

# Laser Damage Thresholds of Optical Coatings (UV to near-IR)

**CVI**  
Technical  
Optics

Presented by CVI

# Introduction

With laser power levels rising steadily it has become more and more important to improve optical coatings with respect to their laser damage threshold (LDT). However, the phenomenon of laser damage in optical coatings is still not fully understood and research activity continues in this field.

Based on the latest CVI Technical Optics test results, we hope this document will provide guidance as to what LDT can be expected at different wavelengths and how to scale and compare this data to values at different wavelengths and pulse durations.

## LDT measurement techniques

The typical setup for LDT measurements consists of firing a laser at a test sample until the optical coating is destroyed. However, there are many different methods of measuring LDT. In order to faithfully compare data one has to examine very carefully *how* the data was measured.

When testing with pulsed lasers, it is important to know whether the sample was exposed to a single shot or multiple shots. For both testing methods there are draft international standards available that will become ISO standards in future. For single-shot (1 on 1 test) the standard is ISO/DIS 11254-1.2, for multiple shot it is ISO/DIS 11254-2:1995.

Surface damage is defined as any permanent laser radiation induced change of the surface characteristics of the test sample, for either LDT test methods. The 1 on 1 test uses only one single shot on each unexposed site of the test sample. Whereas, the multiple shot test uses multiple shots in the same location on the test sample. CVI Technical Optics' samples are usually tested using the multiple shot test (s-on-1).

For both methods it is important to know the spot-size of the test beam as well as the pulse duration. With this information it is possible to scale the results to compare different sets of data.

Another complicating factor is the definition of Laser Damage Threshold. The most common definition is the value at which there is zero probability of laser damage. This also corresponds to the draft international standards. For single shot tests another definition is often used: the arithmetic average between the lowest power where

damage occurred and the highest power where no damage occurred. This value corresponds to a 50% likelihood of laser damage occurring. By definition, this value will be higher than the first method.

## Scaling of test data

Test data obtained for a specified pulse duration can be scaled to another pulse duration as long as it is understood that the result will have an error of a few percent.

For pulse durations 0.5ns to 50ns, use the following calculation. X is the original pulse duration given in ns. Y is the second pulsed duration for which LDT is being calculated.

$$LDT(Y) = LDT(X) \sqrt{\frac{Y}{X}}$$

Example: The LDT is given as 6J/cm<sup>2</sup> for 1ns and has to be scaled for a pulse duration of 10ns.

$$\text{Result: } LDT(Y) = (6J/cm^2) \sqrt{\frac{10ns}{1ns}} = 18.97J/cm^2$$

For femtosecond pulses a different damage mechanism applies and this scaling method is not valid.

## Laser damage mechanisms

The two main mechanisms that cause laser damage to an optical coating are dielectric breakdown and thermal absorption.

The most prominent dielectric breakdown occurs at a surface effect. Surface defects cause failure at lower power levels than one would expect from the bulk material properties. Factors which significantly reduce the LDT are scratches, pores, and inclusions. The substrates must be thoroughly cleaned prior to coating. They should also be handled in a clean-room environment throughout the coating process.

The second damage mechanism is thermal absorption. This can be in the form of bulk or surface absorption. Bulk absorption can be caused by impurities or color centers. Surface absorption is usually caused by an adsorbing layer: particulate matter or residual polishing compound.

In both cases an optimization of coating procedures and parameters can significantly minimize these problems and therefore increase the laser damage threshold.

## CVI Technical Optics Laser Damage Threshold Data

Optic type	0% fail conditions	50% fail conditions
<b>1064 nm</b>		
High Reflectivity Coating at 45°	30.1J/cm <sup>2</sup> in 20ns *	> 50J/cm <sup>2</sup> in 20ns *
High Reflectivity Coating at 0°	23.7J/cm <sup>2</sup> in 20ns *	>50J/cm <sup>2</sup> in 20ns *
50% Reflective Coating at 0°	17.7J/cm <sup>2</sup> in 20ns *	50J/cm <sup>2</sup> in 20ns*
Anti-Reflective Coating at 0°	10.8J/cm <sup>2</sup> in 20ns*	30J/cm <sup>2</sup> in 20ns*
<b>268 nm – 850 nm</b>		
High Reflectivity Coating (750-850nm) at 45° s-POL	4J/cm <sup>2</sup> in 300ps avg power 8J/cm <sup>2</sup> in 300ps peak power	7J/cm <sup>2</sup> in 300ps avg power 14J/cm <sup>2</sup> in 300ps peak power
High Reflectivity Coating (694nm) at 45°	1.4J/cm <sup>2</sup> in 30ns **	62J/cm <sup>2</sup> in 30ns **
50% Reflective Coating (694nm) at 0°	24J/cm <sup>2</sup> in 30nsl**	74J/cm <sup>2</sup> in 30ns**
High Reflectivity Coating (532nm) at 0°	9.7J/cm <sup>2</sup> in 10ns *	15J/cm <sup>2</sup> in 10ns*
High Reflectivity Coating (355nm) at 45°	4.6J/cm <sup>2</sup> in 10ns*	6.88J/cm <sup>2</sup> in 10ns*
97% Reflective Coating (268nm) at 45° s-POL	2J/cm <sup>2</sup> in 60ps****	3.4J/cm <sup>2</sup> in 60ps****
<b>193 nm</b>		
High Reflectivity Coating at 0°	4.3J/cm <sup>2</sup> in 15 ns (1 on 1)***	1.54J/cm <sup>2</sup> (1000 on 1)
High Reflectivity Coating at 45°	2.63J/cm <sup>2</sup> in 15 ns (1 on 1)***	1.17J/cm <sup>2</sup> (1000 on 1)
Anti-Reflective Coating on CaF2 0°	1.10J/cm <sup>2</sup> in 15 ns (1 on 1)***	0.81J/cm <sup>2</sup> (1000 on 1)

