TECHNICAL REPORT

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

Part 4: Inspection, detection and measurement

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

Partie 4: Inspection, détection et mesurages

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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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 21254-4 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

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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: Definition and general principles*

— *Part 2: Threshold determination*

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

— *Part 4: Inspection, detection and measurement*

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Introduction

Detection programmes for laser-induced damage threshold always involve sensitive techniques for the inspection of surfaces and the detection of damage. In a typical detection protocol, each sample is inspected prior to the test by microscopic methods to evaluate the surface quality and to assess imperfections. During the irradiation of the sample in S-on-1, damage testing, a variety of online-monitoring schemes is applied to detect damage.

Examples of these methods include the detection of light scattered by the test area, the collection of plasma radiation, or photothermal detection schemes. In most cases, the detection system is directly linked to the laser to interrupt the irradiation of the sample promptly at the first instance of damage. In this way catastrophic damage of the component can be avoided, and the number of pulses until the appearance of first damage can be determined precisely. Also, this direct information on the state of damage can be processed in the course of the running test to determine energy levels for the following interrogations optimised to minimise detection uncertainties. For the same reason, sophisticated detection schemes based on direct imaging and online image processing can be often found in 1-on-1 detection facilities. The irradiation sequence on the samples is followed by inspection using an appropriate technique to identify the damaged sites and to gain information on the contributing damage mechanisms. This inspection of the interrogated sites is essential for an accurate determination of the damage thresholds because it is the final and most sensitive assessment of the state of damage.

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This Technical Report describes selected techniques for the inspection of optical surfaces prior to and after damage testing, and damage detection techniques integrated in detection facilities. The described damage detection methods are examples of practical solutions tested and often applied in detection facilities. The application of other schemes for the detection or inspection of damage in optical components is not excluded by this Technical Report.

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

Part 4: Inspection, detection and measurement

1 Scope

This part of ISO 21254 describes techniques for the inspection and detection of laser-induced damage on optical surfaces and in the bulk of optical components.

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.

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

ISO 21254-1, *Lasers and laser-related equipment — Test methods for laser-induced damage threshold — Part 1: Definitions and general principles*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145 and ISO 21254-1 apply.

4 Damage detection methods

4.1 General

For damage test methods involving more than one pulse per test site, an appropriate online damage detection system is needed to evaluate the state of the surface under test according ISO 21254-1. It is recommended that the online damage detection system should have the facility for cutting off subsequent pulses and for stopping the pulse counter after detection of damage.

For online damage detection, any appropriate principle can be used. Techniques suited to this purpose are for instance online microscopic techniques, photoacoustic and photothermal detection, as well as scatter detections using a separate laser or radiation from the damaging laser. In the following examples for online damage detection schemes are described which are based on the collection of radiation from the sample, the detection of specific sample properties, and photothermal methods. In addition, a technique based on transient pressure sensing is outlined as an example for a non-optical online detection method. The described techniques are illustrated by schemes published in the open literature. This selection of practical examples is considered for descriptive purposes only and does not indicate any preferences or recommendation for these schemes.

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4.2 Summary of damage detection methods

The major features of the described online damage detection methods are compiled in Table 1. Besides the fundamental principle, specific advantages and disadvantages are considered.

