

P10C - July 20, 2021

Item # P10C was discontinued on July 20, 2021. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

PRECISION PINHOLES, GOLD-PLATED COPPER FOILS

- ▶ Pinholes in Ø10, Ø25, or Ø50 µm Sizes
- ▶ Gold-Plated Copper Foils in Ø1" Aluminum Housings
- ▶ High Damage Threshold Useful for High-Power Applications



P10C
Ø10 µm Pinhole

P25C
Ø25 µm Pinhole

P50C
Ø50 µm Pinhole

OVERVIEW

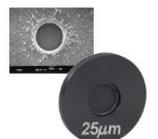
Features

- Precision Pinholes in Copper Foils
 - Gold Plated (96% Reflectivity @ 800 nm) on One Side
 - Black-Oxide Coated on the Reverse Side
- Ø10, Ø25, or Ø50 µm Aperture
- 25 µm Thickness at Aperture
- Mounted in Ø1" Black-Anodized Aluminum Housings
- High Damage Threshold:
 - 5 x 10⁵ W/mm², 75 ns Pulse @ 700 nm
 - 1 x 10⁶ W/mm², 10 ns Pulse @ 700 nm
 - 10 W/mm², CW @ 10.6 µm

Item #	Pinhole Diameter	Diameter Tolerance	Pinhole Thickness	Housing Material
P10C	10 µm	±1 µm	25 µm (0.001")	6061-T6 Aluminum
P25C	25 µm	±2 µm		
P50C	50 µm	±3 µm		

Apertures Selection Guide
Single Precision Pinholes
Circular in Stainless Steel Foils
Circular in Tungsten Foils
Circular in Gold-Plated Copper Foils
Square in Stainless Steel Foils
Pinhole Wheels
Manual
Motorized
Pinhole Spatial Filter
Slits
Annular Apertures
Alignment Tools

Single, mounted, precision pinholes offer small optical apertures for applications such as alignment, beam conditioning, and imaging. The pinholes offered here use copper foils with gold plating on one side and a black-oxide coating on the reverse. They are available with Ø10 µm, Ø25 µm, or Ø50 µm apertures and are mounted in Ø1/2" or Ø1" black-anodized aluminum housings. The foil can be taken out of the housing by removing the retaining ring using a small tweezer or pliers; use care as the foil is very thin. We also offer pinholes with a variety of other foil materials; see the table to the right for options.



These mounted precision pinholes are designed to withstand high power densities and should be used with the beam incident on the gold-plated side. We recommend aligning the pinhole at low power, increasing the laser to full power after ensuring good throughput.

[Click to Enlarge
Black-Oxide-Coated
Surface of High-Power
Mounted Pinhole](#)

For many applications, such as holography, spatial intensity variations in the laser beam are unacceptable. Using precision pinholes in conjunction with positioning and focusing equipment such as our KT310(/M) Spatial Filter System creates a "noise" filter, effectively stripping variations in intensity out of a Gaussian beam. Please see the *Tutorial* tab for more information on spatial filters.

Precision Pinhole Options

Thorlabs' precision pinholes are available with an assortment of foil materials and coatings. The choice of a particular size and material should depend on the application. Low-power applications may benefit more from the absorbance of blackened stainless steel foils, while high-power applications may need the high damage threshold and reflectivity of gold-plated copper foils or the high melting point and lower reflectivity of our tungsten foils. Please see the *Material Properties* tab for more information.

In addition to single pinholes, Thorlabs also offers pinhole wheels that contain 16 radially-spaced pinholes that are lithographically etched onto a chrome-plated fused silica substrate. These wheels allow the user to test multiple pinhole sizes within a setup.

If you do not see what you need among our stock pinhole offerings, it is possible to special order pinholes that are fabricated from different substrate materials, have different pinhole sizes, incorporate multiple holes in one foil, or provide different pinhole configurations. Customized pinhole housings are also available. Please contact Tech Support to discuss your specific needs.

FOIL MATERIALS

Precision Pinholes and Slits

Thorlabs offers precision pinholes with blackened stainless steel, tungsten, or gold-plated copper foils. Our pinholes with stainless steel foils are blackened on both sides for increased absorbance and are available from stock in circles from $\varnothing 1 \mu\text{m}$ to $\varnothing 2 \text{mm}$ and squares from $100 \mu\text{m} \times 100 \mu\text{m}$ to $1 \text{mm} \times 1 \text{mm}$. Our pinholes with tungsten foils are uncoated and available with pinhole diameters from $5 \mu\text{m}$ to 2mm . Lastly, our pinholes with gold-plated copper foils, plated with gold on one side and black-oxide coated on the reverse, are offered in $10 \mu\text{m}$, $25 \mu\text{m}$, or $50 \mu\text{m}$ diameters. We also offer slits in blackened stainless steel foils from stock with slit widths from 5 to $200 \mu\text{m}$.

If you do not see what you need among our stock pinhole and slit offerings, it is also possible to special order pinholes and slits that are made with different foil materials, have different hole sizes and shapes, incorporate multiple holes in one foil, or provide different hole configurations. Please contact Tech Support to discuss your specific needs. For more information on the properties of the bulk materials from which the pinholes are fabricated, see the table below.

Material Properties

Depending on the application, it can be important to consider the material properties of the pinhole or slit. The material used to construct the aperture can have varying levels of melting point, density, and thermal conductivity, as detailed in the table below.

