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Lasers and laser-related equipment — Determination of laser-induced damage threshold of optical surfaces —

Part 2: **S-on-1 test**

Lasers et équipements associés aux lasers — Détermination du seuil d'endommagement provoqué par laser sur les surfaces optiques —

Partie 2: Essai S sur 1

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 11254 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 11254-2 was prepared by Technical Committee ISO/TC 172, *Optics and optical instruments*, Subcommittee SC 9, *Electro-optical systems*.

ISO 11254 consists of the following parts, under the general title *Lasers and laser-related equipment — Dtermination of laser-induced damage threshold of optical surfaces*:

— *Part 1: 1-on-1 test*

— *Part 2: S-on-1 test*

Annexes A to D of this part of ISO 11254 are for information only.

Introduction

Repetitive laser radiation may deteriorate and damage optical surfaces at irradiation levels below those measured for single shot damage (ISO 11254-1 refers). Besides reversible mechanisms induced by thermal heating and distortion, irreversible damage mechanisms due to ageing, microdamage and generation or migration of defects are observed. This part of ISO 11254 is concerned with the determination of irreversible damage of optical surfaces under the influence of a repetitively pulsed laser beam. The degradation of the optical quality is a function of the laser operating parameters and the optical system in which the component is placed.

In this part of ISO 11254, two evaluation methods are described for the reduction of raw data of a damage test. The characteristic damage curve method is based on a large number of S-on-1 test sites on the optical surface of the specimen. The characteristic damage curve comprises a set of three graphs indicating energy density values with damage probability values of 10 %, 50 % and 90 % for a selected number of pulses. The characteristic damage curve represents the results of a complete and extended laser-induced damage test, and it is recommended for basic investigations in newly developed or critical laser optics.

The second method, the extrapolation method, is created from a considerably smaller number of test sites. This method generates a distribution diagram of damage and non-damage regions for the behaviour of the damage threshold as a function of the number of pulses per site. This diagram is of limited reliability and may be employed for the quality control of optical laser components, which are already qualified by a complete damage test, or for the preparation of extended damage testing.

The present state of research in laser-induced damage and ageing is not sufficient for an accurate quantitative determination of the service life for optical components under real operating conditions. Realistic laser damage tests adapted to industrial applications are dependent on a large number of pulses (10^9 to 10^{11} pulses) and require a disproportionate experimental expense. This part of ISO 11254 therefore also outlines a procedure for an extrapolation of the S-on-1 threshold from the characteristic damage curve to estimate the real lifetime of an optical component.

NOTE 1 This part of ISO 11254 is provisionally restricted to irreversible damage of optical surfaces. Laser-induced damage to the bulk of optical components shall be considered in a revision of this part of ISO 11254.

NOTE 2 The laser-induced damage threshold (LIDT) of an optical component which is subjected to repetitive radiation can be affected by a variety of different degradation mechanisms including contamination, thermal heating, migration or generation of internal defects and structural changes. These mechanisms are influenced by the laser operating parameters, the environment and the mounting conditions of the component under test. For these reasons, it is necessary to record all parameters and to realize that the damage behaviour may differ in systems with altered operating conditions.

Safety Warning: The extrapolation of damage data may lead to bad or erroneous calculated results and to an overestimation of the LIDT. This may in the cases of toxic materials (e.g. ZnSe, GaAs, CdTe, ThF_4, chalcogenides, Be, Cr, Ni) lead to severe health hazards. See annex D for further comments.

Lasers and laser-related equipment — Determination of laser-induced damage threshold of optical surfaces —

Part 2:
S-on-1 test

1 Scope

This part of ISO 11254 specifies a test method for determining the laser-induced damage threshold of optical surfaces subjected to a succession of similar laser pulses.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 11254. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 11254 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 10110-7:1996, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 7: Surface imperfection tolerances*.

ISO 11145:1994, *Optics and optical instruments — Lasers and laser-related equipment — Vocabulary and symbols*.

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this part of ISO 11254, the terms and definitions given in ISO 11145 and the following apply.

3.1.1
surface damage
any permanent laser radiation-induced change of the surface characteristics of the specimen which can be observed by an inspection technique described within this part of ISO 11254

3.1.2
S-on-1 test
test programme that uses a series of pulses with constant energy density on each unexposed site with a short and constant time interval between two successive pulses

NOTE The length of the time interval between the pulses of a series is given by the inverse value of the pulse repetition rate of the laser source.

3.1.3
typical pulse
pulse with temporal and spatial shapes that represent the average properties of the pulses forming the pulse series

3.1.4
minimum number of pulses
number of incident pulses causing detectable surface damage

3.1.5
threshold
highest quantity of laser radiation incident upon the optical surface for which the extrapolated probability of damage is zero

NOTE 1 The quantity of laser radiation may be expressed in energy density H_{th}, power density E_{th}, or linear power density F_{th}, depending on the pulse duration.