\* Multiple shot (200 shots) with 20 Hz repetition rate

\*\* Multiple shot (10 shots) with 0.2 Hz repetition rate

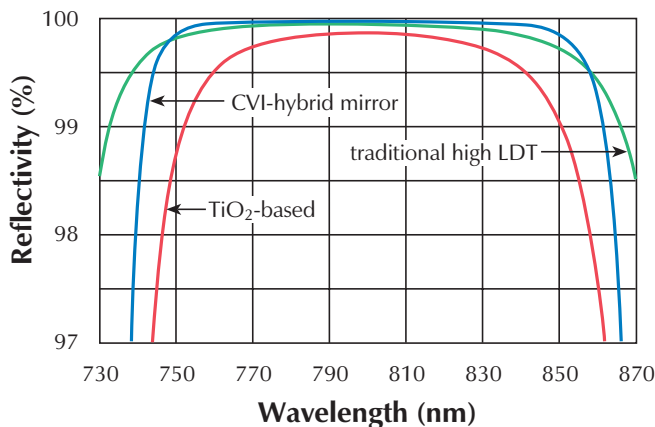
\*\*\*Multiple shot with 100 Hz repetition rate

\*\*\*\* Multiple shot (100 shots), LDT value is arithmetic average of lowest damage and highest survival power

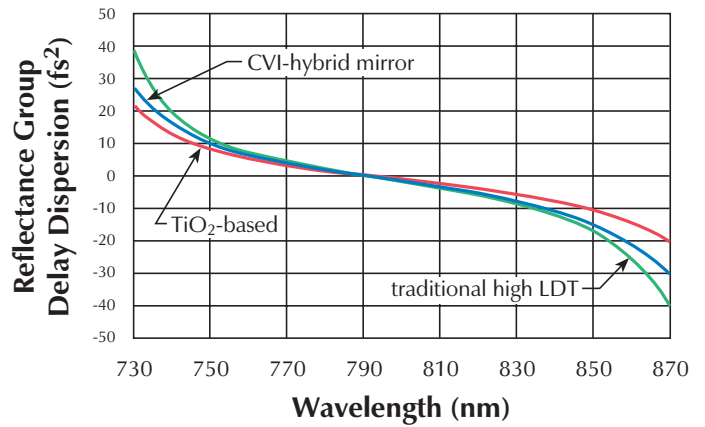
## New products for femtosecond applications

Traditionally high-LDT, low dispersion mirrors were limited in the broadness of the reflectivity band. A broader reflectivity band can be achieved by using TiO<sub>2</sub> but this will reduce the damage threshold.

CVI Technical Optics has actively researched methods of combining a broad reflectivity band and low dispersion with the benefits of a high LDT optic. The positive results, compared to existing products, are shown below:



A comparison of Reflectivity vs. Wavelength of TiO<sub>2</sub>-based, traditional high LDT, and the new CVI-hybrid mirror.



A comparison of Reflectance Group Delay Dispersion vs. Wavelength of TiO<sub>2</sub>-based, traditional high LDT, and the new CVI-hybrid mirror.

The LDT has been tested by Prof. Jean-Paul Chambaret of the Applied Optical Laboratory in Palaiseu, France, using a 200ps pulse. The LDT of the broadband-low dispersion mirror matches the LDT of the existing, traditional high-LDT mirror.

These new mirrors are available for all Ti:Sapphire laser-related center wavelengths.

## New developments in high power UV laser optics

Recently there has been rising demand for high power laser optics with large coated apertures. In the past, high LDT coatings for UV applications at 308nm or below could only be deposited over small apertures in order to avoid crazing of the coating. CVI Technical Optics has developed a coating technique where the coated aperture is only limited by the size of the coating chamber. We have successfully coated optics with diameters up to 235mm. Using the scaling method described previously the measured value of 2J/cm<sup>2</sup> for a 60ps pulse corresponds to an LDT of 10J/cm<sup>2</sup> for a 10ns pulse and about 17J/cm<sup>2</sup> for a 30 ns pulse. These values are at the forefront of industry standards.

Similar results apply to coatings for 248nm. Additionally, we are currently working on improving damage threshold, increasing maximum coated aperture, and increasing maximum reflectivity for 193nm optics.



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