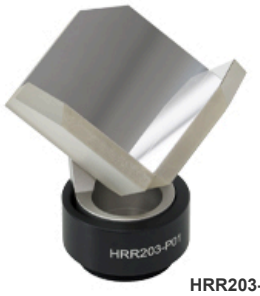
THORLABS 43 Sparta Avenue Newton, NJ 07860 | Sales: (973) 300-3000 | www.thorlabs.com

HRR201-P01 - November 11, 2025

Item # HRR201-P01 was discontinued on November 11, 2025. For informational purposes, this is a copy of the website content at that time and is valid only for the stated product.

MOUNTED HOLLOW RETROREFLECTOR MIRRORS

- **Reflective Design Eliminates Dispersion, Chromatic Aberrations, and Material Absorption**
- **UV-Enhanced Aluminum, Protected Silver, Protected Gold, or Unprotected Gold Coating**
- **Beam Deviation: <20 arcsec**
- **Ø0.6", Ø0.9", or Ø1.8" Clear Aperture Mirrors**

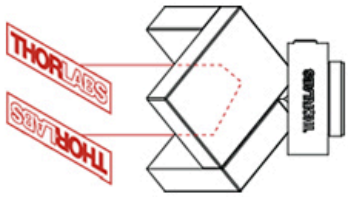


HRR203-P01
Protected Silver Coating,
SM1-Threaded Mount



HRR201-M01
Protected Gold Coating,
SM05-Threaded Mount

Mirror Reflects an Inverted and Reversed Image Back to Source





Application Idea
HRR201-M01 Mirror in a LMR05 Mount on a XRN25P Linear Stage

OVERVIEW

Features

- Mirror Reflects an Inverted and Reversed Image Back to Source
- Four Metallic Coating Options
  - Protected UV-Enhanced Aluminum (N-BK7 Substrate)
  - Protected Silver Coating (N-BK7 or UV Fused Silica Substrate)
  - Protected Gold Coating (UV Fused Silica Substrate)
  - Unprotected Gold Coating (N-BK7 Substrate)
- Three Entrance Aperture Options: Ø0.60", Ø0.90", and Ø1.80"
- SM05- or SM1-Threaded Mounts
- Custom Coatings Available (Contact Tech Support)



Click to Enlarge
Figure 1.1 SM05-threaded retroreflector mirrors are shipped inside a storage case composed of a modified OC22 Canister and OC2SM05 Lid. Note that the canister has had its top magnet removed.

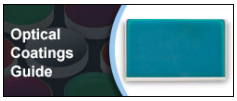
Thorlabs' Hollow Retroreflector Mirrors use three orthogonal surfaces to reflect light back to the source at the same angle as the incident beam, regardless of changes in position or alignment, creating an inverted image. This insensitivity to mirror alignment and lack of refraction through glass make these hollow retroreflectors ideal for applications where dispersion, chromatic aberrations, material absorption, or front surface reflections from glass prisms are undesirable. Examples of such applications include interferometry and optical delay lines.

These hollow retroreflector mirrors are constructed using three substrates of either N-BK7 or UV fused silica. A UV-enhanced aluminum, protected silver, protected gold, or unprotected gold coating is applied on the polished faces. Each mirror is mounted in an engraved adapter that has either external SM05 (0.535"-40) or SM1 (1.035"-40) threads for compatibility with SM05- or SM1-threaded mounts. The robust corner cube construction, rotational symmetry, and stability result in low beam deviation of <20 arcsec. Each mirror with an SM05-threaded mount is shipped inside one of our objective containers for protection and storage; please refer to Figure 1.1 for details. Retroreflectors with SM1-threaded mounts are shipped in a unique container to accommodate the mount size; please refer to the product photos of Item #'s HRR203-F01, HRR203-P01, or HRR203-M03 for details. Thorlabs also offers unmounted, replicated aluminum hollow retroreflector mirrors with the same reflection geometry.

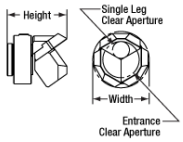
Note that unless the incident and reflected beams strike the exact center of the hollow retroreflector, they will not overlap but rather be shifted with respect to each other, as illustrated in Video 1.2. For example, if the incident beam strikes the optic 3 mm to the right of center, the retroreflected beam will emerge 3 mm to the left of center.

Video 1.2 This video shows the beampath when using a mounted retroreflector mirror. Note that the coating has been rendered translucent for illustration purposes.





SPECS



Click to Enlarge
Figure 2.1 Retroreflector Dimensions

UV-Enhanced Aluminum-Coated Retroreflector

Item #		HRR203-F01
Clear Aperture		Entrance: Ø1.80" (45.7 mm) Single Leg: Ø0.84" (21.2 mm)
Coating		UV-Enhanced Aluminum
Reflectance per Surface (Average, 0° to 45° AOI[a])		>90% for 250 - 450 nm
Reflectance Curves (Click for Plot)		12° AOI 45° AOI
Substrate Thickness		6 mm
Substrate[b]		N-BK7
Surface Flatness		<λ/4 at 633 nm
Surface Quality		40-20 Scratch-Dig
Beam Deviation (Parallelism)		<20 arcsec
Damage Threshold	**Pulsed**	0.25 J/cm^2 (266 nm, 10 ns, 10 Hz, Ø0.150 mm) 0.3 J/cm^2 (355 nm, 10 ns, 10 Hz, Ø0.381 mm)
	CW[c]	300 W/cm (1.064 µm, Ø0.044 mm) 500 W/cm (10.6 µm, Ø0.339 mm)
Threading		SM1 (1.035"-40)
Dimensions (H x W)[d]		2.33" x Ø2.52" (59.1 mm x Ø64.0 mm)

a. The angle of incidence (AOI) is given relative to the individual surfaces.
b. Click Link for Detailed Specifications on the Substrate Glass
c. The power density of your beam should be calculated in terms of W/cm. For an explanation of why the linear power density provides the best metric for long pulse and CW sources, please see the *Damage Thresholds* tab.
d. See Figure 2.1 for how these dimensions are defined.