NOTE 2 The maximum power density E_{max} of the typical pulse is given by:

$$E_{max} = \frac{H_{max}}{\tau_{eff}} \quad (1)$$

3.1.6
target plane
plane tangential to the surface of the specimen at the point of intersection of the test laser beam axis with the surface of the specimen

3.1.7
effective area
ratio of pulse energy to maximum energy density in the target plane

NOTE 1 For spatial beam profiling perpendicular to the direction of beam propagation and angles of incidence differing from 0 rad, the cosine of the angle of incidence is included in the calculation of the effective area. In this case, the effective area may be approximated by the following formula:

$$A_{T,eff} = \frac{Q}{H_{max}\cos(\alpha)} \quad (2)$$

NOTE 2 For the special case of a circular flat-top beam profile with diameter d_{100}, the effective area is given by:

$$A_{T,eff} = \frac{Q}{H_{max}} = \frac{H_{max}\pi d_{100}^2}{H_{max}} = \pi d_{100}^2 \quad (3)$$

For a focused Gaussian beam with a beam diameter $d_{86,5}$, the effective area is given by:

$$A_{T,eff} = \frac{Q}{H_{max}} = \frac{H_{max}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{-8\frac{x^2+y^2}{d_{86,5}^2}}\,dxdy}{H_{max}} = 2\pi\int_0^{\infty} e^{-\frac{8r^2}{d_{86,5}^2}}\,rdr = \frac{1}{8}\pi d_{86,5}^2 \quad (4)$$

With the definition of the second moment of the energy density distribution function $H(x,y,z)$ at the location z,

$$\sigma^2(z) = \frac{\int_0^{\infty}\int_0^{2\pi} r^2 H(r,\varphi)\, r\, dr\, d\varphi}{\int_0^{\infty}\int_0^{2\pi} H(r,\varphi)\, r\, dr\, d\varphi} \tag{5}$$

and the definition of the beam diameter d_σ as a function of the second moment

$$d_\sigma(z) = 2\sqrt{2}\sigma(z) \tag{6}$$

the effective area can be expressed in the following forms:

a) flat top beam: $A_{\mathrm{T,eff}} = \frac{1}{4}\pi d_{100}^2 = \frac{1}{4}\pi d_\sigma^2 = 2\pi\sigma^2$; $d_{100} = d_\sigma$ (7)

b) Gaussian beam: $A_{\mathrm{T,eff}} = \frac{1}{8}\pi d_{86,5}^2 = \frac{1}{8}\pi d_\sigma^2 = \pi\sigma^2$; $d_{86,5} = d_\sigma$ (8)

3.1.8
effective beam diameter
double the square root of the effective area divided by the factor π:

$$d_{\mathrm{T,eff}} = 2\sqrt{\frac{A_{\mathrm{T,eff}}}{\pi}} \tag{9}$$

3.1.9
effective pulse duration
ratio of pulse energy to maximum pulse power

3.1.10
characteristic damage curve
representation of the S-on-1 laser-induced damage threshold as a function of the number of pulses per site at a specified pulse repetition rate

3.2 Symbols and units

Table 1 — Symbols and units of measurement

Symbol	Unit	Term
λ	nm	wavelength
α	rad	angle of incidence
p		degree of polarization
N_{min}		minimum number of pulses causing damage
N_{p}		number of pulses per site
N_{TS}		total number of sites for the test
d_{T}	mm	beam diameter in the target plane
$d_{\text{T,eff}}$	mm	effective beam diameter in the target plane
$A_{\text{T,eff}}$	cm^2	effective area in the target plane
τ_{H}	ns, µs, s	pulse duration
τ_{eff}	ns, µs, s	effective pulse duration
f_{p}	Hz	pulse repetition rate
Q	J	pulse energy
P_{pk}	W	peak pulse power
E_{max}	W/cm^2	maximum power density
F_{max}	W/cm^2	maximum linear power density
H_{max}	J/cm^2	maximum energy density
E_{th}	W/cm^2	threshold power density
F_{th}	W/cm	threshold linear power density
H_{th}	J/cm^2	threshold energy density
P_{av}	W	average power

4 Sampling

Either a functional component or a witness specimen shall be tested. If a witness specimen is tested, the substrate material and surface finish shall be the same as for the component, and the witness specimen shall be coated in the same coating run as the component. The coating run number and date shall be identified for the test component.

