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Optics and photonics — Lasers and laser-related equipment — Test method for absorptance of optical laser components

Optique et photonique — Lasers et équipements associés aux lasers — Méthode d'essai du facteur d'absorption des composants optiques pour lasers

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee 9, *Laser and electro-optical systems*.

This third edition cancels and replaces the second edition ISO 11551:2003 which has been technically revised.

The main changes compared to the previous edition are as follows:

a) Introduction: The assumptions were revised in the second paragraph. Minor wording and example adjustment in third paragraph.

b) Clause 4: Table for symbols and units was corrected.

c) Clause 5: More detailed specification of environmental conditions for UV- and IR applications are provided in the second paragraph. ISO 7 specification was deleted.

   In the fourth paragraph, Annex A is explicitly mentioned for the dependence of absorption on other test parameters.

   In the fifth paragraph, Annex B is explicitly mentioned to account for the critical issue of finite heat conductivity.

d) In 7.2.3: In the first paragraph, the calibration procedure is specified in more detail, including the consideration of the heating scheme for thick samples.

   Note 1 is complemented by the restriction for thin samples.

   Note 2 is complemented with the consideration of heating scheme for finite heat conduction.

e) In 7.3: In the first paragraph the specifications for the ambient temperature drift were clarified.

   The requirements to the total temperature rise during heating were generalized.

In the third paragraph the terminology “pre-irradiation” was replaced by “drift record”. The description of the duration of the cooling period was complemented.

f) In 8.1: In the first paragraph “heat capacity” was replaced by “specific heat capacity”.

g) In A.1: “irradiation dose” added as influencing parameter.

h) In A.3: Generalization of nonlinear absorption dependencies.

i) In B.3: More detailed comments on the convergence of the temperature curves in Figure B.1. Correction of Formulae (B.2) and (B.3). An additional paragraph with explanations for thick test samples, including two references.

This corrected version of ISO 11551:2019 incorporates the following corrections:

— In 7.2.3, Formulae (B.1), (B.2) and (B.3), the symbol "α" has been changed into "a";

— Two signs have been corrected in Formula (C.4) to read "$-B$exp" and "$-t_k$" instead of "Bexp" and "t_k".

Introduction

To characterize an optical component, it is important to know its absorptance. When radiation impinges upon a component, a part of that radiation is absorbed, increasing the temperature of the component. In this document only the part of the absorbed power/energy, that is converted into heat, is measured. If enough energy is absorbed, the optical properties of the component can change, and the component can even be destroyed. Absorptance is the ratio of the radiant flux absorbed to the radiant flux of the incident radiation.

In the procedures described in this document, the absorptance is determined calorimetrically as the ratio of power or energy absorbed by the component to the total power or energy, respectively, impinging upon the component. The assumption is made that the absorptance of the test sample is constant within the temperature fluctuations experienced by the component during the measurement.

For most optical bulk materials, the absorptance depends on the position of the irradiating beam on the sample surface. Several infrared materials exhibit a strong dependence of absorptance on temperature, especially at high temperatures.

Optics and photonics — Lasers and laser-related equipment — Test method for absorptance of optical laser components

1 Scope

This document specifies procedures and techniques for obtaining comparable values for the absorptance of optical laser components.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 11145, *Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols*

ISO 14644-1:2015, *Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness by particle concentration*

ISO 80000-7, *Quantities and units — Part 7: Light and radiation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145 and ISO 80000-7 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
absorptance
a
ratio of the radiant flux absorbed to the radiant flux of the incident radiation

Note 1 to entry: The definition of absorptance used for this document is limited to absorptance processes which convert the absorbed energy into heat. For certain types of optics and radiation, additional non-thermal processes can result in absorption losses which will not be detected by the test procedure described here (see Annex A).

