INTERNATIONAL STANDARD

ISO 21254-1

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Lasers and laser-related equipment — Test methods for laser-induced damage threshold —

Part 1:
Definitions and general principles

Lasers et équipements associés aux lasers — Méthodes d'essai du seuil d'endommagement provoqué par laser —

Partie 1: Définitions et principes de base

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 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21254-1 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

This first edition of ISO 21254-1:2011, together with ISO 21254-2:2011, cancels and replaces ISO 11254-1:2000 and ISO 11254-2:2001, which have been technically revised.

ISO 21254 consists of the following parts, under the general title *Lasers and laser-related equipment — Test methods for laser-induced damage threshold*:

— *Part 1: Definitions and general principles*

— *Part 2: Threshold determination*

— *Part 3: Assurance of laser power (energy) handling capabilities*

— *Part 4: Inspection, detection and measurement* [Technical Report]

Introduction

Optical components can be damaged by laser irradiation of sufficiently high energy or power. At any specified laser irradiation level and operation mode of the laser source, 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 frequently given by the damage threshold of its surface which might be coated to influence the optical properties. Bulk damage is observed if the electrical field strength in the bulk of the component is enhanced by self-focusing, interference, scattering or other effects. Also, imperfections, such as inclusions, dislocations, colour centres or inhomogeneities, can reduce the power-handling capability in the bulk of an optical component. Damage by single laser pulses is often induced by defects or mechanical stress in the coating, contamination of the surface, or optical absorption, leading to catastrophic heating of the surface. For multiple-pulse operation, not only reversible mechanisms induced by thermal heating and distortion but also irreversible damage mechanisms induced by ageing, microdamage, moisture damage and generation or migration of defects are observed. The various parts of this International Standard are concerned with the determination of irreversible damage of the optical surfaces and the bulk of an optical component under the influence of a laser beam. Depending on the environmental conditions, damage is a function of the material properties and the laser parameters, in particular wavelength, spot size and irradiation duration.

This part of ISO 21254 is dedicated to the fundamentals and general principles of the measurement of laser-induced damage thresholds (LIDTs). On the basis of the apparatus and measurement protocols described in ISO 21254-1, ISO 21254-2 and ISO 21254-3, this part of ISO 21254 outlines procedures for damage testing under different conditions. The protocols for the determination of the 1-on-1 and S-on-1 damage thresholds are described in ISO 21254-2. The 1-on-1 test is a damage threshold measurement procedure that uses one shot of laser radiation on each unexposed site on the specimen surface. In contrast to this, the S-on-1 measurement programme is based on a series of pulses with constant energy density applied to each unexposed site of the specimen surface. This test reflects the operational conditions of the sample in typical applications but, compared to the 1-on-1 measurement protocol, the experimental effort necessary for S-on-1 tests is significantly higher. ISO 21254-3 concentrates on the assurance of the power or energy density handling capability of optical surfaces, leaving samples that pass the test undamaged. ISO/TR 21254-4, which considers damage detection methods and the inspection of tested surfaces, is a Technical Report which complements ISO 21254-1.

Lasers and laser-related equipment — Test methods for laser-induced damage threshold —

Part 1: Definitions and general principles

WARNING — The extrapolation of damage data can lead to an overestimation of the laser-induced damage threshold. In the case of toxic materials (e.g. ZnSe, GaAs, CdTe, ThF_4, chalcogenides, Be, Cr, Ni), this can lead to serious health hazards. See Annex A for further comments.

1 Scope

This part of ISO 21254 defines terms used in conjunction with, and the general principles of, test methods for determining the laser-induced damage threshold and for the assurance of optical laser components subjected to laser radiation.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 11145, *Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols*

ISO 11146-1, *Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios — Part 1: Stigmatic and simple astigmatic beams*

ISO 11146-2, *Lasers and laser-related equipment — Test methods for laser beam widths, divergence angles and beam propagation ratios — Part 2: General astigmatic beams*

ISO 21254-2, *Lasers and laser-related equipment — Test methods for laser-induced damage threshold — Part 2: Threshold determination*