Material Properties			
Material	300 Series Stainless Steel ^a	Tungsten	Copper ^b
Melting Point	1390 - 1450 °C	3422 °C	1085 °C
Density	8.03 g/cm ³	19.25 g/cm ³	8.96 g/cm ³
Brinell Hardness	170 MPa	2570 MPa	878 MPa
Thermal Expansion Coefficient	16.2 (μm/m)/°C	4.5 (μm/m)/°C	16.7 (μm/m)/°C
Specific Heat @ 20 °C	485 J/(K*kg)	134 J/(K*kg)	385 J/(K*kg)
Thermal Conductivity	16.2 W/(m*K)	173 W/(m*K)	401 W/(m*K)
Thermal Diffusivity @ 300 K	3.1 mm ² /s	80 mm ² /s	111 mm ² /s

- Stainless steel pinholes and slits are blackened on both sides to increase absorbance. The material properties will be predominantly that of bulk stainless steel.
- Gold-plated copper pinholes have a thin coating of gold on one side of the bulk copper foil. With a beam incident on this side, reflectivity will be that of gold (96% @ 800 nm) while thermal properties will be predominantly copper-based.

Principles of Spatial Filters

For many applications, such as holography, spatial intensity variations in the laser beam are unacceptable. Our KT310 spatial filter system is ideal for producing a clean Gaussian beam.

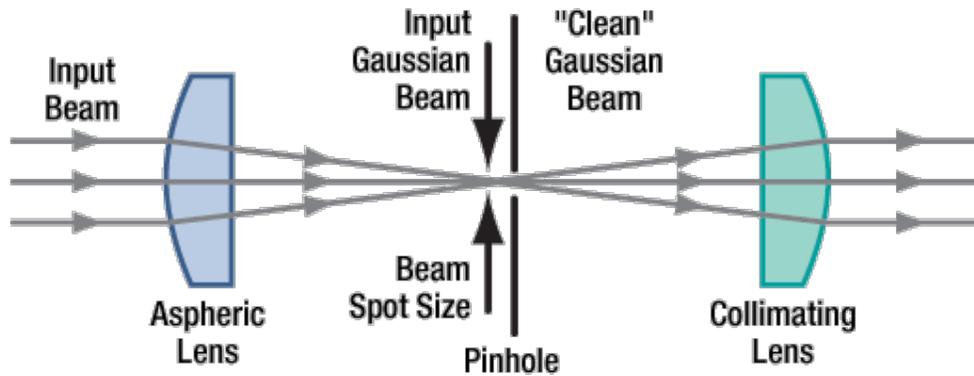


Figure 1: Spatial Filter System

The input Gaussian beam has spatially varying intensity "noise". When a beam is focused by an aspheric lens, the input beam is transformed into a central Gaussian spot (on the optical axis) and side fringes, which represent the unwanted "noise" (see Figure 2 below). The radial position of the side fringes is proportional to the spatial frequency of the "noise".

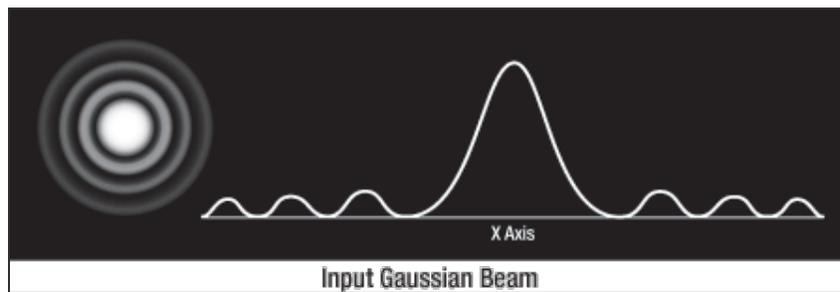


Figure 2

By centering a pinhole on a central Gaussian spot, the "clean" portion of the beam can pass while the "noise" fringes are blocked (see Figure 3 below).

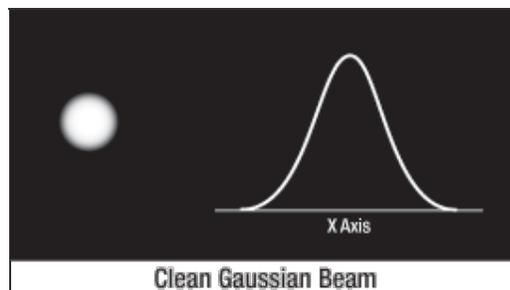


Figure 3

The diffraction-limited spot size at the 99% contour is given by:

$$D = \frac{\lambda f}{r}$$

where λ = wavelength, f =focal length and r = input beam radius at the $1/e^2$ point.

Choosing the Correct Optics and Pinhole for Your Spatial Filter System

The correct optics and pinhole for your application depend on the input wavelength, source beam diameter, and desired exit beam diameter.

For example, suppose that you are using a 650 nm diode laser source that has a diameter ($1/e^2$) of 1.2 mm and want your beam exiting the spatial filter system to be about 4.4 mm in diameter. Based on these parameters, the C560TME-B mounted aspheric lens would be an appropriate choice for the input side of spatial filter system because it is designed for use at 650 nm, and its clear aperture measures 5.1 mm, which is large enough to accommodate the entire diameter of the laser source.

