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Optics and photonics — Optical coatings —

Part 2: Optical properties

Optique et photonique — Traitements optiques —

Partie 2: Propriétés optiques

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

This third edition cancels and replaces the second edition (ISO 9211-2:2010), which has been technically revised.

The main changes are as follows:

— additional symbols (T, R, and A) for transmittance, reflectance and absorption added;

— definitions have been provided for average spectral characteristics;

— default wavelength units of nm added;

— more examples are provided;

— text added and modified for clarity;

— the use of the symbols of Annex A have been generalized.

A list of all parts in the ISO 9211 series can be found on the ISO website.

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.

Optics and photonics — Optical coatings —

Part 2:
Optical properties

1 Scope

This document indicates how to specify optical properties of coatings and to represent their spectral characterization graphically in the ISO 9211 series, which defines the specifications for optical coatings excluding ophthalmic optics (spectacles). It defines the general characteristics and the test and measurement methods whenever necessary, but is not intended to define the process method.

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 9211-1, *Optics and photonics — Optical coatings — Part 1: Vocabulary*

ISO 15368, *Optics and photonics — Measurement of reflectance of plane surfaces and transmittance of plane parallel elements1*

ISO 19962, *Optics and photonics — Spectroscopic measurement methods for integrated scattering by plane parallel optical elements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9211-1 and 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/

4 Optical properties to be specified

When specifying optical properties, the refractive indices of the incident medium and the emergent medium shall be given. The polarization state of the incident radiation shall also be indicated if the angle of incidence, θ, is different from zero or a range of angles of incidence is given. If there is no indication of polarization, unpolarized radiation is assumed.

The optical properties $\tau(\lambda)$, $\rho(\lambda)$, $\alpha(\lambda)$ (or alternatively $T(\lambda)$, $R(\lambda)$ and $A(\lambda)$), $D(\lambda)$ and $\Delta\Phi(\lambda)$ of a coating shall be specified by using the formulation given and explained in 6.2 in order to provide a comprehensive description of a coating with regard to its minimum set of optical properties. Other optical properties such as scattering or colorimetric parameters etc. shall be subject to agreement between manufacturer and customer if appropriate.

If the coating optical properties are required to be achieved at a specific temperature or range of temperatures, this shall be indicated with a note.

5 Measurement conditions

The measurement conditions for the spectrophotometric characterization shall be in accordance with ISO 15368, ISO 19962 or an equivalent method. These conditions depend on the principle of the measurement method and the instruments used, including the angle of incidence, the state of polarization, the spectral range and bandwidth of the measurement beam, etc. and shall be recorded in sufficient detail to enable verification of the measurement.

6 Numerical specification and graphical representation of spectral characteristics

6.1 General

This document defines the rules for the spectrophotometric characterization of optical coatings. If no units are given for wavelength, the units are assumed to be nanometres. The limit values of τ, ρ and α are unitless.

6.2 Rules for the numerical specification of spectral characteristics

The general structure of a numerical specification, as distinguished from a graphical specification, of a spectral optical property shall follow the structure of an inequality with the following terms:

(lower limit term) < or ≤ (spectral optical property term) < or ≤ (upper limit term).

If both a lower limit term and an upper limit term are used, the lower limit will always come first. If a specific wavelength increment has to be used, this shall be specified in a note.

EXAMPLE 1 0,85 < ρ(380 nm to 450 nm, 45°) < 0,95

The subscript “ave” or “avg” is used to denote the spectral characteristic average across the spectral band. If no subscript is used, the spectral characteristic is required to meet the specification at all wavelengths in the specified spectral band.

EXAMPLE 2 1,9 ≤ D_{ave}(350 nm to 1 100 nm) ≤ 2,1

If a range of angles is indicated, the spectral characteristic is required to meet the specification over all angles indicated. If a specific angle increment is to be used, this shall be specified in a note.

EXAMPLE 3 0,45 ≤ τ(1,064 µm, 35° to 55°) < 0,65

The inequality may contain only two terms if the spectral optical property needs to be bounded only on one side. If no units are given for the wavelength range, the wavelengths are assumed to be in nm.

EXAMPLE 4 R(400 to 700, 0° to 35°) ≤ 0,02

If only a lower limit term is used, the comparator sign may be reversed for clarity

EXAMPLE 5 τ_{avg}(0,4 µm to 0,65 µm) ≥ 0,98

If a range of angles is indicated with a spectral characteristic average, the spectral characteristic average is required to meet the specification over all angles. If the spectral characteristic is intended to be averaged over both wavelength and angle, this shall be indicated with a note.

EXAMPLE 6 R_{ave}(0,38 µm to 0,95 µm, 0° to 10°) ≤ 0,04

An arrow (→) is used to indicate a linear change of the specification over the indicated spectral range.

EXAMPLE 7 0,75 → 0,60 < α (700 nm to 1 100 nm) < 0,90 → 0,75

Table 1 gives a schematic representation of elements necessary for the numerical specification of spectral characteristics, where (upper case) Z is used to indicate the coating property such as τ, ρ, etc., and (lower case) z indicates a lower or upper allowed value of Z. A coating may require more than one spectral characteristic specification. Specific examples for some common coating types are shown in Table 2.

