BS ISO 11382:2010

BSI Standards Publication

Optics and photonics — Optical materials and components — Characterization of optical materials used in the infrared spectral range from 0,78 μm to 25 μm

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A list of organizations represented on this committee can be obtained on request to its secretary.

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INTERNATIONAL STANDARD

ISO 11382

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Optics and photonics — Optical materials and components — Characterization of optical materials used in the infrared spectral range from 0,78 µm to 25 µm

Optique et photonique — Matériaux et composants optiques — Caractérisation des matériaux optiques utilisés dans la bande spectrale infrarouge de 0,78 µm à 25 µm

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 11382 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 3, *Optical materials and components*.

Introduction

Many standards for optical glass exist that are primarily used for the visible range, however, it is not easy to apply these standards directly to infrared materials.

Often, the properties of infrared materials are known with less certainty than those used in the visible range because the methods of measurements are different, incomplete or inaccurate.

Optics and photonics — Optical materials and components — Characterization of optical materials used in the infrared spectral range from 0,78 µm to 25 µm

1 Scope

This International Standard provides guidelines for the description of data sheets for infrared materials. It specifies the nomenclature and the properties of infrared materials which are reported on such data sheets. These data sheets do not necessarily contain information on every property identified in this International Standard.

This International Standard also specifies the parameters needed to characterize optical materials intended for use in the infrared spectral range from 0,78 µm to 25 µm and provides various methods to be used for measuring these parameters.

This International Standard is applicable only to materials used in the manufacture of passive optical components. The properties of materials used in active applications (e.g. optoelectronics) are not taken into account.

Materials specified in this International Standard can also transmit in other spectral domains (microwaves, visible or ultraviolet).

2 Normative references

The following referenced documents are indispensable for the application 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 10110-3, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 3: Material imperfections — Bubbles and inclusions*

ISO 12123, *Optics and photonics — Specification of raw optical glass*

ISO 15368, *Optics and optical instruments — Measurement of reflectance of plane surfaces and transmittance of plane parallel elements*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12123, ISO 80000-7 and the following apply.[1)]

3.1
regular transmittance
ratio of the regularly transmitted part of the (whole) transmitted flux to the incident flux

3.2
regular reflectance
specular reflectance
ratio of the regularly reflected part of the (whole) reflected flux to the incident flux

3.3
absorptance
ratio of the absorbed radiant flux to the incident flux

3.4
scatter
scatterance
ratio of the scattered radiant flux to the incident flux

3.5
standard uncertainty
uncertainty of the result of a measurement expressed as a standard deviation

3.6
expanded uncertainty
quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

4 Symbols and units

For the purposes of this document, the following symbols and units apply.

d thickness of the sample, expressed in millimetres

α absorptance

δ scatter

λ wavelength, expressed in micrometres

ρ reflectance

τ transmittance

5 Nomenclature

5.1 General

The optical materials covered by this International Standard shall be identified as follows:

a) the name (see 5.2);

1) These terms and definitions are consistent with those given in IEC 60050-845 and ISO/IEC Guide 98-3.

b) the manufacturer reference (see 5.3);

c) the material structure (optional) (see 5.4);

d) the manufacturing process (see 5.5);

e) a reference to this International Standard.

5.2 Name

Either the trademark or the generic name (e.g. germanium or sapphire), followed by reference to the method of manufacture, shall be given in the nomenclature.

5.3 Manufacturer reference

A reference to the manufacturer shall be given in the nomenclature.

5.4 Material structure

If known, the type of the material structure shall be given, i.e. the following:

— amorphous material (e.g. glasses and some plastics);

— polycrystalline material;

— crystal (natural or synthetic);

— ceramics, etc.

5.5 Manufacturing process

The manufacturing process shall be given in the nomenclature; this description may be simplified (e.g. CVD instead of chemical vapour deposition). If a change in the manufacturing process modifies one or several properties of the material, another reference shall be used.

NOTE A great number of materials which transmit in the infrared spectral range exist in nature. However, due to their scarcity, small size, or impurity levels, the optical materials are usually manufactured or refined by industrial processes.

5.6 Form of nomenclature

The nomenclature shall be expressed in sequence, separated by dashes, as shown in the following examples.