The equation for diffraction limited spot size at the 99% contour is given above, and for this example, $\lambda = (650 \times 10^{-9} \text{ m})$, $f = 13.86 \text{ mm}$ for the C560TM-B, and $r = 0.6 \text{ mm}$. Substitution yields

$$D = \frac{(650 \times 10^{-9} \text{ m})(13.86 \text{ mm})}{0.6 \text{ mm}} \approx 15 \mu\text{m}$$

Diffraction-Limited Spot Size (650 nm source, Ø1.2 mm beam)

The pinhole should be chosen so that it is approximately 30% larger than D . If the pinhole is too small, the beam will be clipped, but if it is too large, more than the TEM_{00} mode will get through the pinhole. Therefore, for this example, the pinhole should ideally be 19.5 microns. Hence, we would recommend the mounted pinhole P20D, which has a pinhole size of 20 μm . Parameters that can be changed to alter the beam waist diameter, and thus the pinhole size required, include changing the input beam diameter and focal length of focusing lens. Decreasing the input beam diameter will increase the beam waist diameter. Using a longer focal length focusing lens will also increase the beam waist diameter.

Finally, we need to choose the optic on the output side of the spatial filter so that the collimated beam's diameter is the desired 4.4 mm. To determine the correct focal length for the lens, consider the following diagram in Figure 4, which is not drawn to scale. From the triangle on the left-hand side, the angle is determined to be approximately 2.48° . Using this same angle for the triangle on the right-hand side, the focal length for the plano-convex lens should be approximately 50 mm.

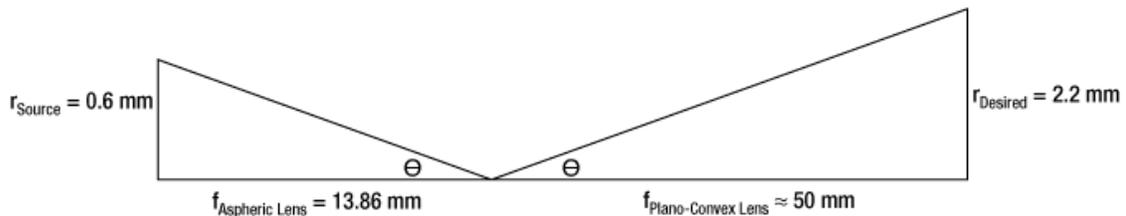


Figure 4: Beam Expansion Example

For this focal length, we recommend the LA1131-B plano-convex lens [with $f = 50 \text{ mm}$ at the design wavelength ($\lambda = 633 \text{ nm}$), this is still a good approximation for f at the source wavelength ($\lambda = 650 \text{ nm}$)].

Note: The beam expansion equals the focal length of the output side divided by the focal length of the input side.

For optimal performance, a large-diameter aspheric lens can be used in place of a plano-convex lens if the necessary focal length on the output side is 20 mm (see AL2520-A, AL2520-B, AL2520-C). These lenses are 25 mm in diameter and can be held in place using the supplied SM1RR Retaining Ring.

DAMAGE THRESHOLDS

Damage Threshold Data for Thorlabs' Gold-Plated Copper Pinholes

Damage Threshold Specifications

The specifications to the right are measured data for Thorlabs' high-power gold-plated copper pinholes.

Item #	Damage Threshold
P10C, P25C, P50C	5×10^5 W/mm ² , 75 ns Pulse @ 700 nm
	1×10^6 W/mm ² , 10 ns Pulse @ 700 nm
	10 W/mm ² , CW @ 10.6 μ m

Laser Induced Damage Threshold Tutorial

The following is a general overview of how laser induced damage thresholds are measured and how the values may be utilized in determining the appropriateness of an optic for a given application. When choosing optics, it is important to understand the Laser Induced Damage Threshold (LIDT) of the optics being used. The LIDT for an optic greatly depends on the type of laser you are using. Continuous wave (CW) lasers typically cause damage from thermal effects (absorption either in the coating or in the substrate). Pulsed lasers, on the other hand, often strip electrons from the lattice structure of an optic before causing thermal damage. Note that the guideline presented here assumes room temperature operation and optics in new condition (i.e., within scratch-dig spec, surface free of contamination, etc.). Because dust or other particles on the surface of an optic can cause damage at lower thresholds, we recommend keeping surfaces clean and free of debris. For more information on cleaning optics, please see our *Optics Cleaning* tutorial.

Testing Method

Thorlabs' LIDT testing is done in compliance with ISO/DIS 11254 and ISO 21254 specifications.

First, a low-power/energy beam is directed to the optic under test. The optic is exposed in 10 locations to this laser beam for 30 seconds (CW) or for a number of pulses (pulse repetition frequency specified). After exposure, the optic is examined by a microscope (~100X magnification) for any visible damage. The number of locations that are damaged at a particular power/energy level is recorded. Next, the power/energy is either increased or decreased and the optic is exposed at 10 new locations. This process is repeated until damage is observed. The damage threshold is then assigned to be the highest power/energy that the optic can withstand without causing damage. A histogram such as that below represents the testing of one BB1-E02 mirror.



The photograph above is a protected aluminum-coated mirror after LIDT testing. In this particular test, it handled 0.43 J/cm² (1064 nm, 10 ns pulse, 10 Hz, \varnothing 1.000 mm) before damage.

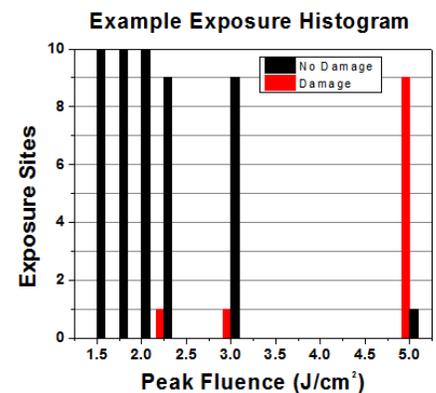
According to the test, the damage threshold of the mirror was 2.00 J/cm² (532 nm, 10 ns pulse, 10 Hz, \varnothing 0.803 mm). Please keep in mind that these tests are performed on clean optics, as dirt and contamination can significantly lower the damage threshold of a component. While the test results are only representative of one coating run, Thorlabs specifies damage threshold values that account for coating variances.

