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Damage Test Descriptions

Introduction

Quantel USA provides a full range of laser exposure test services. This document provides a general description of a representative test station, its calibration, optics handling, test procedure and documentation associated with laser exposure testing of customer-supplied optical samples. A wide variety of test sources, providing key laser wavelengths from the UV to IR, are available. Only the q-switched Nd:YAG test stations are described here, but the overall methodology in testing is similar in all Quantel USA laser sources.

Test Station Layout

A representative exposure test arrangement is shown in Figure 1, and pertinent parameters, for two Nd:YAG test stations, are summarized in Tables I and II. The test sources are flashlamp-pumped, electro-optically q-switched, Nd:YAG oscillator-amplifiers constrained to operate in a single transverse mode (TEM$_{00}$) using an intracavity aperture. The three color station has frequency doubling and tripling crystals. It uses a thin intracavity etalon to limit the number of longitudinal modes, resulting in a smooth temporal waveform (with approximately 5% high frequency amplitude modulation superimposed on it). Pulse width is set to the required value by altering q-switch timing, laser resonator length or both.

The output of a test sources is set to the desired level with a variable attenuator, combined at a dichroic with the visible beam from a helium-neon laser (HeNe), and delivered to the test sample located at or behind the focus of a best form positive lens. Use of a lens permits generating destructive energy densities (fluences) at the test sample. The lens is mounted on a translation carriage which allows setting the irradiated spot size to the desired value; one set, the spot size is held constant during the test. The sample is mounted in a precision multi-axis manipulator which is used to position different test sites in the beam, and to set the incidence angle. The polarization state is selected with a waveplate. The incident laser pulse is sampled with uncoated quartz wedges; portions of the beam are directed to various detectors for measurement of total pulse energy, spatial profile and temporal waveform. The sample surface and the visible laser radiation scattered from it are observed with a 20x optical microscope (not shown).

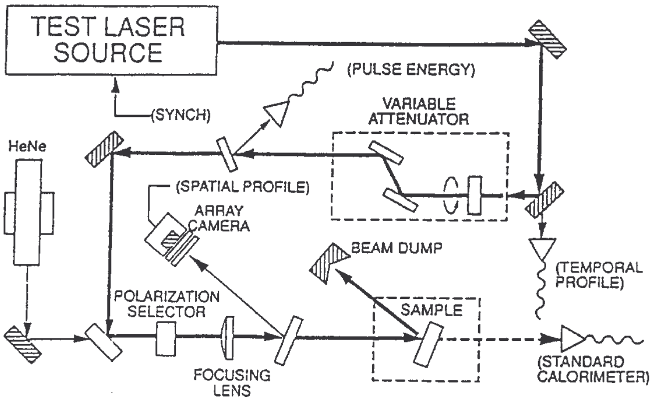


Figure 1: Production (20/20) Nd:YAG Test Station Layout.

Table 1
Three Color Nd:YAG Test Station Specifications

Wavelength	1064 nm, 532 nm, 355 nm
Pulse Energy	750 mJ, 300 mJ, 100 mJ
Repetition Rate	Up to 20 Hz in discrete steps
Temporal Profile	Etalon smoothed waveform
Pulse Duration	10-35 nsec, FWHM
Spatial Profile	TEM_{00}
Spot Size	Up to 8 mm, $FW1/e^2$
Incidence Angle	Normal to grazing
Polarization State	Linear or circular

Table 2
Production (20/20) Nd:YAG Test Station Specifications

Wavelength	1064 nm
Pulse Energy	100 mJ
Repetition Rate	Up to 20 Hz in discrete steps
Temporal Profile	Single maximum
Pulse Duration	20 nsec
Spatial Profile	TEM_{00}
Spot Size	0.5, 1, 1.5, 2 mm
Incidence Angle	Normal to grazing
Polarization State	Linear or circular
Exposure Sequence	Fully programmable

Laser Pulse Characterization

Damage test results are usually reported in terms of maximum (peak) fluence (J/cm^2). The parameter routinely varied in an exposure test, however, is the total pulse energy (J), since this can be done easily and accurately by adjusting the attenuator and measuring energy per pulse incident at the sample under test. Evaluation of the energy distribution in space (spatial profile) and time (temporal profile) is more complex, and is performed periodically. Rigorous relationships between pulse intensity, fluence, and energy follow from integration of the pulse profiles.

