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Small Optics Laser Damage Test Procedure

A. Wolfe

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SPECIFICATION

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING, LIVERMORE

Title:	Author:	Date:
Small Optics Laser Damage Test Procedure	Justin Wolfe	June 9, 2005
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1. SCOPE

This specification defines the requirements and procedure for laser damage testing of coatings and bare surfaces designated for small optics in the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL).

2. DEFINITIONS

2.1. **Damage**: Damage refers to any laser radiation induced change of the surface characteristics of the sample that can be observed by inspection techniques as described within this procedure. Damage sites occurring in the bulk material shall not be considered.

2.2. **Damage Growth**: Minor growth during the first 20 shots is interpreted as cleanup and stabilization of the initiated damage site rather than growth and is acceptable. Discernable growth after the first 20 shots is classified as damage growth and causes part to fail test.

2.3 **Coating Destruction**: The occurrence of one or more of the following:

- 2.3.1 Damage at more than 1% of the (nominally 2400) sites
- 2.3.2 Damage site(s) larger than 100 microns
- 2.3.3 Damage which grows upon further illumination (considered to be catastrophic damage)

2.4 **Optical Surfaces**: This refers to the optical surfaces of the part under test.

- 2.4.1 Front Surface: The surface which the test beam irradiates first.
- 2.4.2 Back Surface: The surface which the test beam irradiates last.

2.4.3 Target Plane: The target plane is the plane perpendicular to the axis of propagation of the test laser beam at the sample's surface

2.5 **Certification**: There are 2 ratings for laser damage certification: Pass and Fail.

2.5.1 **PASS**: The coating/substrate tested meets the pass criteria of the specified protocol to the specified fluence.

2.5.2 **FAIL**: The coating/substrate tested does not meet the pass criteria of the specified protocol to the specified fluence.

3 SAMPLE AND TEST REQUEST

Either an actual part or a witness sample may be tested. If a witness sample is tested, the substrate material and surface fabrication process shall be the same as for the actual part, and the witness shall be coated in the same coating run as the part. The witness sample dimensions are typically 50±0.5 mm diameter, 10±0.5 mm thick, and have a clear aperture greater than 45 mm diameter. For scarce materials, the witness sample dimensions may be smaller. The sample shall be identified with a unique label such as the coating run number, associated NIF Part and Serial number, etc.

The request for testing should include the following information:

Identification:

Requestor's name and contact information
Associated production part number (for reference)
Coating lot number
Witness sample ID# and whether test part is a witness or a production optic
Location of test area on test part (if necessary)
Substrate material
Nominal size of test part and surface to be tested (how is test surface designated?)
Location that test part will be shipped from and anticipated delivery date

Test:

Type of coating and fluence level specification
Test conditions (angle of incidence, polarization, test wavelength, pulse width, quadrant, etc.)
Quadrants (if any) that have been previously tested.
Test protocol (from table 3).

4 TEST METHOD

4.1 Principle

The basic approach to laser damage testing is shown in Figure 1. The output of a well-characterized laser is set to the desired energy density with a variable attenuator, and delivered to the sample located in the far field of a focusing telescope. The use of a focusing system permits generation of destructive power densities at the test sample. The incident test beam is sampled with a beamsplitter that directs a portion of the beam to a diagnostic package. The beam diagnostics package permits simultaneous determination of the total pulse energy, the spatial and the temporal profile.

4.2 Apparatus

4.2.1 Laser:

The test laser shall consist of a pulsed, Q-switched Nd:YAG or Nd:Glass laser. The laser output shall be either at a wavelength of 1064 nm or 1053 nm. The laser shall operate at a fixed pulse repetition frequency of not less than 1 Hz and not greater than 20 Hz. It shall have a full-width half-maximum (FWHM) pulse duration of not less than 1 ns and not greater than 10 ns. A reproducible near-Gaussian spatial profile with variations of less than 20% of the peak-power density is required. The pulse energy shall be stable within ±5%, pulse duration shall be stable within ± 10%, and the spot area stable within ±5%. The pulse fluence shall be within ±0.5 J/cm^2 for pulses of 3 J/cm^2 or less, or ± 15% for pulses of 4 J/cm^2 or more of the nominal fluence level. For example, for a scan at 3J/cm^2 the average pulse fluence shall be between 2.5 and 3.5 J/cm^2 and for a scan at 8 J/cm^2 the average pulse fluence shall be between 7.2 and 8.8 J/cm^2.