Continuous Wave and Long-Pulse Lasers

When an optic is damaged by a continuous wave (CW) laser, it is usually due to the melting of the surface as a result of absorbing the laser's energy or damage to the optical coating (antireflection) [1]. Pulsed lasers with pulse lengths longer than 1 μ s can be treated as CW lasers for LIDT discussions.

When pulse lengths are between 1 ns and 1 μ s, laser-induced damage can occur either because of absorption or a dielectric breakdown (therefore, a user must check both CW and pulsed LIDT). Absorption is either due to an intrinsic property of the optic or due to surface irregularities; thus LIDT values are only valid for optics meeting or exceeding the surface quality specifications given by a manufacturer. While many optics can handle high power CW lasers, cemented (e.g., achromatic doublets) or highly absorptive (e.g., ND filters) optics tend to have lower CW damage thresholds. These lower thresholds are due to absorption or scattering in the cement or metal coating.

Pulsed lasers with high pulse repetition frequencies (PRF) may behave similarly to CW beams. Unfortunately, this is highly dependent on factors such as absorption and



Example Test Data			
Fluence	# of Tested Locations	Locations with Damage	Locations Without Damage
1.50 J/cm ²	10	0	10
1.75 J/cm ²	10	0	10
2.00 J/cm ²	10	0	10
2.25 J/cm ²	10	1	9
3.00 J/cm ²	10	1	9
5.00 J/cm ²	10	9	1

thermal diffusivity, so there is no reliable method for determining when a high PRF laser will damage an optic due to thermal effects. For beams with a high PRF both the average and peak powers must be compared to the equivalent CW power. Additionally, for highly transparent materials, there is little to no drop in the LIDT with increasing PRF.

In order to use the specified CW damage threshold of an optic, it is necessary to know the following:

1. Wavelength of your laser
2. Beam diameter of your beam ($1/e^2$)
3. Approximate intensity profile of your beam (e.g., Gaussian)
4. Linear power density of your beam (total power divided by $1/e^2$ beam diameter)

Thorlabs expresses LIDT for CW lasers as a linear power density measured in W/cm. In this regime, the LIDT given as a linear power density can be applied to any beam diameter; one does not need to compute an adjusted LIDT to adjust for changes in spot size, as demonstrated by the graph to the right. Average linear power density can be calculated using the equation below.

$$\text{Linear Power Density} = \frac{\text{Power}}{\text{Beam Diameter}}$$

The calculation above assumes a uniform beam intensity profile. You must now consider hotspots in the beam or other non-uniform intensity profiles and roughly calculate a maximum power density. For reference, a Gaussian beam typically has a maximum power density that is twice that of the uniform beam (see lower right).

Now compare the maximum power density to that which is specified as the LIDT for the optic. If the optic was tested at a wavelength other than your operating wavelength, the damage threshold must be scaled appropriately. A good rule of thumb is that the damage threshold has a linear relationship with wavelength such that as you move to shorter wavelengths, the damage threshold decreases (i.e., a LIDT of 10 W/cm at 1310 nm scales to 5 W/cm at 655 nm):

$$\text{Adjusted LIDT} = \text{LIDT Power} \left(\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}} \right)$$

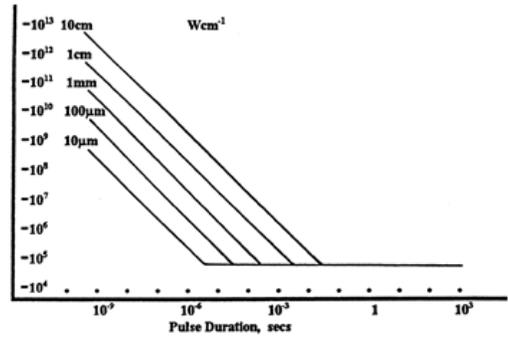
While this rule of thumb provides a general trend, it is not a quantitative analysis of LIDT vs wavelength. In CW applications, for instance, damage scales more strongly with absorption in the coating and substrate, which does not necessarily scale well with wavelength. While the above procedure provides a good rule of thumb for LIDT values, please contact Tech Support if your wavelength is different from the specified LIDT wavelength. If your power density is less than the adjusted LIDT of the optic, then the optic should work for your application.

Please note that we have a buffer built in between the specified damage thresholds online and the tests which we have done, which accommodates variation between batches. Upon request, we can provide individual test information and a testing certificate. The damage analysis will be carried out on a similar optic (customer's optic will not be damaged). Testing may result in additional costs or lead times. Contact Tech Support for more information.

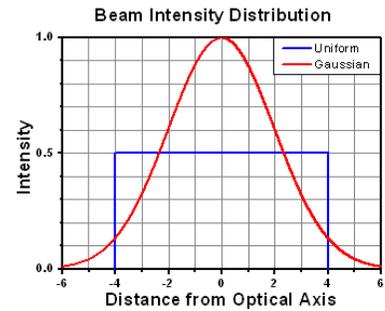
Pulsed Lasers

As previously stated, pulsed lasers typically induce a different type of damage to the optic than CW lasers. Pulsed lasers often do not heat the optic enough to damage it; instead, pulsed lasers produce strong electric fields capable of inducing dielectric breakdown in the material. Unfortunately, it can be very difficult to compare the LIDT specification of an optic to your laser. There are multiple regimes in which a pulsed laser can damage an optic and this is based on the laser's pulse length. The highlighted columns in the table below outline the relevant pulse lengths for our specified LIDT values.

