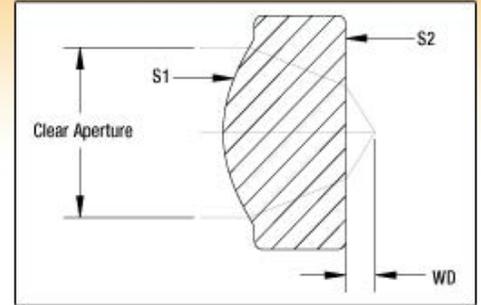


**390021-F - October 30, 2017**

Item # 390021-F was discontinued on October 30, 2017. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

**MOLDED IR ASPHERIC LENSES**

- ▶ High NA (up to 0.85)
- ▶ Diffraction-Limited Performance
- ▶ Broadband AR-Coated Optics
- ▶ Collimate or Focus Light with a Single Element



390028-D



390028-F



390036-E



C036TME-D



C028TME-E



C028TME-F

**OVERVIEW**

**Features**

- Focus or Collimate Light without Introducing Spherical Aberration
- Ø4.00 mm, Ø5.00 mm, or Ø7.60 mm Unmounted Clear Aperture
- AR Coated for 1.8 - 3 µm (-D), 3 - 5 µm (-E), or 8 - 12 µm (-F)
- Available Unmounted or Mounted in a Threaded, Engraved Stainless Steel Housing
- Black Diamond Substrate Provides Stable Operation up to 130 °C

Spherical aberration often prevents a spherical lens from achieving diffraction-limited performance. The surfaces of an aspheric lens are corrected for spherical aberration, thereby providing a robust single element solution for many applications, such as collimating the output of a fiber or laser diode, coupling light into a fiber, spatial filtering, or imaging light onto a detector. In particular, our IR aspheric lenses are ideal for collimating light from mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR) sources, including Quantum Cascade Lasers (QCLs).

**Webpage Features**

	Click for complete specifications, documents, and drawings.
Performance Hyperlink	Click to view item-specific focal length shift data and spot diagrams at various wavelengths.

**Zemax Files**

Click on the red Document icon next to the item numbers below to access the Zemax file download. Our entire Zemax Catalog is also available.

**Alternative Aspheric Lenses**

Coating Designation	Spectral Range
Uncoated	Visible and NIR
-A	350 - 700 nm
-B	650 - 1050 nm
-C	1050 - 1620 nm
-D	1.8 - 3 µm
-E	3 - 5 µm
-F	8 - 12 µm
-405	405 nm
-1064	1064 nm

**Common Specifications**

These molded glass lenses are available unmounted or premounted in stainless steel lens housings that are engraved with the part number for easy identification. These housings have a

<b>Substrate</b>	Black Diamond-2
<b>Refractive Index</b>	2.630 at 2.5 $\mu\text{m}^a$
<b>Damage Threshold (Typical)<sup>b</sup></b>	100 W/cm <sup>2</sup> (1064 nm, CW) 0.1 J/cm <sup>2</sup> (1064 nm, 10 ns)
<b>Surface Quality (Bulk Material)</b>	80-50 Scratch-Dig
<b>Coefficient of Thermal Expansion</b>	$13.5 \times 10^{-6} / ^\circ\text{C}$
<b>Thermooptic Coefficient (<math>\Delta n / \Delta T</math>)</b>	$91 \times 10^{-6} / ^\circ\text{C}$

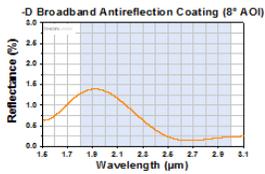
- See the *Refractive Index* tab for the wavelength-dependent refractive index.
- The damage threshold of these lenses is limited by the AR coating and is not guaranteed.

metric external threading that makes them easy to integrate into an optical setup or OEM application. For example, they are readily adapted to our SM1 (1.035"-40) Lens Tubes by using our Aspheric Lens Adapters. Mounted aspheres can also be used as a drop-in replacement for multi-element microscope objectives in conjunction with our RMS-threaded Objective Replacement Adapters.