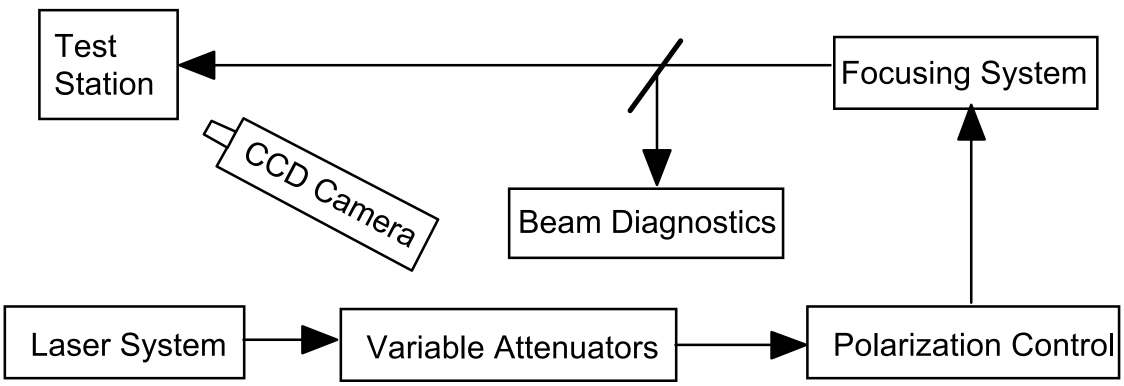

Figure 1 Laser damage test set-up

4.2.2 Polarization

The polarization contrast shall be greater than 100:1. The polarization-state of the incident test beam shall be set with an appropriate waveplate.

4.2.3 Variable Attenuator:

The laser output shall be attenuated to the required level with an external variable attenuator.

4.2.4 Focusing System:

The minimum aperture of the focusing system shall be 6 times the beam radius at the focusing system. The beam f-number shall be f/50 or slower to minimize spot size variations during translation. The target plane shall be located at or near the focal waist formed by the focusing system. The beam diameter in the target plane shall be greater than 0.8 mm at the $1/e^2$ power level.

4.2.5 Sample Holder:

The test station shall be equipped with a manipulator capable of raster scanning 1 cm^2 of area precisely on the test part. The manipulator shall hold the sample at the incident angle during the test.

4.2.6 Damage detection:

An in-situ scatter based diagnostic for the detection of laser damage shall be used. The illumination source consists of a HeNe (or other with LLNL approval) laser beam with a power of 10 mW or greater. This probe beam shall be co-aligned with the test beam at the test plane. It shall overlap the damage-test beam. A CCD video camera with a band-pass filter for the probe beam wavelength and a long focal length microscope objective shall be used to view laser-induced scatter changes. The signal may be recorded onto a VCR for later review. Detection of 20-40 micron scatter sites shall be possible. Plasma emission may be noted, but is not considered laser damage.

This diagnostic shall not preclude the use of secondary diagnostics based on detection of plasma or changes in scatter using photodiode or photomultiplier tubes. Such diagnostics can include in-situ transmission measurements and measurements of surface scatter before and after each laser pulse.

The sample may be inspected between tests using appropriate Nomarski/Darkfield microscopy up to and including 100x magnification.

Alternate methods for damage detection may be acceptable, but must be approved by LLNL.

4.2.7 Beam Diagnostics

4.2.7.1 Total Energy:

The diagnostic package shall be equipped with a calibrated detector to measure total pulse energy delivered to the target plane. This instrument must be traceable to a national standard with an absolute accuracy better than ±5%.

4.2.7.2 Temporal Profile:

The diagnostic package shall include suitable instrumentation for analyzing the temporal profile of the laser to determine the pulse duration. For lasers with pulse widths less than 3 ns, the temporal resolution shall be less than 0.3 ns. For lasers with pulse widths between 3 to 10 ns, the temporal resolution shall be less than 1.0 ns.

4.2.7.3 Spatial profile:

During initial set-up of the laser beamline, the spatial profile shall be analyzed in the target plane. Subsequently, the diagnostic package shall be equipped with instrumentation to measure the two-dimensional spatial profile in an equivalent optical plane with a spatial resolution of 3% of the normal beam diameter or better. A commercial beam-profiling system shall be used and the camera shall have a minimum intensity resolution of 8-bits (256 levels) and a pixel size not greater than 24 x 24 square microns.

