

## VBC05-1550 - August 18, 2017

Item # VBC05-1550 was discontinued on August 18, 2017. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

### 30 MM CAGE CUBE-MOUNTED CIRCULAR POLARIZERS

- ▶ Creates Circularly Polarized Output from Arbitrarily Polarized Input
- ▶ 30 mm Cage Cube Housing
- ▶ Wave Plate can be Rotated to Output Linear or Elliptical Polarization



Cubes Feature an Engraved Beam Diagram



## OVERVIEW

### Features

- Polarizing Beamsplitter and Rotating Quarter-Wave Plate
- Generate Circularly, Elliptically, or Linearly Polarized Light from an Unpolarized or P-Polarized Input Beam
- Optic is Housed in a 30 mm Cage Cube
- SM1-Threaded (1.035"-40) Input Port and SM05-Threaded (0.535"-40) Output Port



These Free-Space Circular Polarizing Cubes are comprised of a polarizing beamsplitter cube and a quarter-wave plate, both housed in a 30 mm cage cube. The assembly comes prealigned to produce right-hand circular polarization from an unpolarized or P-polarized input beam (relative to the beamsplitting plane). These cubes can also function as a polarization controller by unlocking and rotating the quarter-wave plate. A variety of circular, elliptical, or linear polarization states can then be generated (see the *Polarization Control* tab for details).

Each cube has four 4-40 tapped holes on both the input and output faces for compatibility with our 30 mm cage system. Additionally, the input port is SM1 (1.035"-40) threaded for use with Ø1" lens tubes, while the output port has SM05 (0.535"-40) threading for use with Ø1/2" lens tubes. Please note that the SM05-threaded section rotates with the wave plate. 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. 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).

As with all of our 30 mm cage-cube-mounted optics, these circular polarizers can be connected to other cage cubes through the use of our cage rods and ERSCA adapters. Each beamsplitter cube is epoxied within the cage cube mount and cannot be removed from the mount. However, Thorlabs also offers empty compact 30 mm cage cubes for mounting a variety of different cube-shaped optics or prisms. Our empty cubes have four SM1-threaded ports, with options available for having up to two Ø1/2" rotation mounts premounted on different faces of the cube. Additional cube-compatible SM1-threaded Ø1/2" rotation

mounts are also offered separately. For a complete selection of our 30 mm cage-cube-mounted optics, please see the *Mounted Optics Guide* tab.

SPECS

Item #	VBC05-532 and VC5-532/M	VBC05-633 and VC5-633/M	VBC05-780 and VC5-780/M	VBC05-1064 and VC5-1064/M	VBC05-1550 and VC5-1550/M
Design Wavelength	532 nm	633 nm	780 nm	1064 nm	1550 nm
Beamsplitter					
Extinction Ratio <sup>a</sup>	T <sub>p</sub> /T <sub>s</sub> > 1000:1				
Surface Quality	40-20 Scratch-Dig				
Transmitted Wavefront Error	λ/4 @ 633 nm				
Reflectance	<0.5% per Surface (420-680 nm)		<0.5% per Surface (620-1000 nm)	<0.5% per Surface (900-1300 nm)	<0.5% per Surface (1200-1600 nm)
Damage Threshold	2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, Ø0.803 mm	2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, Ø0.803 mm	2 J/cm <sup>2</sup> at 810 nm, 10 ns, 10 Hz, Ø0.166 mm	2 J/cm <sup>2</sup> at 1064 nm, 10 ns, 10 Hz, Ø0.484 mm	5 J/cm <sup>2</sup> at 1542 nm, 10 ns, 10 Hz, Ø0.181 mm
Wave Plate					
Retardance Accuracy	λ/300 (Typical)				
Transmitted Wavefront Error	λ/8 @ 633 nm				
Surface Quality	20-10 Scratch-Dig				
Reflectance	<1.00% at Design Wavelength				
Assembly					
Transmitted Beam Deviation <sup>b</sup>	±10 arcmin				
Reflected Beam Deviation <sup>b</sup>	90° ± 30 arcmin				
Output Polarization (Through Waveplate)	λ/4 ± λ/100 at Design Wavelength				
Clear Aperture <sup>a</sup>	Ø10.0 mm				

- 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.

POLARIZATION CONTROL

The rotation mount on the front of these cubes houses the quarter-wave plate. The cubes are shipped with the rotation mount prealigned and locked so that the outputted light has a right-handed, circular polarization. However, by loosening the setscrew on the side of the rotation mount (0.035" hex, hex key included), the wave plate can be rotated to produce a number of different output polarization states. In the chart below, the rotation mount is rotated the given number of degrees on the engraved scale, starting at the factory-aligned right-hand circular polarization state. For rotation angles from 180° to 360°, add 180° to the numbers shown.

