

## VBA05-633 - June 16, 2017

Item # VBA05-633 was discontinued on June 16, 2017. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

### VARIABLE BEAMSPLITTER/ATTENUATOR

- ▶ Continuously Variable Split Ratios (T:R) from 1:99 to 99:1
- ▶ Available Wavelengths: 532, 633, 780, 1064, 1550 nm
- ▶ 30 mm Cage and SM1 Lens Tube Compatible



VBA05-1064



VBA05-1550



[Hide Overview](#)

#### OVERVIEW

##### Features

- Zero-Order Half-Wave Plate
- Beamsplitter AR-Coating Performance:  $R_{avg} < 0.5\%$  per Surface
- Clear Aperture:  $\varnothing 10$  mm
- $\varnothing 1/2$ " Post Mountable

Thorlabs' Variable Beamsplitter and Attenuator, which has applications in holography and interferometry, allows the user to continuously vary the transmitted intensity of a linearly polarized beam of light. The attenuator accomplishes this by using a zero-order half-wave plate in a rotation mount and a polarizing beamsplitter cube. This combination allows it to achieve split ratios of 1:99 to 99:1 for P:S polarized light.

The Variable Beamsplitter and Attenuator is aligned to be easily incorporated into systems using Thorlabs' SM1 series of lens tubes and 30 mm cage systems. The attenuator uses a half-wave plate mounted in a compact rotation mount design that will not interfere with using cage rods on the same side as the rotation mount. The cube can also be connected directly to another cage cube using our CM1-CC coupler, on any face other than the one with the rotation mount. This allows wave plate rotation for continuous adjustment of the attenuation/split ratio. Additional wave plates can be used to isolate the input beam port from back reflections or to rotate the output polarization, shown in the *Applications* tab.



Click to Enlarge  
[APPLIST]  
[APPLIST]

ERSCA Rod Adapters are Used to Connect the C4W Cage Cube to the VBA05-780 Variable Beamsplitter Cube

| Item #                    | Damage Threshold                                                     |
|---------------------------|----------------------------------------------------------------------|
| VBA05-532 and VA5-532/M   | 2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, $\varnothing 0.803$ mm  |
| VBA05-633 and VA5-633/M   | 2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, $\varnothing 0.803$ mm  |
| VBA05-780 and VA5-780/M   | 2 J/cm <sup>2</sup> at 810 nm, 10 ns, 10 Hz, $\varnothing 0.166$ mm  |
| VBA05-1064 and VA5-1064/M | 2 J/cm <sup>2</sup> at 1064 nm, 10 ns, 10 Hz, $\varnothing 0.484$ mm |
| VBA05-1550 and VA5-1550/M | 5 J/cm <sup>2</sup> at 1542 nm, 10 ns, 10 Hz, $\varnothing 0.181$ mm |

Each beamsplitter cube is epoxied within the cage cube mount and cannot be removed from the mount. A bottom-located M6 x 0.5 or M4 tap is included for

post mounting. Cubes with M6 x 0.5 taps come with 8-32 and M4 adapters for imperial and metric post compatibility (the M6 x 0.5 tap is only compatible with the included adapters). These cage cubes have four SM1-threaded ports. Additional cube-compatible SM1-threaded Ø1/2" rotation mounts are also offered seperately.

If you require an attenuator for higher power applications, consider constructing your own using our mounted high-power polarizing beamsplitter cubes, Ø1/2" zero-order half-wave plates, and the CRM05 continuous rotation mount. Simply remove the Ø1/2" half-wave plate from its mount and secure it in the CMR05, which can be mounted directly in the entrance port of the high-power beamsplitter cube. Attenuators with different wavelengths can also be built in the same way. Thorlabs' also offers empty compact 30 mm cage cubes for mounting a variety of different cube optics or prisms.

For a complete selection of our cube-mounted optics please see the *Mounted Optics Guide* tab.

