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**Optics and photonics — Laser  
and laser-related equipment  
— Photothermal technique for  
absorption measurement and  
mapping of optical laser components**

*Optique et photonique — Lasers et équipements associés aux lasers  
— Technique photothermique pour la mesure et la cartographie de  
l'absorption des composants laser optiques*

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Published in Switzerland

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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.

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](http://www.iso.org/directives)).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

With the rapid development of high-power/high-energy laser technology, laser-induced damage to optical laser components and laser-induced thermal distortion in laser components become the most important limiting factors for the operation and applications of high-power/high-energy laser systems. Normally, the laser-induced damages to optical laser components are caused by absorbing defects on the surface or within the laser components which result in thermal stress or melting of the laser components and lead to damage. The thermal distortions, which induce wavefront distortions and therefore beam quality deteriorations to the laser beam, are caused by non-uniform thermal expansion or refractive index change due to absorption irregularities (such as absorbing defects) inside the laser components. To improve the laser-induced damage threshold (LIDT) and reduce the laser-induced thermal distortion of laser components used in high-power/high-energy laser systems, there are needs not only to measure precisely the absorptance of the laser components, but also to detect various absorbing defects on/within the laser components, therefore to improve the performance of these laser components via optimizing fabrication/coating processes.

Currently, the ISO 11551 standardized testing method - laser calorimetry for absorptance measurements of optical laser components can only measure test samples with small sizes (normally less than 50 mm in diameter and 10 mm in thickness) and has almost no capability to measure the absorptance of large-sized laser components (100 mm in diameter and over) widely used in high-power/high-energy laser systems. In addition, laser calorimetry has only limited capability to map the absorptance distribution of an optical laser component.

The measurement procedures in this document have been optimized to allow the mapping of absorbing defects of optical laser components and measurement of absolute absorptance of large-sized laser optics actually used in high-power/high-energy laser systems using photothermal techniques which provide absorption measurement/mapping with high sensitivity, high spatial resolution, and high reliability.

In addition to absorption measurement/mapping of optical laser components with photothermal amplitude, the photothermal phase measurement/mapping can also find applications in thermo-physical characterization of laser optics, which will be helpful for a better understanding of defect properties of laser optics and laser-defect interaction that would lead to a better understanding of laser-induced damage mechanism of laser optics.



# Optics and photonics — Laser and laser-related equipment — Photothermal technique for absorption measurement and mapping of optical laser components

## 1 Scope

This document specifies procedures for the absorption measurement and high spatial-resolution two-dimensional or three-dimensional absorption mapping of optical laser components, and upon calibration, the measurement of absolute absorptance of laser optics.

The methods given in this document are intended to be used for the two-dimensional or three-dimensional absorption mapping of optical laser components, that is, measurement of absorption as a function of position, as well as absorption/absorptance measurement and mapping of laser optics used in high-power/high-energy laser systems.

## 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, *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 terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

### 3.1

#### **absorption**

radiant flux absorbed by the optical laser component

### 3.2

#### **absorptance**

ratio of the radiant flux absorbed to the radiant flux of the incident radiation

## 3.3

**absorption map  
absorptance map**

measured *absorption* (3.1)/*absorptance* (3.2) as a function of sample position

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 may result in absorption losses which will not be detected by the test procedure described here.