Note: The factory-aligned, right-handed, circularly polarized output corresponds to a given angle on the rotation mount's engraved scale; this angle may vary between individual polarizer cubes. Before rotating the wave plate, please record the angle at which the cube was aligned to provide right-handed circularly polarized output, both as a guide to produce the polarization states below as well as a way to easily return the cube to the factory settings.

Wave Plate Rotation		Wave Plate Rotation	
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Angle <sup>a</sup>	Vector Diagram	Angle <sup>a</sup>	Vector Diagram
Right-Hand Circular		Left-Hand Circular	
0° (Factory Aligned, See Note Above)		90°	
Elliptical		Elliptical	
22.5°		112.5°	
Linear Horizontal (P)		Linear Horizontal (P)	
45°		135°	
Elliptical		Elliptical	
67.5°		157.5°	

• Corresponds to the number of degrees the rotation mount should be rotated past the factory-aligned right-hand circular polarization setting. The absolute angular setting on the engraved scale for each polarization state will vary from cube to cube, as it is dependent on the angle on the scale at the prealigned factory setting. See the Note above the images for more information.

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

DAMAGE THRESHOLDS

Damage Threshold Data for Thorlabs' Circular Polarizing Cubes

The specifications to the right are measured data for Thorlabs' Circular Polarizing Cubes. These damage thresholds are limited by the beamsplitter cubes.

Damage Threshold Specifications	
Item #	Damage Threshold
VBC05-532 and VC5-532/M	2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, Ø0.803 mm
VBC05-633 and VC5-633/M	2 J/cm <sup>2</sup> at 532 nm, 10 ns, 10 Hz, Ø0.803 mm
VBC05-780 and VC5-780/M	2 J/cm <sup>2</sup> at 810 nm, 10 ns, 10 Hz, Ø0.166 mm
VBC05-1064 and VC5-1064/M	2 J/cm <sup>2</sup> at 1064 nm, 10 ns, 10 Hz, Ø0.484 mm
VBC05-1550 and VC5-1550/M	5 J/cm <sup>2</sup> at 1542 nm, 10 ns, 10 Hz, Ø0.181 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 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

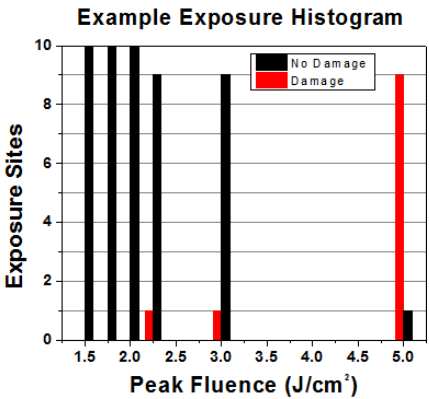
When an optic is damaged by a continuous wave (CW) laser, it is usually due to the melting of the surface as a result of absorbing the laser's energy or damage to the optical coating (antireflection) [1]. Pulsed lasers with pulse lengths longer than 1 μs can be treated as CW lasers for LIDT discussions.

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.

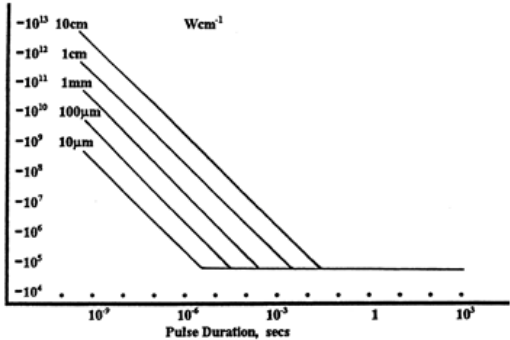
Pulsed lasers with high pulse repetition frequencies (PRF) may behave similarly to CW beams. Unfortunately, this is highly dependent on factors such as absorption and thermal diffusivity, so there is no reliable method for determining when a high PRF laser will damage an optic due to thermal effects. 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>)



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

- 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.

*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):

*Adjusted LIDT = 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.