4 Symbols and units of measure

Symbol	Term	Unit
C_{eff}	Thermal capacity of test sample, holder, etc.	J/K
c_{p}	Specific heat capacity of test sample	J/(kg·K)
$d_{\sigma x}$, $d_{\sigma y}$	Beam width on test sample	mm
m_{i}	Mass of test sample, holder, etc.	kg
P	cw power	W

Symbol	Term	Unit
P_{av}	Average laser power for continuous pulse mode operation	W
P_{pk}	Typical peak power for repetitive pulse mode operation	W
t_B	Duration of irradiation	s
Δt	Time interval	s
T_{amb}	Ambient temperature	K
ΔT	Temperature difference	K
a	Absorptance	1
β	Angle of incidence	Rad
γ	Thermal loss coefficient	1/s
λ	Wavelength	nm
κ	Heat conductivity	W/(mK)
η	Mass density	kg/m^3
Q	Heat source	W/m^3

5 Preparation of test sample and measuring arrangement

Storage, cleaning and the preparation of the test samples are carried out in accordance with the manufacturer's instructions for normal use.

The environment of the testing place shall be adapted to the application and test wavelength. It should consist of dust-free filtered air with less than 50 % relative humidity. The residual dust shall be reduced in accordance with cleanroom class 7 as defined in ISO 14644-1:2015. However, some specific spectral ranges might require nitrogen purged environments (deep UV) or zero humidity (several IR wavelengths). Nitrogen quality for the deep UV range should be at 99,999 % or higher. If these conditions cannot be supplied, absorption within the surrounding atmosphere will be included in the test result. An environment free from draughts is very important in order to keep thermal disturbances and heat loss by convection as small as possible. Measurements in ambient atmosphere and vacuum can have different influences on the measured absorptance.

A laser shall be used as the radiation source. To keep errors as low as possible, the laser power chosen for measurements is as high as possible but without causing any deterioration to the component.

Wavelength, angle of incidence and state of polarization of the laser radiation used for the measurement shall correspond to the values specified by the manufacturer for the use of the test sample. If also ranges are accepted for these three quantities, any combination of wavelength, angle of incidence and state of polarization may be chosen from those ranges. The absorption of an optical component can depend on further parameters, e.g. power density or irradiation dose. In such cases, the measurement sequence should be chosen individually. For more details, refer to Annex A.

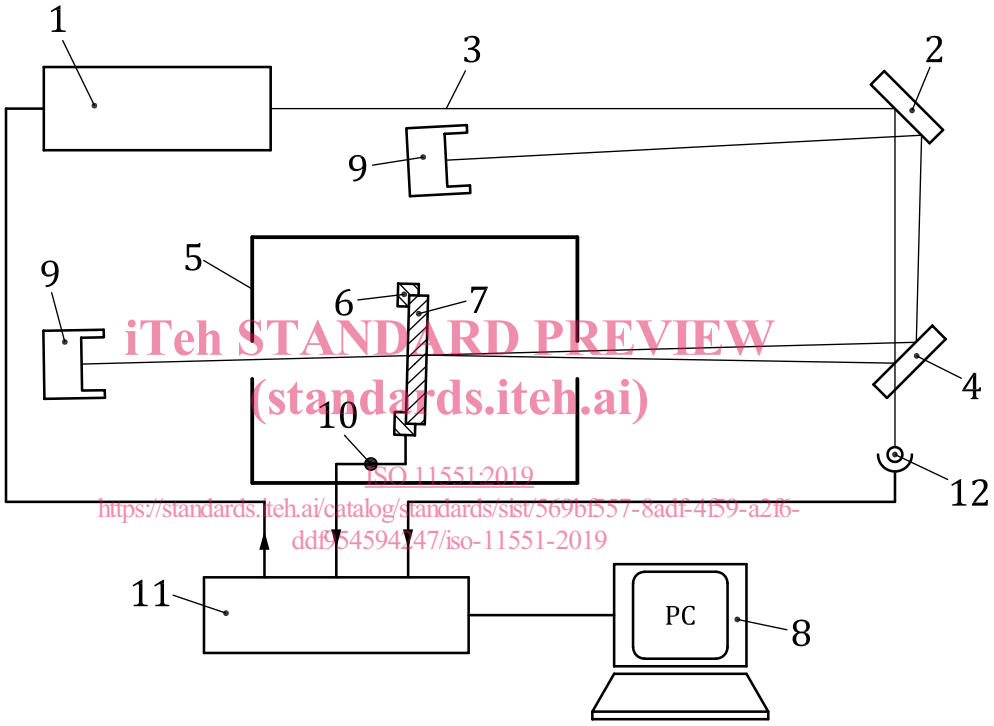
The test sample is mounted in a suitable holder. It is preferable to mount the sample in a manner that minimizes any thermal contact between the sample and the holder. In this arrangement, the thermal sensor is attached directly to the sample surface. Reproducible thermal contact between the thermal sensor and the sample surface is important. Also, care should be taken to maintain constant thermal impedance between the sample and the holder. Accurate calibration is critically dependent on the location of the thermal sensor, on the material the sample is made of, and on the sample geometry. Refer to Annex B for a detailed discussion of these considerations.