## 4 Symbols used and units of measure

Table 1 — Symbols used and units of measure

Symbol	Term	Unit
$A$	Absorptance of test sample	
$A_0$	Absorptance of calibration sample	
$S$	Photothermal amplitude of test sample	
$S_0$	Photothermal amplitude of calibration sample	
$P, P_0$	Pump laser power	W
$\Delta I, I_0$	Probe beam intensity change and dc probe intensity detected in photothermal lensing	
$I_1, I_2$	Probe beam intensity detected by the two photo-detectors of a bi-cell photo-detector in photothermal deflection	
$D$	Thermal diffusion coefficient of test sample	$\text{m}^2\text{s}^{-1}$
$\Delta\varphi(x, y)$	Photothermally induced optical phase shift to probe beam	
$\alpha_{th}$	Linear thermal expansion coefficient of test sample	$\text{K}^{-1}$
$dn/dT$	Temperature coefficient of refractive index of test sample	$\text{K}^{-1}$
$\nu$	Poisson ratio of test sample	
$f$	Modulation frequency of pump laser power	Hz
$\mu_{th}$	Thermal diffusion length of test sample	m
$a$	Pump beam radius in test sample	m
$\lambda$	Probe laser wavelength	m
$z$	Detection distance	m
$T(x, y, z)$	Photothermally induced temperature rise distribution inside test or calibration sample	K
$B, C$	Proportional coefficients	
$\beta$	Slope of linear fit of the measured absorptance dependence of the power-normalized photothermal amplitude of calibration samples	

## 5 Test method

## 5.1 Test principle

## 5.1.1 General

Based on photothermal effects, photothermal techniques are highly sensitive for the measurement of weak absorptance of optical laser components. In a typical photothermal experiment, a continuous-wave or highly repetitive pulsed excitation laser (pump laser) beam is used to irradiate the sample under test, heat is created within the sample due to optical absorption, and a temperature rise distribution within the sample is formed. For optical laser components, a displacement is induced on the sample surface due to thermal expansion, and a refractive index gradient is formed within the sample due to the temperature dependence of refractive index. By employing photothermal techniques to detect the surface displacement or refractive index gradient with a second probe laser beam, the

absorptance (absorption) of the sample can be determined. The absolute absorptance can be obtained by calibrating the photothermal amplitude. By measuring the absorption/absorptance as a function of position, the absorption/absorptance map of a laser component is obtained.

Photothermal lensing (or thermal lens - TL) and photothermal deflection (PTD) are appropriate detection techniques for absorption measurement and mapping of optical laser components. Two detection schemes, both reflected and transmitted probe beam detections, can be used to measure the photothermal signal amplitude, which is linearly proportional to the absorption/absorptance of optical laser components under test when the photothermally induced optical phase shift to the probe beam is relatively small as compared to the probe beam wavelength (small signal approximation).

### 5.1.2 Photothermal lensing (TL)

In a typical TL scheme, an unfocused probe beam irradiates the pump laser-induced surface displacement zone or the refractive index gradient zone which acts as a negative (or positive) lens. The photothermal signal is represented by the intensity change at the centre of either the reflected probe beam (in surface TL – STL scheme) or the transmitted probe beam (in transmitted TL – TTL scheme). This probe beam intensity change can be detected by a pinhole photodetector (a photodetector with a pinhole in front of it).

### 5.1.3 Photothermal deflection (PTD)

In a typical PTD scheme, a tightly focused probe beam irradiates the pump laser-induced surface displacement zone or the refractive index gradient zone, the reflected probe beam is deflected due to the slope of the surface displacement in a reflected PTD configuration, or the transmitted probe beam is deflected due to the refractive index gradient in a transmitted PTD configuration. The photothermal signal is represented by the probe beam deflection, which can be easily detected by a position-sensitive photodetector (for example, a bi-cell photodetector).

### 5.1.4 Rules for selecting reflected and transmitted photothermal detection schemes

Selecting between the reflected or transmitted photothermal detection schemes (both TL and PTD) should be considered as follows. As a general rule, the detection scheme with a higher detection sensitivity should be selected for more sensitive and precise absorption measurement. For an optical laser component with a (much) larger linear thermal expansion coefficient so that the photothermally induced optical phase shift to the probe beam by the thermal expansion caused surface displacement is large, a reflected photothermal detection scheme is preferable. On the other hand, a transmitted photothermal detection scheme should be selected if the temperature coefficient of refractive index of the component is much larger so that the optical phase shift to the probe beam caused by the temperature rise induced refractive index change is much larger than that caused by the surface displacement. However, if the sample under test is opaque to the probe beam, the reflected photothermal detection scheme should be selected.

For photothermal absorption measurement of bulk samples and separation of surface absorption and bulk absorption, the transmitted photothermal detection scheme is preferable. The reflected photothermal detection scheme may be used for measurement of bulk samples only when the bulk sample is homogeneous and has negligible surface absorption.

