Plasma Optik Techne System —
Qualification for High Fluence Optical Applications

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Executive Summary

Thin films exposed to high laser fluence levels benefit from having both high laser damage threshold and low absorption values. The need for high laser damage threshold is clear. Low absorption is also important due to the need to keep the optic from experiencing absorption-based heating effects while in use. Thin film stack absorption under optical load can lead to issues such as thermal lensing and premature failure of the optic. Plasma Process Group has developed the Techne Ion Beam Sputtering deposition tool designed for manufacturing these challenging coatings. Plasma Optik has optimized Techne process parameters to both maximize laser damage threshold and minimize absorption. This paper details the laser damage and absorption testing methods and these methods are discussed. Also included is laser damage and absorption performance data measured by testing of 1064nm and 532nm high reflector mirrors made with the Techne system.

High fluence laser optics are a significant manufacturing challenge. Applications range from a window on a laser welder, to an industrial laser component all the way to an optic to guide light for laser fusion experiments. Different applications have different requirements for laser wavelength, pulse duration and repetition rate. There are common wavelengths that can be considered standards for the purposes of talking about laser-initiated damage. One such common laser standard is the 1064nm laser.

1064nm lasers are based on the Neodymium -Yag (Nd: YAG) lasing medium. Nd: YAG lases very efficiently at 1064nm when pumped with 808nm input power. Part of the popularity of Nd: YAG lasers arises from the ability of laser manufacturers to frequency double, triple or quadruple the 1064nm output. The 1064nm laser therefore acts as the basis of lasers at 1064nm, 532nm, 355nm and 266nm. For many high-power applications, the 1064nm laser continues to be the wavelength of choice.

The mechanisms leading to laser damage vary depending on the wavelength of laser light being assessed. In the nanosecond pulse regime, we can usually consider the mechanism leading to laser damage to be defect driven[1]. In this case, the laser beam meets a small particle or defect in the coating or on the substrate and the laser power causes the particle to

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explode. ISO 21254 is one standard describing a testing process used to determine laser damage threshold.

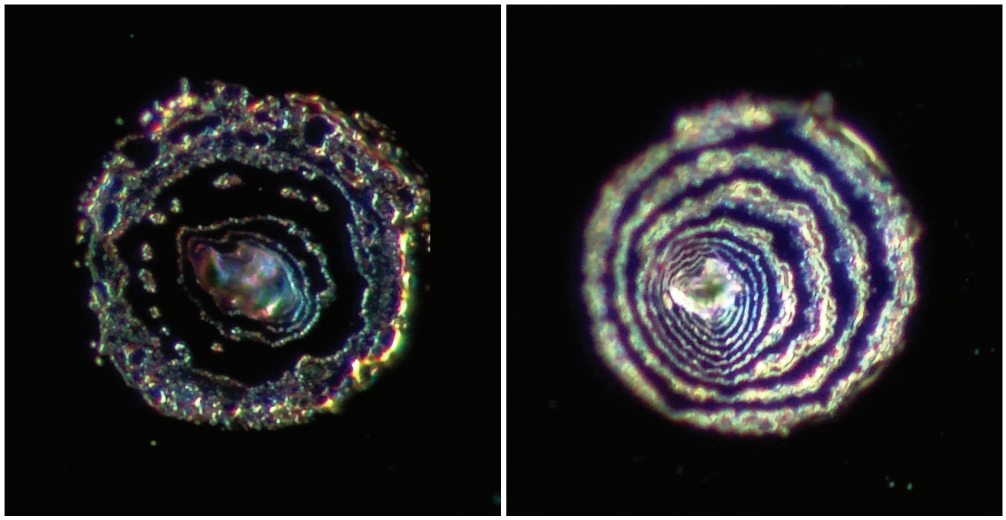

Figure 1. Differential Interference Contrast Images of Laser Damage on Plasma Optik Tested Optics. Left image appears to be a mid-structure failure and the right appears to have revealed a defect at substrate level. Note that these failures occurred at very high fluence levels!

