

Optics and photonics — Lasers and laser- related equipment — Measurement and evaluation of absorption-induced effects in laser optical components

ICS 31.260

National foreword

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This document comprises a front cover, an inside front cover, the PD ISO/TR title page, pages ii to vi, pages 1 to 19, an inside back cover and a back cover.

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 9 January 2006

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Amendments issued since publication

Amd. No.	Date	Comments

TECHNICAL REPORT

**ISO/TR
22588**

First edition
2005-09-15

Optics and photonics — Lasers and laser-related equipment — Measurement and evaluation of absorption-induced effects in laser optical components

*Optique et instruments d'optique — Lasers et équipement associé aux
lasers — Mesurage et évaluation de la déformation et de la distorsion
des composants optiques dans un faisceau laser*



Reference number
ISO/TR 22588:2005(E)

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Foreword

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ISO/TR 22588 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

Introduction

This Technical Report has been promulgated in order to highlight the problem and to specify meaningful, standard measurement techniques in order to provide useful information to reduce conflict between users and suppliers of optical components.

When a laser beam impinges upon an optical component (lenses, windows and mirrors) some of the energy is absorbed. Depending on the intensity of the laser beam and the absorption properties of the component material the component temperature will rise. Even if a uniform intensity laser beam fills the whole area of the component, temperature gradients will be created across the aperture. Unless the material has a negligible expansion coefficient, temperature gradients lead to differential expansion, and this will lead to distortion, strain and a change in the birefringence properties of transmissive components. The refractive index of most optical materials is also temperature dependent. If the optical figure of the component changes, the transmitted and/or reflected beam will tend to change shape and/or change its divergence. If the beam path involves a polariser, a beam splitter or a beam deflector the power/energy output and/or the beam propagation of the laser system may change. These effects may be amplified if the component is rigidly restrained. If the strain is high enough the component may crack.

The absorption coefficients of most materials are usually only slightly non-linear with increase in temperature. However, transmissive components made from most semi-conducting materials exhibit a highly non-linear absorption coefficient with a sharp threshold, significantly below the melting point of the material. This phenomenon is termed "thermal runaway" and effectively limits the optical power loading at which these materials can be used. This thermal runaway threshold is accompanied by a sharp increase in the absorption and an increase in the accompanying distortion and thermal lensing. The refractive indices and linear expansion coefficients are both temperature sensitive but do not necessarily have the same sign.

Distortion will occur when a component is irradiated nonuniformly and especially when it is held rigidly and constrained from expanding. The material will expand because of the thermal loading and if this is not uniform the component will bow or lens, thus changing the optical figure. In addition, in the case of transmissive components, it is possible that the temperature dependence of the refractive index of the material will cause a thermal lensing effect. In general, non-uniform expansion changes the focussing properties of the component. In the case of non-linear absorbing windows and mirrors (e.g. Ge, ZnS and ZnSe used with infrared beams) the effects have been observed to severely affect the transmitted beam divergence. In the case of planar reflective interferometric components these have been observed to become convex. In practice, even minor distortion of *in-situ* laser components leads to changes in the divergence and beam propagation ratio of the laser beam and to loss of laser output.

Strain in crystalline components leads to induced birefringence and thus to changes in transmission/reflection and this leads to fluctuations in the system output, to the necessity for raising the input power and to non-linearity in the input/output characteristics of the system. Even homogeneous materials can exhibit birefringence if the thermal loading is non-uniform and the component mounting constrains the material from expanding. The laser output of optically thin laser rods in a flash-tube pumped close coupled or elliptical pumping chamber is governed by the circularly symmetric induced birefringence. Changes in birefringence commonly lead to a change of the transmission of the laser beam through the system, particularly if polarisation sensitive elements are in the beam train.