Absolute single-point calibration of the energy monitoring system is performed by removing the sample and allowing the laser pulse to enter a calibrated volume-absorbing disk calorimeter directly. The calorimeter is a commercial device, with manufacturer's stated accuracy of 3%, NIST traceable. Periodic calibration verification is performed by direct comparison to a second calorimeter and in accordance with MIL-C-45662A.

The temporal profile is observed with a fast silicon photodiode and calibrated 400 MHz oscilloscope. A typical q-switched pulse waveform is shown in Figure 2. The shape is nearly Gaussian, but with an extended tail which contains a non-negligible fraction of the pulse energy. Numerical integration of this waveform yields the ratio of total pulse energy to pulse peak power. This ratio is called the effective pulse width. The photodiode is also used to monitor shot-to-shot variation in the temporal profile which is typically less than 5%.

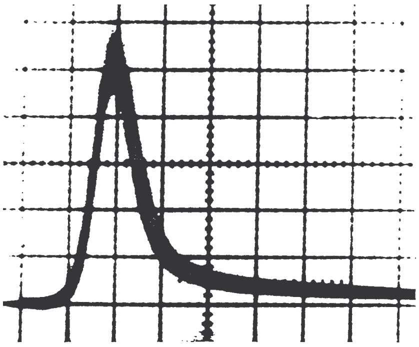
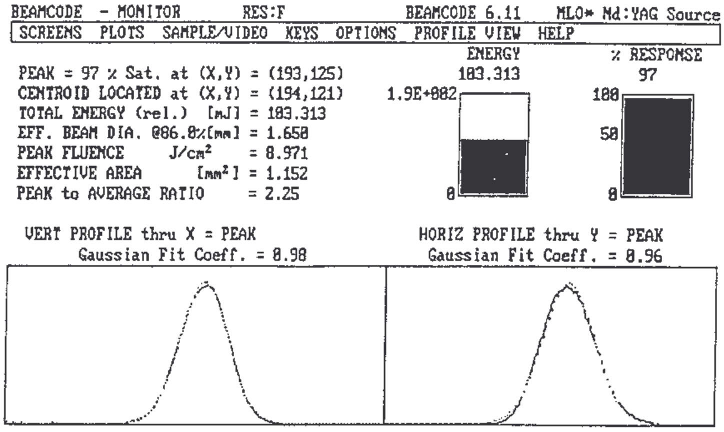


Figure 2: Temporal Profile Pulse duration: 20 nsec, FWHM

Periodically, a complete two-dimensional analysis of the spatial profile is performed with a BEAMCODE diagnostics system using a silicon array camera and video frame grabber. The camera array is located precisely in the target plane or equivalent. Data acquired by the frame grabber are transferred to a computer for near real-time analysis of individual laser pulses. Software permits quantitative determination of pulse energy and maximum fluence, and provides graphics displays of the spatial profile in several formats (Figure 3).



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BEAMCODE  - MONITOR       RES:F               BEAMCODE 6.11    MLO* Md:YAG Source
SCREENS  PLOTS  SAMPLE/VIDEO  KEYS  OPTIONS  PROFILE VIEW  HELP
                                                   ENERGY          % RESPONSE
 PEAK = 97 % Sat. at (X,Y) = (193,125)             103.313              97
 CENTROID LOCATED at (X,Y) = (194,121)      1.9E+002                100
 TOTAL ENERGY (rel.)  [mJ] = 103.313
 EFF. BEAM DIA. @86.0%[mm] = 1.650                                   50
 PEAK FLUENCE      J/cm²   = 0.971
 EFFECTIVE AREA      [mm²] = 1.152
 PEAK to AVERAGE RATIO     = 2.25                  0                  0

  VERT PROFILE thru X = PEAK                  HORIZ PROFILE thru Y = PEAK
       Gaussian Fit Coeff. = 0.98              Gaussian Fit Coeff. = 0.96
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Figure 3: Spatial Profile Obtained with Array Camera
Spot size: 1.65 mm, FW1/e^2

Independent verification of the radiation distribution in the target plane is obtained by scanning at that location with a pinhole and silicon photodiode. Figure 4 shows the excellent agreement between BEAMCODE measurements and pinhole scans. Numerical integration of this extremely Gaussian spatial profile yields the ratio of total pulse energy to maximum fluence in the target plane. This ratio is called the effective area. Shot-to-shot variation of effective area is typically less than 5%.