EXAMPLE 1 Germanium – Manufacturer A – Monocrystalline n type – Zone fusion – ISO 11382:2010

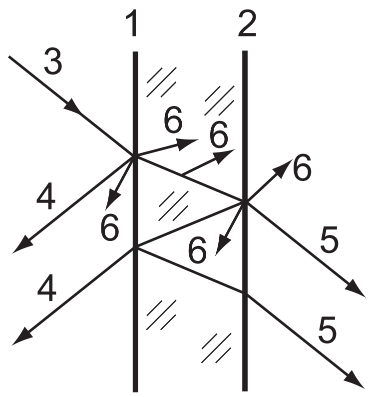
EXAMPLE 2 ZnS – Manufacturer B – Polycrystalline – Hot isostatic pressed – ISO 11382:2010

6 Optical properties

6.1 General

The methods for obtaining data should be reported. If the data are quoted from a reference, the reference document and publication data date shall be reported.

The material is assumed to be in the form of a plane-parallel element with optically polished surfaces 1 and 2, as shown in Figure 1.



Key

1, 2 optically polished surfaces
3 incident light beam
4 reflected part
5 transmitted part
6 scattered part

Figure 1 — Schematic of the light propagation through an element

The light beam incident on the schema given in Figure 1 is divided into

— a reflected part,

— a transmitted part,

— a scattered part, and

— an absorbed part.

If m denotes a surface number, the light beam incident can be described by Equations (1) to (3), as follows:

$$\tau_m + \rho_m + \alpha_m + \delta_m = 1 \tag{1}$$

$$\tau_\mathrm{t} = \frac{\tau_1 \tau_\mathrm{i} \tau_2}{1 - \tau_\mathrm{i}^2 \rho_1 \rho_2} \text{ or } \tau_\mathrm{t} = \frac{\tau_\mathrm{s}^2 \tau_\mathrm{i}}{1 - \tau_\mathrm{i}^2 \rho_\mathrm{s}^2} \qquad (2)\ (3)$$

where

τ_t is the transmittance of the element;

τ_m is the regular transmittance of the surface m;

τ_1 is the regular transmittance of surface 1;

τ_2 is the regular transmittance of surface 2;

τ_s is the regular transmittance of the surface m when surfaces 1 and 2 are identical;

$\tau_{\mathrm{d}m}$ is the scattered transmittance of the surface m;

τ_i is the internal transmittance of the element;

ρ_m	is the regular reflectance of the surface m;
ρ_1	is the regular reflectance of surface 1;
ρ_2	is the regular reflectance of surface 2;
ρ_s	is the regular reflectance of the surface m when surfaces 1 and 2 are identical;
ρ_{dm}	is the scattered reflectance of the surface m;
α_m	is the absorptance of the surface m;
$\delta_m = \rho_{dm} + \tau_{dm}$	is the total scatter of the surface m.

6.2 Transmittance

6.2.1 Specification to be provided

The measurement shall be made in accordance with ISO 15368.

The transmittance shall be measured at 20^{+3}_{-1} °C. The standard thicknesses of the specimens shall be (2 ± 0,1) mm, (5 ± 0,1) mm or (10 ± 0,2) mm.

The transmittance shall be represented by a graph, with the wavelength (or wave number) as the X-axis, and the transmittance as the Y-axis. Uncertainty [e.g. standard uncertainty ($\pm\sigma$) or expanded uncertainty ($\pm k\sigma$) with $k = 2$] for the transmittance shall be provided by error bars on the curves, or in a statement in the graph description.

The following shall be reported:

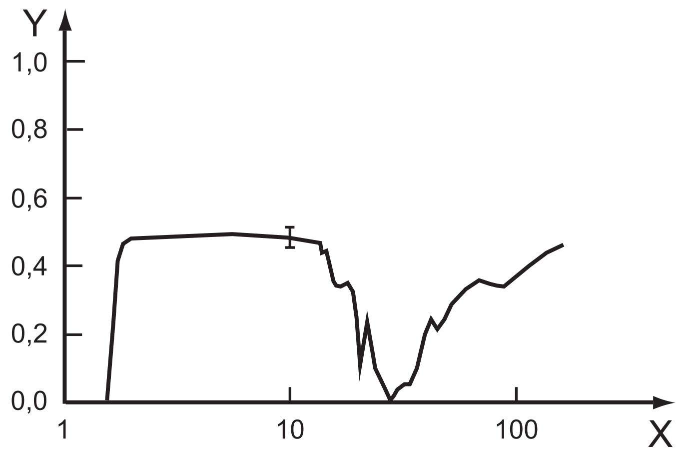
— the thickness of the sample (in the case of multiple curves, with suitable annotation, denoting different thicknesses should be on the same graph);

— the temperature of the piece during the measurement, with its uncertainty of measurement;

— the value of the parameters affecting the transmittance (e.g. resistivity for a semiconductor).