4.2.8 Fluence determination:

The damage performance is reported as a function of fluence in J/cm^2 for pulse widths of 3ns. The fluence is determined using a commercial beam profiler and shall be the peak fluence defined as:

$$F_p = 2E_o / \pi\, w_o^2 \qquad \text{Eqn. [1]}$$

Where E_o = average beam energy, w_o = beam waist radius at zero degrees incidence. Equation [2] shall be used to convert the laser-induced damage threshold (LIDT) results obtained at pulse widths other than 3ns ($t_b \neq t_a = 3$ ns). The exponent depends on the coating as shown in Table 1. These results were based on tests performed on the various coatings and supersede the value of 0.35 typically used on NIF optical component drawings.

$$LIDT_a = LIDT_b\,(t_a / t_b)^x \qquad \text{Eqn. [2]}$$

Table 1

Coating	Exponent (x)
Anti-reflection @ 0 degrees	0.35
High Reflector @ 45 degrees	0.0
Polarizer @ 55.4 degrees	0.18
Bare Surfaces	0.5

4.3 Preparation of Test Samples

Samples shall be stored in clean PET-G containers when available, at a temperature of 20±5°C, and relative humidity of 45±15%. The sample shall acclimate to the temperature and relative humidity conditions before testing. The sample shall be handled on the non-optical surfaces using gloves or finger cots. Before laser damage testing, the samples may be cleaned with a clean room wipe, dampened with spectroscopic grade solvent (e.g. acetone, ethanol, methanol, etc.).

4.4 Procedure

Typical test requirements for angle-of-incidence, polarization, and test surface orientation are given in Table 2 for specific NIF small optics coatings. Variations to the general set-ups are allowed to match the test parameters to the operational parameters of the optic. For example, the fluence changes induced by testing an anti-reflective coated lens shall be accounted for. The test and probe beams are co-aligned at the target plane. The diagnostic camera is focused at the target plane. Note that some samples, such as anti-reflective coatings and bare surfaces, are tested on the back surface, where the incident beam enters the test sample on the front surface, propagates through the substrate, and irradiates the surface under test.

Table 2

Coating Type	Angle-of-incidence	Polarization	Target plane
Anti-reflective	Normal	Linear	Back Surface
High Reflector	45°	P-pol	Front Surface
Polarizer	55.4°	P-pol	Front Surface
Bare Surface	Normal	Linear	Back Surface

The angle-of-incidence and polarization of the test laser radiation used in the tests shall be in accordance with the customer's specifications. If ranges are given for various parameters, an arbitrary combination of angle-of-incidence and polarization within these ranges may be used.

Unless otherwise specified and if sample is large enough, the optic shall be tested in quadrant 1 (see Test Part Quadrant Definition below) . The scan area shall represent the quality of the test surface as viewed with an unaided eye using a high intensity light source. If such an area does not exist in the specified quadrant, another quadrant may be chosen (unless specified otherwise) which represents the quality of the test surface. The scan area shall not have been irradiated prior to damage test, i.e. was not in the beam path for a damage test of opposite surface or a previous test

Test Part Quadrant Definition
Quadrants are defined relative to the substrate, without regard to the testing configuration. This reduces the variables when determining which area(s) of a part have been tested.

The arrow (if present) on the barrel of the part points to laser damage test side 1. If no arrow is present, side 1 is up when the writing on the part right-reading. Note: This side designation for the laser damage testing may be different than S1/S2 as described on drawings. For laser damage testing, the definition contained in this document supersedes other definitions. If no arrow or similar fiducial is present, the first letter of the part number shall be considered the fiducial for determination of the quadrant locations.

Figure 2 shows the layout of the quadrants on the part with the arrow at the top. If there is no arrow the first letter of the part number or serial number shall be the fiducial for determining quadrants (see Fig. 3). The quadrants are defined continuously through the part, that is, if a beam enters normally through quadrant one of the first surface, it will exit quadrant one of the second surface.

