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Optics and optical instruments — Test methods for radiation scattered by optical components

Optique et instruments d'optique — Méthodes d'essai du rayonnement diffusé par les composants optiques

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Contents

Page

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 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 13696 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

Annexes A to D of this International Standard are for information only.

In this corrected version of ISO 13696:2002, the following changes have been incorporated:

page 10, equation (5) reads $S_{\text{for}} = \frac{1}{N}\sum_{i=1}^{N}\frac{V_{\text{s,for}}(r_i) - (\tau_{\text{s}}\, V_{\text{u}})}{V_{\text{c}}(r_i) - V_{\text{u}}}$

equation (6) reads $S_{\text{bac}} = \frac{1}{N}\sum_{i=1}^{N}\frac{V_{\text{s,bac}}(r_i) - (1+\rho_{\text{s}})\, V_{\text{u}}}{V_{\text{c}}(r_i) - V_{\text{u}}}$

equation (7) reads $S_{\text{for}}(r_i) = \frac{V_{\text{s,for}}(r_i) - (\tau_{\text{s}}\, V_{\text{u}})}{V_{\text{c}} - V_{\text{u}}}$

page 11, equation (8) reads $S_{\text{bac}}(r_i) = \frac{V_{\text{s,bac}}(r_i) - (1+\rho_{\text{s}})\, V_{\text{u}}}{V_{\text{c}} - V_{\text{u}}}$

page 19, equation (C2) reads $\sigma_{\text{s}} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(M_{\text{s}} - S_{\text{bac,sc}}(r_i)\right)^2}$

page 26, the year of publication of ISO 12005 has been inserted.

Introduction

In most applications, scattering in optical components reduces the efficiency and deteriorates the image-forming quality of optical systems. Scattering is predominantly produced by imperfections of the coatings and the optical surfaces of the components. Common surface features which contribute to optical scattering are imperfections of substrates, thin films and interfaces, surface and interface roughness, or contamination and scratches. These imperfections deflect a fraction of the incident radiation from the specular path. The spatial distribution of this scattered radiation is dependent on the wavelength of the incident radiation and on the individual optical properties of the component. For most applications in laser technology and optics, the amount of total loss produced by scattering is a useful quality criterion of an optical component.

This International Standard describes a testing procedure for the corresponding quantity, the total scattering (TS) value, which is defined by the measured values of backward scattering and forward scattering. The measurement principle described in this International Standard is based on an Ulbricht sphere as the integrating element for scattered radiation. An alternative apparatus with a Coblentz hemisphere, which is also frequently employed for collecting scattered light, is described in annex A. Currently, advanced studies on the comparability and the limitations of both light collecting elements are being performed (e.g. round robin tests, EUREKA-project EUROLASER: CHOCLAB).

Optics and optical instruments — Test methods for radiation scattered by optical components

1 Scope

This International Standard specifies procedures for the determination of the total scattering by coated and uncoated optical surfaces. Procedures are given for measuring the contributions of the forward scattering and backward scattering to the total scattering of an optical component.

This International Standard applies to coated and uncoated optical components with optical surfaces that have a radius of curvature of more than 10 m. The wavelength range includes the ultraviolet, the visible and the infrared spectral regions.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

ISO 14644-1:1999, *Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1
scattered radiation
fraction of the incident radiation that is deflected from the specular optical path

3.1.2
front surface
optical surface that interacts first with the incident radiation

3.1.3
rear surface
surface that interacts last with the transmitted radiation

3.1.4
backward scattering
fraction of radiation scattered by the optical component into the backward halfspace

NOTE Backward halfspace is defined by the halfspace that contains the incident beam impinging upon the component and that is limited by a plane containing the front surface of the optical component.

3.1.5
forward scattering
fraction of radiation scattered by the optical component into the forward halfspace

NOTE Forward halfspace is defined by the halfspace that contains the beam transmitted by the component and that is limited by a plane containing the rear surface of the optical component.

3.1.6
total scattering
ratio of the total power generated by all contributions of scattered radiation into the forward or the backward halfspace or both to the power of the incident radiation

NOTE The halfspace in which the scattering is measured should be clearly stated.

3.1.7
diffuse reflectance standard
diffuse reflector with known total reflectance

NOTE Commonly used diffuse reflectance standards are fabricated from barium sulfate or polytetrafluoroethylene powders (see Table 2). The total reflectance of reflectors freshly prepared from these materials is typically greater than 0,98 in the spectral range given in Table 2, and it can be considered as a 100 % reflectance standard. For increasing the accuracy, diffuse reflectance standards with lower reflectance values can be realized by mixtures of polytetrafluoroethylene powder and powders of absorbing materials. (See reference [5] in the Bibliography.)