Pulses shorter than 10^{-9} s cannot be compared to our specified LIDT values with much reliability. In this ultra-short-pulse regime various mechanics, such as multiphoton-avalanche ionization, take over as the predominate damage mechanism [2]. In contrast, pulses between 10^{-7} s and 10^{-4} s may cause damage to an optic either because of dielectric breakdown or thermal effects. This means that both CW and pulsed damage thresholds must be compared to the laser beam to determine whether the optic is suitable for your application.



LIDT in linear power density vs. pulse length and spot size. For long pulses to CW, linear power density becomes a constant with spot size. This graph was obtained from [1].



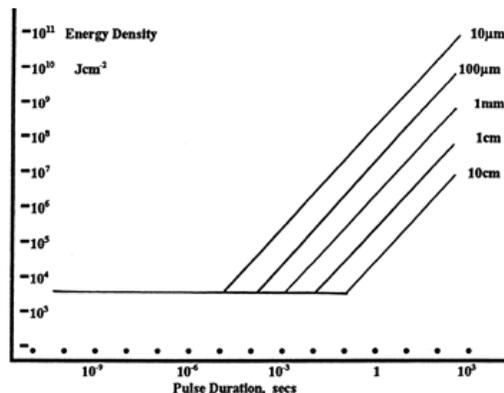
Pulse Duration	$t < 10^{-9}$ s	$10^{-9} < t < 10^{-7}$ s	$10^{-7} < t < 10^{-4}$ s	$t > 10^{-4}$ s

Damage Mechanism	Avalanche Ionization	Dielectric Breakdown	Dielectric Breakdown or Thermal	Thermal
Relevant Damage Specification	No Comparison (See Above)	Pulsed	Pulsed and CW	CW

When comparing an LIDT specified for a pulsed laser to your laser, it is essential to know the following:

1. Wavelength of your laser
2. Energy density of your beam (total energy divided by $1/e^2$ area)
3. Pulse length of your laser
4. Pulse repetition frequency (prf) of your laser
5. Beam diameter of your laser ($1/e^2$)
6. Approximate intensity profile of your beam (e.g., Gaussian)

The energy density of your beam should be calculated in terms of J/cm^2 . The graph to the right shows why expressing the LIDT as an energy density provides the best metric for short pulse sources. In this regime, the LIDT given as an energy density can be applied to any beam diameter; one does not need to compute an adjusted LIDT to adjust for changes in spot size. This calculation assumes a uniform beam intensity profile. You must now adjust this energy density to account for hotspots or other nonuniform intensity profiles and roughly calculate a maximum energy density. For reference a Gaussian beam typically has a maximum energy density that is twice that of the $1/e^2$ beam.



LIDT in energy density vs. pulse length and spot size. For short pulses, energy density becomes a constant with spot size. This graph was obtained from [1].

Now compare the maximum energy density to that which is specified as the LIDT for the optic. If the optic was tested at a wavelength other than your operating wavelength, the damage threshold must be scaled appropriately [3]. A good rule of thumb is that the damage threshold has an inverse square root relationship with wavelength such that as you move to shorter wavelengths, the damage threshold decreases (i.e., a LIDT of $1 J/cm^2$ at $1064 nm$ scales to $0.7 J/cm^2$ at $532 nm$):

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}}}$$

You now have a wavelength-adjusted energy density, which you will use in the following step.

Beam diameter is also important to know when comparing damage thresholds. While the LIDT, when expressed in units of J/cm^2 , scales independently of spot size; large beam sizes are more likely to illuminate a larger number of defects which can lead to greater variances in the LIDT [4]. For data presented here, a $<1 mm$ beam size was used to measure the LIDT. For beams sizes greater than $5 mm$, the LIDT (J/cm^2) will not scale independently of beam diameter due to the larger size beam exposing more defects.

The pulse length must now be compensated for. The longer the pulse duration, the more energy the optic can handle. For pulse widths between $1 - 100 ns$, an approximation is as follows:

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Pulse Length}}{\text{LIDT Pulse Length}}}$$

Use this formula to calculate the Adjusted LIDT for an optic based on your pulse length. If your maximum energy density is less than this adjusted LIDT maximum energy density, then the optic should be suitable for your application. Keep in mind that this calculation is only used for pulses between $10^{-9} s$ and $10^{-7} s$. For pulses between $10^{-7} s$ and $10^{-4} s$, the CW LIDT must also be checked before deeming the optic appropriate for your application.

Please note that we have a buffer built in between the specified damage thresholds online and the tests which we have done, which accommodates variation between batches. Upon request, we can provide individual test information and a testing certificate. Contact Tech Support for more information.

[1] R. M. Wood, Optics and Laser Tech. **29**, 517 (1998).

[2] Roger M. Wood, *Laser-Induced Damage of Optical Materials* (Institute of Physics Publishing, Philadelphia, PA, 2003).

[3] C. W. Carr *et al.*, Phys. Rev. Lett. **91**, 127402 (2003).

[4] N. Bloembergen, Appl. Opt. **12**, 661 (1973).