## 5.2 Measurement arrangement and test equipment

### 5.2.1 Photothermal detection arrangement

There are four photothermal detection arrangements that may be used to measure and map the absorption of optical laser components. That is, surface thermal lens (STL), transmitted thermal lens (TTL), reflected photothermal deflection (or photothermal displacement) (reflected PTD), and transmitted photothermal deflection (transmitted PTD).

Figures 1 to 4 show typical experimental arrangements for the STL, TTL, reflected PTD, and transmitted PTD detection schemes, respectively.

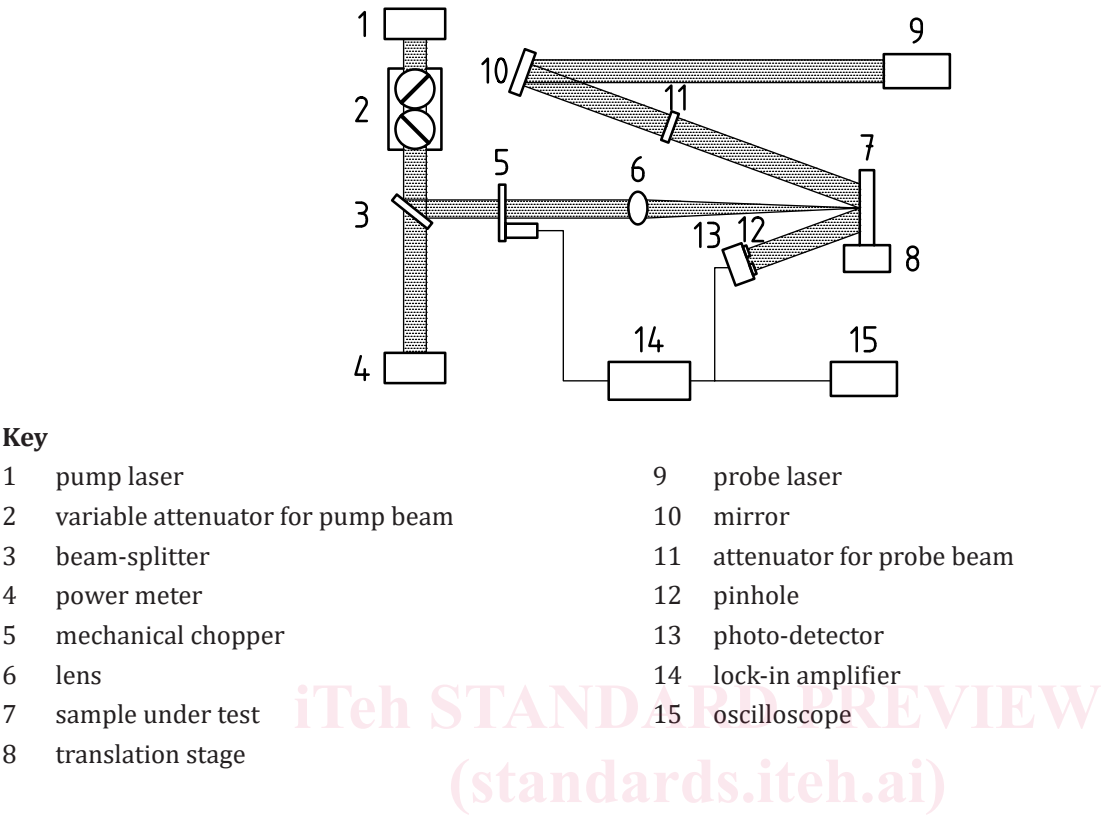


Figure 1 — Typical experimental arrangement for the STL detection scheme

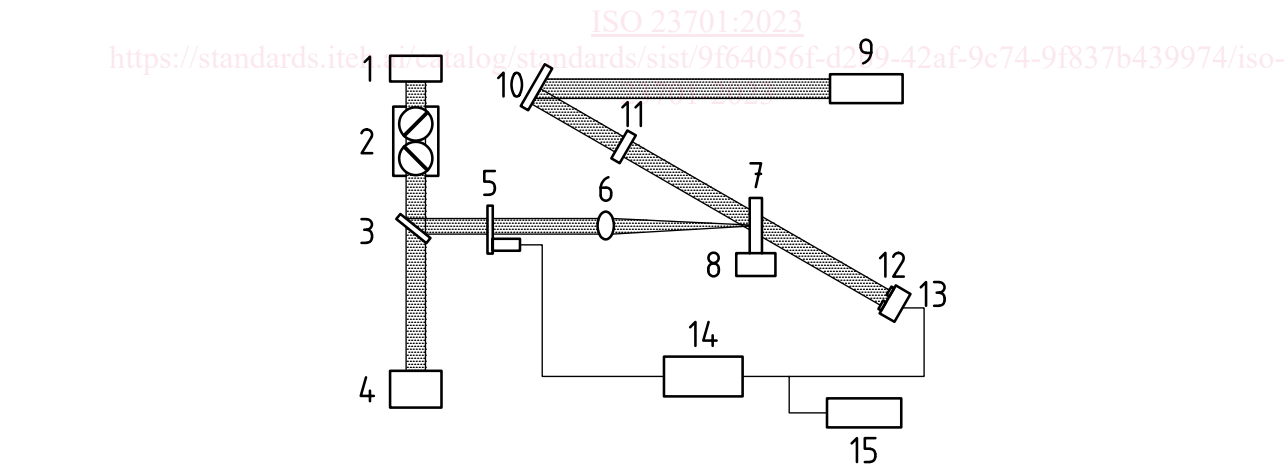
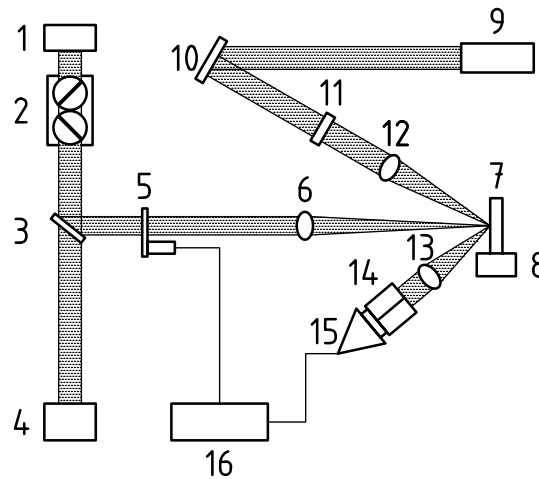
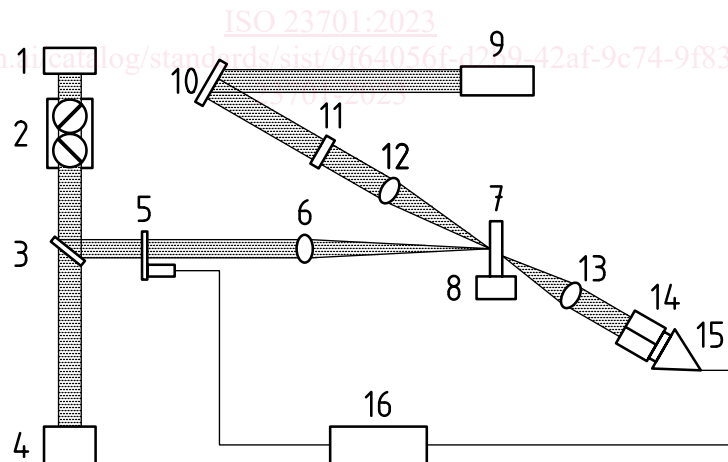


Figure 2 — Typical experimental arrangement for the transmitted TL detection scheme

**Key**

- |   |                                   |        |                           |
|---|-----------------------------------|--------|---------------------------|
| 1 | pump laser                        | 9      | probe laser               |
| 2 | variable attenuator for pump beam | 10     | mirror                    |
| 3 | beam-splitter                     | 11     | attenuator for probe beam |
| 4 | power meter                       | 12, 13 | lens                      |
| 5 | mechanical chopper                | 14     | bi-cell photo-detector    |
| 6 | lens                              | 15     | differential amplifier    |
| 7 | sample under test                 | 16     | lock-in amplifier         |
| 8 | translation stage                 |        |                           |

