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

Part 1:
1-on-1 test

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

Partie 1: Essai 1 sur 1

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Contents

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 11254-1 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 *Laser and laser-related equipment — Determination of laser-induced damage threshold of optical surfaces*:

— *Part 1: 1-on-1 test*

— *Part 2: S-on-1 test*

Annexes A, B and C of this part of ISO 11254 are for information only.

Introduction

Optical components can be damaged by laser irradiation of sufficiently high energy or power. At any specified laser irradiation level, the probability for laser damage is usually higher for the surface of a component than for the bulk. Thus the limiting value of an optical component is usually given by the damage threshold of its surface.

This part of ISO 11254 describes a standard procedure for determining the laser-induced damage threshold (LIDT) of optical surfaces, both coated and uncoated. The procedure has been promulgated in order to provide a method for obtaining consistent measurement results, which may be rapidly and accurately compared among different testing laboratories. In order to simplify the comparison of laser-damage measurement facilities, laser groups are defined in this part of ISO 11254.

This part of ISO 11254 is applicable to single-shot testing only (1-on-1 tests). For multi-shot testing (S-on-1) refer to ISO 11254-2.

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

Part 1: 1-on-1 test

1 Scope

This part of ISO 11254 specifies a test method for determining the single-shot laser radiation-induced damage threshold (LIDT) of optical surfaces.

This test procedure is applicable to all combinations of different laser wavelengths and pulse lengths. However comparison of laser damage threshold data may be misleading unless the measurements have been carried out at identical wavelengths, pulse lengths and beam diameters.

Application of this part of ISO 11254 is provisionally restricted to irreversible damage of optical surfaces.

NOTE Examples of units and scaling of laser-induced damage thresholds are given in annex C.

WARNING — The extrapolation of damage data can lead to inaccurate or wrong calculated results and to an overestimation of the LIDT. In the case of toxic materials (e.g. ZnSe, GaAs, CdTe, ThF_4, chalcogenides, Be, Cr, Ni) this could lead to severe health hazards.

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 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
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

3.2
1-on-1 test
test programme that uses one shot of laser radiation on each unexposed site on the specimen surface

3.3
threshold
highest quantity of laser radiation incident upon the optical surface for which the extrapolated probability of damage is zero

NOTE The quantity of laser radiation may be expressed as energy density H_{max} or power density E_{max} (see annex C).

3.4
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

3.5
effective area
$A_{T,eff}$
ratio of power [pulse energy] to maximum power [energy] density

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 formulae:

$$A_{T,eff} = \frac{Q}{H_{max}\cos(\alpha)} \tag{1}$$

$$A_{T,eff} = \frac{P}{E_{max}\cos(\alpha)} \tag{2}$$

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

$$A_{T,eff} = \frac{Q}{H_{max}} = \frac{H_{max}\pi d_{100}^2}{4H_{max}} = \frac{1}{4}\pi d_{100}^2 \tag{3}$$

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

$$A_{T,eff} = \frac{Q}{H_{max}} = \frac{H_{max}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{-8\frac{x^2+y^2}{d_{86,5}^2}}\,dx\,dy}{H_{max}} = 2\pi\int_0^{\infty} e^{-\frac{8r^2}{d_{86,5}^2}} r\,dr = \frac{1}{8}\pi d_{86,5}^2 \tag{4}$$

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: $$A_{T,eff} = \frac{1}{4}\pi d_{100}^2 = \frac{1}{4}\pi d_\sigma^2 = 2\pi\sigma^2; \quad d_{100} = d_\sigma \tag{7}$$

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

3.6
effective beam diameter
$d_{T,eff}$
double the square root of the effective area divided by the factor pi

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

3.7
effective pulse duration
ratio of total pulse energy to maximum pulse power

4 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
d_T	mm	beam diameter in the target plane
$d_{T,eff}$	mm	effective beam diameter in target plane
$A_{T,eff}$	cm^2	effective area in the target plane
t_H	ns, µs, s	pulse duration
t_{eff}	ns, µs, s	effective pulse duration (see 6.2.6.2)
Q	J	pulse energy
P_{pk}	W	peak pulse power
P	W	power
H_{max}	J/cm^2	maximum energy density
E_{max}	W/cm^2	maximum power density
H_{th}	J/cm^2	threshold energy density
E_{th}	W/cm^2	threshold power density
F_{th}	W/cm	threshold linear power density
N_{TS}		total number of sites for the test

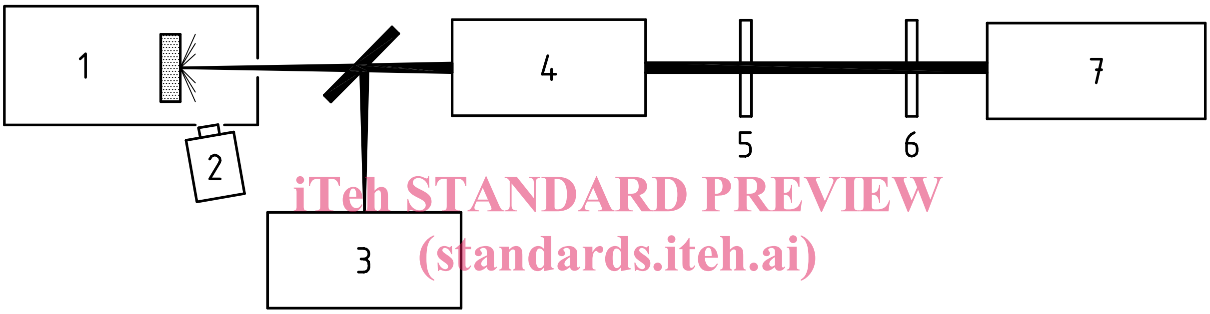
5 Sampling

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.