ISO 21254-3, *Lasers and laser-related equipment — Test methods for laser-induced damage threshold — Part 3: Assurance of laser power (energy) handling capabilities*

ISO/TR 21254-4, *Lasers and laser-related equipment — Test methods for laser-induced damage threshold — Part 4: Inspection, detection and measurement*

3 Terms and definitions

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

3.1
surface damage
any permanent laser-radiation-induced change in the characteristics of the surface of the specimen which can be observed by an inspection technique and at a sensitivity related to the intended operation of the product concerned

NOTE Damage may occur on the front surface or the rear surface of the optical component. The damage threshold value for the front surface may differ from that for the rear surface.

3.2
bulk damage
any permanent laser-radiation-induced change in the characteristics of the bulk of the specimen which can be observed by an inspection technique and at a sensitivity related to the intended operation of the product concerned

3.3
1-on-1 test
test programme that uses one shot of laser radiation on each unexposed site on the specimen surface

3.4
linear power density
F_{th}
linear power density threshold, expressed in watts per centimetre (W/cm), above which damage might occur

NOTE The linear power density is applicable for cw and long-pulse operation. For laser damage considerations, a long pulse is assumed when the thermal transit distance $(2D\tau_{eff})^{1/2}$, where D is the thermal diffusivity, is of the same order of size as the test spot diameter $d_{T,eff}$.

3.5
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, where the length of the time interval between the pulses of a series is given by the reciprocal of the pulse repetition rate of the laser source

3.6
number of shots per interrogation site
S
number of pulses in a pulse train used in an S-on-1 test

3.7
threshold
highest quantity of laser radiation incident upon the optical component for which the extrapolated probability of damage is zero, where the quantity of laser radiation may be expressed as energy density H_{th}, power density E_{th}, or linear power density F_{th}

3.8
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

3.9
effective area
$A_{T,eff}$
ratio of pulse energy to maximum energy density of the laser pulse in the target plane

NOTE For spatial beam profiling perpendicular to the direction of beam propagation and for angles of incidence differing from 0 rad, the cosine of the angle of incidence is included in the calculation of the effective area.

3.10
effective beam diameter
$d_{T,eff}$
double the square root of the effective area divided by π:

$$d_{T,eff} = 2\sqrt{\frac{A_{T,eff}}{\pi}} \quad (1)$$

3.11
effective pulse duration
τ_{eff}
ratio of pulse energy to peak pulse power of the pulse

3.12
typical pulse
pulse with temporal and spatial shapes that represent the average properties of the pulses forming a pulse series used in an S-on-1 test

3.13
minimum number of pulses
N_{min}
number of incident pulses necessary to cause detectable damage

3.14
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

4 Symbols and units of measurement

The symbols and units of measurement used are the following:

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 the target plane
$A_{T,eff}$	cm^2	effective area in the target plane
τ_H	s	pulse duration
τ_{eff}	s	effective pulse duration
f_p	Hz	pulse repetition rate
P_{av}	W	average power
Q	J	pulse energy
F_{max}	W/cm	maximum linear power density
E_{max}	W/cm^2	maximum power density
H_{max}	J/cm^2	maximum energy density
P_{pk}	W	peak pulse power

E_{th}	W/cm^2	threshold power density
F_{th}	W/cm	threshold linear power density
H_{th}	J/cm^2	threshold energy density
N_{min}		minimum number of pulses causing damage
S		number of shots per interrogation site
N_{ts}		total number of sites for the test

