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Optics and photonics — Optical materials and components — Test method for homogeneity of optical glasses by laser interferometry

Optique et photonique — Matériaux et composants optiques — Méthode d'essai d'homogénéité des verres optiques par interférométrie laser

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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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and Photonics*, Subcommittee SC 3, *Optical materials and components*.

This second edition cancels and replaces the first edition (ISO 17411:2014), which has been technically revised.

The main changes are as follows:

— the PHom method was added;

— the FT-PSI method and the SCI method were added;

— the linear change of the refractive index is described as an evaluation target.

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.

Introduction

The International Organization for Standardization (ISO) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent.

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Optics and photonics — Optical materials and components — Test method for homogeneity of optical glasses by laser interferometry

1 Scope

This document specifies the measuring method for the homogeneity of the refractive index of optical glasses by laser interferometry to cope with the grades from ISO 10110-18 and ISO 12123.

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 80000-1, *Quantities and units — Part 1: General*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
homogeneity of the refractive index
peak to valley (PV) of the refractive index variation within the predetermined area in a single test part

3.2
index-matching liquid
transparent liquid with the refractive index which is equivalent or approximate to the refractive index of a test part at the wavelength of the laser to be used and the measurement temperature

3.3
oil-on plate
plane plate, used for flatness correction, obtained by polishing an optical glass, which is attached to a test part by using an *index-matching liquid* (3.2) (where the index matching liquid is sometimes called "oil") as an intermediate liquid

3.4
peak to valley of wavefront
PV value of wavefront
W_{PV}
maximum minus the minimum value of the wavefront in the observation range, as observed by the interferometer when light passes through the test part under test once

Note 1 to entry: W_{PV} is analogous to the peak to valley of f_{WD} in ISO 14999-4[3].

4 Principle

The peak to valley of wavefront, W_{PV}, of a light beam that transmitted through a test object with sufficient flatness is measured using a laser interferometer, and the homogeneity of the refractive index of the test part is obtained.

One of the following methods may be used:

a) Transmission method.

The transmission method is the preferred method for polished parts with plane parallel optical surfaces (e.g. optical windows) to avoid contamination with index matching liquid. One disadvantage of this method is that wavefront deformations caused by surface deformation of the test part influence the resulting PV value of wavefront, W_{PV}, and cannot be separated from the wavefront deformations caused by refractive index inhomogeneity.

b) PHom method.

The PHom method is the preferred method for covering a broad range of materials with different refractive indices, leads to high trueness and precision results for refractive index homogeneity, therefore should be used for high homogeneous material (refractive index difference ≤ 2×10^{-6}).

c) Oil–on plate method.

The oil-on plate method needs lower effort for test part preparation and measurement setup, but each type of glass needs its own index-matching liquid.

By minimizing error factors (e.g. temperature stabilization, preparation of refractive index matching liquid) and improving the skill of the metrologist, the same trueness and precision as the PHom method can be achieved.

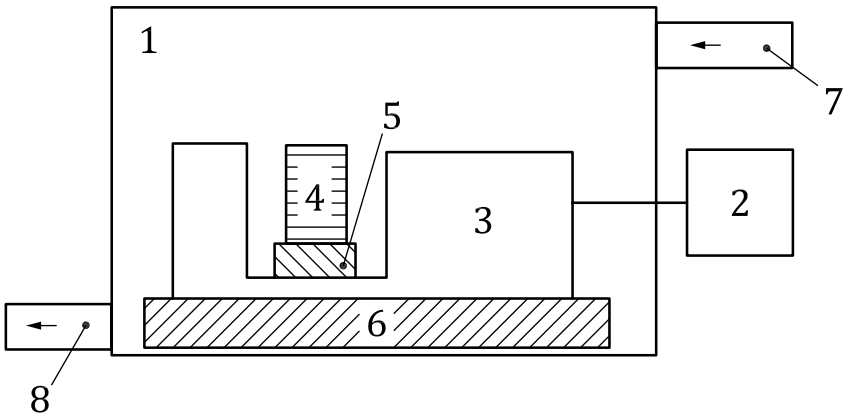
d) FT-PSI method and SCI method.

With the Fourier Transform Phase Shifting Interferometry (FT-PSI method[4]) and the spectrally controlled interferometry (SCI method[5][6]) it is possible to observe the linear change component of the refractive index (see Annex G).