3.1.8
range of acceptance angle
range from the minimum to the maximum angle with respect to the reflected or transmitted beam that can be collected by the integrating element

3.1.9
angle of polarization
γ
angle between the major axis of the instantaneous ellipse of the incident radiation and the plane of incidence

NOTE 1 For non-normal incidence, the plane of incidence is defined by the plane which contains the direction of propagation of the incident radiation and the normal at the point of incidence.

NOTE 2 The angle of polarization, γ, is identical to the azimuth, Φ (according to ISO 12005), if the reference axis is located in the plane of incidence.

3.2 Symbols and units of measure

Table 1 — Symbols and units of measure

Symbol	Term	Unit
λ	Wavelength	nm
α	Angle of incidence	degrees
γ	Angle of polarization	degrees
d_σ	Beam diameter on the surface of the specimen	mm
P_{inc}	Power of the incident radiation	W
P_{bac}	Total power, backward scattered radiation	W
P_{for}	Total power, forward scattered radiation	W
S_{bac}	Backward scattering	
S_{for}	Forward scattering	
$V_{\text{s,bac}}$	Detector signal for the specimen, backward scattering	V
$V_{\text{s,for}}$	Detector signal for the specimen, forward scattering	V
V_{c}	Detector signal, diffuse reflectance standard	V
V_{u}	Detector signal, test ports open	V
τ_{s}	Transmittance of specimen at wavelength, λ	
ρ_{s}	Reflectance of specimen at wavelength, λ	
r_i	Sample position	mm
N	Number of test sites per surface	

4 Test method

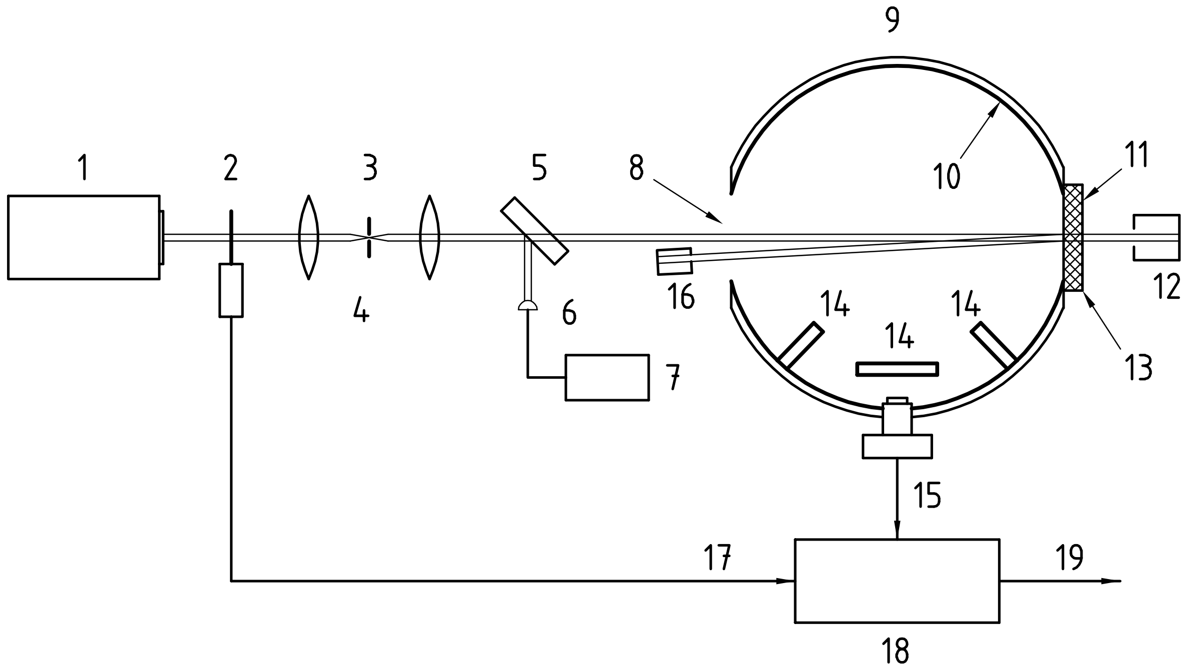
4.1 Principle

The fundamental principle (see Figure 1) of the measurement apparatus is based on the collection and integration of the scattered radiation. For this purpose, a hollow sphere with a diffusely reflecting coating on the inner surface (Ulbricht sphere) is employed. Beam ports are necessary for the transmission of the test beam and the specularly reflected beam through the wall of the sphere. The sample is attached to one of these ports forming a part of the inner surface of the sphere. For the measurement of the backward scattering, the specimen is located at the exit port. The forward scattering is determined by mounting the specimen to the entrance port. The scattered radiation is integrated by the sphere and measured by a suitable detector, that is attached to an additional port at an appropriate position. A diffuse reflectance standard is used for calibration of the detector signal.