LIDT CALCULATIONS

In order to illustrate the process of determining whether a given laser system will damage an optic, a number of example calculations of laser induced damage threshold are given below. For assistance with performing similar calculations, we provide a spreadsheet calculator that can be downloaded by clicking the button to the right. To use the calculator, enter the specified LIDT value of the optic under consideration and the relevant parameters of your laser system in the green boxes. The spreadsheet will then calculate a linear power density for CW and pulsed systems, as well as an energy density value for pulsed systems. These values are used to calculate adjusted, scaled LIDT values for the optics based on accepted scaling laws. This calculator assumes a Gaussian beam profile, so a correction factor must be introduced for other beam shapes (uniform, etc.). The LIDT scaling laws are determined from empirical relationships; their accuracy is not guaranteed. Remember that absorption by optics or coatings can significantly reduce LIDT in some spectral regions. These LIDT values are not valid for ultrashort pulses less than one nanosecond in duration.

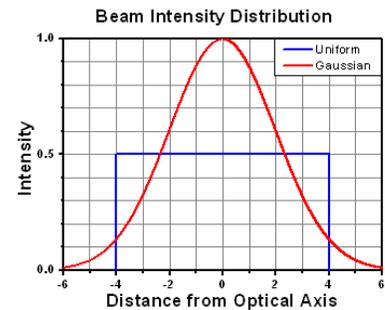
[LIDT Calculator](#)

CW Laser Example

Suppose that a CW laser system at 1319 nm produces a 0.5 W Gaussian beam that has a $1/e^2$ diameter of 10 mm. A naive calculation of the average linear power density of this beam would yield a value of 0.5 W/cm, given by the total power divided by the beam diameter:

$$\text{Linear Power Density} = \frac{\text{Power}}{\text{Beam Diameter}}$$

However, the maximum power density of a Gaussian beam is about twice the maximum power density of a uniform beam, as shown in the graph to the right. Therefore, a more accurate determination of the maximum linear power density of the system is 1 W/cm.



A Gaussian beam profile has about twice the maximum intensity of a uniform beam profile.

An AC127-030-C achromatic doublet lens has a specified CW LIDT of 350 W/cm, as tested at 1550 nm. CW damage threshold values typically scale directly with the wavelength of the laser source, so this yields an adjusted LIDT value:

$$\text{Adjusted LIDT} = \text{LIDT Power} \left(\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}} \right)$$

The adjusted LIDT value of $350 \text{ W/cm} \times (1319 \text{ nm} / 1550 \text{ nm}) = 298 \text{ W/cm}$ is significantly higher than the calculated maximum linear power density of the laser system, so it would be safe to use this doublet lens for this application.

Pulsed Nanosecond Laser Example: Scaling for Different Pulse Durations

Suppose that a pulsed Nd:YAG laser system is frequency tripled to produce a 10 Hz output, consisting of 2 ns output pulses at 355 nm, each with 1 J of energy, in a Gaussian beam with a 1.9 cm beam diameter ($1/e^2$). The average energy density of each pulse is found by dividing the pulse energy by the beam area:

$$\text{Energy Density} = \frac{\text{Pulse Energy}}{\text{Beam Area}}$$

As described above, the maximum energy density of a Gaussian beam is about twice the average energy density. So, the maximum energy density of this beam is $\sim 0.7 \text{ J/cm}^2$.

The energy density of the beam can be compared to the LIDT values of 1 J/cm^2 and 3.5 J/cm^2 for a BB1-E01 broadband dielectric mirror and an NB1-K08 Nd:YAG laser line mirror, respectively. Both of these LIDT values, while measured at 355 nm, were determined with a 10 ns pulsed laser at 10 Hz. Therefore, an adjustment must be applied for the shorter pulse duration of the system under consideration. As described on the previous tab, LIDT values in the nanosecond pulse regime scale with the square root of the laser pulse duration:

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Pulse Length}}{\text{LIDT Pulse Length}}}$$

This adjustment factor results in LIDT values of 0.45 J/cm^2 for the BB1-E01 broadband mirror and 1.6 J/cm^2 for the Nd:YAG laser line mirror, which are to be compared with the 0.7 J/cm^2 maximum energy density of the beam. While the broadband mirror would likely be damaged by the laser, the more specialized laser line mirror is appropriate for use with this system.

Pulsed Nanosecond Laser Example: Scaling for Different Wavelengths

Suppose that a pulsed laser system emits 10 ns pulses at 2.5 Hz, each with 100 mJ of energy at 1064 nm in a 16 mm diameter beam ($1/e^2$) that must be attenuated with a neutral density filter. For a Gaussian output, these specifications result in a maximum energy density of 0.1 J/cm^2 . The damage threshold of an NDUV10A Ø25 mm, OD 1.0, reflective neutral density filter is 0.05 J/cm^2 for 10 ns pulses at 355 nm, while the damage threshold of the similar NE10A absorptive filter is 10 J/cm^2 for 10 ns pulses at 532 nm. As described on the previous tab, the LIDT value of an optic scales with the square root of the wavelength in the nanosecond pulse regime:

$$\text{Adjusted LIDT} = \text{LIDT Energy} \sqrt{\frac{\text{Your Wavelength}}{\text{LIDT Wavelength}}}$$

This scaling gives adjusted LIDT values of 0.08 J/cm^2 for the reflective filter and 14 J/cm^2 for the absorptive filter. In this case, the absorptive filter is the best choice in order to avoid optical damage.