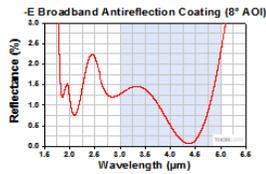
#### Black Diamond

Black Diamond-2 (BD-2), a chalcogenide made of an amorphous mixture of germanium (28%), antimony (12%), and selenium (60%), has several advantages over germanium, which is traditionally used to fabricate IR optics. BD-2's thermally stable refractive index (see the *Refractive Index* tab) and low coefficient of thermal expansion ( $13.5 \times 10^{-6} / ^\circ\text{C}$ ) result in a smaller change in focal length as a function of temperature than for germanium. Additionally, germanium suffers from transmission loss as temperature increases, while BD-2 aspheric lenses can be used in environments up to 130  $^\circ\text{C}$ . This material performs particularly well over the 1.7 - 2.2  $\mu\text{m}$  spectral range, providing >99% transmission and a flat dispersion curve. Click here to download a pdf of the MSDS for BD-2.

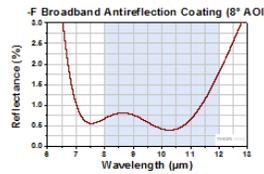
If an unmounted aspheric lens is being used to collimate the light from a point source or laser diode, the side with the greater radius of curvature should face the point source or laser diode. To collimate light using one of our mounted aspheric lenses, orient the housing so that the externally threaded end of the mount faces the source.



[Click to Enlarge](#)  
[Click Here for Raw Data](#)



[Click to Enlarge](#)  
[Click Here for Raw Data](#)

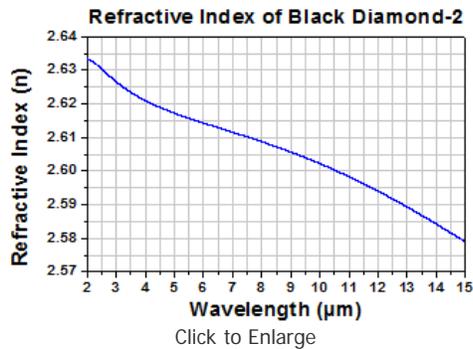


[Click to Enlarge](#)  
[Click Here for Raw Data](#)

The shaded region in each graph indicates the range for which the coating is specified.

Please note that these curves are typical, so slight variations may occur within the specifications between individual lenses with these coatings.

## REFRACTIVE INDEX



The refractive index of Black Diamond-2 (BD-2) as a function of wavelength, shown above, was calculated using the Herzberger Equation, an infrared-specific analog of the Sellmeier Equation. The Herzberger coefficients for BD-2 are given to the table to the right.

Herzberger Equation (for  $\lambda$  in  $\mu\text{m}$ )

Herzberger Coefficient	Value
A	2.614
B	$1.491 \times 10^{-1}$
C	$-2.875 \times 10^{-1}$
D	$-9.573 \times 10^{-5}$
E	$-5.109 \times 10^{-7}$
F	$9.894 \times 10^{-10}$

$$n = A + BL + CL^2 + D\lambda^2 + E\lambda^4 + F\lambda^6$$

$$L = \frac{1}{\lambda^2 - 0.028}$$

## FIBER COUPLING

### Choosing a Lens for Fiber Coupling

Aspheric lenses are commonly used to couple incident light with a spot size of 1 - 5 mm into a single mode fiber. The following simple example illustrates the key specifications to consider when trying to choose the correct lens.