Protected Silver-Coated Retroreflectors

Item #	HRR202-P01	HRR201-P01	HRR203-P01
Clear Aperture	Entrance: Ø0.60" (15.2 mm) Single Leg: Ø0.28" (7.1 mm)	Entrance: Ø0.90" (22.9 mm) Single Leg: Ø0.41" (10.4 mm)	Entrance: Ø1.80" (45.7 mm) Single Leg: Ø0.84" (21.2 mm)
Coating	Protected Silver		
Reflectance per Surface (Average, 0° to 45° AOI[a])	>97.5% for 450 nm - 2 µm >96% for 2 - 20 µm	>97% for 450 nm - 2 µm >95% for 2 - 20 µm	>97.5% for 450 nm - 2 µm >96% for 2 - 20 µm
Reflectance Curves (Click for Plot)	12° AOI 45° AOI		
Substrate Thickness	4 mm	6 mm	5 mm
Substrate[b]	N-BK7	UV Fused Silica	N-BK7
Surface Flatness	λ/4 at 633 nm	λ/8 at 633 nm	λ/4 at 633 nm
Surface Quality	40-20 Scratch-Dig		
Beam Deviation (Parallelism)	<20 arcsec		

Damage Threshold	**Pulsed**	-	0.225 J/cm^2 (800 nm, 99 fs, 1 kHz, Ø0.167 mm) 1 J/cm^2 (1064 nm, 10 ns, 10 Hz, Ø1.010 mm)	-
	CW[c]	-	500 W/cm (1.07 µm, Ø0.974 mm) 1500 W/cm (10.6 µm, Ø0.339 mm)	-
Threading		SM05 (0.535"-40)		SM1 (1.035"-40)
Dimensions (H x W)[d]		0.99" x Ø0.93" (25.1 mm x Ø23.7 mm)	1.41" x Ø1.52" (35.8 mm x Ø38.7 mm)	2.33" x Ø2.52" (59.1 mm x Ø64.0 mm)

a. The angle of incidence (AOI) is given relative to the individual surfaces.
b. Click Link for Detailed Specifications on the Substrate Glass
c. The power density of your beam should be calculated in terms of W/cm. For an explanation of why the linear power density provides the best metric for long pulse and CW sources, please see the *Damage Thresholds* tab.
d. See Figure 2.1 for how these dimensions are defined.

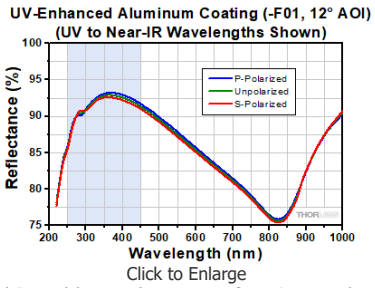
Protected and Unprotected Gold Retroreflectors

Item #		**HRR201-M01**	**HRR203-M03**
Clear Aperture		Entrance: Ø0.90" (22.9 mm) Single Leg: Ø0.41" (10.4 mm)	Entrance: Ø1.80" (45.7 mm) Single Leg: Ø0.84" (21.2 mm)
Coating		Protected Gold	Unprotected Gold
Reflectance per Surface (Average, 0° to 45° AOI[a])		>96% for 800 nm - 20 µm	>97% for 800 nm - 20 µm
Reflectance Curves (Click for Plot)		12° AOI 45° AOI	45° AOI
Substrate Thickness		6 mm	
Substrate[b]		UV Fused Silica	N-BK7
Surface Flatness		λ/8 at 633 nm	<λ/4 at 633 nm
Surface Quality		40-20 Scratch-Dig	
Beam Deviation (Parallelism)		<20 arcsec	
Damage Threshold	**Pulsed**	2 J/cm^2 (1064 nm, 10 ns, 10 Hz, Ø1.000 mm)	4 J/cm^2 (10.6 µm, 100 ns, 1 Hz, Ø0.435 mm)
	CW[c]	500 W/cm (1.07 µm, Ø0.089 mm) 750 W/cm (10.6 µm, Ø0.339 mm)	1000 W/cm (10.6 µm, Ø1.18 mm)
Threading		SM05 (0.535"-40)	SM1 (1.035"-40)
Dimensions (H x W)[d]		1.41" x Ø1.52" (35.8 mm x Ø38.7 mm)	2.33" x Ø2.52" (59.1 mm x Ø64.0 mm)

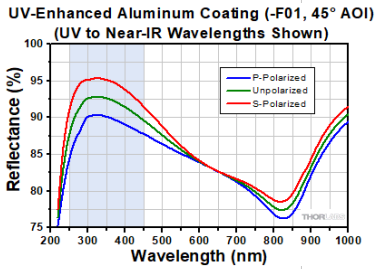
a. The angle of incidence (AOI) is given relative to the individual surfaces.
b. Click Link for Detailed Specifications on the Substrate Glass
c. The power density of your beam should be calculated in terms of W/cm. For an explanation of why the linear power density provides the best metric for long pulse and CW sources, please see the *Damage Thresholds* tab.
d. See Figure 2.1 for how these dimensions are defined.

