



# Laser Damage Thresholds of Optical Coatings, UV-NIR

by Dr. Helmut Kessler of CVI Technical Optics

## 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 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.

## 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 defect. 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.

## 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.

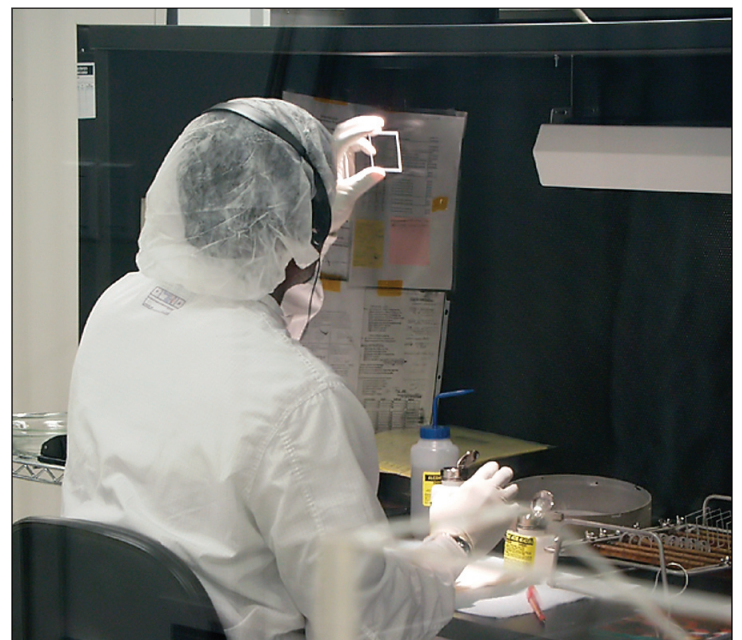
When testing with pulsed lasers, it is important to know whether the sample was exposed to a single shot or multiple shots. For both testing methods there are draft international standards available that will become ISO standards in future.

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 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.



*continued*



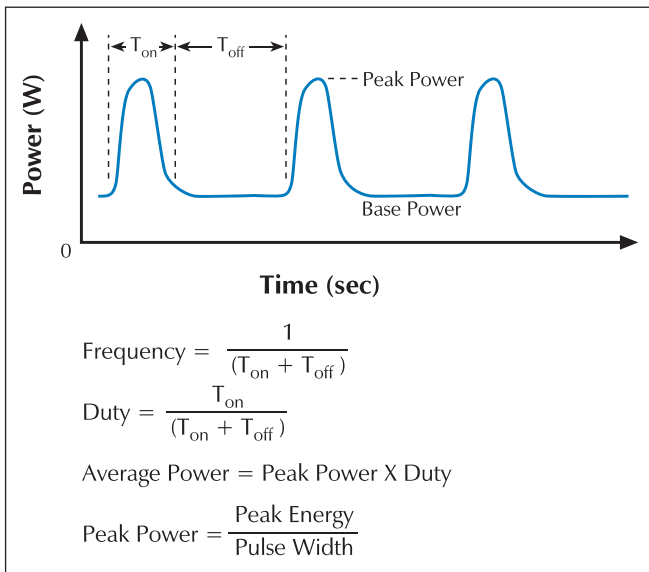
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## Scaling of test data

Most laser-cutting systems utilize pulsed output, either short or long pulses. The pulse characteristics required will be based on the end application. Often these pulse characteristics are not of exactly the same pulse width or repetition rate of the laser damage testing of the optics being considered for the application.



Two common test conditions are 8ns at 10Hz and 20ns at 20Hz. Test data obtained for a specified pulse duration may 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.

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.

Note: These scaling rules may only be used as a rule of thumb. There are many variables which affect laser damage threshold such as bulk material, coating materials, spot size, repetition rate, and wavelength.

## Damage Threshold Data from CVI

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 30ns**	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

## Useful References:

- 1) Jean-François Bisson, et al. "Laser Damage Threshold of Ceramic YAG" *Jpn. J. Appl. Phys. Vol. 42 (2003) pp. L 1025–L 1027, Part 2, No. 8B, 15 August 2003*
- 2) *Laser-Induced Damage Threshold and Certification Procedures for Optical Materials, NASA Reference Publication 1395 June 1997. <http://techreports.larc.nasa.gov/ltrs/ltrs.html>*
- 3) L. Gallais, J.Y. Natoli and C. Amra, "Statistical study of single and multiple pulse laser-induced damage in glasses", *Optics Express vol.10, n° 25, pp. 1465-1474, 2002.*
- 4) E.W. Van Stryland, M.J. Soileau, A.L. Smirl and W.E. Williams, "Pulse-width and dependence of laser-induced breakdown," *Phys. Rev. B 23, 2144–2151 (1981)*