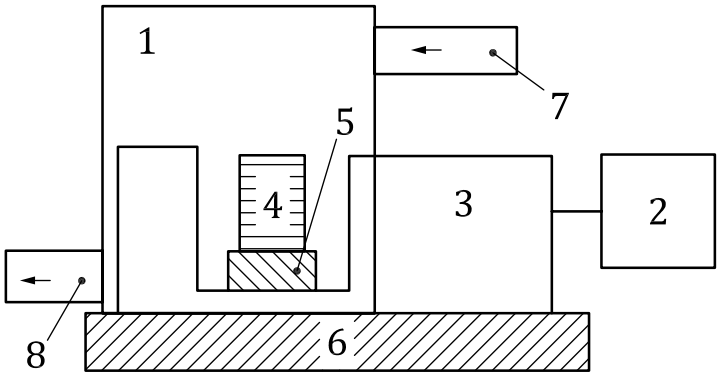
5 Measuring apparatus

5.1 General

Examples for a measuring apparatus are shown in Figure 1. More details are specified in 5.2 to 5.6.



a) First example of composition of measuring apparatus



b) Second example of composition of measuring apparatus

Key

1 thermostatic chamber
2 interferogram analysis device
3 laser interferometer
4 test object composition set (test part, oil-on plate and device to hold them)
5 biaxial adjustment platform (for PHom, FT-PSI and SCI method)
6 vibration isolation table
7 conditioned air inlet
8 ventilation outlet

Figure 1 — Examples of composition of measuring apparatus

5.2 Laser interferometer

The laser interferometer to be used shall have a laser as a light source and an optical system in which the wavefront of a light beam forms a plane. Examples of such interferometers are given in Annex A.

5.3 Interferogram analysis device

The interferogram analysis device to be used shall be capable of obtaining the W_{PV} from an interferogram.

5.4 Thermostatic chamber

The thermostatic chamber to be used shall be capable of maintaining the interferometer and the test object at a certain temperature. The temperature of the atmospheric conditions shall be between 20 °C and 25 °C depending on the purpose of testing. The temperature fluctuation range (spatial and during measurement time) should be smaller than 0,4 °C. See Annex B.

5.5 Vibration isolation device

The vibration isolation device to be used shall be capable of eliminating the effect of vibration from the outside to the interferometer and the test object composition. It should be provided for performing high trueness and precision measurements.

5.6 Biaxial adjustment platform

The biaxial adjustment platform shall be used for the PHom method. The PHom method requires alignment of the reflected light beam on the front and back surfaces of the test object. At this time,

the pan/tilt angle of the test object is adjusted by this equipment. Not required unless measurement is performed by the PHom, FT-PSI and SCI method.

6 Preparation of test part

6.1 General

The test part shall comprise at least two parallel surfaces (the end surfaces), and its thickness (height) direction shall be the direction of observation (which is the direction of the optical axis of the beam pass of an interferometer). The thickness in the direction of observation shall be sufficient to obtain precise and true measured values.

6.2 Transmission method

Both end surfaces (the surfaces orthogonal to the optical axis) of a test part shall be polished flat to a flatness of smaller than 32 nm PV ($\lambda/20$ where λ is the laser wavelength). Poor flatness leads to measurement error as described in Annex D. In the event that the required flatness cannot be achieved, either PHom (see 6.3), oil-on plate (see 6.4), or FT-PSI/SCI (see 6.5) methods are recommended instead.

6.3 PHom method

Both end surfaces (the surfaces orthogonal to the optical axis) of a test part shall be polished flat to a flatness of smaller than 1 900 nm PV (3 waves PV).

A small wedge angle between the end surfaces is required to avoid interferences between reflected wavefront from these end surfaces (e.g. 0,10° ± 0,05° valid for test part diameter up to 350 mm and thickness up to 230 mm).

For more information on the PHom-Method see Annex F.

6.4 Oil-on plate method

Both end surfaces (the surfaces orthogonal to the optical axis) of a test part shall be fine ground and flat to a flatness of smaller than 20 000 nm PV. To achieve results of higher precision and trueness, better flatness might be useful. More details see Annex C.

6.5 FT-PSI and SCI method

These two methods can use test parts that are polished plane parallel plates (see Annex G). They are essential when it is necessary to observe the linear change of the refractive index. In this case, the degree of parallelism on shall be such that interference fringes on the front surface reflection, back surface reflection and transmitted wavefront of the observation area can be observed simultaneously. The flatness is the same as the test parts of the PHom method (see 6.3).