#### Example

- Wavelength: 2  $\mu\text{m}$
- Fiber: P1-2000-FC-1
- Collimated Beam Diameter Prior to Lens: 1.2 mm

At 2  $\mu\text{m}$ , Thorlabs' P1-2000-FC-1 single mode patch cable is specified with a mode field diameter (MFD) of 13  $\mu\text{m}$ . This specification should be matched to the diffraction-limited spot size given by the following equation:

$$\phi_{spot} = \frac{4\lambda f}{\pi D}$$

Here,  $f$  is the focal length of the lens,  $\lambda$  is the wavelength of the input light, and  $D$  is the diameter of the collimated beam incident on the lens. Solving for the desired focal length of the collimating lens yields

$$f = \frac{\pi D (MFD)}{4\lambda} = \frac{\pi (0.0012 \text{ m})(13 \times 10^{-6} \text{ m})}{4(2 \times 10^{-6} \text{ m})} = 6.13 \text{ mm}$$

The mounted aspheric lens that is AR coated for our 2  $\mu\text{m}$  wavelength and most closely matches the desired focal length of 6.13 mm is our C028TME-D ( $f = 5.95 \text{ mm}$ ), shown below. Its clear aperture of 7.60 mm is easily larger than the collimated beam diameter of 1.2 mm. It therefore meets the requirements of the example setup.

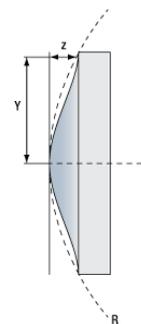
For optimal coupling, the spot size of the focused beam should be smaller than the MFD of the single mode fiber. Therefore, if an aspheric lens is not available that provides an exact match, choose an aspheric lens with a focal length that is shorter than that yielded by the calculation above. Alternatively, assuming the clear aperture of the aspheric lens is sufficiently large, the beam can be expanded before the aspheric lens to allow the focused beam to have a tighter spot.

## LENS EQUATION

### Aspheric Lens Design Formula

- Positive Radius Indicates that the Center of Curvature is to the Right of the Lens
- Negative Radius Indicates that the Center of Curvature is to the Left of the Lens

Definitions of Variables	
z	Sag (Surface Profile)
Y	Radial Distance from Optical Axis



Click to Enlarge Reference Drawing

R	Radius of Curvature
k	Conic Constant
A <sub>4</sub>	4th Order Aspheric Coefficient
A <sub>6</sub>	6th Order Aspheric Coefficient
A <sub>n</sub>	nth Order Aspheric Coefficient

The target values of these constants are available by clicking on the Info Icons below or by viewing the .pdf and .dxf files available for each lens. Links to the files can be found by clicking on the item number in the price tables below.

$$z = \frac{Y^2}{R \left( 1 + \sqrt{1 - (1 + k) \frac{Y^2}{R^2}} \right)} + A_4 Y^4 + A_6 Y^6 + \dots + A_n Y^n$$

Aspheric Lens Equation

## DAMAGE THRESHOLDS

### Damage Threshold Data for Thorlabs' Molded IR Aspheric Lenses

The specifications to the right are measured data for Thorlabs' molded IR aspheric lenses. Damage threshold specifications are constant for all black diamond IR aspheric lenses, regardless of the focal point of the lens. These specifications are limited by the AR coating and are not guaranteed.

Damage Threshold Specifications <sup>a</sup>	
Damage Specification Type	Damage Threshold
Pulsed	0.1 J/cm <sup>2</sup> (1064 nm, 10 ns)
CW	100 W/cm <sup>2</sup> (1064 nm)

- The damage threshold of these lenses is limited by the AR coating and is not guaranteed.

### 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/DIS11254 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/cm<sup>2</sup> (1064 nm, 10 ns pulse, 10 Hz, Ø1.000 mm) before damage.

According to the test, the damage threshold of the mirror was 2.00 J/cm<sup>2</sup> (532 nm, 10 ns pulse, 10 Hz, Ø0.803 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 µs can be treated as CW lasers for LIDT discussions.

When pulse lengths are between 1 ns and 1 µs, 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 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.

