after collimation:

$$r' = f * \tan(\Theta'/2) = 4.6 \text{ mm} * \tan(4^\circ) = 0.32 \text{ mm}$$



The minor beam diameter is double the semi-minor axis, or 0.64 mm. In order to magnify the minor diameter to be equal to the major diameter of 2.5 mm, we will need an anamorphic prism pair that yields a magnification of 3.9. Thorlabs offers both mounted and unmounted prism pairs. Mounted prism pairs provide the benefit of a stable housing to preserve alignment, while unmounted prism pairs can be positioned at any angle to achieve the exact desired magnification.

The PS883-B mounted prism pair provides a magnification of 4.0 for a 950 nm wavelength beam. Because shorter wavelengths undergo greater magnification when passing through the prism pair, we can expect our 780 nm beam to be magnified by slightly more than 4.0X. Thus, the beam will still maintain a small degree of ellipticity.

Alternatively, we can use the PS871-B unmounted prism pair to achieve the precise magnification of the minor diameter necessary to produce a circular beam. Using the data available here, we see that the PS871-B achieves a magnification of 4.0 when the prisms are positioned at the following angles for a 670 nm wavelength beam:

$$\alpha_1: +34.608^\circ \quad \alpha_2: -1.2455^\circ$$

Refer to the diagram to the right for α_1 and α_2 definitions. Our 780 nm laser will experience slightly less magnification than a 670 nm beam passing through the prisms at these angles. Some trial and error may be required to achieve the exact desired magnification. In general:

- To increase magnification, rotate the first prism clockwise (increasing α_1) and rotate the second prism counterclockwise (decreasing α_2).
- To reduce magnification, rotate the first prism counterclockwise (decreasing α_1) and rotate the second prism clockwise (increasing α_2).

Remember that the prism pair introduces a linear offset between the input and output beams which increases with greater magnification.

LD OPERATION

Video Insight: Setting Up a TO Can Laser Diode

Installing a TO can laser diode in a mount and setting it up to run under temperature and current control presents many opportunities to make a mistake that could damage or destroy the laser. This step-by-step guide includes tips for keeping humans and laser diodes safe from harm.

When operated within their specifications, laser diodes have extremely long lifetimes. Most failures occur from mishandling or operating the lasers beyond their maximum ratings. Laser diodes are among the most static-sensitive devices currently made and proper ESD protection should be worn whenever handling a laser diode. Due to their extreme electrostatic sensitivity, laser diodes cannot be returned after their sealed package has been opened. Laser diodes in their original sealed package can be returned for a full refund or credit.

Handling and Storage Precautions

Because of their extreme susceptibility to damage from electrostatic discharge (ESD), care should be taken whenever handling and operating laser diodes.

Wrist Straps

Use grounded anti-static wrist straps whenever handling diodes.

Anti-Static Mats

Always work on grounded anti-static mats.

Laser Diode Storage

When not in use, short the leads of the laser together to protect against ESD damage.

Operating and Safety Precautions

Use an Appropriate Driver

Laser diodes require precise control of operating current and voltage to avoid overdriving the laser. In addition, the laser driver should provide protection against power supply transients. Select a laser driver appropriate for your application. **Do not use a voltage supply with a current-limiting resistor** since it does not provide sufficient regulation to protect the laser diode.

Power Meters

When setting up and calibrating a laser diode with its driver, use a NIST-traceable power meter to precisely measure the laser output. It is usually safest to measure the laser diode output directly before placing the laser in an optical system. If this is not possible, be sure to take all optical losses (transmissive, aperture stopping, etc.) into consideration when determining the total output of the laser.

Reflections

Flat surfaces in the optical system in front of a laser diode can cause some of the laser energy to reflect back onto the laser's monitor photodiode, giving an erroneously high photodiode current. If optical components are moved within the system and energy is no longer reflected onto the monitor photodiode, a constant-power feedback loop will sense the drop in photodiode current and try to compensate by increasing the laser drive current and possibly overdriving the laser. Back reflections can also cause other malfunctions or damage to laser diodes. To avoid this, be sure that all surfaces are angled 5-10°, and when necessary, use optical isolators to attenuate direct feedback into the laser.

Heat Sinks

Laser diode lifetime is inversely proportional to operating temperature. Always mount the laser diode in a suitable heat sink to remove excess heat from the laser package.

Voltage and Current Overdrive

Be careful not to exceed the maximum voltage and drive current listed on the specification sheet with each laser diode, even momentarily. Also, reverse voltages as little as 3 V can damage a laser diode.

ESD-Sensitive Device

Laser diodes are susceptible to ESD damage even during operation. This is particularly aggravated by using long interface cables between the laser diode and its driver due to the inductance that the cable presents. Avoid exposing the laser diode or its mounting apparatus to ESD at all times.

ON/OFF and Power-Supply-Coupled Transients

Due to their fast response times, laser diodes can be easily damaged by transients less than 1 μ s. High-current devices such as soldering irons, vacuum pumps, and fluorescent lamps can cause large momentary transients, and thus surge-protected outlets should always be used when working with laser diodes.

If you have any questions regarding laser diodes, please contact Thorlabs Technical Support for assistance.