Pulsed Microsecond Laser Example

Consider a laser system that produces 1 µs pulses, each containing 150 µJ of energy at a repetition rate of 50 kHz, resulting in a relatively high duty cycle of 5%. This system falls somewhere between the regimes of CW and pulsed laser induced damage, and could potentially damage an optic by mechanisms associated with either regime. As a result, both CW and pulsed LIDT values must be compared to the properties of the laser system to ensure safe operation.

If this relatively long-pulse laser emits a Gaussian 12.7 mm diameter beam ($1/e^2$) at 980 nm, then the resulting output has a linear power density of 5.9 W/cm and an energy density of $1.2 \times 10^{-4} \text{ J/cm}^2$ per pulse. This can be compared to the LIDT values for a WPQ10E-980 polymer zero-order quarter-wave plate, which are 5 W/cm for CW radiation at 810 nm and 5 J/cm^2 for a 10 ns pulse at 810 nm. As before, the CW LIDT of the optic scales linearly with the laser wavelength, resulting in an adjusted CW value of 6 W/cm at 980 nm. On the other hand, the pulsed LIDT scales with the square root of the laser wavelength and the square root of the pulse duration, resulting in an adjusted value of 55 J/cm^2 for a 1 µs pulse at 980 nm. The pulsed LIDT of the optic is significantly greater than the energy density of the laser pulse, so individual pulses will not damage the wave plate. However, the large average linear power density of the laser system may cause thermal damage to the optic, much like a high-power CW beam.

LAB FACTS

Comparison of Circularization Techniques for Elliptical Beams

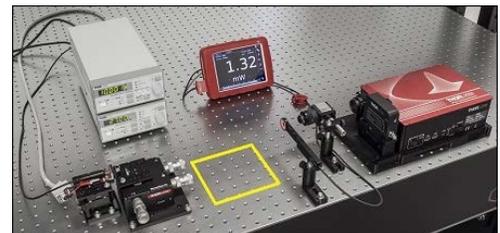
Edge-emitting laser diodes emit elliptical beams as a consequence of the rectangular cross sections of their emission apertures. The component of the beam corresponding to the narrower dimension of the aperture has a greater divergence angle than the orthogonal beam component. As one component diverges more rapidly than the other, the beam shape is elliptical rather than circular.

Elliptical beam shapes can be undesirable, as the spot size of the focused beam is larger than if the beam were circular, and as larger spot sizes have lower irradiances (power per area). Techniques for circularizing an elliptical beam include those based on a pair of cylindrical lenses, an anamorphic prism pair, or a spatial filter. This work investigated all three approaches. The characteristics of the circularized beams were evaluated by performing M^2 measurements, wavefront measurements, and measuring the transmitted power.

While it was demonstrated that each circularization technique improves the circularity of the elliptical input beam, each technique was shown to provide a different balance of circularization, beam quality, and transmitted power. The results of this work, which are documented in this Lab Fact, indicate that an application's specific requirements will determine which is the best circularization technique to choose.



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Figure 1: The beam circularization systems were placed in the area of the experimental setup highlighted by the yellow rectangle.



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Figure 2:
Cylindrical Lens Pair System



Click to Enlarge
Figure 3:
Anamorphic Prism Pair System



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Figure 4: Spatial Filter System

Experimental Design and Setup

The experimental setup is shown in Figure 1. The elliptically-shaped, collimated beam of a temperature-stabilized 670 nm laser diode was input to each of our circularization systems shown in Figures 2 through 4. Collimation results in a low-divergence beam, but it does not affect the beam shape. Each system was based on one of the following:

- LJ1874L2-A and LJ1638L1-A Plano-Convex Convex Cylindrical Lenses (Figure 2)
- PS873-A Unmounted Anamorphic Prism Pair (Figure 3)
- KT310 Spatial Filter System with P5S Ø5 µm Pinhole (Figure 4)

The beam circularization systems, shown to the right, were placed, one at a time, in the vacant spot in the setup highlighted by the yellow rectangle. With this arrangement, it was possible to use the same experimental conditions when evaluating each circularization technique, which allowed the performance of each to be directly compared with the others. This experimental constraint required the use of fixturing that was not optimally compact, as well as the use of an unmounted anamorphic prism pair, instead of a more convenient mounted and pre-aligned anamorphic prism pair.

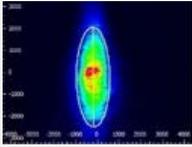
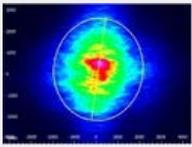
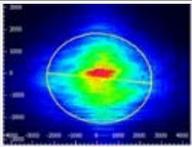
The characteristics of the beams output by the different circularization systems were evaluated by making measurements using a power meter, a wavefront sensor, and an M^2 system. In the image of the experimental setup, all of these systems are shown on the right side of the table for illustrative purposes; they were used one at a time. The power meter was used to determine how much the beam circularization system attenuated the intensity of the input laser beam. The wavefront sensor provided a way to measure the aberrations of the output beam. The M^2 system measurement describes the resemblance of the output beam to a Gaussian beam. Ideally, the circularization systems would not attenuate or aberrate the laser beam, and they would output a perfectly Gaussian beam.

Edge-emitting laser diodes also emit astigmatic beams, and it can be desirable to force the displaced focal points of the orthogonal beam components to overlap. Of the three circularization techniques investigated in this work, only the cylindrical lens pair can also compensate for astigmatism. The displacement between the focal spots of the orthogonal beam components were measured for each circularization technique. In the case of the cylindrical lens pair, their configuration was tuned to minimize the astigmatism in the laser beam. The astigmatism was reported as a normalized quantity.