GRAPHS

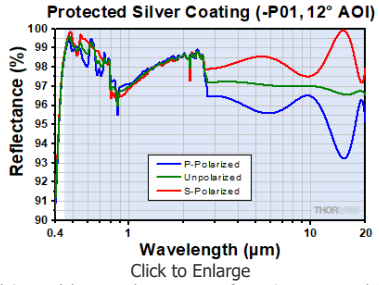
The shaded regions in the graphs denote the ranges over which we guarantee the specified reflectance. Please note that the reflectance outside of these bands is typical and can vary from lot to lot, especially in out-of-band regions where the reflectance is fluctuating or sloped. The reflectance is specified per surface and the angle of incidence (AOI) is given relative to the individual surfaces.



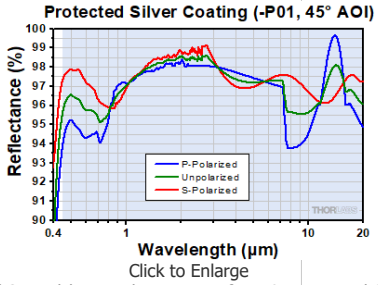
Click to Enlarge
Excel Spreadsheet with Raw Data for -F01 UV Enhanced Aluminum Coating



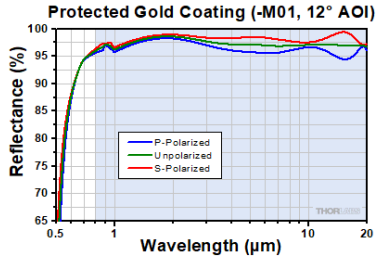
Click to Enlarge
Excel Spreadsheet with Raw Data for -F01 UV Enhanced Aluminum Coating



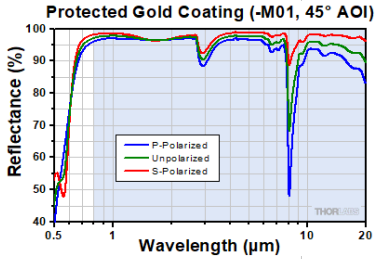
Click to Enlarge
Excel Spreadsheet with Raw Data for -P01 Protected Silver Coating



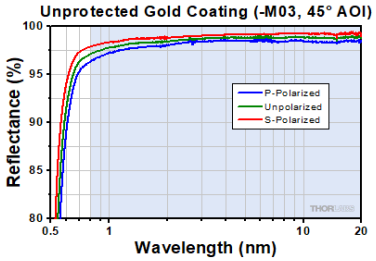
Click to Enlarge
Excel Spreadsheet with Raw Data for -P01 Protected Silver Coating



Click to Enlarge
Excel Spreadsheet with Raw Data for -M01 Protected Gold



Click to Enlarge
Excel Spreadsheet with Raw Data for -M01 Protected Gold



Click to Enlarge
Excel Spreadsheet with Raw Data for -M03 Unprotected Gold Coating

DAMAGE THRESHOLDS

Damage Thresholds for Thorlabs' Mounted Hollow Retroreflector Mirrors

The specifications in Table 4.1 are for Thorlabs' Mounted Hollow Retroreflector Mirrors.

Table 4.1 Damage Threshold Specifications

Coating Designation (Item # Suffix)	Type	Damage Threshold
-F01	Pulsed	0.25 J/cm^2 (266 nm, 10 ns, 10 Hz, Ø0.150 mm) 0.3 J/cm^2 (355 nm, 10 ns, 10 Hz, Ø0.381 mm)
	CW[a]	300 W/cm (1.064 µm, Ø0.044 mm) 500 W/cm (10.6 µm, Ø0.339 mm)
-P01	Pulsed	0.225 J/cm^2 (800 nm, 99 fs, 1 kHz, Ø0.167 mm) 1 J/cm^2 (1064 nm, 10 ns, 10 Hz, Ø1.010 mm)
	CW[a]	500 W/cm (1.07 µm, Ø0.974 mm) 1500 W/cm (10.6 µm, Ø0.339 mm)
-M01	Pulsed	2 J/cm^2 (1064 nm, 10 ns, 10 Hz, Ø1.000 mm)
	CW[a]	500 W/cm (1.07 µm, Ø0.089 mm) 750 W/cm (10.6 µm, Ø0.339 mm)
-M03	Pulsed	4 J/cm^2 (10.6 µm, 100 ns, 1 Hz, Ø0.435 mm)
	CW[a]	1000 W/cm (10.6 µm, Ø1.18 mm)

a. The power density of your beam should be calculated in terms of W/cm. For an explanation of why the linear power density provides the best metric for long pulse and CW sources, please see the "Continuous Wave and Long-Pulse Lasers" section below.