L A S E R S A F E T Y

Laser Safety and Classification

Safe practices and proper usage of safety equipment should be taken into consideration when operating lasers. The eye is susceptible to injury, even from very low levels of laser light. Thorlabs offers a range of laser safety accessories that can be used to reduce the risk of accidents or injuries. Laser emission in the visible and near infrared spectral ranges has the greatest potential for retinal injury, as the cornea and lens are transparent to those wavelengths, and the lens can focus the laser energy onto the retina.

Safe Practices and Light Safety Accessories

- Laser safety eyewear must be worn whenever working with Class 3 or 4 lasers.
- Regardless of laser class, Thorlabs recommends the use of laser safety eyewear whenever working with laser beams with non-negligible powers, since metallic tools such as screwdrivers can accidentally redirect a beam.
- Laser goggles designed for specific wavelengths should be clearly available near



laser setups to protect the wearer from unintentional laser reflections.


- Goggles are marked with the wavelength range over which protection is afforded and the minimum optical density within that range.
- Laser Safety Curtains and Laser Safety Fabric shield other parts of the lab from high energy lasers.
- Blackout Materials can prevent direct or reflected light from leaving the experimental setup area.
- Thorlabs' Enclosure Systems can be used to contain optical setups to isolate or minimize laser hazards.
- A fiber-pigtailed laser should always be turned off before connecting it to or disconnecting it from another fiber, especially when the laser is at power levels above 10 mW.
- All beams should be terminated at the edge of the table, and laboratory doors should be closed whenever a laser is in use.
- Do not place laser beams at eye level.
- Carry out experiments on an optical table such that all laser beams travel horizontally.
- Remove unnecessary reflective items such as reflective jewelry (e.g., rings, watches, etc.) while working near the beam path.
- Be aware that lenses and other optical devices may reflect a portion of the incident beam from the front or rear surface.
- Operate a laser at the minimum power necessary for any operation.
- If possible, reduce the output power of a laser during alignment procedures.
- Use beam shutters and filters to reduce the beam power.
- Post appropriate warning signs or labels near laser setups or rooms.
- Use a laser sign with a lightbox if operating Class 3R or 4 lasers (i.e., lasers requiring the use of a safety interlock).
- Do not use Laser Viewing Cards in place of a proper Beam Trap.



Laser Classification

Lasers are categorized into different classes according to their ability to cause eye and other damage. The International Electrotechnical Commission (IEC) is a global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The IEC document 60825-1 outlines the safety of laser products. A description of each class of laser is given below:

Class	Description	Warning Label
1	This class of laser is safe under all conditions of normal use, including use with optical instruments for intrabeam viewing. Lasers in this class do not emit radiation at levels that may cause injury during normal operation, and therefore the maximum permissible exposure (MPE) cannot be exceeded. Class 1 lasers can also include enclosed, high-power lasers where exposure to the radiation is not possible without opening or shutting down the laser.	CLASS 1 LASER PRODUCT
1M	Class 1M lasers are safe except when used in conjunction with optical components such as telescopes and microscopes. Lasers belonging to this class emit large-diameter or divergent beams, and the MPE cannot normally be exceeded unless focusing or imaging optics are used to narrow the beam. However, if the beam is refocused, the hazard may be increased and the class may be changed accordingly.	LASER RADIATION DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 1M LASER PRODUCT
2	Class 2 lasers, which are limited to 1 mW of visible continuous-wave radiation, are safe because the blink reflex will limit the exposure in the eye to 0.25 seconds. This category only applies to visible radiation (400 - 700 nm).	LASER RADIATION DO NOT STARE INTO BEAM CLASS 2 LASER PRODUCT
2M	Because of the blink reflex, this class of laser is classified as safe as long as the beam is not viewed through optical instruments. This laser class also applies to larger-diameter or diverging laser beams.	LASER RADIATION DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 2M LASER PRODUCT
3R	Class 3R lasers produce visible and invisible light that is hazardous under direct and specular-reflection viewing conditions. Eye injuries may occur if you directly view the beam, especially when using optical instruments. Lasers in this class are considered safe as long as they are handled with restricted beam viewing. The MPE can be exceeded with this class of laser; however, this presents a low risk level to injury. Visible, continuous-wave lasers in this class are limited to 5 mW of output power.	LASER RADIATION AVOID EXPOSURE TO BEAM CLASS 3R LASER PRODUCT
3B	Class 3B lasers are hazardous to the eye if exposed directly. Diffuse reflections are usually not harmful, but may be when using higher-power Class 3B lasers. Safe handling of devices in this class includes wearing protective eyewear where direct viewing of the laser beam may occur. Lasers of this class must be equipped with a key switch and a safety interlock; moreover, laser safety signs should be used, such that the laser cannot be used without the safety light turning on. Laser products with power output near the upper range of Class 3B may also cause skin burns.	LASER RADIATION AVOID EXPOSURE TO BEAM CLASS 3B LASER PRODUCT
	This class of laser may cause damage to the skin, and also to the eye, even from the viewing of diffuse reflections. These hazards	

4	may also apply to indirect or non-specular reflections of the beam, even from apparently matte surfaces. Great care must be taken when handling these lasers. They also represent a fire risk, because they may ignite combustible material. Class 4 lasers must be equipped with a key switch and a safety interlock.	
	All class 2 lasers (and higher) must display, in addition to the corresponding sign above, this triangular warning sign.	