Table 1 — Advantages and disadvantages of damage detection methods

Damage detection method (reference)	Advantages	Disadvantages
Scatter detection techniques (4.3.1)	▪ low experimental expense ▪ clear correlation to and preferred for morphological damage ▪ suitable for automatic sequences ▪ high sensitivity and reliability ▪ small reaction time (ns) ▪ selective detection of surface or bulk and surface damage	▪ indirect detection: signal not correlated to damage mechanism ▪ less suitable for layer structures with overcoatings or rugate filters ▪ not sensitive to compaction
Plasma and thermal radiation (4.3.2)	▪ low experimental expense ▪ signal amplitude correlated to damage mechanisms ▪ small reaction time (ns)	▪ dependent on environment ▪ reduced sensitivity: plasma radiation might appear without surface damage and vice versa ▪ signal interpretation with respect to damage difficult ▪ difficult data reduction
Fluorescence (4.3.3)	▪ signal correlated to damage mechanisms and interpretable ▪ small reaction time (ns) ▪ preferred for colour centre detection	▪ high experimental expense ▪ reduced sensitivity: correlation of damage to fluorescence signal might be complex and sample specific ▪ signal interpretation with respect to damage difficult ▪ material specific calibration necessary
Reflectance transmittance (4.4.1)	▪ low experimental expense ▪ high sensitivity and clear correlation to functional damage ▪ suitable for automatic sequences ▪ high reliability ▪ small reaction time (ns)	▪ indirect detection: signal not correlated to damage mechanism ▪ not suitable for all kind of optics
Online microscopy (4.4.2)	▪ direct image generation ▪ reliability best achievable for surfaces ▪ complex data reduction possible ▪ suitable for automatic sequences	▪ high experimental expense ▪ low response time (10 ms-range)
Photothermal deflection and lensing and Mirage effect (4.5)	▪ evaluation of absorptance ▪ high sensitivity ▪ signal correlated to damage mechanisms ▪ pre-damage effects detectable ▪ photoacoustic and thermal effects (Mirage effect)	▪ signal interpretation with respect to damage difficult ▪ low temporal resolution (ms)
Transient pressure sensing (4.6)	▪ vibration and misalignment insensitive ▪ suitable for curved or scattering samples ▪ analysis of ablated species possible allowing for an interpretation of damage mechanisms (with mass spectrometer)	▪ only suitable for high vacuum conditions ▪ not suitable for small (< 200 µm) spot sizes (low ablated mass)

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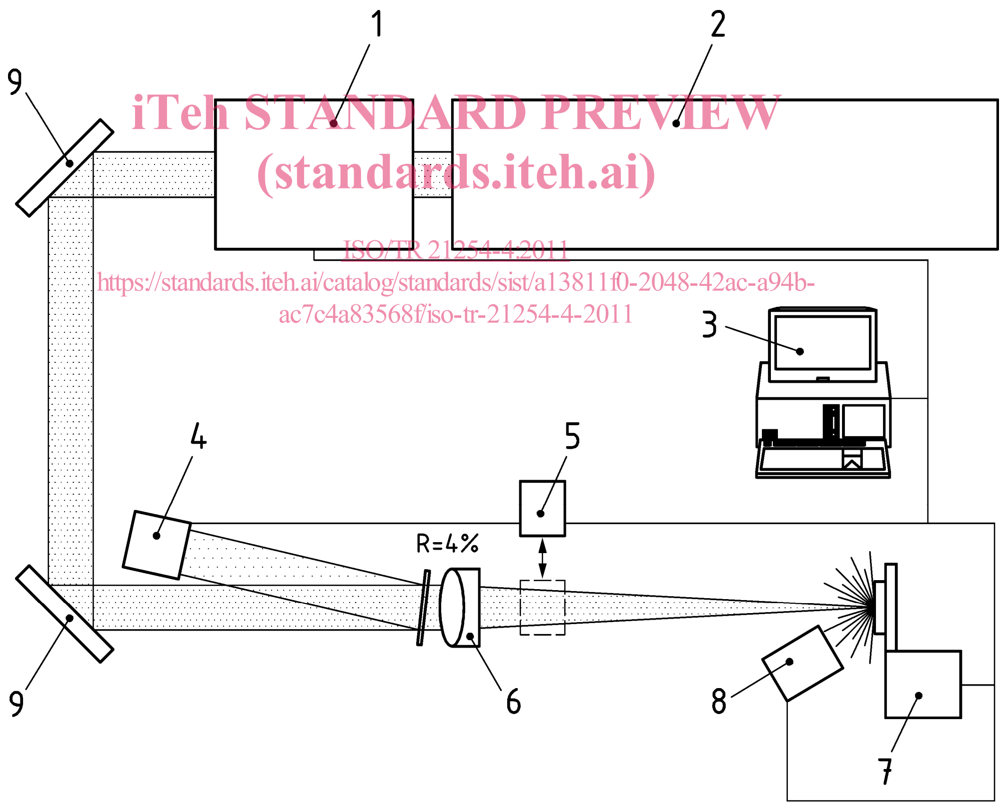
4.3 Collection of radiation from the sample