It can be difficult to attach the thermal sensor to a small test sample or a sample having an irregular shape. Such a sample is mounted to the holder in a manner that maximizes thermal contact between the sample and the holder, while the thermal sensor is attached to or integrated into the holder. Reproducible thermal contact between the thermal sensor and the holder is important. Also, care should be taken to maintain constant thermal conductance between the sample and the holder.

In order to increase the precision of the measurements, the sample should be mounted inside a chamber designed for thermal shielding, with apertures for the laser beam. Special attention shall be given to ensure that the temperature measurement itself does not cause a change of the sample temperature.

Suitable diaphragms should be placed in the beam path in front of and behind the test sample to ensure that only the test sample is irradiated by the measuring beam and that reflected or stray radiation will not strike the holder or the chamber walls. The number of transmissive optics employed for beam guiding should be minimized in order to reduce possible distortions by multi-reflections or scattered radiation. The transmitted and reflected partial beams shall be directed on to beam dumps with minimized back scatter.

Figure 1 shows a schematic measuring arrangement. The curved folding mirror M1 is recommended for imaging the laser output window on to the sample in order to avoid diffracted radiation influencing the measurement.



Key

1	laser	7	test sample
2	mirror M1	8	personal computer
3	optical axis	9	beam stop
4	mirror M2	10	thermal sensor
5	test chamber	11	control unit
6	sample holder	12	power detector

Figure 1 — Typical arrangement for measurement of the absorptance

6 Characteristic features of the laser radiation

The following physical quantities are needed for characterizing the laser radiation used for the test:

— wavelength, λ;

— angle of incidence, β;

— state and degree of polarization;

— beam widths on the test sample, $d_{\sigma x}$, $d_{\sigma y}$;

— average power, P_{av}, for cw or continuously pulsed lasers;

— typical peak power, P_{pk}, and pulse energy Q in the case of continuously pulsed lasers;

— duration of irradiation, t_B.

7 Test procedure

7.1 General

The following auxiliary tests shall be performed on a regular basis and whenever the measuring arrangement has been altered.

7.2 Calibration

7.2.1 Calibration of the power signal

Calibrate the power signal by placing a calibrated laser power detector at the location of the test components and, in order to obtain correct calibration, compare the measured laser power to the signal of the power monitor used during absorptance tests.

7.2.2 Calibration of the temperature signal

Calibrate the temperature signal by fixing a test sample, to which a calibrated thermal sensor is attached, to the sample holder. Compare the temperature signals of this calibrated sensor and the sensors used during absorptance tests while varying the ambient temperature slowly over the linearity range of the temperature detectors at the typical test temperature.

7.2.3 Calibration of the thermal response

For certain types of sample materials and geometries, the temperature rise induced by the absorbed heat may differ from the theoretical response expected for ideal materials having infinite thermal conductivity. In these cases, a correction factor f_c shall be determined, which compensates for the influence of such phenomena on the absorptance test result. f_c is unity if the influence of limited thermal conductivity can be neglected. In order to derive a correct value for f_c, the heating scheme of the calibration routine needs to be consistent with the heating characteristic of the samples to be tested. Surface absorbers shall be related to a correction factor derived from a calibration based on surface heating. And a bulk absorber shall be corrected with a bulk heated calibration sample.