Laser Induced Damage Threshold Tutorial

The following is a general overview of how laser induced damage thresholds are measured and how the values may be utilized in determining the appropriateness of an optic for a given application. When choosing optics, it is important to understand the Laser Induced Damage Threshold (LIDT) of the optics being used. The LIDT for an optic greatly depends on the type of laser you are using. Continuous wave (CW) lasers typically cause damage from thermal effects (absorption either in the

coating or in the substrate). Pulsed lasers, on the other hand, often strip electrons from the lattice structure of an optic before causing thermal damage. Note that the guideline presented here assumes room temperature operation and optics in new condition (i.e., within scratch-dig spec, surface free of contamination, etc.). Because dust or other particles on the surface of an optic can cause damage at lower thresholds, we recommend keeping surfaces clean and free of debris. For more information on cleaning optics, please see our *Optics Cleaning* tutorial.

Testing Method

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

First, a low-power/energy beam is directed to the optic under test. The optic is exposed in 10 locations to this laser beam for 30 seconds (CW) or for a number of pulses (pulse repetition frequency specified). After exposure, the optic is examined by a microscope (~100X magnification) for any visible damage. The number of locations that are damaged at a particular power/energy level is recorded. Next, the power/energy is either increased or decreased and the optic is exposed at 10 new locations. This process is repeated until damage is observed. The damage threshold is then assigned to be the highest power/energy that the optic can withstand without causing damage. A histogram such as that shown in Figure 37B represents the testing of one BB1-E02 mirror.



Figure 37A This photograph shows a protected aluminum-coated mirror after LIDT testing. In this particular test, it handled 0.43 J/cm^2 (1064 nm, 10 ns pulse, 10 Hz, Ø1.000 mm) before damage.

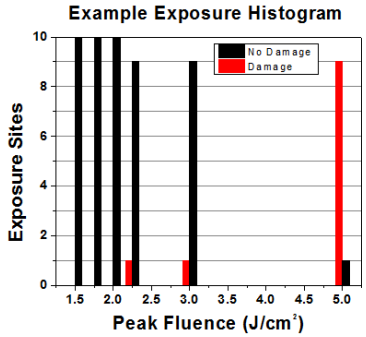


Figure 37B Example Exposure Histogram used to Determine the LIDT of BB1-E02 Mirror

According to the test, the damage threshold of the mirror was 2.00 J/cm^2 (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.

Table 37C Example Test Data

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

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

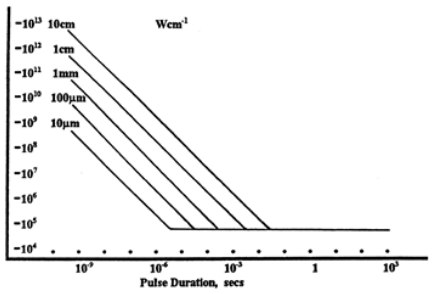


Figure 37D LIDT in linear power density vs. pulse length and spot size. For long pulses to CW, linear power density becomes a constant with spot size. This graph was obtained from [1].

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 in Figure 37D. Average linear power density can be calculated using this equation.

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

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 Figure 37E).

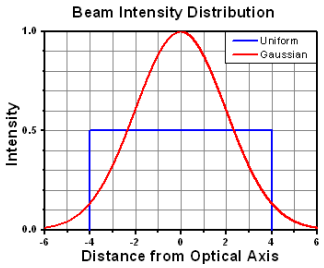


Figure 37E Intensity Distribution of Uniform and Gaussian Beam Profiles

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):

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

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 Table 37F 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.

Table 37F Laser Induced Damage Regimes

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. Figure 37G 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.

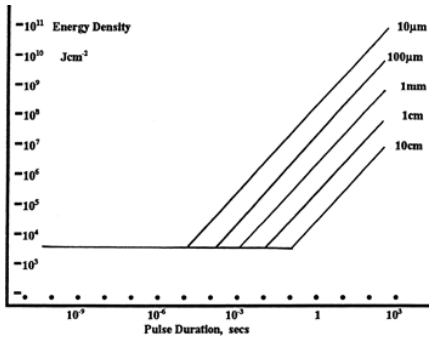


Figure 37G LIDT in energy density vs. pulse length and spot size. For short pulses, energy density becomes a constant with spot size. This graph was obtained from [1].

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

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

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/cm², 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/cm2) 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:

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

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

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

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[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 LIDT Calculator button. To use the calculator, enter the specified LIDT value of the optic under consideration and the relevant parameters of your laser system in the green boxes. The spreadsheet will then calculate a linear power density for CW and pulsed systems, as well as an energy density value for pulsed systems. These values are used to calculate adjusted, scaled LIDT values for the optics based on accepted scaling laws. This calculator assumes a Gaussian beam profile, so a correction factor must be introduced for other beam shapes (uniform, etc.). The LIDT scaling laws are determined from empirical relationships; their accuracy is not guaranteed. Remember that absorption by optics or coatings can significantly reduce LIDT in some spectral regions. These LIDT values are not valid for ultrashort pulses less than one nanosecond in duration.

LIDT Calculator

CW Laser Example

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

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

However, the maximum power density of a Gaussian beam is about twice the maximum power density of a uniform beam, as shown in Figure 71A. Therefore, a more accurate determination of the maximum linear power density of the system is 1 W/cm.

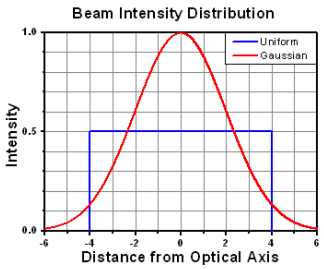


Figure 71A A Gaussian beam profile has about twice the maximum intensity of a uniform beam profile.

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:

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

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:

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

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 ~0.7 J/cm^2.