Hide Specs

S P E C S

VBA05 Series Specifications

| Item #                                  | VBA05-532 and<br>VA5-532/M                                | VBA05-633 and<br>VA5-633/M                                | VBA05-780 and<br>VA5-780/M                                | VBA05-1064 and<br>VA5-1064/M                               | VBA05-1550 and<br>VA5-1550/M                               |
|-----------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------------|------------------------------------------------------------|
| Beamsplitter                            |                                                           |                                                           |                                                           |                                                            |                                                            |
| Extinction Ratio <sup>a</sup>           | $T_p/T_s > 1000:1$                                        |                                                           |                                                           |                                                            |                                                            |
| Surface Quality                         | 40-20 Scratch-Dig                                         |                                                           |                                                           |                                                            |                                                            |
| Transmitted Wavefront Error             | $\lambda/4 @ 633 \text{ nm}$                              |                                                           |                                                           |                                                            |                                                            |
| Reflectance                             | <0.5% per Surface<br>(420-680 nm)                         |                                                           | <0.5% per Surface<br>(620-1000 nm)                        | <0.5% per Surface<br>(900-1300 nm)                         | <0.5% per Surface<br>(1200-1600 nm)                        |
| Damage Threshold                        | 2 J/cm <sup>2</sup> at 532 nm,<br>10 ns, 10 Hz, Ø0.803 mm | 2 J/cm <sup>2</sup> at 532 nm,<br>10 ns, 10 Hz, Ø0.803 mm | 2 J/cm <sup>2</sup> at 810 nm,<br>10 ns, 10 Hz, Ø0.166 mm | 2 J/cm <sup>2</sup> at 1064 nm,<br>10 ns, 10 Hz, Ø0.484 mm | 5 J/cm <sup>2</sup> at 1542 nm,<br>10 ns, 10 Hz, Ø0.181 mm |
| Wave Plate                              |                                                           |                                                           |                                                           |                                                            |                                                            |
| Retardance Accuracy                     | $\lambda/300$ (Typical)                                   |                                                           |                                                           |                                                            |                                                            |
| Transmitted Wavefront Error             | $\lambda/8 @ 633 \text{ nm}$                              |                                                           |                                                           |                                                            |                                                            |
| Surface Quality                         | 20-10 Scratch-Dig                                         |                                                           |                                                           |                                                            |                                                            |
| Reflectance                             | <1.00% @ 532 nm                                           | <1.00% @ 633 nm                                           | <1.00% @ 780 nm                                           | <1.00% @ 1064 nm                                           | <1.00% @ 1550 nm                                           |
| Assembly                                |                                                           |                                                           |                                                           |                                                            |                                                            |
| Transmitted Beam Deviation <sup>b</sup> | $\pm 10 \text{ arcmin}$                                   |                                                           |                                                           |                                                            |                                                            |
| Reflected Beam Deviation <sup>b</sup>   | $90^\circ \pm 30 \text{ arcmin}$                          |                                                           |                                                           |                                                            |                                                            |

- The extinction ratio (ER) is the ratio of maximum to minimum transmission of a linearly polarized input. When the transmission axis and input polarization are parallel, the transmission is at its maximum; rotate the polarizer by 90° for minimum transmission.
- Defined with respect to the mechanical housing.

Hide Applications

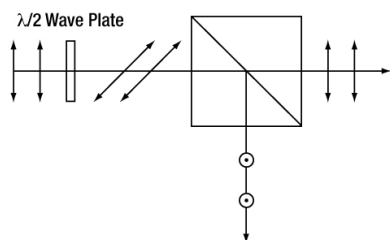
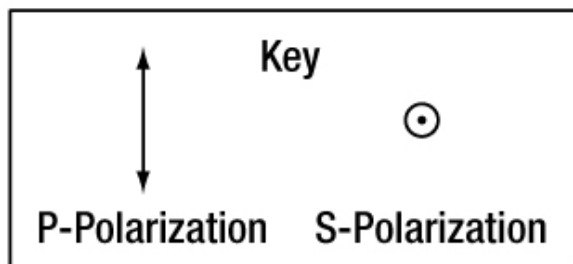
A P P L I C A T I O N S

Isolation of the Input Port

In normal operation, the variable beamsplitter/attenuator utilizes a half-wave plate to rotate the polarization of a previously linearly polarized beam of light. At the beamsplitter interface, p-polarized light will be transmitted, while s-polarized light will be reflected. By choosing the correct orientation with the half-wave plate, one can determine the amount of p-polarized and s-polarized light incident upon the interface (as shown in Figure 1 below).