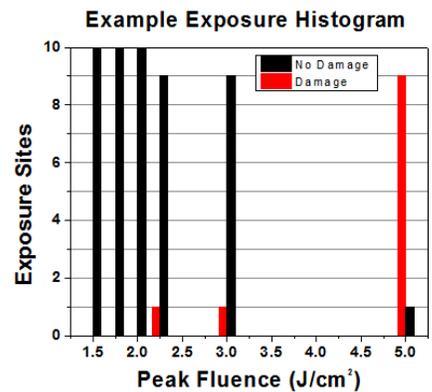
In order to use the specified CW damage threshold of an optic, it is necessary to know the following:

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

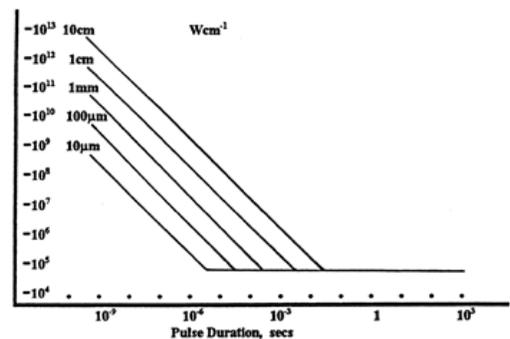
Thorlabs expresses LIDT for CW lasers as a linear power density measured in W/cm. In this regime, the LIDT given as a linear power density can be applied to any beam diameter; one does not need to compute an adjusted LIDT to adjust for changes in spot size, as demonstrated by the graph to the right.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

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

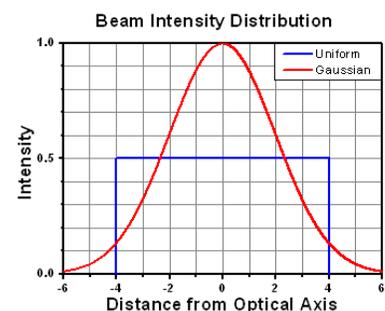
The calculation above assumes a uniform beam intensity profile. You must now consider



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



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].



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.

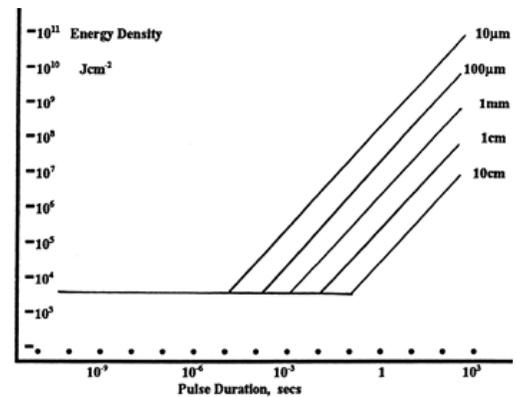
Pulses shorter than  $10^{-9}$  s cannot be compared to our specified LIDT values with much reliability. In this ultra-short-pulse regime various mechanics, such as multiphoton-avalanche ionization, take over as the predominate damage mechanism [2]. In contrast, pulses between  $10^{-7}$  s and  $10^{-4}$  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.

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 at 1064 nm scales to 0.7 J/cm 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<sup>2</sup>, 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<sup>2</sup>) 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<sup>-9</sup> s and 10<sup>-7</sup> s. For pulses between 10<sup>-7</sup> s and 10<sup>-4</sup> 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.