4.3.1 Scatter detection techniques

A prominent concept for online damage detection is the collection of radiation scattered by the component under test. The increase in optical scattering of the test site is interpreted as a direct consequence of the bulk or surface properties altered by the contributing damage mechanisms. The arrangements can be operated directly by the detection of scattered radiation from the test laser (see Figure 1) or on the basis of scattering from a beam of a separate laser superimposed with the test laser beam on the test site (see Figure 2). In systems based on scattering of test laser radiation, the method can be implemented with a few additional optical components collecting the scattered radiation on a detector. For collection of the scattered radiation on the detector element lenses or concave mirrors are employed. For set-ups with separate source a laser with excellent pointing stability and minimum intensity fluctuations is used as radiation source. The laser light is refined by a beam preparation system that normally consists of telescope systems with apertures, spatial filters and optical components for modulating the laser power density. After beam preparation, the laser beam is focused onto the actual site of the specimen under damage test. The scattered radiation is collected by a lens and detected by a photo detector. The fraction of the laser beam reflected by the specimen surface is cut out by a negative aperture. To achieve high sensitivity and low interference with other light sources in the environment of the set-up, phase sensitive detection techniques and an interference filter for the laser wavelength are recommended. In all set-ups the detector signal should be recorded with sufficient temporal resolution to identify the onset of damage instantly in correlation to the individual pulses of the test laser.



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NOTE See Reference [5].

Key

1 motorized attenuator
2 Ti: Sapphire CPA-Laser
3 measurement controlling PC
4 energy detector
5 power meter
6 achromate
7 sample translator
8 online damage detector
9 HR 45°

Figure 1 — Typical set-up for an online scatter detection system on the basis of radiation scattered from the test laser beam

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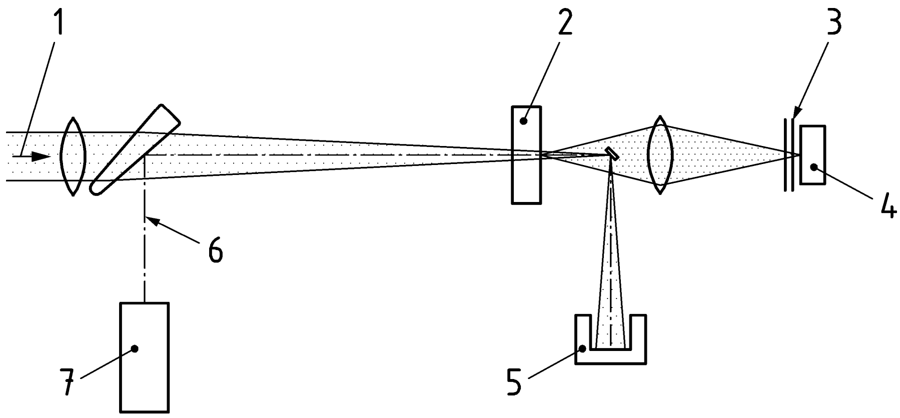
Scatter detection systems for damage detection demonstrate high reliability for damage mechanisms which influence the structure of the surface or induce defects in the bulk of the test sample. The detection scheme is occasionally not appropriate for specimens which are damaged by effects involving a complete delamination of coatings from the surface. In some cases a reduction of the scatter signal is observed during the initial irradiation phase which is attributed to surface cleaning or conditioning effects.



Key

1 test beam
2 test sample
3 filter stack
4 detector
5 beam dump
6 probe beam
7 probe laser

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Figure 2 — Typical set-up for an online scatter detection system with a separate laser source and a negative aperture

4.3.2 Detection of plasma and thermal radiation

Often the emission of radiation from laser-induced plasma is observed in the event of surface damage[6][15]. This radiation can be detected as a damage indicator with an arrangement similar to the detection system used for direct online scatter detections. To select the plasma emission from the radiation of the test laser, a set of filters with high optical density for the test laser wavelength is recommended. Plasma radiation can be measured in a broad spectral range from the MIR to DUV. In some set-ups the wavelength is selected in the NIR and is simultaneously interpreted as a pyrometric signal for an in-situ detection of the sample temperature (see Figure 3). Although a temperature calibration of the system is dependent on a variety of specific parameters of the sample, the evaluation of the temperature radiation allows for additional insights into the contributing damage mechanisms. Detection schemes based on plasma radiation suffer from the fact that plasma can also occur during laser irradiation without surface damage.

4.3.3 Fluorescence

The spectrophotometric detection of fluorescence radiation allows for a detailed interpretation of electronic states and transitions during irradiation of the sample material. As a consequence of high photon energies the method offers interesting aspects for the damage testing in the UV/DUV-spectral range. In most cases, fluorescence occurs already at relatively small irradiation energies well below the damage threshold of the test component. Therefore, damage detection is dependent on a complex evaluation of the fluorescence spectra which restricts the principle to special applications and specimens.