4.2 Measurement arrangement and test equipment

4.2.1 General

The measurement facility employed for the determination of the total scattering is divided into four functional sections, which are described in detail below. One functional section consists of the radiation source and the beam preparation system. Two different components are defined by the integration and detection of the scattered radiation. Another section is formed by the sample holder and its optional accessories.



Key

1 Radiation source
2 Chopper
3 Spatial filter
4 Telescope
5 Beam splitter
6 Power detector
7 Power meter
8 Entrance port
9 Ulbricht sphere
10 Coating
11 Exit port
12 Beam stop
13 Sample
14 Radiation baffles
15 Detector, diffuser
16 Beam stop
17 Chopper signal
18 Lock-in amplifier
19 Detector signal, V_s

Figure 1 — Schematic arrangement for the measurement of total scattering (configuration for backward scattering)

4.2.2 Radiation source

As radiation sources, lasers are preferred because of their excellent beam quality and the high power density achievable on the sample surface. For special applications involving the wavelength dependence of scattering, different conventional radiation sources may be used in conjunction with spectral filters or monochromators. Different types of discharge, arc or tungsten lamps are suitable for wavelength-resolved total scatter measurements.

The temporal power variation of the radiation source shall be measured and documented. For this purpose, a beam splitter and a monitor detector are installed. The monitor detector shall be calibrated to the power at the sample surface for both test locations at the entrance and exit port of the integrating element.

4.2.3 Beam preparation system

The beam preparation system consists of a spatial filter and additional apertures, if necessary, for cleaning the beam. For measurements involving conventional radiation sources, additional optical elements are required for the shaping and collimation of the beam. The beam diameter, d_σ, at the surface of the specimen shall be greater than 0,4 mm. No radiation power shall be present in the collimated beam profile beyond radial positions exceeding the beam diameter by a factor of 2,5.

NOTE 1 The behaviour of the measured total scatter value may be dependent on the beam diameter and the beam profile (see annex D).

On the sample surface, the beam profile shall be smooth without local power density values exceeding the average power density within the beam diameter, d_σ, by a factor of three. For measurement systems with a laser as the radiation source, a TEM_{00}-operation with a diffraction-limited Gaussian beam profile is recommended. The defined state and angle of polarization shall be selected. For measurement systems using conventional radiation sources, an unpolarized beam with a circular profile shall be realized. The beam profile on the sample surface shall be free of diffraction patterns and parasitic spots in the outward region. The spatial beam profile on the sample surface shall be recorded and documented.

NOTE 2 Beam deflection mirrors and beam splitters may have a reflectivity which depends on the polarization state of the incident radiation, and they may also deteriorate the sensitivity of the measurement. The last optical element in front of the integrating sphere shall be positioned such that the measurement is not influenced by it.

For the fractions of the beam reflected and transmitted by the sample, efficient beam dumps shall be employed to suppress backscattering into the integrating sphere.

NOTE 3 An efficient beam dump may be constructed with a stack of optically absorbing neutral density filters. These filters are arranged for non-normal angles of incidence in a housing with optically absorbing inner walls.

4.2.4 Integrating sphere

An integrating sphere is employed for the collection and integration of the radiation scattered by the sample. The sphere shall be equipped with beam ports for the entrance and the exit of the probe beam and the fraction of the beam which is specularly reflected by the specimen. The inner surface shall be coated with a highly diffusive reflecting material with a Lambertian characteristic. Selected materials suitable for this coating and the corresponding spectral ranges are listed in Table 2.