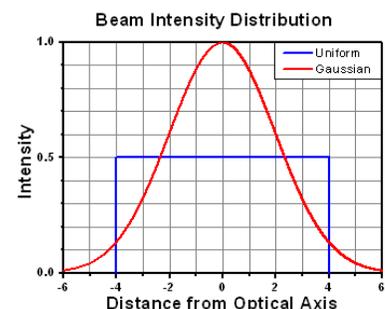
[LIDT Calculator](#)

### CW Laser Example

Suppose that a CW laser system at 1319 nm produces a 0.5 W Gaussian beam that has a 1/e<sup>2</sup> 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 W/cm x (1319 nm / 1550 nm) = 298 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  $1 \text{ J/cm}^2$  and  $3.5 \text{ J/cm}^2$  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  $0.45 \text{ J/cm}^2$  for the BB1-E01 broadband mirror and  $1.6 \text{ J/cm}^2$  for the Nd:YAG laser line mirror, which are to be compared with the  $0.7 \text{ J/cm}^2$  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  $0.1 \text{ J/cm}^2$ . The damage threshold of an NDUV10A Ø25 mm, OD 1.0, reflective neutral density filter is  $0.05 \text{ J/cm}^2$  for 10 ns pulses at 355 nm, while the damage threshold of the similar NE10A absorptive filter is  $10 \text{ J/cm}^2$  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  $0.08 \text{ J/cm}^2$  for the reflective filter and  $14 \text{ J/cm}^2$  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  $1 \mu\text{s}$  pulses, each containing  $150 \mu\text{J}$  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  $1.2 \times 10^{-4}$  J/cm<sup>2</sup> 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<sup>2</sup> 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<sup>2</sup> for a 1  $\mu$ s 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.

### Molded IR Aspheric Lenses, AR Coated: 1.8 - 3 $\mu$ m (-D)

Item # (Unmounted/ Mounted)	Info	EFL <sup>a</sup>	NA	OD	CA	WD <sup>b</sup>	DW	AR Range <sup>c</sup>	M	Glass	Performance	Thread	Suggested Spanner Wrench
390037-D	i	1.873 mm	0.85	5.50 mm	4.00 mm	0.723 mm	9.5 $\mu$ m	1.8 - 3 $\mu$ m	$\infty$	BD-2	37_Asph.pdf	-	-
C037TME-D				9.24 mm		0.34 mm						M9 x 0.5	SPW301
390036-D	i	4.00 mm	0.56	6.50 mm	5.00 mm	3.05 mm	2.5 $\mu$ m	1.8 - 3 $\mu$ m	$\infty$	BD-2	36_Asph.pdf	-	-
C036TME-D				9.24 mm		2.67 mm						M9 x 0.5	SPW301
390028-D	i	5.95 mm	0.56	8.0 mm	7.60 mm	5.0 mm	4.1 $\mu$ m	1.8 - 3 $\mu$ m	$\infty$	BD-2	23046-S01.pdf	-	-
C028TME-D				10.3 mm		4.0 mm						M10 x 0.5	SPW801

- EFL is specified at the design wavelength.
- WD is specified at the design wavelength.
- The average reflectance for the broadband AR coating is <1.0%.

EFL = Effective Focal Length  
 NA = Numerical Aperture  
 CA = Clear Aperture  
 WD = Working Distance  
 DW = Design Wavelength  
 OD = Outer Diameter  
 M = Magnification

Part Number	Description	Price	Availability
390037-D	f = 1.873 mm, NA = 0.85, Unmounted Geltech Aspheric Lens, AR: 1.8 - 3 $\mu$ m	\$300.00	Today
C037TME-D	f = 1.873 mm, NA = 0.85, Mounted Geltech Aspheric Lens, AR: 1.8 - 3 $\mu$ m	\$326.00	Today
390036-D	f = 4.0 mm, NA = 0.56, Unmounted Geltech Aspheric Lens, AR: 1.8 - 3 $\mu$ m	\$300.00	Today
C036TME-D	f = 4.0 mm, NA = 0.56, Mounted Geltech Aspheric Lens, AR: 1.8 - 3 $\mu$ m	\$326.00	Today
390028-D	f = 5.95 mm, NA = 0.56 Unmounted Geltech Aspheric Lens, AR: 1.8 - 3 $\mu$ m	\$300.00	Today
C028TME-D	f = 5.95 mm, NA = 0.56 Mounted Geltech Aspheric Lens, AR: 1.8 - 3 $\mu$ m	\$326.00	Today