**Figure 3 — Typical experimental arrangement for the reflected PTD detection scheme****Key**

- |   |                                   |        |                           |
|---|-----------------------------------|--------|---------------------------|
| 1 | pump laser                        | 9      | probe laser               |
| 2 | variable attenuator for pump beam | 10     | mirror                    |
| 3 | beam-splitter                     | 11     | attenuator for probe beam |
| 4 | power meter                       | 12, 13 | lens                      |
| 5 | mechanical chopper                | 14     | bi-cell photo-detector    |
| 6 | lens                              | 15     | differential amplifier    |
| 7 | sample under test                 | 16     | lock-in amplifier         |
| 8 | translation stage                 |        |                           |

**Figure 4 — Typical experimental arrangement for the transmitted PTD detection scheme**

### 5.2.2 Pump laser

The pump laser is a continuous-wave or highly repetitive pulsed laser used to heat the test sample. Wavelength of the laser source, angle of incidence and state of polarization shall correspond to those specified by the manufacturer for the use of the test sample. The state of polarization ( $p$  or  $s$ ) of the laser beam shall be selected by the polarizer. If the value ranges are acceptable for these three quantities, any combination of the wavelength, angle of incidence and state of polarization may be chosen within these ranges.

The (average) power of the pump laser should be sufficiently high so that the surface displacement or refractive index gradient created by the pump beam absorption of the test sample is highly detectable. The pump laser power should be adjustable via a variable attenuator which should not create any change to the beam profile of the pump beam during power adjustment. The pump beam profile shall be the same at all times, during the calibration and during the photothermal measurement at each adjusted power. The pump laser power is periodically modulated by a mechanical chopper or an acoustic-optic modulator. The modulation frequency is selected for optimal signal-to-noise ratio (SNR) of the photothermal signal.

For absorption mapping performed longer than several minutes, the power stability of the pump laser shall be monitored by a power meter or photo-detector as shown in [Figures 1](#) to [4](#), and if needed its influence on the absorption mapping shall be eliminated by normalizing the photothermal amplitude with the monitored output power.

The pump beam is focused into the test sample to create enough temperature rise inside the test sample. The beam size of the pump beam on/inside the test sample is optimized taking into account the SNR of the photothermal signal, the area and spatial resolution of absorption mapping. Care shall be taken to avoid laser damage to the test sample due to too tight focusing.

### 5.2.3 Probe laser

The probe laser is a continuous-wave laser used to detect the photothermal signal. Normally a highly stable He-Ne or diode laser with a TEM<sub>00</sub> mode output is used as the probe laser. The output power of the probe laser should be low so that the heat created by the probe beam absorption of the test sample is negligible.

For TL detection, the probe beam is normally not focused, or the probe beam size is at least five times larger than that of the focused pump beam in the interaction zone of the two beams. For PTD detection, the probe beam is focused. The size of the focused probe beam is at least smaller than that of the pump beam in the interaction zone. The separation between the pump and probe beams has to be adjusted to maximize the photothermal (lensing or deflection) amplitude for optimum SNR.

For absorbance measurements and two-dimensional absorption mapping, the angle of incidence of the probe beam with respect to the sample normal should be small, for example smaller than 10 degrees. For three-dimensional absorption mapping or separation of surface absorption and bulk absorption, the angle of incidence of the probe beam with respect to the pump beam should be adjusted taking into consideration depth resolution and SNR of photothermal signal. The angle of incidence of the probe beam should be documented.

A detailed description on the separation of surface and bulk absorption is given in [Annex B](#).

### 5.2.4 Translation stage

A two-dimensional/three-dimensional translation stage is used to move the test sample in order to measure the absorption as a function of position, so that a two-dimensional or three-dimensional absorption map is obtained. The translation stage should be motorized with a position resolution better than 10  $\mu\text{m}$  and controlled by a computer software.