Thermally induced strain, due to non-uniform irradiation, can occur even in a freely mounted component. Most optical components are, however, mounted in a holder, which is used to control the angular position of the component. If this mount does not allow differential expansion to take place, then the component will become increasingly strained as the component is irradiated. When this strain reaches the elastic limit the component will crack. This is perhaps one of the main causes of the unusually low laser induced damage thresholds encountered in practice. The effect is mainly encountered in high prf (pulse repetition frequency), long pulse and cw (continuous waves) laser systems. Thermally induced strain, due to rigidity in the component mounting and/or lack of expansion gaps in the component/mount combination, is perhaps the greatest cause of laser

components failing in the active system context. The induced strain either cracks the component or lowers the thermal loading at which melting occurs.

The thermally induced effects are minimised if the component is held freely and maximised if clamped hard. The stress involved can be positive or negative depending on the relative differences in the coefficients of thermal expansion between the holder and the component. As this is the decisive factor it is necessary to make the measurement with the component in its holder under, as near as possible, the system working conditions and environment. In practice, this may make it hard/impossible to perform some of the measurements suggested. Therefore, although the measurement of distortion is the most basic and relevant, it may be necessary to monitor either the changes in birefringence or the changes in beam propagation ratio of the transmitted beam. Measurement of the change in the laser induced damage threshold between free and clamped components is not expected to be routine as it is catastrophic.

All the effects mentioned lead to a shortening of the component life and/or a change in the output characteristics of the laser [1]. They also form the main source of friction between the component suppliers and the system manufacturers/users. The effects are most commonly observed in the case of high prf, long pulse and cw laser systems (e.g. welding lasers). However they have also been seen to influence the energy/power output of single-shot Q-switched Nd:YAG lasers operating at 1 064 μm and the transmission and divergence of planar Ge windows under short pulse CO_2 , 10,6 μm laser irradiation.

Optics and photonics — Lasers and laser-related equipment — Measurement and evaluation of absorption-induced effects in laser optical components

1 Scope

This Technical Report specifies standard measurement and evaluation techniques for determining the absorption-induced effects caused by lasers in laser optical components in order to provide useful information to reduce conflict between users and suppliers of optical components.

2 Absorption

2.1 General

Absorption is a fundamental property of a material. It is directly related to the electronic structure of the material and the wavelength of the probe radiation. For transmitting materials the absorption is directly related to the band gap. A schematic of the spectral transmission of a material is shown in Figure 1. The exact placing and spacing of the different absorption edges are defined by the material structure, including impurities. In the case of materials used for optical windows, which transmit in the visible, the absorption coefficient is small and hardly varies with increasing temperature. In the case of both ultra-violet and infra-red transmitting materials the absorption coefficient is non-negligible and has to be taken into account. In addition, most, but not all, infra-red transmitting materials are semi-conducting and exhibit non-linear optical absorption. These materials have low, usable, absorption characteristics at low/room temperatures but exhibit a thermal runaway threshold at elevated temperatures. Above this thermal runaway temperature the absorption coefficient increases sharply and the transmission of the window drops. In addition any non-linearity in the incident beam is reflected in a lensing effect which changes the quality of the transmitted beam drastically.

Most optically transmitting window materials are, nowadays, homogeneous. However the absorption of a material may be vitally affected by impurities, both localised and diffused through the lattice.

The reasons for absorption may be broken down into a variety of effects.

a) Bulk absorption

$$I = I_0 e^{-\alpha x}$$

This absorption may be permanent or induced. Absorption in the visible, for example, may be induced by absorption of ultra-violet radiation, forming colour centres (trapping of electrons at negative ion vacancies). This commonly occurs in the halides (NaCl and KCl) and in Nd:YAG laser crystal [2]. The latter example is the reason why many Nd:YAG lasers gradually lose output with time and why it is sensible to fit a Nd:YAG pump cavity with an ultra-violet filter. Most instances of colour centres can be nullified by suitable heat treatment.

Absorption is a function both of the electronic structure of a material and the wavelength at which it is irradiated. Single-photon absorption will occur if the photon energy is great enough to bridge the energy gap between the valence band and the conduction band. This is independent of the energy density (Beer's law) but is crucially dependent on the wavelength of the probe radiation. Two-photon absorption can occur if the two photons arrive simultaneously and the sum of the energies exceeds the band gap. At