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

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

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

Pulsed Nanosecond Laser Example: Scaling for Different Wavelengths

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

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

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

Pulsed Microsecond Laser Example

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

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

INSIGHTS

Insights into Retroreflectors



Scroll down to read about interactions between light and corner-cube retroreflectors.

- How does alignment affect the beam path through a retroreflector?
- Why coat the backsides of solid prism retroreflectors with metal?
- Does the angle of incidence affect the output beam power from a corner-cube retroreflector?

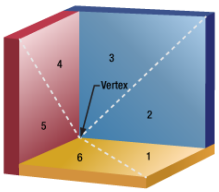
Click here for more insights into lab practices and equipment.

How does alignment affect the beam path through a retroreflector?

Beams output from corner-cube retroreflectors travel parallel to the input beam, but in the opposite direction. The input beam can be aligned to the vertex or to a point on one of the three faces. The input and output beams are colinear if the input beam is aligned to the vertex. The two beams will be separated if the input beam spot does not overlap the vertex.

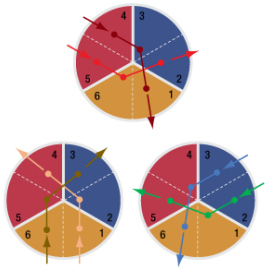
Input beams aligned to one of the retroreflector's faces will reflect from that face and then the other two before exiting the retroreflector. For a range of incident angles, there are six possibilities for the order in which the beam will reflect from the three different faces. It can be useful to select the path through the retroreflector for reasons that include optimal beam positioning and minimizing polarization effects.

For a beam to follow a particular sequence of reflections, it is not sufficient to align the beam so that it is incident on a specific face. The beam must also be incident on the proper half of that face.



Click to Enlarge

Figure 195A The three reflective faces of a corner-cube retroreflector are shown in false color and with numerical labels assigned to each half. Retroreflectors are designed to reflect an incident beam once from each face and provide an output beam parallel to the input.



Click to Enlarge

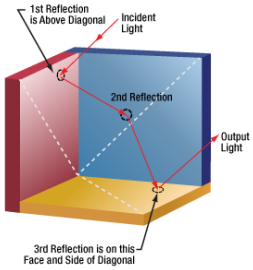
Figure 195B There are six possible sequences of reflections for a beam. The zone in which the first reflection occurs determines the sequence. These maps apply to beams approximately parallel with the retroreflector's normal axis. The beam paths are indicated by arrows, and dots mark reflections.

Tracing the Beam Path

When looking into the vertex of the retroreflector, reflective effects make it possible to see the six halves of the three faces. Here, they are identified using dashed diagonal lines (Figure 195A). In addition, the three faces of the retroreflector are shaded with false color for illustrative purposes. The normal axis is not shown, but it passes through the vertex and is equidistant from all three faces.

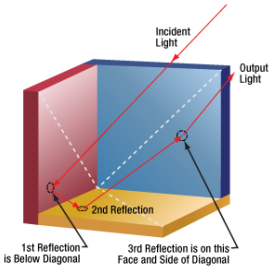
The six different possible reflection sequences can vary with angle of incidence. The maps in Figure 195B apply to beams nearly parallel with the normal axis. While a hollow retroreflector is used for these illustrations, these sequences of reflections also apply to prism retroreflecting mirrors.

The position of the first reflection determines which sequence of reflections the beam will follow through the retroreflector. The beam always exits from a different face than it entered.



Click to Enlarge

Figure 195C When the first reflection occurs above the diagonal of the red face, and the beam is parallel to the retroreflector's normal axis, the second reflection occurs from the blue face. The beam then reflects from the yellow face before exiting the retroreflector.



Click to Enlarge

Figure 195D Shifting the position of the first reflection to below the diagonal of the red face causes the next reflection to occur from the yellow face. After the third reflection, from the blue face, the beam exits the retroreflector travelling parallel to but shifted from the output beam in Figure 195C.

Example

Figures 195C and 195D illustrate the two orders of reflections that can occur when the first reflection occurs from the left-most vertical face. The incident beam is parallel to the retroreflector's normal axis.

When the first reflection occurs above the diagonal, as shown in Figure 195C, the last reflection occurs from the horizontal (yellow) mirror. However, locating the first reflection below the diagonal results in a last reflection from the other vertical (blue) mirror. The output beams of these two cases are parallel to, but shifted from, one another.

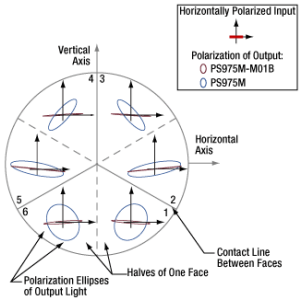
Date of Last Edit: July 8, 2020

Why coat the backsides of solid prism retroreflectors with metal?

When the backsides of solid prism retroreflectors are coated with metal, polarization changes induced in the output beam are significantly reduced.

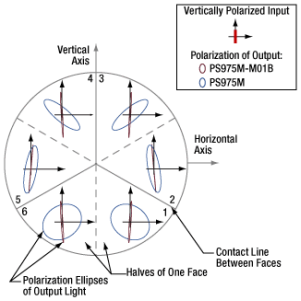
This is due to the difference between specular reflections, which occur from interfaces between glass and the higher refractive index metal, and reflections that occur due to total internal reflection (TIR), which require the backside material, like air, to have a lower refractive index.

Compared with TIR, a specular reflection from a glass-metal interface better preserves the input beam's polarization ellipticity.