Table 2 — Selected materials for coating of the inner surface of the integrating sphere

Material	Spectral range µm
Barium sulfate	0,35 to 1,4
Magnesium oxide	0,25 to 8,0
Polytetrafluoroethylene	0,20 to 2,5
Gold coating, matt	0,70 to 20

The diameters of the beam ports shall be equal and shall exceed the beam diameter, d_σ, of the probe beam at the beam ports by at least a factor of five. The port for the detector shall be adapted to the sensitive area of the detecting element. The detailed shape of the ports shall be optimized for minimum deterioration of the integrating action and for a contact-free installation of the test sample. Baffles coated with the same material as the inner surface of the sphere shall be installed between the exit and entrance port and the detector port. Radiation baffles in front of the detector port are recommended in order to shield the detector against radiation directly scattered by the specimen to the location of the detector. For compensation of spatial inhomogeneities of the detector sensitivity, an optional diffuser may be attached to the detector.

An interval from 2° to 85° is defined as the minimum range of the acceptance angle for scattered radiation. The minimum size of the integrating sphere is specified by the lower limit of 2,0° for the acceptance angle.

NOTE The determination of the minimum size of the integrating sphere originates from the beam diameter, d_σ, at the beam ports of the Ulbricht sphere. The minimum diameter of the entrance port is directly related to this beam diameter by the factor of five. The minimum sphere diameter is then calculated on the basis of the minimum diameter of the entrance port and the lower limit for the acceptance angle. (The minimum diameter of the integrating sphere is approximately 72 times the beam diameter, d_σ.)

For measurement systems with radiation sources other than lasers or special measurement conditions, the beam diameter, d_σ, achievable may result in an impractically large size of the integrating sphere. In such cases, the diameters of the entrance and exit ports shall be adjusted to a value that guarantees no vignetting of the incident, transmitted and reflected beams. The lower and upper limits for the acceptance angles shall be documented.

For specific problems caused by limitations of the integrating element, the detectors and radiation source shall be taken into account for an application of ISO 13696 below a wavelength of 250 nm. The amount of radiation scattered at a discontinuity is a function of both the discontinuity dimensions and the wavelength of the radiation. In practice, scattering becomes less important at longer wavelengths.

As an alternative, a Coblentz half-sphere with an appropriate reflecting surface may be employed. A typical set-up and the corresponding measurement procedure are described in annex A.

4.2.5 Detection system

For detection of the scattered radiation, a detector is employed that is appropriate for the wavelength range of the radiation source. The detector system shall have a sufficient sensitivity for the radiation source and a dynamic range greater than 10^5 with a deviation from linearity of less than 2 %. The size of the sensitive detector area shall be optimized in order to exclude a deterioration of the integration process in the sphere and influence of speckle on the measurement. The detector is attached to the detection port of the sphere with its sensitive area forming approximately one part of the inner surface.

For shielding the detector against the direct radiation scattered onto the sensitive area by the specimen, radiation baffles shall be installed in the integrating sphere. The surfaces of these baffles shall be coated with the same material as the inner surface of the integrating sphere. An additional diffusing window may be installed in front of the detector in order to compensate for spatial variations of the detector sensitivity.

A phase sensitive detection technique is recommended for improved detection sensitivity. A radiation chopper shall be installed into the beam path to modulate the output beam of the radiation source. The processing of the detector signal is performed by a lock-in amplifier that is synchronized to the radiation chopper.

4.2.6 Specimen holder

The specimen holder shall allow for a non-destructive mounting and for a precise placement of the specimen with respect to the ports of the integrating sphere. For scanning the surface of the specimen, the holder may be equipped with a positioning system that is adapted to the desired lateral motion of the sample.

4.3 Arrangement with high sensitivity

For total scatter measurements of specimens with total scattering values below 10^{-4}, steps shall be taken to maximize the sensitivity of the arrangement. In this case, only lasers operating in a stable TEM_{00}-mode shall be employed as a radiation source. The integrating sphere shall be installed at a large enough distance from the last refractive optical element of the beam preparation system to enable scattering from the spatial filter to be removed. To eliminate the need for neutral density filters for calibration, a dynamic range of the detection system greater than twice the reciprocal value of the minimum detectable total scattering is recommended. To decrease the contribution from Rayleigh scattering to the background noise of the measurement system, flushing of the arrangement with pure Helium gas or evacuation is recommended. Shielding the apparatus from radiation sources in the vicinity is recommended.

4.4 Preparation of specimens

The specimen shall have specified optical imaging properties, that are defined by its refractive, reflective or diffractive functioning. This test method is not destructive and shall be applied to the actual part.

Wavelength, angle of incidence and polarization of the radiation as used in the test shall be in accordance with the specifications given by the manufacturer for normal use. If ranges are given for the values of these parameters, an arbitrary combination of wavelength, angle of incidence and polarization within these ranges may be chosen.