### Molded IR Aspheric Lenses, AR Coated: 3 - 5 $\mu$ m (-E)

Item # (Unmounted/ Mounted)	Info	EFL <sup>a</sup>	NA	OD	CA	WD <sup>b</sup>	DW	AR Range <sup>c</sup>	M	Glass	Performance	Thread	Suggested Spanner Wrench
390037-E	i	1.873 mm	0.85	5.50 mm	4.00 mm	0.723 mm	9.5 $\mu$ m	3 - 5 $\mu$ m	$\infty$	BD-2	37_Asph.pdf	-	-
C037TME-E				9.24 mm		0.34 mm						M9 x 0.5	SPW301
390036-E	i	4.00 mm	0.56	6.50 mm	5.00 mm	3.05 mm	2.5 $\mu$ m	3 - 5 $\mu$ m	$\infty$	BD-2	36_Asph.pdf	-	-
C036TME-E				9.24 mm		2.67 mm						M9 x 0.5	SPW301
390028-E	i	5.95 mm	0.56	8.0 mm	7.60 mm	5.0 mm	4.1 $\mu$ m	3 - 5 $\mu$ m	$\infty$	BD-2	23046-S01.pdf	-	-
C028TME-E				10.3 mm		4.00 mm						M10 x 0.5	SPW801

- EFL is specified at the design wavelength.
- WD is specified at the design wavelength.
- The average reflectance for the broadband AR coating is <0.6%.

EFL = Effective Focal Length  
 NA = Numerical Aperture  
 CA = Clear Aperture  
 WD = Working Distance  
 DW = Design Wavelength  
 OD = Outer Diameter  
 M = Magnification

Part Number	Description	Price	Availability
390037-E	f = 1.873 mm, NA = 0.85, Unmounted Geltech Aspheric Lens, AR: 3 - 5 $\mu$ m	\$300.00	Today
C037TME-E	f = 1.873 mm, NA = 0.85, Mounted Geltech Aspheric Lens, AR: 3 - 5 $\mu$ m	\$326.00	Today
390036-E	f = 4.0 mm, NA = 0.56, Unmounted Geltech Aspheric Lens, AR: 3 - 5 $\mu$ m	\$300.00	Today
C036TME-E	f = 4.0 mm, NA = 0.56, Mounted Geltech Aspheric Lens, AR: 3 - 5 $\mu$ m	\$326.00	Today
390028-E	f = 5.95 mm, NA = 0.56, Unmounted Geltech Aspheric Lens, AR: 3 - 5 $\mu$ m	\$300.00	Today
C028TME-E	f = 5.95 mm, NA = 0.56, Mounted Geltech Aspheric Lens, AR: 3 - 5 $\mu$ m	\$326.00	Today

### Molded IR Aspheric Lenses, AR Coated: 8 - 12 $\mu$ m (-F)

Item # (Unmounted/ Mounted)	Info	EFL <sup>a</sup>	NA	OD	CA	WD <sup>b</sup>	DW	AR Range <sup>c</sup>	M	Glass	Performance	Thread	Suggested Spanner Wrench
390037-F	i	1.873 mm	0.85	5.50 mm	4.00 mm	0.723 mm	9.5 $\mu$ m	8 - 12 $\mu$ m	$\infty$	BD-2	37_Asph.pdf	-	-
C037TME-F				9.24 mm		0.34 mm						M9 x 0.5	SPW301
390036-F	i	4.00 mm	0.56	6.50 mm	5.00 mm	3.05 mm	2.5 $\mu$ m	8 - 12 $\mu$ m	$\infty$	BD-2	36_Asph.pdf	-	-
C036TME-F				9.24 mm		2.67 mm						M9 x 0.5	SPW301
390028-F	i	5.95 mm	0.56	8.0 mm	7.60 mm	5.0 mm	4.1 $\mu$ m	8 - 12 $\mu$ m	$\infty$	BD-2	23046-S01.pdf	-	-
C028TME-F				10.3 mm		4.00 mm						M10 x 0.5	SPW801
390021-F	i	11.00 mm	0.18	5.1 mm	4.00 mm	9.8 mm	3.5 $\mu$ m	8 - 12 $\mu$ m	$\infty$	BD-2	23094-S01.pdf	-	-