For calibration, a reference sample of known absorptance, which is identical to the samples under investigation with respect to substrate geometry and thermal diffusivity, is tested for absorptance as described below. The irradiation time and evaluation method used for calibration shall be the same as for the sample under test.

Depending on the evaluation method used for the absorptance test, the correction coefficient can be calculated by substituting the value of the known calibration sample absorptance for a in Formula (2) (see 8.3) or Formula (5) (see 8.4), and solving for f_c.

A known absorptance can be achieved by applying a thin, high-absorbing coating to the sample surface area that is exposed to irradiation. High absorptance values can be determined with sufficient accuracy, e.g. by measuring the fraction of transmitted, reflected and scattered radiation. For absorptance testing of samples with high absorptance values, the laser power should be suitably attenuated in order to avoid damage to the samples and to ensure that the resulting temperature rise is in the same order of magnitude as the temperature which is achieved for typical measurements. This procedure applies only for samples of high surface absorption, where bulk absorption can be neglected.

As an alternative to irradiating a calibration sample of known absorptance with the laser beam, the thermal energy may be deposited electrically in the test sample by attaching an electric resistor to the tested surface. The absorbed power is given by RI^2, where R is the electrical resistance and I is the electric current during "irradiation". Care should be taken to ensure good thermal contact between resistor and sample. Furthermore, especially in the case of samples with low thermal conductivity, the area of the resistor should match the area irradiated by the laser beam under normal test conditions. This procedure can in principle be applied to both surface and bulk absorbing samples. Care should be taken to ensure that the heating scheme of the calibration sample is close or identical to the expected heating scheme of the test samples.

7.2.4 Measurement of the background signal

For maximum accuracy and suppression of possible signal distortions, the imaging and alignment of the laser beam shall be optimized. A measurement with an empty holder or with an absorptance-free component can be used to verify that the measuring arrangement is not influenced by reflected or stray radiation. The amplitude of the temperature fluctuations during the test interval shall be at least one order of magnitude below the temperature rise occurring during an absorptance test.

7.3 Determining the absorptance

The absorptance of optical components is determined calorimetrically by means of a measuring arrangement as shown in Figure 1. Before measurement commences, thermal equilibrium shall be established, so that the ambient temperature drift is approximately linear and the temperature noise (standard deviation) is at least one order of magnitude below the maximum temperature rise induced by irradiation. The maximum temperature rise during the test should be in accordance to the linearity of the temperature detector.

If the absorptance is dependent either on the power or energy density of the impinging radiation, or the irradiation dose, this shall be noted in the test report. The test shall be performed under the conditions of the foreseen use of the components.

The test is performed in three successive intervals:

— the drift recording interval $[t_0, t_1]$ (at least 30 s);

— the heating interval $[t_1, t_2]\,(t_B = t_2 - t_1 = 5\,\text{s to}\,300\,\text{s})$ during which the laser beam impinges on the test sample surface;

— the cooling interval of at least 200 s.

For test samples with high thermal losses, the irradiation should end significantly before the temperature rise saturates due to a balance of absorbed power and thermal loss.

During the test, the sample temperature signal $T(t)$ and the laser power signal $P(t)$ are recorded. The resulting calorimetric data sets $[t_k, T(t_k)]$ and $[t_k, P(t_k)]$ with k, enumeration index, are stored for the evaluation of the absorptance.

8 Evaluation

8.1 General

The mass, m_i, of components heated during irradiation (test sample, holder, etc.) is determined by weighing. The specific heat capacity c_{pi} is taken from tables.

For the calculation of absorptance, two alternative methods can be used: the exponential method or the pulse method. In general, the pulse method is applicable for irradiation times up to 120 s, while the exponential method can be applied for irradiation times from 60 s. Which method is preferable depends also on the individual properties of the tested specimen and the circumstances of the test. In