Click to Enlarge

Figure 195E Horizontally polarized beams were input to a TIR solid prism retroreflector (PS975M) and a backside-gold-coated solid prism retroreflector (PS975M-M01B). The polarization ellipse of each output beam is shown in the zone that provided the beam's third reflection. For a



Click to Enlarge

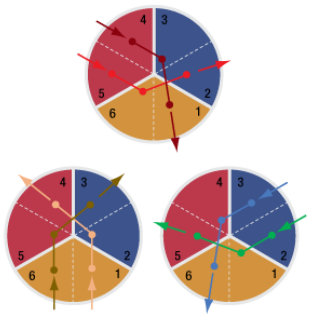
Figure 195F Vertically polarized beams were input to a TIR solid prism retroreflector (PS975M) and a backside-gold-coated solid prism retroreflector (PS975M-M01B). The polarization ellipse of each output beam is shown in the zone that provided the beam's third reflection. For a plot of the ellipticity angle (χ) and orientation

Polarization and Beam Path Diagrams

Beam paths through a retroreflector can be described by dividing its three reflective faces into six wedge-shaped zones (Figures 195E, 195F and 195G). Solid gray boundary lines mark physical lines of contact between reflective faces. Dotted gray lines indicate boundaries between the halves of each face.

The retroreflectors in these figures are oriented with one face-to-face interface aligned with the vertical axis. When the input beam is normal to these figures' viewing planes, Figure 195G describes the order in which the input beam reflects from the three faces before being output.

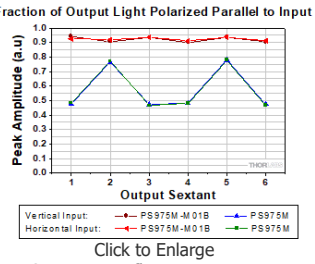
plot of the ellipticity angles (ψ) with respect to the horizontal axis, click here.



Click to Enlarge

Figure 195G A retroreflector is designed to reflect an input beam once off of each face. When the beam is approximately normal to the viewing plane illustrated in Figures 195E and 195F, the beam will follow one of six beam paths.

angles (ψ) with respect to the horizontal axis, click here.



Click to Enlarge

Figure 195H Retroreflectors convert some of the input light to the orthogonal polarization. Over 90% of the light output from the backside-gold-coated solid prism retroreflector (PS975M-M01B) remained polarized in the input state. In the case of the TIR solid prism retroreflector (PS975M), that percentage strongly depended on beam path and did not exceed 80%.

Output Polarization State

Two sets of six measurements were made for both a PS975M TIR solid prism retroreflector and a PS975M-M01B backside-gold-coated solid prism retroreflector. Input light was linearly polarized, vertically for one set of measurements and horizontally for the other. In a set, each measurement was taken with the beam aligned to a different zone. At all three reflections, the beam was confined within a single zone.

In Figures 195E and 195F, the polarization states of the output beam are represented using polarization ellipses. Each output beam's polarization ellipse is shown in the zone that provided the third reflection.

Ideally, the output beam would have the same polarization state as the input beam. However, these measurements indicate the retroreflectors converted some of the incident light to the orthogonal polarization. The plot in Figure 195H is a measure of the fraction of light in the output beam that was polarized parallel to the input.

The backside-gold-coated solid prism retroreflector was significantly more successful in maintaining the polarization state of these linearly polarized input beams.

Date of Last Edit: July 7, 2020

Does the angle of incidence affect the output beam power from a corner-cube retroreflector?

The beam power output by solid prism retroreflectors may oscillate around an average value as the angle of incidence (AOI) varies. This is due to a multiple-beam interference effect that can occur when the coherence length of the light source is at least twice the optical path length through the retroreflector.

When the front face of a solid retroreflector has an anti-reflective coating, oscillation amplitudes for all AOIs are substantially reduced. Hollow metal-coated retroreflectors provide output beams whose power is approximately independent of AOI.

Beam Path

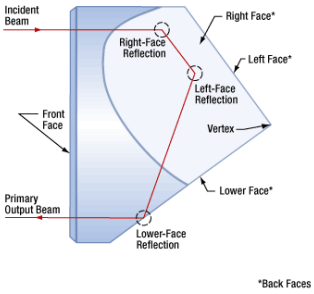
These corner-cube retroreflectors provide an output beam that travels in a direction parallel and opposite to the incident beam. Figure 195J shows one beam path.

The AOI is determined using a reference axis normal to the front face of the retroreflector. This axis passes through the vertex and is equidistant from the three back faces.

Reflections from the Front Face

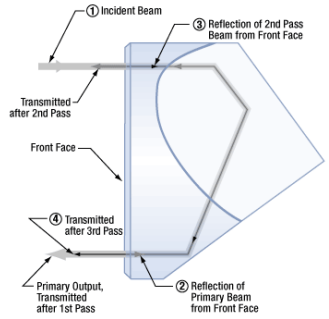
As illustrated in Figure 195K, light can make multiple passes through a solid prism retroreflector, depending on whether the light reflects from or is transmitted through interfaces between the front face and the surrounding medium.

When a glass retroreflector is surrounded by air, ~96% of the light is in the primary output beam,



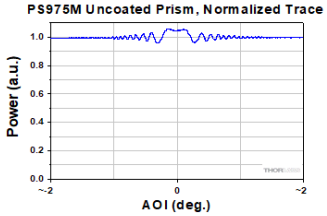
Click to Enlarge

Figure 195J The beam path through a corner-cube retroreflector includes a reflection from each of the three back faces, in an order determined by the position of the incident beam. The incident beam shown here has a 0° AOI and is displaced from the vertex.