6 Test method

6.1 Principle

The basic approach to laser damage testing is shown in Figure 1. The output of a well-characterized stable 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 focussing system. The use of a focussing system permits the generation of destructive energy densities or power densities at the test specimen.



Key

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

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

The specimen is mounted in a manipulator which is used to position different test sites in the beam and 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.

Microscopic examination of the testing site before and after irradiation is used to detect damage.

The specimen is positioned at different non-overlapping test sites in reference to the beam, and irradiated at different energy densities or power densities. From these data the damage threshold can be determined.

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

Table 2 — Laser groups

Group	Description	Pulse duration
1	very short pulse	1 ns to 3 ns
2	short pulse	10 ns to 30 ns
3	medium pulse	1 µs to 3 µs
4	long pulse	200 µs to 1000 µs
5		pulse length to be specified
6	cw	1 s
NOTE Damage thresholds of pulsed lasers (Groups 1 to 4) are usually expressed in units of energy density (J/cm^2). The pulse duration of the test laser shall be documented in the test report. Group 6: Damage thresholds of continuous-wave (cw) lasers are usually expressed in units of linear power density (W/cm). Power density refers to the average power during the irradiation time. Examples for units of laser-induced damage thresholds are described in annex C.		

6.2 Apparatus

6.2.1 Laser, delivering pulses with a reproducible near-Gaussian or near-flat-top spatial profile.

The temporal profile of the pulses is monitored during the measurement. For the different laser groups, the maximum allowable variations of the pulse parameters are compiled in Table 3. As a minimum specification of a laser system of Group 5, 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.

Table 3 — Maximum percentage variation of laser parameters and corresponding percentage variation of maximum pulse power density E_{max}

Laser group	Pulse energy Q	Average power P_{av}	Pulse duration τ_{eff}	Effective area $A_{T,eff}$	Power density E_{max}
1	± 5	—	± 10	± 10	± 15
2	± 5	—	± 5	± 6	± 10
3	± 5	—	± 5	± 6	± 10
4	± 5	—	± 5	± 6	± 10
6	—	± 5	—	± 6	± 20

6.2.2 Variable attenuator and beam delivery system

The laser output shall be attenuated to the required level with an external variable attenuator that is free of drifts in transmissivity and imaging properties.

The beam delivery system and the attenuator shall not affect the properties of the laser beam in a manner inconsistent with the tolerances given in 6.2.1. In particular, the polarization state of the laser beam shall not be altered by the beam delivery system.

6.2.3 Focussing system

The arrangement of the focussing system should be adapted to the special requirements of the laser system and to the intended beam profile in the target plane. The specific arrangement and the parameters of the focussing system shall be documented in the test report. The specifications of the active area and the energy density shall be referred to the location of the test surface.

For Gaussian beams, it is advisable to select an aperture of the focussing system which amounts to not less than three times the beam diameter at the entrance of the focussing system. A minimum effective *f*-number of 50 and a beam diameter in the target plane of not less than 0,8 mm are recommended. The target plane should be located at or near the focal waist formed by the focussing system. For Groups 3 to 6, the beam diameter may be reduced depending on the power density necessary, but should not be smaller than 0,2 mm. In such cases the effective *f*-number may be reduced below a value of 50.

For near-flat-top laser beams, it is advisable to position the test surface in the image plane of the focussing system with a focal length > 0,2 m that forms an image of a suitable aperture in the optical path.

Coherence effects in specimens with parallel surfaces can occur and affect the measurement. These effects shall be eliminated by appropriate techniques, such as wedging or tilting of the specimen. The application of a highly converging beam is also a practical method for removing coherence effects in the specimen.

6.2.4 Specimen holder

The test station shall be equipped with a manipulator which allows for a precise placement of the test sites on the specimen with an accuracy sufficient for the specimen size.

6.2.5 Damage-detection microscope, to inspect the surface before and after the test.

The investigations shall be made with an incident light microscope having Nomarski-type differential interference contrast. A magnification in the range from 100× to 150× shall be used.

NOTE 1 For routine inspection and objective measurement of laser damage, an image analyser may be attached to the microscope.

NOTE 2 An appropriate on-line damage detection system may be installed for evaluating the state of the surface under test or for switching off the laser in long-pulse and cw damage-measurement facilities to avoid catastrophic damage of the specimen. For on-line detection, any appropriate technique may be used. Techniques suited to this purpose are for instance on-line microscopic techniques in conjunction with image analysers, photoacoustic and photothermal detection, as well as scatter measurements using a separate laser or radiation from the damaging laser. A typical set-up for an on-line scatter measurement system is described in ISO 11254-2.

6.2.6 Beam diagnostics

6.2.6.1 Measurement of total pulse energy and power

The diagnostic package shall be equipped with a calibrated detector to measure the pulse energy or beam power delivered to the target plane. This instrument shall be traceable to a national standard with an absolute uncertainty of ± 5 % or better.