- EFL is specified at the design wavelength.
- WD is specified at the design wavelength.
- The average reflectance for the broadband AR coating is <1.0%.

EFL = Effective Focal Length  
NA = Numerical Aperture  
CA = Clear Aperture  
WD = Working Distance  
DW = Design Wavelength  
OD = Outer Diameter  
M = Magnification

Part Number	Description	Price	Availability
390037-F	f = 1.873 mm, NA = 0.85, Unmounted Geltech Aspheric Lens, AR: 8 - 12 $\mu$ m	\$300.00	Today
C037TME-F	f = 1.873 mm, NA = 0.85, Mounted Geltech Aspheric Lens, AR: 8 - 12 $\mu$ m	\$326.00	Today
390036-F	f = 4.0 mm, NA = 0.56, Unmounted Geltech Aspheric Lens, AR: 8 - 12 $\mu$ m	\$300.00	Today
C036TME-F	f = 4.0 mm, NA = 0.56, Mounted Geltech Aspheric Lens, AR: 8 - 12 $\mu$ m	\$326.00	Today
390028-F	f = 5.95 mm, NA = 0.56, Unmounted Geltech Aspheric Lens, AR: 8 - 12 $\mu$ m	\$369.00	Today
C028TME-F	f = 5.95 mm, NA = 0.56, Mounted Geltech Aspheric Lens, AR: 8 - 12 $\mu$ m	\$399.00	Today
390021-F	f = 11.0 mm, NA = 0.18, Unmounted Geltech Aspheric Lens, AR: 8 - 12 $\mu$ m	\$228.00	Lead Time

Specifications Glass AR Coating Aspheric Coefficients

All Dimensions in mm

390021 Unmounted Lens

C021TME Mounted Lens

Lens Specifications			
Design Wavelength	3500 nm	Magnification	Infinite
Numerical Aperture	0.18	Window Thickness	N/A
Clear Aperture	4.0 mm	Laser Window Material / Index	N/A
Effective Focal Length	11.0 mm	Glass	BD-2
Working Distance	9.8 mm	Surface Quality	80-50 Scratch-Dig (Entire Bulk Material)

Specifications Glass AR Coating Aspheric Coefficients

BD-2 Uncoated Transmission: 5 mm Thick Sample

Glass Specifications	
V <sub>d</sub> Number	-
CTE (10 <sup>-6</sup> / °C)	13.5
Thermo Optic Coefficient (10 <sup>-6</sup> / °C) (Δn/ΔT)	91

Specifications Glass AR Coating Aspheric Coefficients

-F Broadband Antireflection Coating (8° AOI)

Specifications Glass AR Coating Aspheric Coefficients

Surface	Side 1	Side 2
R (mm)	17.858297	PLANO
k	-2.168822	0

a. Side 1 and Side 2 are labeled as ASP1 and ASP2, respectively, on the drawings shown on the Specifications tab.

$$z = \frac{y^2}{R(1 + \sqrt{1 - (1+k)y^2/R^2})} + A_2y^2 + A_4y^4 + A_6y^6 + A_8y^8 + A_{10}y^{10} + A_{12}y^{12} + A_{14}y^{14} + A_{16}y^{16}$$

Legend			
z	SAG as a Function of Y	k	Conic Constant
R	Radius of Curvature	A <sub>n</sub>	n <sup>th</sup> Order Aspheric Coefficient