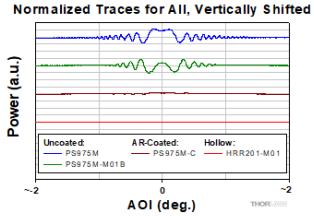
Click to Enlarge

Figure 195K Since the refractive indices of glass and air are different, the beam reflects at the front face. Reflected light can make multiple passes through the retroreflector before being output. Coherent overlapping beams produce interference effects.



Click to Enlarge

Figure 195L The power output by a TIR solid prism retroreflector (PS975M) was measured as a function of AOI. The incident beam was provided by a DBR1064S 1064 nm laser source, whose coherence length was several meters. The largest-amplitude oscillations resulted around 0° AOI, where the first- and third-pass beams overlapped. The $1/e^2$ beam diameters did not overlap for AOIs larger than ±1° at a distance of 30 cm from the front face of the retroreflector.



Click to Enlarge

Figure 195M Output power as a function of AOI differed depending on the type of corner-cube retroreflector. Data from measurements, made as described in Figure 195L, were normalized to the same scale, and traces were vertically shifted as a visual aid. Oscillation amplitude was strongly suppressed when the front face was AR-coated (PS975-C). Oscillations were not observed for the hollow retroreflector (HRR201-M01).

which makes a single pass through the retroreflector, and ~0.16% is in the beam that completes an additional round trip. In this work, light making additional round trips had negligible intensity.

Conditions for Interference

Since the output of solid prism retroreflectors consists of beams that have travelled different optical path lengths, they will interfere if:

- The beams overlap, which is more likely when the AOI of the incident beam is near 0° and the output is measured closer to the retroreflector. At larger distances, the beam deviation specified for the retroreflector and the AOI will more widely separate the first- and third-pass beams.
- The coherence length of the source is longer than the difference in path length between the primary beam and the overlapping beam that has made more than one pass through the retroreflector.

Corner-Cube Retroreflectors Compared

The variation of output power with small AOI was compared for four different types of corner-cube retroreflectors: a PS975M TIR solid prism retroreflector, a PS975M-M01B backside-gold-coated solid prism retroreflector, a PS975M-C TIR solid prism retroreflector with an antireflective-coated front face, and a HRR201-M01 that has a hollow construction. The input source was a DBR1064S 1064 nm laser diode with a coherence length of several meters, and the power detector was placed 30 cm from the front face of the retroreflectors. The beam size was small enough to ensure that each reflection occurred from a single face.

Figure 195L plots the normalized measurements made for the TIR solid prism retroreflector. As the AOI increased, the centers of the first- and third-pass beams shifted away from one another. At AOIs greater than around ±1°, the beams' $1/e^2$ diameters no longer overlapped. This resulted in the oscillation amplitude decreasing with AOI. The range of AOIs over which oscillations were significant would increase if the detector were located closer to the front face.

Figure 195M plots the trace from Figure 195L, as well as traces measured for the other three retroreflectors, on the same scale but vertically shifted as a visual aid. These results indicate that an antireflective-coated front face suppresses power oscillations in beams output by solid prism retroreflectors. The power output by hollow retroreflectors does not oscillate, since there is no material boundary at the front face.

Date of Last Edit: July 7, 2020

Mounted Hollow Retroreflector, UV-Enhanced Aluminum



- UV-Enhanced Aluminum Coating
  - R_{avg} > 90% from 250 to 450 nm
- N-BK7 Substrate
- SM1-Threaded Mount

This hollow retroreflector features a UV-enhanced aluminum coating for the 250 to 450 nm wavelength range on 6 mm thick N-BK7 substrates. It is mounted in an engraved SM1P1 adapter that has external SM1 (1.035"-40) threads for compatibility with our wide range of SM1-threaded mounts.

Item #	HRR203-F01
Clear Aperture	Entrance: Ø1.80" (45.7 mm) Single Leg: Ø0.84" (21.2 mm)
Coating	UV-Enhanced Aluminum
Reflectance per Surface[a] (Average)	>90% (250 - 450 nm)
Substrate[b]	N-BK7
Substrate Thickness	6 mm
Surface Flatness	<λ/4 at 633 nm
Dimensions[c]	2.33" x Ø2.52" (59.1 mm x Ø64.0 mm)
Mount Threading	SM1 (1.035"-40)

a. 0° to 45° Angle of Incidence Relative to Each Surface
b. Click Link for Detailed Specifications on the Substrate Glass
c. Height x Width. The height includes the aluminum mount. See the *Specs* tab for a diagram.

Part Number	Description	Price	Availability
HRR203-F01	N-BK7 Hollow Retroreflector, Ø1.8" Clear Aperture, UV-Enhanced Aluminum Coating, SM1-Threaded Mount	$810.48	Today

Mounted Hollow Retroreflectors, Protected Silver

- Protected Silver Coating
- N-BK7 or UV Fused Silica Substrates
- SM05- or SM1-Threaded Mounts (See Table G2.1)

These hollow retroreflectors feature a protected silver coating for the 450 nm to 20 µm wavelength range on N-BK7 or UV Fused Silica substrates. Each retroreflector is mounted in either an engraved SM05P05 adapter with external SM05 threads or an SM1P1 adapter with external SM1 threads for compatibility with our SM05-



threaded or SM1-threaded mounts, respectively.