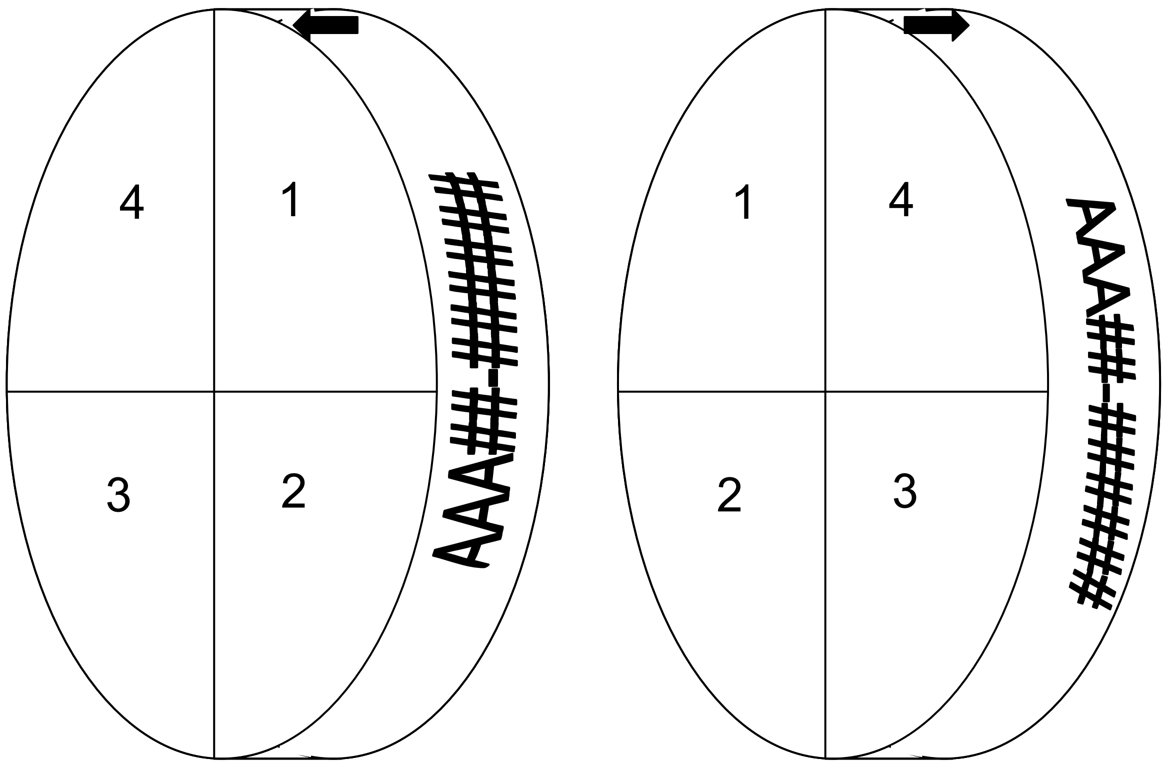

Figure 2. Diagram of quadrants defined for laser damage testing (arrow shown offset from top for visibility, should be at top for quadrant definition). Diagram on left shows LD test side 1 to left. Diagram on right shows LD test side 1 to right.

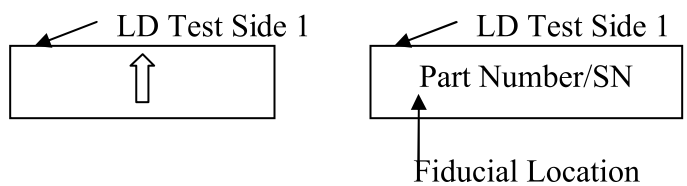

Figure 3. Diagrams showing LD Test Side 1 and fiducial for parts with and without an arrow

The quadrant tested shall be reported in the documentation.

The damage test shall consist of repeated raster-scanning of a 1 cm^2 region in serpentine fashion at fluences starting at 1, 2, or 3 J/cm^2 and increasing in accordance with the specified protocol. In between each scan, analysis of the surface, including microscopic inspection, may be performed in order to determine conformance to damage threshold criteria.

The “X” stage velocity shall be set to provide 1 pulse/site, with a site defined as the beam diameter at 90% of the peak fluence. The stage velocity shall be computed according to the formula

$$Velocity = D*R/N, \qquad \text{Eqn. [3]}$$

Where D = the diameter of a site, N = the number of shots/site, and R = the laser repetition frequency. The spacing between rows (i.e. the "Y" direction) shall be equal to the beam diameter at 90% of the peak fluence.

4.5 Test Protocols

The test protocols are given in Table 3 (next page). Coating Type identifies which protocols may be used with a given coating type. Test Identification is the term used to identify a particular protocol and is the term that shall be used on test request and result forms. Protocol describes the sequence of scans over the 1cm x 1cm area. Pass Criteria describes the requirements for the part to pass. If the requirements of the Pass Criteria are not met, the result shall be FAIL. Any test may be ended when the requirements of the Termination Criteria are met.

For Bare Substrates use the Test to Destruction.