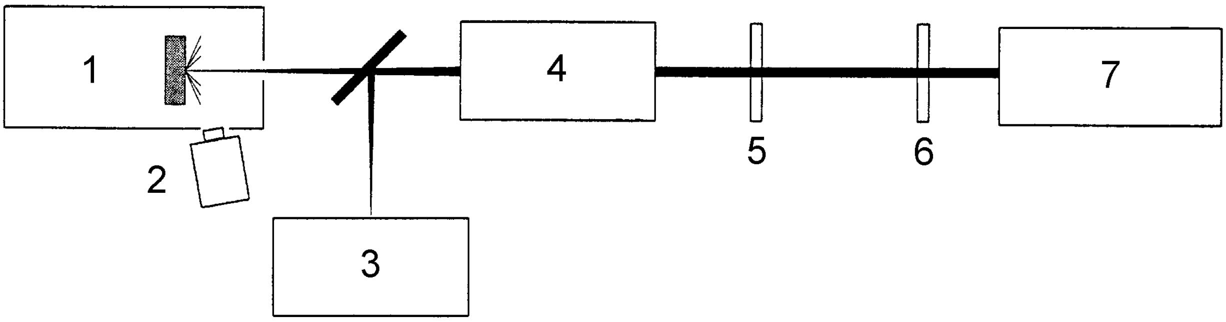
5 Test method

5.1 General

For determining the S-on-1 damage threshold, extensions of the set-up and the evaluation procedure for 1-on-1 damage thresholds measurements (ISO 11245-1 refers) are necessary. However, the S-on-1 measurement facility described in this part of ISO 11245 can be applied for 1-on-1 measurements if the on-line damage detection system is combined with a Nomarski-type differential interference contrast microscope. It is recommended that the on-line damage detection system should have the facility for cutting off subsequent pulses and for stopping the pulse counter.

5.2 Principle

The basic approach to laser damage testing is shown in Figure 1. The output of a well-characterized stable repetitive laser is set to the desired energy or power with a variable attenuator, and delivered to the specimen located at or near the focus of a focusing system.



Key

1 Sample compartment
2 On-line damage detector
3 Beam diagnostic
4 Focusing system
5 Waveplate
6 Variable attenuator
7 Laser system

Figure 1 — Basic approach to S-on-1 laser damage testing

The specimen is mounted in a manipulator which is used to position different test sites in the beam and to set the angle of incidence. The polarization state is set with an appropriate waveplate. The incident laser beam is sampled with a beamsplitter which directs a portion of the beam to a diagnostic unit. The beam diagnostic unit permits simultaneous determination of the total pulse energy and the spatial and temporal profiles.

The specimen is positioned at a defined location with reference to the laser beam at the specified angle of incidence. Each test site is irradiated with pulse trains of constant energy density and repetition rate. Each test is conducted without moving the sample, and subsequent tests are made moving the test point across the sample at a known distance between each test site. It is recommended that the distance between each test site be greater than three times the laser spot diameter d_T. During the series of tests, a sufficient number of test sites shall be tested at different energy densities. The determination of the damage threshold is based on the total data and not on the state of damage for any individual site.

This procedure is applicable to testing with all pulsed laser systems, irrespective of pulse length, repetition rate, and wavelength. Pulse durations widely used in industrial and scientific applications are summarized and grouped in Table 2.

Table 2 — Laser groups

Group	Pulse duration
1	1 ns to 3 ns
2	10 ns to 30 ns
3	1 µs to 3 µs
4	200 µs to 1 000 µs
5	to be specified

Repetition rate classes widely used in industrial and scientific applications are given in Table 3. Lasers of these classes are recommended for S-on-1 tests. Pulse repetition rates other than those specified in Table 3 are allowed for the purposes of this part of ISO 11254. The pulse repetition rate classes are permitted in conjunction with every possible laser group. The pulse duration and the pulse repetition rate of the test laser shall be documented in the test report.

Laser-induced damage threshold values are dependent on the operating parameters of the laser system employed for testing. For a comparison of threshold data under slightly different operating conditions, scaling laws, which are based on modelling of experimental data, may be used. Safety aspects shall be considered for the application of scaling laws to hazardous materials.

Table 3 — Repetition rate classes

Class	Pulse repetition rate f_p in Hz
A	1
B	10
C	30
D	100
E	300
F	1 000
G	to be specified

5.3 Apparatus

The test facility consists of individual sections with specific functions.

5.3.1 Laser

A laser delivering pulses with a reproducible near-Gaussian or near-flat-top spatial profile is required. The temporal profile of the pulses is monitored during the measurement. Pulse trains containing pulses with a maximum power density exceeding the variation of E_{max} in Table 4 shall be rejected for the evaluation procedure. The pulse repetition rate shall be constant within an error margin of ± 1 %. For the different laser groups, the maximum allowable variations of the pulse parameters are compiled in Table 4. As a minimum specification of a laser system not included in rows 1 to 4 in Table 2, the pulse-to-pulse variation of the maximum power density shall be less than ± 20 %. Stability criteria for the beam parameters shall be determined and documented in an error budget.