ISO 21254 – "Test methods for laser induced damage threshold"[2] contains good, general information on test methods for laser damage testing. Typical laser damage testing irradiates laser optics with increasingly intense laser shots until damage is visible under darkfield microscope examination. The most common testing methodology is called 1-on-1 testing. The typical number of laser shots for 1-on-1 testing might be around ten. This is a cost-effective way to estimate the laser damage of batches of parts. Due to the statistical nature of the mostly defect driven laser damage failure mechanism in this pulse width regime, however, this method of testing can give falsely high or falsely low values for laser damage resistance[3].

A more thorough investigation of laser damage failure uses the S-on-1 procedure. The S-on-1 procedure uses a series of laser pulses in place of the single shot used in the 1-on-1 process. The "S" represents some number of laser shots at common fluence level, typically in the hundreds. The "Small Optics Laser Damage Testing Procedure" or LLNL-TR-740296 was released in 2005 and updated in 2017[4]. Lawrence Livermore National Labs (LLNL) released this document to support the manufacture of the optics supporting the National Ignition Facility (NIF). Testing is based on a S-on-1 procedure to control for statistical variation due to distributed defects.

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The LLNL-TR-740296 process attempts to remove some of the uncertainty involved in testing by illuminating around 2400 sites while rastering around the substrate clear aperture with increasing laser fluence. At the same time as this laser illumination progresses, the substrate surface is continually inspected for evidence of damage. The increased number of laser shots reduce the chance that the laser will miss small, distributed defects in the thin film structure as compared to one-on-one testing. LLNL-TR-740296 clearly defines the beam specifications for the test laser and the specifics of the testing method. Due to the thoroughness and increased confidence level in the results with this type of laser damage testing, this method was chosen by Plasma Optik for validating the performance of coated optics exposed to high laser fluence.

A pulse width of 3ns is specified in the LLNL-TR-740296 document. Another common pulse width for laser damage testing at 1064nm is 10ns. Scaling of laser damage results from one wavelength, pulse width or beam diameter to another is possible. One way to accomplish this scaling is with the following formula[5]:

$$LIDT(\lambda 2, , \tau 2, \theta 2) = LIDT(\lambda 1, , \tau 1, \theta 1) * \left(\frac{\lambda 2}{\lambda 1}\right) * \sqrt[2]{\frac{\tau 2}{\tau 1}} * \left(\frac{\theta 2}{\theta 1}\right)^{\wedge} 2$$

Where: $\lambda = wavelength, , \tau = pulse\ duration\ and\ \theta\ is\ beam\ diameter$

Plasma Optik prepared and coated multiple fused silica substrates with a MIL-SPEC 10-5 surface quality. These were laser damage tested with a 1064nm laser with 3ns pulses and a 1.01mm beam diameter by Spica Technologies. Below are the results from laser damage testing performed at 3ns with the 10ns values calculated with the formula above.

Sample	Tested Wave-length (nm)	Pulse Duration Desired (ns)	Pulse Duration Tested (ns)	Beam Diameter Desired (mm)	Laser Damage Failure Level (joules/cm^2)
1	1064	10	3	1.01	56.6
1	1064	3	3	1.01	31
2	1064	10	3	1.01	40.2
2	1064	3	3	1.01	22

Table 1. Plasma Optik HR Laser Damage when Tested with NIF 5008633 Protocol at 1064nm and 0° AOI

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Another important parameter for optics used in high laser fluence applications is that they have low absorption. Many variables affect absorption levels. One possibility is sub-stoichiometric oxides. Another possibility is large numbers of small defects dispersed throughout the thin film. Absorption typically results in a thermal transient at the location of the coating defect or absorption zone. The most common and accepted method to assess this absorption in optical coatings is with photo-thermal common path interferometry (PCI).