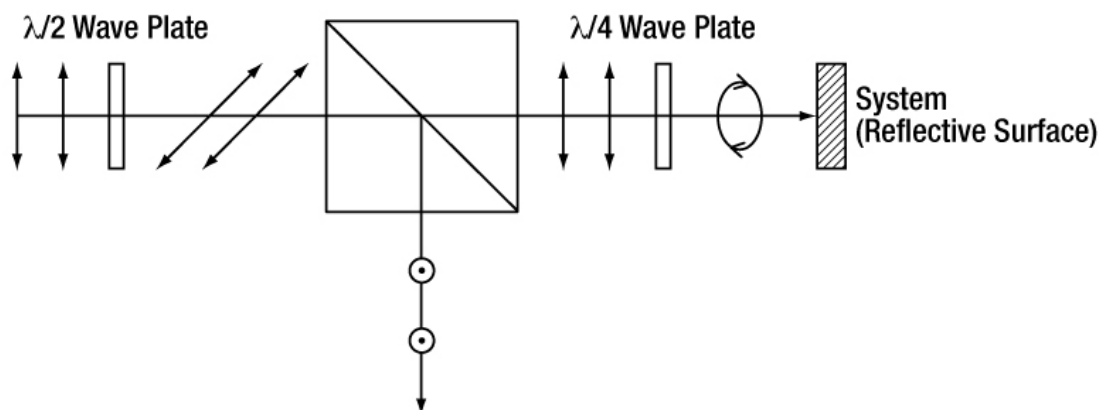
Click to Enlarge



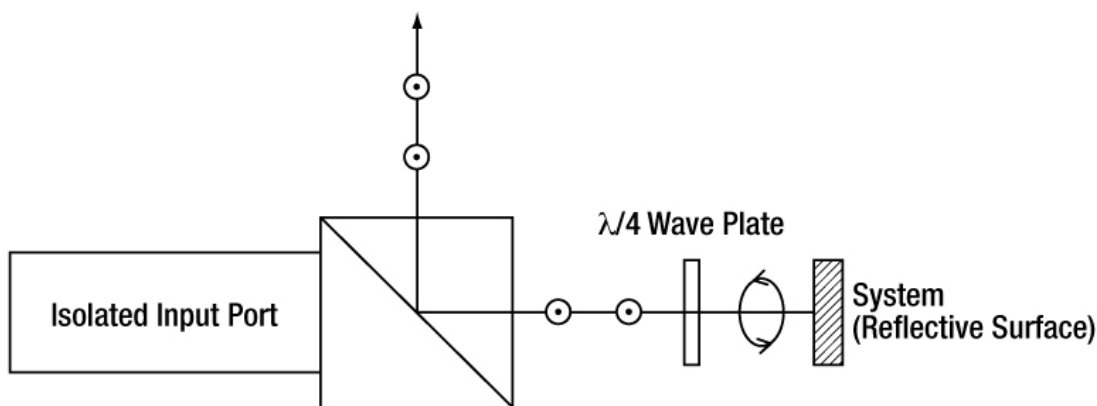
Once through the beamsplitter, light may be reflected back from various optical elements in the system. To protect your light source from these reflections, a simple isolator may be created by the addition of a quarter-wave plate.

This isolation will utilize the transmission/reflection properties of polarized light at the beamsplitter interface. In order to isolate the input port, the polarization of the exit beams must be rotated 90 degrees.

**Figure 1. Normal Variable Beamsplitter Operation** As seen in Figure 2 below, once light exits the beamsplitter, the quarter-wave plate converts the p-polarized light into right circularly polarized light. To ensure circular polarization, the polarization axis of the output beam (the beam transmitted straight through the beamsplitter cube in Figure 2) must be incident upon the quarter-wave plate at an angle of 45° with respect to the fast and slow axis. This can be accomplished, as shown above, by using our CRM1P Precision Cage Rotation Mount.