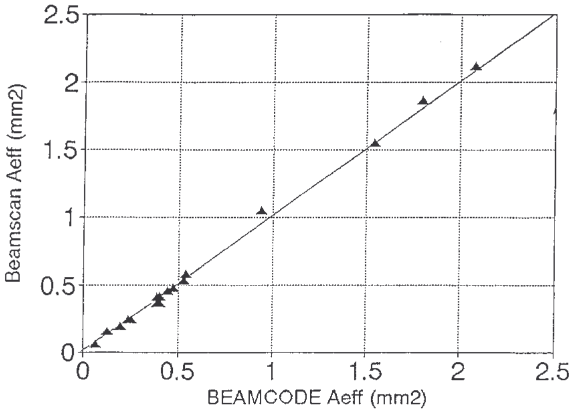

Figure 4: Spatial Profile Comparison, BEAMCODE to Pinhole Scan

Test Samples
The damage test station is equipped with a variety of interchangeable fixtures to permit mounting test samples of different geometry. When certifying laser damage resistance to a drawing or other procurement specification, it's preferable that actual laser optics, rather than witness samples, be tested to be assured of representative parts. Where used, witness samples usually are coated glass pieces; typically one inch in diameter by 3/8 inches thick. In most cases, one surface (the entrance face) has been carefully polished and coated while the exit face is generally uncoated and has a commercial grade "window" polish. It's best that transmissive samples with an uncoated exit face have a 3^0 wedge. Pieces of unusual geometry occasionally require fabrication of specialized holders.

Before testing, any loose particulates are removed by applying a low-pressure stream of nitrogen gas, followed by drawing a lens tissue saturated with methanol, acetone or other high purity solvent across the test surface. More vigorous cleaning procedures are performed if required by the customer. After exposure, samples are returned to the customer or archived at Quantel USA for possible additional testing.

Exposure Test Procedures
There are five major types of laser exposure tests: damage threshold, optical durability certification, transmission vs. fluence, optical density and specialty (such as lifetime testing). Each is described briefly here; variants are mode depending upon the optic and test specifications.

1. **Damage Threshold**: "Damage" is usually defined as any permanent laser-induced change which is observable at high magnification with a differential interference contrast of dark field microscope. It may be defined differently if the application requires. "Threshold" is defined to be the lowest fluence sufficient to induce damage at any test site. To determine the damage threshold, a number of samples sites are irradiated at different fluences. Each site is observed immediately before, during and after irradiation with the on-line 20x microscope, and any visible change, plasma formation, or change in the scatter of the HeNe laser beam is noted. After exposure and if required by the test, the test sites are examined microscopically to confirm damage and characterize laser-induced changes. Color photomicrography in several formats is available.

   Damage Frequency Method: This is the standard damage threshold procedure specified by the International Standards Organizations. The test sample is irradiated at several different fluence levels with a predetermined number of sites (usually 10) at each level. The levels are purposefully chosen so that at the higher fluence levels a high probability of damage exists whereas at the lower levels, a low probability of damage exists. The percentage of failures at each fluence is plotted against the fluence levels. A least squares linear fit to this data is calculated and the zero percent failure intercept defines the damage threshold level. A typical exposure data set is shown in Figure 5. This method provides the most accurate measurement of damage threshold, but requires a relatively large sample, since many sites must be exposed.