5 Sampling

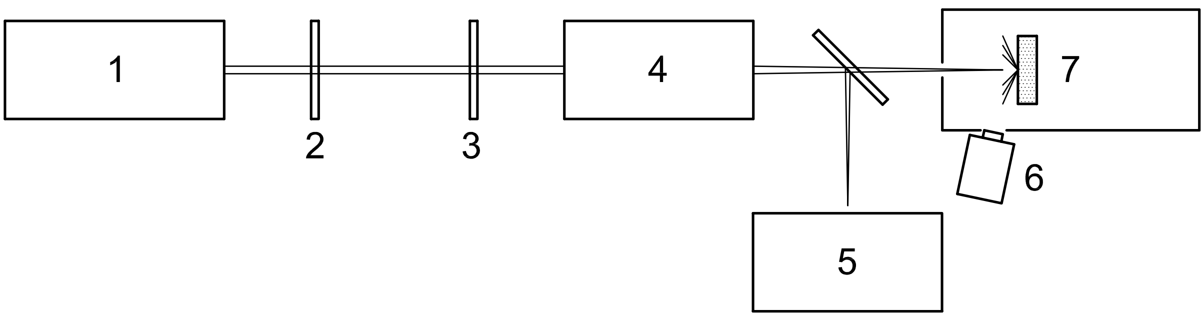
For testing, either an actual part or a witness specimen may be chosen. If a witness specimen is tested, the substrate material and surface finish shall be the same as for the actual part. In the case of a coated sample, the witness specimen shall be coated in the same coating run as the actual part. The coating run number and date shall be identified for the specimen. If bulk damage is expected, the substrate material of the test component shall be identical to that of the actual part.

6 Test methods

6.1 Principle

The fundamental arrangement for laser damage testing is depicted in Figure 1. The output of a well-characterized, stable laser source is adjusted to the desired pulse energy or cw-power by a variable attenuator and delivered to the specimen located at or near the focus of a focusing system.

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 beam splitter that directs a portion of the laser energy to a beam-diagnostic unit. The beam diagnostic unit permits simultaneous determination of the total pulse energy and the spatial and temporal profiles.



Key

1 laser system
2 variable attenuator
3 waveplate
4 focusing system
5 beam diagnostic unit
6 online damage detector
7 specimen compartment

Figure 1 — Basic approach to laser damage testing

The specimen is positioned at a defined location with reference to the laser beam at the specified angle of incidence. Depending on the requirements of the test, test sites on the specimen are irradiated with single laser pulses or with trains of pulses of constant energy density at a constant repetition rate. The specimen is mounted in a holder. Each separate irradiation test is conducted without moving the specimen in the beam. It is recommended that the distance between the test sites be greater than three times the laser spot diameter d_T. For reliable tests, a sufficient number of test sites shall be tested at specific energy densities or power densities. The determination of the damage threshold is based on the entire data set acquired during the complete test and not on the state of damage at any individual site.

This procedure is applicable to testing with cw-lasers and pulsed laser systems irrespective of pulse length, repetition rate, and wavelength.

Damage thresholds of pulsed lasers 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. Damage thresholds of cw-lasers are usually expressed in terms of units of linear power density (W/cm). The power density is taken as the average power during the irradiation time. Examples of units used for laser-induced damage thresholds are given in Annex A.

For pulsed lasers, any possible pulse repetition rate is permitted in conjunction with a specified pulse duration. 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 should be considered for the application of scaling laws to hazardous materials.

6.2 Apparatus

The test facility consists of individual sections with specific functions.

6.2.1 Laser

A laser delivering a beam with a reproducible Gaussian or flat-top spatial profile (in accordance with ISO 11146-1 and ISO 11146-2) is required. The temporal profile of the pulses is monitored during the measurement. Pulses or pulse trains containing pulses whose maximum power density E_{max} varies by more than 20 % shall be rejected. For S-on-1 tests the pulse repetition rate shall be constant within an error margin of ±1 %. As a minimum specification of a laser system for damage testing, 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.

Beam diagnostic unit packages for lasers operating in the femtosecond regime exhibit a significantly lower accuracy than typical measurement systems for longer pulse durations. As a minimum specification for fs-lasers, the measured percentage variation of the maximum power density shall not exceed ±25 %.

6.2.2 Variable attenuator and beam delivery system

The laser output shall be attenuated to the required level with a device that is free of drift in its transmittance 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 Focusing system

The arrangement of the focusing system should be suited to the specific requirements of the laser system and to the intended beam profile in the target plane. The specific arrangement and the parameters of the focusing 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. The effective area shall not be altered during the damage threshold measurement procedure. The self-focusing or filamentation threshold in the test environment shall not be exceeded.