**Figure 2. Initial Pass through System**



**Figure 3. Reflected Beam Path**

Upon reflection from the front surface of a lens or mirror, the polarization will be transformed from right to left handed. As seen in figure 3 below, as the light passes through the quarter-wave plate, it will once again be converted to a linearly polarized beam.

It is important to mention that this beam will be orthogonal to the initial polarization direction and will be reflected towards the unused port of the beamsplitter. This prevents contamination of the two linearly polarized output beams.

To truly isolate the input port of the Variable Beamsplitter/Attenuator, two quarter-wave plates must be used. The polarization of each output beam must be individually rotated and accounted for. For isolation of high-power beams or greater isolation levels, please see our line of optical isolators.

The following tables correspond to either the imperial or metric product list for the application above.

[APPLIST]  
[APPLIST]



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[Hide Mounted Optics Guide](#)

MOUNTED OPTICS GUIDE

30 mm Cage-Cube-Mounted Optics Selection Guide

The table below provides links to all of our 30 mm Cage-Cube-Mounted optics. For our selection of 16 mm Cage-Cube-Mounted Optics, please see our 16 mm Cage Systems guide.

|                                                                                     |                                                                                     |                                                                                       |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|    |    |    |
| Non-Polarizing Beamsplitter Cube                                                    | Polarizing Beamsplitter Cube                                                        | High-Power Polarizing Beamsplitter Cube                                               |
|    |    |    |
| Pellicle Beamsplitters                                                              | Laser Line Polarizing Beamsplitter Cube                                             | Circular / Variable Polarizers                                                        |
|  |  |  |
| Penta Prisms                                                                        | Turning Mirrors                                                                     | Variable Beamsplitters / Attenuators                                                  |

30 mm Cage Cube Empty Optic Mounts Selection Guide

|                                                                                     |                                                                                      |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|  |  |
| Rectangular Dichroic Mirrors and Filters                                            | Empty Compact 30 mm Cage Cube                                                        |

[Hide Damage Thresholds](#)

DAMAGE THRESHOLDS

Damage Threshold Data for Thorlabs' Variable Beamsplitters/Attenuators

The specifications to the right are measured data for Thorlabs' variable beamsplitters.

| Damage Threshold Specifications |                                                         |
|---------------------------------|---------------------------------------------------------|
| Item #                          | Damage Threshold                                        |
| VBA05-532 and VA5-532/M         | 2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, Ø0.803 mm  |
| VBA05-633 and VA5-633/M         | 2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, Ø0.803 mm  |
| VBA05-780 and VA5-780/M         | 2 J/cm <sup>2</sup> at 810 nm, 10 ns, 10 Hz, Ø0.166 mm  |
| VBA05-1064 and VA5-1064/M       | 2 J/cm <sup>2</sup> at 1064 nm, 10 ns, 10 Hz, Ø0.484 mm |

## 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

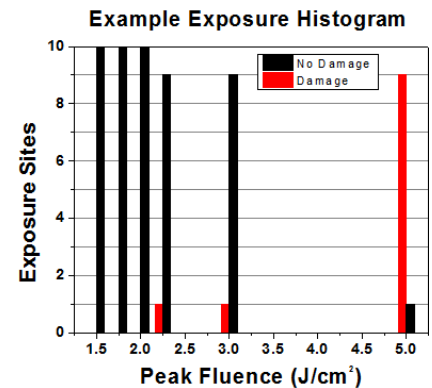
Thorlabs' LIDT testing is done in compliance with ISO/DIS11254 specifications. A standard 1-on-1 testing regime is performed to test the damage threshold.

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 a set duration of time (CW) or 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.