Unless otherwise reported, the incident beam is assumed to be normal to the surface and unpolarized.

An example is given in Figure 2.



Germanium, thickness 2 mm, temperature (20 ± 0,5) °C

Key

X wavelength, µm

Y transmittance

Figure 2 — Example of transmittance

6.2.2 Temperature dependence

The transmittance shall be measured over an appropriate range of temperatures, selected in a suitable manner to clearly show any temperature dependence. Graphs of this data shall be presented as described in 6.2.1.

The usual temperature range is –40 °C to +70 °C, but for specific applications, some materials may be used at cryogenic temperatures (50 K or 77 K), or at high temperatures (⩽ 500 °C or ⩽ 700 °C).

6.3 Absorption coefficient

6.3.1 General

The internal transmittance, τ_i, is expressed in terms of an absorption coefficient, α, as calculated by Equation (4):

$$\tau_\text{i} = e^{-\alpha d} \tag{4}$$

6.3.2 Specification to be provided (to be consistent with 6.5.2)

The values of the absorption coefficient, α, shall be reported, along with the uncertainty values, in the form of tables, including the following:

— wavelength (sampling shall be sufficient to show any significant spectral structure);

— temperature;

— direction of propagation (for anisotropic materials);

— specific parameters (e.g. resistivity for semiconductors).

6.4 Transmittance uniformity

6.4.1 General

Non-uniformity of transmittance may be due to numerous phenomena such as inclusions, bubbles, and local variations in the manufacturing process (e.g. incomplete annealing, local variation of composition).

6.4.2 Bubbles and inclusions

The symbolism of ISO 10110-3 is appropriate and shall be used. However, many infrared materials are opaque or scattering in the visible band, and the measurements are more complex. Experimental apparatus (e.g. those used for the Shadow method) shall be fitted with infrared detectors. In this case, the pixel elements of the apparatus shall be in accordance with the size of the minimum deflection sought.

6.4.3 Local variation of the manufacturing process

The detection of the deflection of light due to inhomogeneity of the material is limited by the sensitivity of the measurement apparatus (interferometer, densitometer, etc.).

The spatial resolution and photometric resolution of the apparatus used shall be reported. These two parameters are usually linked.

6.5 Refractive index

6.5.1 General

Theoretically, the refractive index, $\tilde{n}$, is a complex number, as calculated by Equation (5):

$$\tilde{n} = n + \mathrm{i}k \tag{5}$$

where k is the extinction coefficient and related to the absorption coefficient, α, by Equation (6):

$$k = \frac{\alpha\lambda}{4\pi} \tag{6}$$

When the absorption is negligible, the real part of this number, n, is termed the index of the material.

The refractive index depends on

- the wavelength,
- the direction of propagation (for anisotropic materials),
- the temperature, and
- other parameters, e.g. doping.

The refractive index varies between production batches and with the manufacturing method.

The nominal refractive index represents the average value of the range of values from the particular manufacturing process.

6.5.2 Specification reports to be provided

The refractive index shall be reported at 20^{+3}_{-1} °C, with air as the external medium.

The nominal refractive index should be reported

a) either in the form of a data table, as a function of wavelength, or

b) in the form of one of the formulae of dispersion (e.g. Sellmeier formula).

The values of critical parameters shall be reported for

— the spectral range over which the formula is valid, and

— the maximum uncertainty over the spectral range.

The direction of propagation and polarization shall be reported for anisotropic materials.

6.6 Variation of the refractive index

The value of the refractive index may vary between production batches.

Table 1 gives the tolerance limits for different classes of the refractive index variation.

Classes shall be defined as a function of the maximum difference between the refractive index and the nominal refractive index.

The refractive index should be defined at 4,00 µm or at 10,00 µm. When the material has little or no transmittance at one or other of the above wavelengths, the refractive index shall be measured at one or more wavelengths within the transmittance range, at integer values of the wavelengths, in micrometres.

Six classes are defined depending on the maximum difference between measured refractive index, n_{ms}, and the nominal refractive index, n_{nom}, as shown in Table 1.

Table 1 — Tolerance limits for refractive index variation classes

Class ($\lambda = 4$ µm)[a]	**1**	**2**	**3**	**4**	**5**	**6**
$n_{ms} - n_{nom}$ [b]	$\leqslant$ 0,000 01	$\leqslant$ 0,000 1	$\leqslant$ 0,001	$\leqslant$ 0,005	$\leqslant$ 0,01	$>$ 0,01

[a] The wavelength shall be reported in a given case (e.g. 4 µm in the case shown).