7 Operation

The operation shall be performed as follows:

a) Remove dirt from the test part surfaces and oil-on plates, if used.

b) Install the test object in the interferometer so that the predetermined area of the test object fits within the beam pass of the interferometer. When using oil-on plates, attach the oil-on plates to the test part with the index-matching liquid inserted between the test part surfaces and the oil-on plates. While doing this step, do not allow air bubbles to form in the index-matching liquid.

c) Leave the installed test object to stand until its temperature has returned to the temperature of the measurement environment as given in 5.4. When using oil-on plates, allow the installed test

object to stand until the thickness of the layer of the refractive index-matching liquid between the matched surfaces no longer changes.

d) Adjust the interferometer optics to minimise the number of interference fringes and remove the tilt element of the interference fringes. To avoid common path interference effects inside the test object (in case the test object end surfaces are of good parallelism), the test object shall be tilted with respect to the light beam. An appropriate tilt angle depends on details of test object and interferometer and is often in the order of magnitude of 0,1°. After the adjustment, perform the measurement.

e) Obtain the W_{PV} of the light beam, which is transmitted through the test object measuring system from the interferogram.

8 Measurement

8.1 General

The measurement shall be performed as follows.

The measurement should be performed two or more times by repeating the series of operations described in Clause 7 d) and e). When the average is taken as a measured value, it should be stated in the test report.

The wavefront irregularities of the optical system of the interferometer, the wavefront irregularities due to the homogeneity of the refractive index and the flatness of an oil-on plate contribute errors to the test results. Therefore, to obtain the wavefront of the light beam, which is transmitted through the test object, these errors should be corrected, and the W_{PV} should be obtained from the wavefront after correction. An example of the measurement of the W_{PV} is given in Annex E.

8.2 Transmission method

Two measurements shall be performed.

a) Transmitted wavefront measurement of the test part according to Clause 7.

b) Empty cavity measurement to capture the irregularities of the measurement system.

Correction of irregularities of the optical system of the interferometer can be obtained by subtracting the empty cavity measurement from the test part measurement.

One empty cavity measurement may be used to correct the irregularities for several transmittance measurements of test parts.

8.3 PHom method

Four measurements shall be performed.

a) The front surface of the test part shall be set orthogonal to the optical axis and the reflected wavefront has to be measured in accordance with Clause 7.

a) The rear surface of the test part shall be set perpendicular to the light beam and the reflected wavefront has to be measured in accordance with Clause 7.

d) The transmitted wavefront measurement of the test part shall be performed in accordance with Clause 7.

e) The empty cavity measurement shall be performed to capture the irregularities of the measurement system.

Correction of irregularities of the optical system of the interferometer will be obtained by wavefront calculation in accordance with Annex F.

8.4 Oil-on plate method

Two measurements shall be performed:

a) Attach the test part and the oil-on plates with index matching oil in accordance with Annex C together and perform a transmittance measurement in accordance with Clause 7.

b) Attach only the oil-on plates with index matching liquid in accordance with Annex C together and perform a transmittance measurement to capture the irregularities of the measurement and oil-on plate system.

For correction of irregularities of the optical system of the interferometer and of oil-on plates, see C.2

If several test parts of the same glass type are measured in accordance with 8.4 a), a single measurement according to 8.4 b) may be used to correct the irregularities of all the measurements.

8.5 FT-PSI method and SCI method

Four measurements shall be performed.

For FT-PSI and SCI methods, the respective measurement methods shall be as described in Annex G.

9 Calculation

The calculation of the test result shall be performed as follows:

a) The homogeneity of the refractive index shall be calculated by the following Formula (1).

$$\Delta n_{PV} = \frac{W_{PV} \cdot \lambda}{t} \quad (1)$$

where

Δn_{PV} is the homogeneity of the refractive index of the test part;

W_{PV} is the W_{PV} (wave);

NOTE The W_{PV} is dimensionless. The "wave" here is a name for convenience, not a unit name.

λ is the wavelength of laser (m);

t is the thickness of the test piece (m).

b) For reporting, the homogeneity of the refractive index shall be rounded to two significant figures in accordance with ISO 80000-1. However, when it is smaller than 1×10^{-6}, it shall be rounded to one significant figure.

An example of a calculation is shown in Formula (2). Here

W_{PV} is 0,049 (wave);

λ is $632{,}8 \times 10^{-9}$ (m);

t is 0,041 (m).