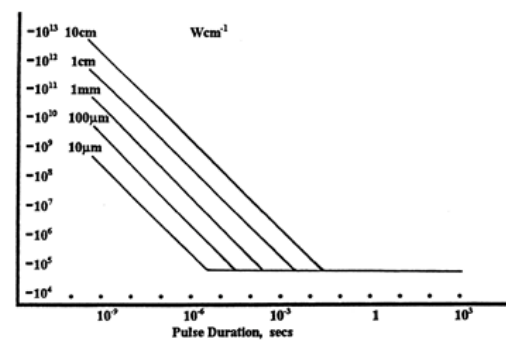


| Example Test Data      |                       |                       |                          |
|------------------------|-----------------------|-----------------------|--------------------------|
| Fluence                | # of Tested Locations | Locations with Damage | Locations Without Damage |
| 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                        |

## 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. Additionally, when pulse lengths are between 1 ns and 1 µs, LIDT can occur either because of absorption or a dielectric breakdown (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 large 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.

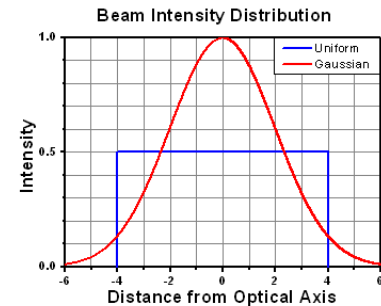


In order to use the specified CW damage threshold of an optic, it is necessary to know the following:

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

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].

The power density of your beam should be calculated in terms of W/cm. The graph to the right shows why expressing the LIDT as a linear power density provides the best metric for long pulse and CW sources. 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. This calculation 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.

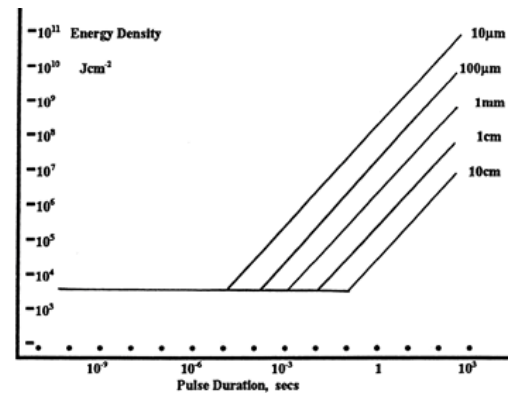
Pulses shorter than  $10^{-9}$  s cannot be compared to our specified LIDT values with much reliability. In this ultra-short-pulse regime various mechanics, such as multiphoton-avalanche ionization, take over as the predominate damage mechanism [2]. In contrast, pulses between  $10^{-7}$  s and  $10^{-4}$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

| 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  $\text{J}/\text{cm}^2$ . 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  $1 \text{ J}/\text{cm}^2$  at  $1064 \text{ nm}$  scales to  $0.7 \text{ J}/\text{cm}^2$  at  $532 \text{ nm}$ ):

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

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  $\text{J}/\text{cm}^2$ , 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  $<1 \text{ mm}$  beam size was used to measure the LIDT. For beams sizes greater than  $5 \text{ mm}$ , the LIDT ( $\text{J}/\text{cm}^2$ ) 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  $1 - 100 \text{ ns}$ , 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  $10^{-9} \text{ s}$  and  $10^{-7} \text{ s}$ . For pulses between  $10^{-7} \text{ s}$  and  $10^{-4} \text{ s}$ , 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 (1997).

[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).

[Hide LIDT Calculations](#)

## 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

[LIDT Calculator](#)

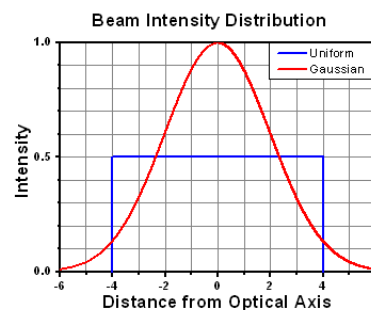
laser system in the green boxes. The spreadsheet will then calculate a linear power density for CW and pulsed systems, as well as an energy density value for pulsed systems. These values are used to calculate adjusted, scaled LIDT values for the optics based on accepted scaling laws. This calculator 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.

#### 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 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 J/cm<sup>2</sup> for the reflective filter and 14 J/cm<sup>2</sup> 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<sup>2</sup>) at 980 nm, then the resulting output has a linear power density of 5.9 W/cm and an energy density of 1.2 x 10<sup>-4</sup> 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 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.

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