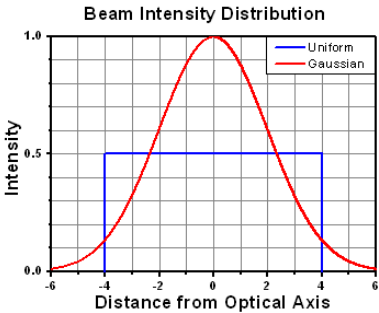
Pulses shorter than 10<sup>-9</sup> s cannot be compared to our specified LIDT values with much reliability. In this ultra-short-pulse regime various mechanics, such as multiphoton-avalanche ionization, take over as the predominate damage mechanism [2]. In contrast, pulses between 10<sup>-7</sup> s and 10<sup>-4</sup> 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 <sup>-9</sup> s	10 <sup>-9</sup> < t < 10 <sup>-7</sup> s	10 <sup>-7</sup> < t < 10 <sup>-4</sup> s	t > 10 <sup>-4</sup> 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<sup>2</sup> area)
- 3. Pulse length of your laser
- 4. Pulse repetition frequency (prf) of your laser
- 5. Beam diameter of your laser (1/e<sup>2</sup> )

pulses to CW, linear power density becomes a constant with spot size. This graph was obtained from [1].





## 6. Approximate intensity profile of your beam (e.g., Gaussian)

The energy density of your beam should be calculated in terms of J/cm<sup>2</sup>. 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<sup>2</sup> beam.

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<sup>2</sup> at 1064 nm scales to 0.7 J/cm<sup>2</sup> 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.

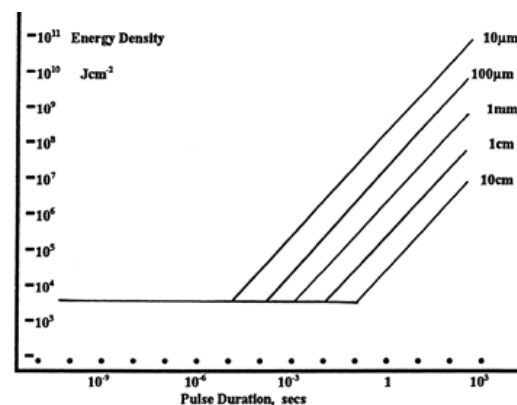
Beam diameter is also important to know when comparing damage thresholds. While the LIDT, when expressed in units of J/cm<sup>2</sup>, scales independently of spot size; large beam sizes are more likely to illuminate a larger number of defects which can lead to greater variances in the LIDT [4]. For 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.



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].

[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).

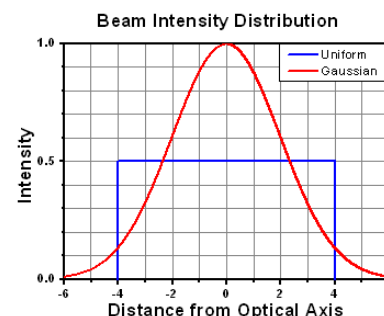
In order to illustrate the process of determining whether a given laser system will damage an optic, a number of example calculations of laser induced damage threshold are given below. For assistance with performing similar calculations, we provide a spreadsheet calculator that can be downloaded by clicking 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.

### 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  $\times$  (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:

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

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 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  $5 \text{ J/cm}^2$  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  $55 \text{ J/cm}^2$  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.

Part Number	Description	Price	Availability
VC5-532/M	Customer Inspired!30 mm Cage-Cube-Mounted Variable Circular Polarizer for 532 nm, M4 Tap	\$765.00	Today
VC5-633/M	Customer Inspired!30 mm Cage-Cube-Mounted Variable Circular Polarizer for 633 nm, M4 Tap	\$765.00	Today
VC5-780/M	Customer Inspired!30 mm Cage-Cube-Mounted Variable Circular Polarizer for 780 nm, M4 Tap	\$765.00	Today
VC5-1064/M	Customer Inspired!30 mm Cage-Cube-Mounted Variable Circular Polarizer for 1064 nm, M4 Tap	\$765.00	Today
VC5-1550/M	Customer Inspired!30 mm Cage-Cube-Mounted Variable Circular Polarizer for 1550 nm, M4 Tap	\$765.00	Today
VBC05-532	30 mm Cage-Cube-Mounted Variable Circular Polarizer for 532 nm	\$765.00	Lead Time
VBC05-633	30 mm Cage-Cube-Mounted Variable Circular Polarizer for 633 nm	\$765.00	Today
VBC05-780	30 mm Cage-Cube-Mounted Variable Circular Polarizer for 780 nm	\$765.00	Today
VBC05-1064	30 mm Cage-Cube-Mounted Variable Circular Polarizer for 1064 nm	\$765.00	Today
VBC05-1550	30 mm Cage-Cube-Mounted Variable Circular Polarizer for 1550 nm	\$765.00	Today