[b] n_{ms} shall be measured under the same conditions (temperature, etc.) as specified for n_{nom}.

6.7 Dependence of the refractive index on temperature

The value $\mathrm{d}n/\mathrm{d}T$ should be reported.

Generally, this value may vary with the wavelength. This value shall be reported for appropriate discrete wavelengths.

The limits of validity, and the uncertainty (standard uncertainty or expanded uncertainty) shall be reported.

Alternatively, an equation may be provided (as a function of wavelength and temperature).

6.8 Optical homogeneity (homogeneity of the refractive index)

The homogeneity of the refractive index across the volume of the material is important. It is assumed that the material temperature is uniform across the volume.

The homogeneity may depend on the size and the form of the piece.

Seven classes of index homogeneity are defined, depending on the variation dn inside the volume of the piece, as shown in Table 2.

Table 2 — Homogeneity of refractive index

Class	**1**	**2**	**3**	**4**	**5**	**6**	**7**
dn	$\leqslant$ 0,000 004	$\leqslant$ 0,000 01	$\leqslant$0,000 04	$\leqslant$ 0,000 1	$\leqslant$ 0,000 4	$\leqslant$ 0,001	$>$ 0,001

6.9 Birefringence

6.9.1 Materials with natural birefringence

Many crystals exhibit double refraction, or birefringence.

In this case, specifications should be reported in a table with two columns:

— one for the ordinary index;

— the other for the extraordinary index.

The conditions (wavelength, direction of propagation, temperature, etc.) shall be reported.

6.9.2 Stress birefringence

Birefringence may occur in normally isotropic materials. It is the result of an internal stress and usually arises from the manufacturing process.

Birefringence produces a difference in the index of refraction in the material for light polarized parallel or perpendicular to the residual stress. This can affect the wave-front quality or optical path difference of the light transmitted by the optical element.

The optical path difference, Δs, between the two orthogonal polarizations of transmitted light over the thickness of the sample is a measure of the birefringence.

This is given by Equation (7):

$$\Delta s = dSK \tag{7}$$

where

d is the thickness of the sample, expressed in mm;

S is the residual stress, expressed in N/mm^2;

K is the difference in photoelastic constants, expressed in mm^2/N.

NOTE ISO 10110-2 and ISO 11455 are also applicable to the stress birefringence.

6.10 Photoelastic constant

The coefficients of the tensor should be reported.

6.11 Dispersion

The dispersion should be reported.

7 Other properties

7.1 General

The following properties should be reported on the data sheet. The methods for obtaining data and the date should be reported. If the data is quoted from a reference, the reference document and publication date or measurement data date shall be reported.

7.2 Specific gravity

The specific gravity should be reported (water at 4 °C as the reference material).

7.3 Molecular weight

The molecular weight should be reported.

Units are not ordinarily specified for atomic or molecular weight.

7.4 Thermal properties

7.4.1 Thermal conductivity

The thermal conductivity should be reported.

7.4.2 Thermal expansion

The coefficients of linear thermal expansion should be reported.

7.4.3 Specific heat

The specific heat should be reported.

7.4.4 Melting temperature and softening temperature

The melting temperature at atmospheric pressure should be reported.

The softening temperature at atmospheric pressure should be reported, if applicable.

7.5 Hardness

The Knoop number should be reported.

7.6 Elastic modulus

The elastic modulus should be reported.

7.7 Maximum dimensions

The manufacturer shall report the following:

a) a preferred shape, and

b) the maximum dimensions of the material that can be obtained with its own manufacturing process.

Classes of dimensions shall be reported in accordance with the given properties. These classes may be related to the following:

— the absolute value of the refractive index,

— the homogeneity of this refractive index, etc.

NOTE The maximum dimensions can be limited by the following:

— the industrial equipment (e.g. ovens);

— the technical capability of the process (e.g. thickness for CVD);

— the volume (e.g. glasses).

Bibliography

[1] ISO 10110-2, *Optics and optical instruments — Preparation of drawings for optical elements and systems — Part 2: Material imperfections — Stress birefringence*

[2] ISO 11455, *Raw optical glass — Determination of birefringence*

[3] ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty measuremen*t (GUM:1995)

[4] IEC 60050-845, *International Electrotechnical Vocabulary — Part 845: Lighting*

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