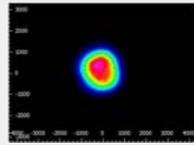
Experimental Results

The experimental results are summarized in the following table, in which the green cells identify the best result in each category. Each circularization approach has its benefits. The best circularization technique for an application is determined by the system's requirements for beam quality, transmitted optical power, and setup constraints.

Spatial filtering significantly improved the circularity and quality of the beam, but the beam had low transmitted power. The cylindrical lens pair provided a well-circularized beam and balanced circularization and beam quality with transmitted power. In addition, the cylindrical lens pair compensated for much of the beam's astigmatism. The circularity of the beam provided by the anamorphic prism pair compared well to that of the cylindrical lens pair. The beam output from the prisms had better M^2 values and less wavefront error than the cylindrical lenses, but the transmitted power was lower.

Method	Beam Intensity Profile	Circularity ^a	M^2 Values	RMS Wavefront	Transmitted Power	Normalized Astigmatism ^b
Collimated Source Output (No Circularization Technique)	 Click to Enlarge Scale in Microns	0.36	X Axis: 1.28 Y Axis: 1.63	0.17	Not Applicable	0.67
Cylindrical Lens Pair	 Click to Enlarge Scale in Microns	0.84	X Axis: 1.90 Y Axis: 1.93	0.30	91%	0.06
Anamorphic Prism Pair	 Click to Enlarge Scale in Microns	0.82	X Axis: 1.60 Y Axis: 1.46	0.16	80%	1.25

Spatial Filter



Click to Enlarge
Scale in Microns

0.93

X Axis: 1.05
Y Axis: 1.10

0.10

34%

0.36

- Circularity = $d_{\text{minor}}/d_{\text{major}}$, where d_{minor} and d_{major} are minor and major diameters of fitted ellipse (1/e intensity) and Circularity = 1 indicates a perfectly circular beam.
- Normalized astigmatism is the difference in the waist positions of the two orthogonal components of the beam, divided by the Rayleigh length of the beam component with the smaller waist.

Components used in each circularization system were chosen to allow the same experimental setup be used for all experiments. This had the desired effect of allowing the results of all circularization techniques to be directly compared; however, optimizing the setup for a circularization technique could have improved its performance. The mounts used for the collimating lens and the anamorphic prism pair enabled easy manipulation and integration into this experimental system. It is possible that using smaller mounts would improve results by allowing the members of each pair to be more precisely positioned with respect to one another. In addition, using made-to-order cylindrical lenses with customized focal lengths may have improved the results of the cylindrical lens pair circularization system. All results may have been affected by the use of the beam profiler software algorithm to determine the beam radii used in the circularity calculation.

Additional Information

Some information describing selection and configuration procedures for several components used in this experimental work can be accessed by clicking the following hyperlinks:

- Mounting Laser Diodes
- Driving a Laser Diode
- Selecting a Collimating Lens
- Aspheric Lenses
- Spatial Filters

APERTURES SELECTION GUIDE

Apertures Selection Guide			
Aperture Type	Representative Image (Click to Enlarge)	Description	Aperture Sizes Available from Stock ^a
Single Precision Pinholes ^a		Circular Pinholes in Stainless Steel Foils	Ø1 µm to Ø2 mm
		Circular Pinholes in Tungsten Foils	Ø5 µm to Ø2 mm
		Circular Pinholes in Gold-Plated Copper Foils	Ø10 to Ø50 µm
		Square Pinholes in Stainless Steel Foils	100 to 1000 µm Square
Slits ^a		3 mm Long Slits in Stainless Steel Foils	Slit Widths: 5 to 200 µm

			
Annular Apertures		Annular Aperture Obstruction Targets on Quartz Substrates with Chrome Masks	Ø300 µm or Ø2 mm Pinholes with ϵ Ratios ^b of 0.85, Ø1 mm Pinholes with ϵ Ratios ^b of 0.05 0.1, or 0.85
Pinhole Wheels		Manual, Mounted or Unmounted, Chrome-Plated Fused Silica Disks with Lithographically Etched Pinholes	Each Disk has 16 Pinholes from Ø25 µm to Ø2 mm and Four Annular Apertures (Ø100 µm Hole, 50 µm Obstruction)
		Motorized Pinhole Wheels with Chrome-Plated Glass Disks with Lithographically Etched Pinholes	Each Disk has 16 Pinholes from Ø25 µm to Ø2 mm and Four Annular Apertures (Ø100 µm Hole, 50 µm Obstruction)

- Single precision pinholes and slits can be special ordered with different aperture sizes, foil materials, shapes, and hole distributions than those offered from stock. Please contact Tech Support with inquiries.
- Ratio of the Obstruction Diameter to the Pinhole Diameter

Pinholes, Gold-Plated Copper Foils, Ø1" Housings

Part Number	Description	Price	Availability
P10C	Ø1" Mounted Pinhole, $10 \pm 1 \mu\text{m}$ Pinhole Diameter, Gold-Plated Copper	\$129.43	5-8 Days
P25C	Ø1" Mounted Pinhole, $25 \pm 2 \mu\text{m}$ Pinhole Diameter, Gold-Plated Copper	\$129.43	Today
P50C	Ø1" Mounted Pinhole, $50 \pm 3 \mu\text{m}$ Pinhole Diameter, Gold-Plated Copper	\$129.43	5-8 Days



10μm