Table G2.1 Specifications			
Item #	**HRR202-P01**	**HRR201-P01**	**HRR203-P01**
Clear Aperture	Entrance: Ø0.60" (15.2 mm) Single Leg: Ø0.28" (7.1 mm)	Entrance: Ø0.90" (22.9 mm) Single Leg: Ø0.41" (10.4 mm)	Entrance: Ø1.80" (45.7 mm) Single Leg: Ø0.84" (21.2 mm)
Coating	Protected Silver		
Reflectance per Surface[a] (Average)	>97.5% (450 nm - 2 µm) >96% (2 - 20 µm)	>97% (450 nm - 2 µm) >95% (2 - 20 µm)	>97.5% (450 nm - 2 µm) >96% (2 - 20 µm)
Substrate[b]	N-BK7	UV Fused Silica	N-BK7
Substrate Thickness	4 mm	6 mm	5 mm
Surface Flatness	λ/4 at 633 nm	λ/8 at 633 nm	λ/4 at 633 nm
Dimensions[c]	0.99" x Ø0.93" (25.1 mm x Ø23.7 mm)	1.41" x Ø1.52" (35.8 mm x Ø38.7 mm)	2.33" x Ø2.52" (59.1 mm x Ø64.0 mm)
Mount Threading	SM05 (0.535"-40)		SM1 (1.035"-40)

a. 0° to 45° Angle of Incidence Relative to Each Surface
b. Click Link for Detailed Specifications on the Substrate Glass
c. Height x Width. The height includes the aluminum mount. See the *Specs* tab for a diagram.

Part Number	Description	Price	Availability
HRR202-P01	**N-BK7 Hollow Retroreflector, Ø0.6" Clear Aperture, Protected Silver Coating, SM05-Threaded Mount**	**$575.56**	**Today**
HRR201-P01	**Customer Inspired! UVFS Hollow Retroreflector, Ø0.9" Clear Aperture, Protected Silver Coating, SM05-Threaded Mount**	**$560.79**	**Today**
HRR203-P01	**N-BK7 Hollow Retroreflector, Ø1.8" Clear Aperture, Protected Silver Coating, SM1-Threaded Mount**	**$810.48**	**Today**

Mounted Hollow Retroreflector, Protected Gold



- Protected Gold Coating
  - R_{avg} > 96% from 800 nm to 20 µm
- UV Fused Silica Substrate
- SM05-Threaded Mount

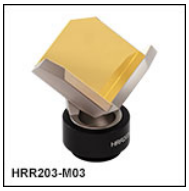
This hollow retroreflector features a protected gold coating for the 800 to 20 µm wavelength range on 6 mm thick UV fused silica substrates. It is mounted in an engraved SM05P05 adapter with external SM05 (0.535"-40) threads for compatibility with our wide range of SM05-threaded mounts.

Item #	HRR201-M01
Clear Aperture	Entrance: Ø0.90" (22.9 mm) Single Leg: Ø0.41" (10.4 mm)
Coating	Protected Gold
Reflectance per Surface[a] (Average)	>96% for 800 nm - 20 µm
Substrate[b]	UV Fused Silica
Substrate Thickness	6 mm
Surface Flatness	λ/8 at 633 nm
Dimensions[c]	1.41" x Ø1.52" (35.8 mm x Ø38.7 mm)
Mount Threading	SM05 (0.535"-40)

a. 0° to 45° Angle of Incidence Relative to Each Surface
b. Click Link for Detailed Specifications on the Substrate Glass
c. Height x Width. The height includes the aluminum mount. See the *Specs* tab for a diagram.

Part Number	Description	Price	Availability
HRR201-M01	**Customer Inspired! UVFS Hollow Retroreflector, Ø0.9" Clear Aperture, Protected Gold Coating, SM05-Threaded Mount**	**$560.79**	**Today**

Mounted Hollow Retroreflector, Unprotected Gold



- Unprotected Gold Coating
  - R_{avg} > 97% from 800 nm to 20 µm
- N-BK7 Substrate
- SM1-Threaded Mount

This hollow retroreflector features an unprotected gold coating for the 800 nm to 20 µm wavelength range on 6 mm thick N-BK7 substrates. It is mounted in an engraved SM1P1 adapter with external SM1 (1.035"-40) threads for compatibility with our wide range of SM1-threaded mounts.

Item #	HRR203-M03
Clear Aperture	Entrance: Ø1.80" (45.7 mm) Single Leg: Ø0.84" (21.2 mm)
Coating	Unprotected Gold
Reflectance per Surface[a] (Average)	>97% for 800 nm - 20 µm
Substrate[b]	N-BK7
Substrate Thickness	6 mm
Surface Flatness	<λ/4 at 633 nm
Dimensions[c]	2.33" x Ø2.52" (59.1 mm x Ø64.0 mm)
Mount Threading	SM1 (1.035"-40)

a. 0° to 45° Angle of Incidence Relative to Each Surface
b. Click Link for Detailed Specifications on the Substrate Glass
c. Height x Width. The height includes the aluminum mount. See the *Specs* tab for a diagram.

Part Number	Description	Price	Availability
HRR203-M03	**N-BK7 Hollow Retroreflector, Ø1.8" Clear Aperture, Unprotected Gold Coating, SM1-Threaded Mount**	**$810.48**	**Today**