Table 3: Test Protocols with Pass Criteria

Coating Type	**Test Identification**	**Protocol: 1 cm x 1 cm scan**	**Pass Criteria**	**Termination Criteria**
Mirrors & Polarizers	MP Certification Test (fluence is specified)	Start at 1, 2, or 3 J/cm^2; continue in 3 J/cm^2 increments until specified fluence is reached	No damage sites initiated up to specified fluence	>5 damage sites OR Scan at specified fluence complete
Mirrors & Polarizers	MP Certification Test to Destruction (fluence is specified)	Start at 1, 2, or 3 J/cm^2; continue in 3 J/cm^2 increments until specified fluence is reached then continue to destruction.	No damage sites initiated up to specified fluence	Destruction: 1) damage at >1% of the nominal 2400 sites 2) damage sites >100 µm 3) damage that grows upon further illumination
Anti-reflection (AR)	AR Certification Test (fluence is specified) [NIF qualified coatings only]	Start at 1, 2, or 3 J/cm^2; continue in 3 J/cm^2 increments until 3 J/cm^2 above specified fluence is reached	$\leq$10 damage sites initiated that are less than 100 µm and do not grow in size in further tests	Failure OR Scan at 3 J/cm^2 over specified fluence complete
Anti-reflection (AR)	AR Certification and Growth Test (fluence is specified)	Start at 1, 2, or 3 J/cm^2; continue in 3 J/cm^2 increments until 3 J/cm^2 above specified fluence is reached; then perform growth test by exposing each damage site to 300 additional shots at the specified fluence.	$\leq$10 damage sites initiated that are less than 100 µm and no growth occurs when damage site are exposed to 300 additional shots at the specified fluence	Failure OR Scan at 3 J/cm^2 over specified fluence complete
Anti-reflection (AR)	AR Certification and Growth Test to Destruction (fluence is specified)	Start at 1, 2, or 3 J/cm^2; continue in 3 J/cm^2 increments until 3 J/cm^2 above specified fluence is reached; then perform growth test by exposing each damage site to 300 additional shots at the specified fluence. Continue scans in 3 J/cm^2 increments to destruction	$\leq$10 damage sites initiated that are less than 100 µm and no growth occurs when damage site are exposed to 300 additional shots at the specified fluence	Destruction: 1) damage at >1% of the nominal 2400 sites 2) damage sites >100 µm 3) damage that grows upon further illumination
Any coated or uncoated substrate	Test to Destruction	Start at 1 J/cm^2; continue in 3 J/cm^2 increments to destruction	Not applicable	Destruction: 1) damage at >1% of the nominal 2400 sites 2) damage sites >100 µm 3) damage that grows upon further illumination

4.6 Documentation

A traveler for each sample shall accompany the sample throughout the test process from initial receipt to submission of the final report. All pertinent information pertaining to the test station configuration, source calibration, cleaning, inspection, exposure parameters, raw and reduced data shall be traceable to a unique run number on the traveler. The test laboratory as a primary reference shall retain the data.

For the purpose of documentation and presentation of the measured data a test report shall contain the following data:

4.6.1 Test Lab Information:

Name and address of the test lab

Test date

Operator Name

Damage Test System identification

4.6.2 Sample Information

Type of sample

Witness or actual part

Substrate material

Coating type

Sample dimension(s)

Company/Agency Name supplying the sample

Part Identification number (part number and serial number)

4.6.3 Test specification Information

Laser parameters:

test protocol
wavelength,
angle-of-incidence,
polarization,
pulse duration
repetition rate
Axial modes
Spot diameter ($1/e^2$)
Test scan area (cm^2)
Test scan location (by quadrant)
Method of storage, cleaning and pre-conditioning.

4.7 Test Results

4.7.1 The test result (Pass or Fail), the specified fluence (J/cm^2 for 3 ns pulse widths), and test protocol.

4.7.2 Table listing number of sites initiated at each fluence tested (J/cm^2 for 3 ns pulse widths) tested.

4.7.3 For tests including Damage Initiation & Growth (DIG) only: Number of sites tested for growth and results

4.7.4 Relevant comments and any unique attributes of the test part or procedure

4.7.5 Quadrant tested

4.7.6 Quadrants previously tested (if listed on request form)

5 REVISION HISTORY

Revision History							
Rev	**Description**	**Author**	**Date**	**Reviewed By**	**Date**	**Approved By**	**Date**
OB	Revised per ECR-XXX	Robert Chow	5/29/03	Mike Runkel John R.Taylor Dennly Becker	5/29/03	Paul Weber	5/29/03
OC	Revised by ECR 6697	Robert Chow	10/30/03	Mike Runkel	10/31/03	John R. Taylor	10/31/03
OD	Revised per ECR-YYY	Justin Wolfe	3/21/05	Mike Runkel Jim Folta Mike Borden Chris Stolz		John R. Taylor	
OE	Revised per ECR-0034592			Ed Krieger	9/7/14	Mike Borden Chris Stolz	9/19/14