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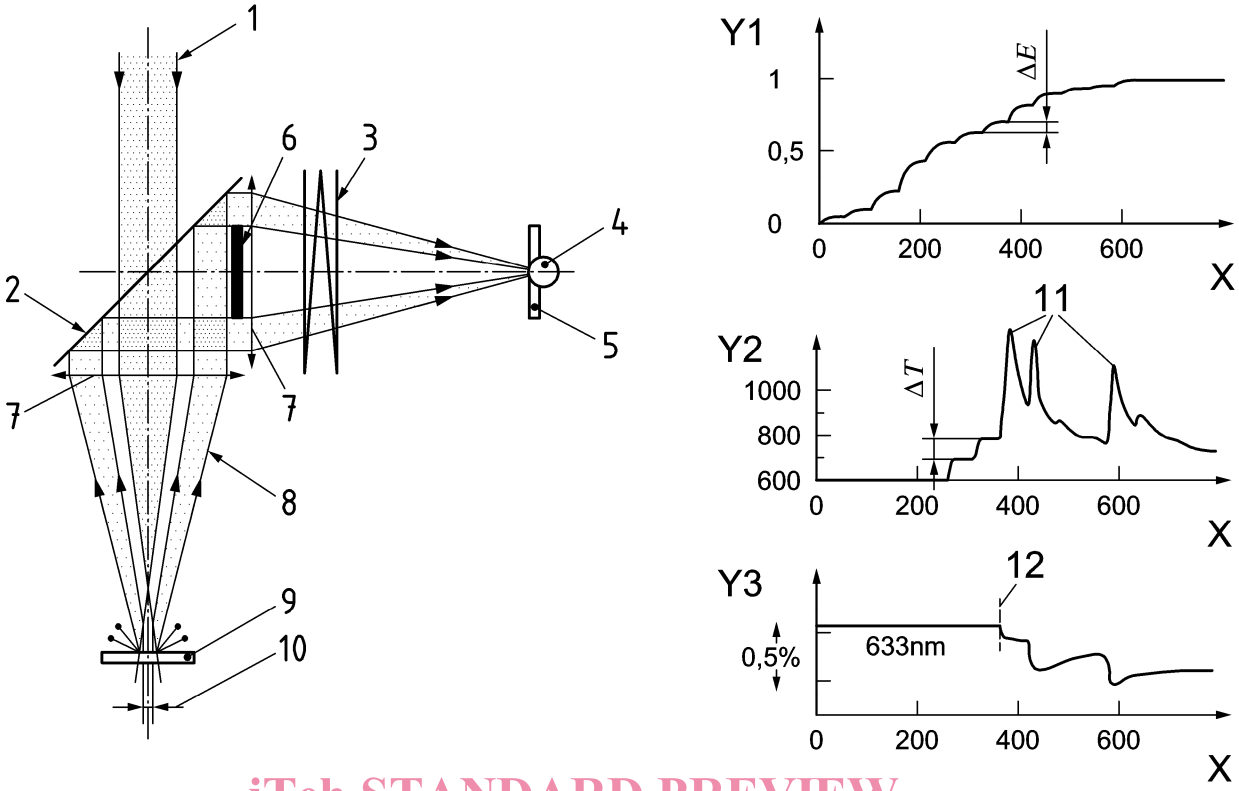

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a) **Example of a set-up**

b) **Signals detected during irradiation by a pulse train** (12 pulses, λ = 1 064 nm, $d_{86,5}$ = 0,5 mm[6])

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Key

1 incident laser beam
2 dichroitic beam splitter HT 1060/HR 850/45°
3 filter set HT 850/HR 1060
4 Si – photodiode
5 aperture adjusted for spot size
6 scatter field
7 focusing lens
8 temperature radiation
9 sample
10 spot size
11 plasma
12 damage
X time scale [µs]
Y1 energy [relative units]
Y2 temperature [°C]
Y3 transmission [%]

Figure 3 — Example of a set-up on the basis of radiation emitted by the sample surface during damage or laser heating; diagram depicting the signals detected during irradiation by a pulse train

4.4 Detection of changes in reflectance or transmittance and imaging techniques

4.4.1 Online detection of changes in reflectance or transmittance

During and after the event of damage, the optical transfer properties of specimen are significantly altered. This effect is the basis for a variety of damage detection schemes involving online detections of the changes in reflectance or transmittance of the specimen. Similar to the scatter detection schemes, the radiation of the test

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