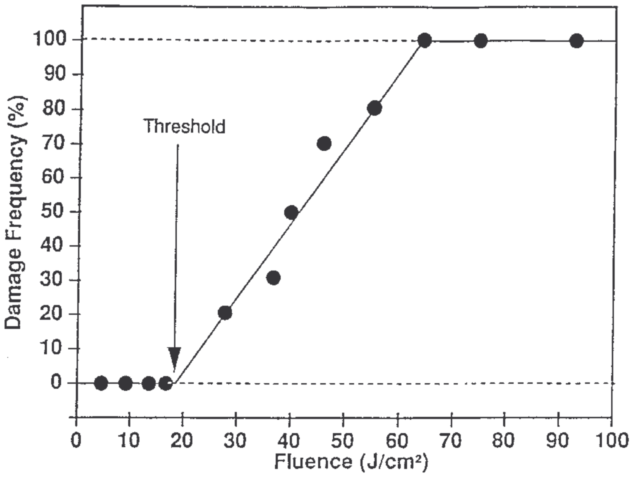

Figure 5: Typical Damage Frequency Method Data

Least Fluence Failure: An abbreviated is used when limited sample area is available for exposure. As before, the fluence levels are distributed approximately uniformly over a range including the anticipated failure level. One site is irradiated at each fluence level and the least fluence failure is taken as an estimate of the damage threshold. If untested sites remain, these are exposed at lower fluence levels for confirmation. A typical data set is shown in Figure 6. If the damage/no damage overlap region is small, as shown, the least fluence failure estimates the damage threshold with good confidence.

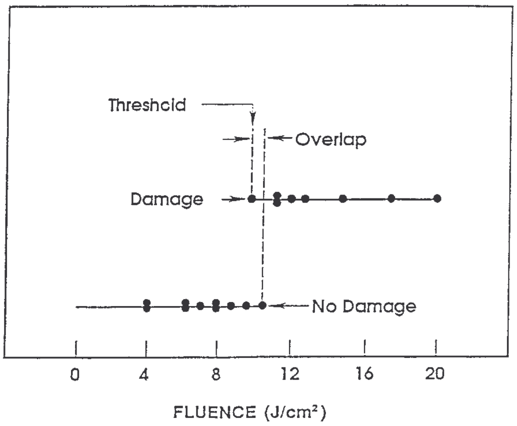

Figure 6: Typical Least Fluence Failure Method Data

On most laser optics, the surface damage threshold is defect driven, meaning it will fail at weak, isolated sites. If these sites are close together compared to the test beam size, relatively few test sites are needed to determine the damage threshold. In this case, the damage frequency plot will yield a near vertical line and the least fluence data will have a small overlap. Conversely, if the weak sites are widely separated compared to the test beam size, a low slope and a large overlap will result.

2. **Durability Certification**: This test is used to verify optic durability to a drawing or other procurement specification. Several test sites (usually chosen on a uniform grid and sampling a representative surface area) are exposed to laser radiation at one specified combination of fluence, repetition rate, pulse duration, spot size and minimum number of pulses per site. The sample is observed as before with the on-line 20x microscope and damage at any site constitutes "failure" in this test. This test is usually done on optics intended for use in laser hardware and seldom on witness samples.

3. **Transmission vs. Fluence**: Some optics, such as optical power limiters, have a nonlinear transmission response with exposed fluence level. This test generates the plot describing this optic characteristic. Such specialized exposure tests are performed to customer requirements. Test procedures are on a case-by-case basis.

4. **Optical Density**: This test measures the ratio of incident to transmitted fluence (or irradiance) under customer specified exposure conditions. Quantel USA has facilities to perform such testing under realistic temperature and humidity conditions as well.

5. **Specialty Testing**: As an example, the lifetime test is an extended version of the certification test when durability must be demonstrated over a prolonged operating period. The sample is exposed for the specified length of time or number of pulses. Photomicrographs of the test site before and after exposure are compared to identify and characterize changes. Other examples of specialty testing include simultaneous exposure at two wavelengths, long pulse Nd:YAG and glass bulk darkening threshold.

Documentation

Each test is assigned a unique run number. All pertinent facts pertaining to test station configuration, source calibration, cleaning, microscopic inspections, exposure parameters, raw data and reduced test results are referenced to this number and retained for permanent record. This enables precise duplication of test conditions as required.

A Summary Test Report is standard. It documents test type, exposure conditions, results and principal conclusions, and is submitted immediately after testing is completed.