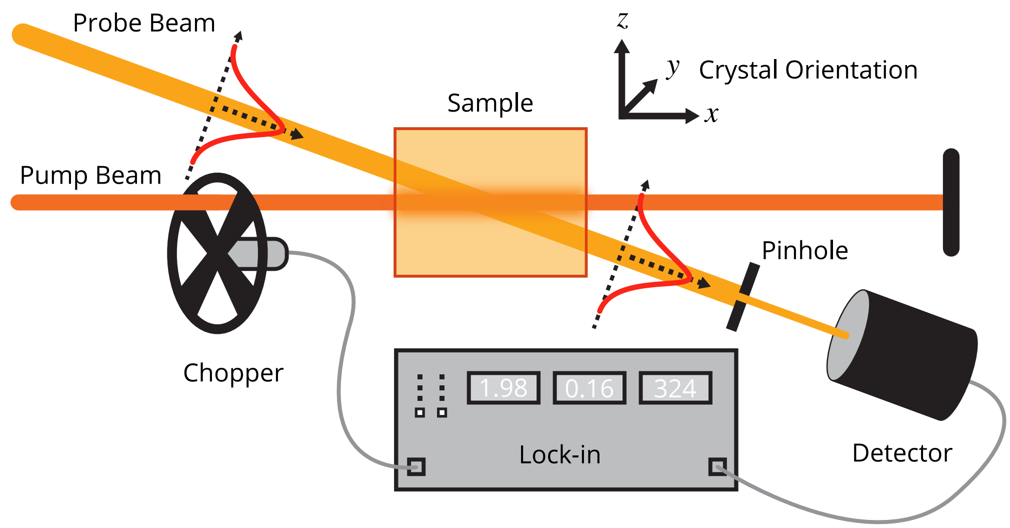

Figure 2. Photothermal Common Path Interferometer Example[6]

PCI utilizes a high-power continuous beam laser, labeled pump beam above, to illuminate the sample. This high energy stimulates absorption centers in a material and causes a refractive index change. Changing the pump laser allows testing different wavelengths. Typically, pump lasers at 1064nm, 532nm or 355nm are used since the pump laser requires a large fluence for maximum absorptive resolution and these wavelengths tend to be available with quite robust specifications. A 633nm laser is normally used for the probe beam laser since here beam quality is more important than power. The probe beam is crossed with the pump beam and aligned with a detector on the far side of the sample. The probe laser experiences a phase change due to the interaction with material heated by the pump laser. Sensitivity is increased with the lock-in amplifier and the probe beam intensity variation is measured at the detector.[7]

Plasma Optik has had several parts evaluated at 532nm and 1064nm by Stanford Photothermal Solutions. Note that in the data below, the absorption limit was reached with our sample at 532nm. Due to the reduced 532nm pump laser power as compared to the 1064nm laser, measurement floor at this wavelength is limited to 2ppm minimum.

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Design	Layers	Substrate	1064nm Absorption (ppm)	532nm Absorption (ppm)	Test Angle
532nm HR	32	Fused Silica		< 2	0°
1064nm HR	32	Fused Silica	0.9		0°
1064nm HR	32	Fused Silica	3.3		45°

Table 2. Sample absorption data taken by Photo-Thermal Common Path Interferometry

Plasma Optik has manufactured and tested laser optics per Lawrence Livermore National Laboratory standard process LLNL-TR-740296. Similar parts have been evaluated with Photothermal Common Path Interferometry. Results from this combination of testing indicates that Plasma Optik manufactured optics are competitive with industry state of the art. Properly prepared optics can withstand very high laser fluence when coated on the Techne coating platform and have been shown to have very low absorption values.

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Plasma Optik manufactures bandpass filters, notch filters, edge filters, polarizing beam splitters, non-polarizing beam splitters, mirrors and anti-reflective coatings. Our optical monitoring capability combined with ion beam sputtering technology allows us to manufacture precision optical coatings from the ultra-violet to near infrared wavelength ranges. Plasma Optik is always happy to talk about high laser damage threshold optics with low absorption.

Contact Plasma Optik for further information and find out how we can help you to optimize performance for your application's thin film optics.