Table 1 — Scheme of elements for the numerical specification of spectral characteristics

Lower limit (subscript L) $i = 1, 2, ...$	**Comparator sign**	**Spectral optical property**	**Wavelength (or wavenumber) range or single wavelength (or wavenumber), angle of incidence**[a] $i = 1, 2, ...$	**Comparator sign**	**Upper limit** (subscript U) $i = 1, 2, ...$	***Z* represents any of**
z_{Li}	< or ≤	Z	$(\lambda_i$ to $\lambda_{i+1}, \theta)$ or (λ_i, θ)	< or ≤	z_{Ui}	$\tau, \rho, \alpha, D, \Delta\Phi$ or $\delta\Phi$
$z_{Li} \rightarrow z_{Li+1}$[b]	< or ≤	Z	$(\lambda_i$ to $\lambda_{i+1}, \theta)$	< or ≤	$z_{Ui} \rightarrow z_{Ui+1}$[b]	$\tau, \rho, \alpha, D, \Delta\Phi$ or $\delta\Phi$
$z_{ave,Li}$	< or ≤	Z_{ave}	$(\lambda_i$ to $\lambda_{i+1}, \theta)$	< or ≤	$z_{ave,Ui}$	$\tau, \rho, \alpha, D, \Delta\Phi$ or $\delta\Phi$
$z_{s,Li}$	< or ≤	Z_s	$(\lambda_i$ to $\lambda_{i+1}, \theta)$ or (λ_i, θ)	< or ≤	$z_{s,Ui}$	τ, ρ, α or D
$z_{s,ave,Li}$	< or ≤	$Z_{s,ave}$	$(\lambda_i$ to $\lambda_{i+1}, \theta)$	< or ≤	$z_{s,ave,Ui}$	τ, ρ, α or D
$z_{p,Li}$	< or ≤	Z_p	$(\lambda_i$ to $\lambda_{i+1}, \theta)$ or (λ_i, θ)	< or ≤	$z_{p,Ui}$	τ, ρ, α or D
$z_{p,ave,Li}$	< or ≤	$Z_{p,ave}$	$(\lambda_i$ to $\lambda_{i+1}, \theta)$	< or ≤	$z_{p,ave,Ui}$	τ, ρ, α or D

[a] Each optical property may be specified for different wavelength (or wavenumber) ranges and/or different single wavelengths (or wavenumbers), if necessary.

If the angle of incidence θ is not explicitly indicated, an angle of 0° is assumed.

For some applications, a range of angles of incidence (θ_1 to θ_2) instead of a single angle may be specified. When a range of angles of incidence is specified, the spectral performance shall be achieved for all angles indicated.

If the angle of incidence θ is different from 0° or a range of angles is given, but neither s- nor p-polarization is defined, the radiation is assumed to be unpolarized.

[b] The arrow → indicates a linear change of the tolerance limit from value z_{Li} at λ_i to value z_{Li+1} at λ_{i+1} (from value z_{Ui} at λ_i to value z_{Ui+1} at λ_{i+1}, respectively).

Table 2 — Numerical examples

Code designation[a]	**Spectral characteristics (numerical specification)**
AB	0,75 → 0,60 < α (500 nm to 600 nm) < 0,90 → 0,75
RE	ρ (400 nm to 700 nm) > 0,98 ρ_{ave} (400 nm to 700 nm) ≥ 0,995
FI-BP	0,85 ≤ τ (535 nm to 565 nm) ≤ 0,95 τ(400 nm to 515 nm) < 0,05 τ(585 nm to 720 nm) < 0,15
PC	89° ≤ $\Delta\Phi$ (10,6 µm, 45°) ≤ 91° ρ(10,6 µm, 45°) > 0,97
PO	ρ_s (450 nm to 650 nm, 45°) > 0,95 ρ_p (450 nm to 650 nm, 45°) < 0,05

[a] The code designations are given in ISO 9211-1.

6.3 Rules for the graphical representation of spectral characteristics

6.3.1 Spectrophotometric characterization consists of indicating the following in a graph:

a) on the abscissa, the spectral region in which the characteristics are specified as a function of wavelength, λ, in nanometres or micrometres, or wavenumber, σ, in reciprocal centimetres;

b) on the ordinate, the values of the individual optical properties (τ, ρ, α, D or $\Delta\Phi$).

6.3.2 The upper and/or lower tolerance limits (indicated by subscripts U and L respectively) within which the spectral characteristics which are to be indicated on the graph with hatched areas outside of the tolerance band. An alternative is the marking with triangles (▲ for the lower tolerance limit and ▼ for the upper tolerance limit) at either or both edges of the corresponding tolerance band. This way of marking is especially suited for tolerance limits at defined single wavelengths. If average values are specified, this shall be indicated as text on the graph, e.g. $\tau_{ave,L} < \tau_{ave}$ (λ_1 to λ_2) $< \tau_{ave,U}$.

6.3.3 If the coating is employed in several spectral regions, the characterization of the function in those different regions may appear on the same representation. Using different scales is permitted if necessary.

6.4 Graphical representation of principal optical functions

6.4.1 General

The following graphical representations of principal optical functions shall be used for specification and actual measurement. If appropriate, specified and measured upper, lower, and/or average values may be combined in one graphical representation. The curves, the limits, and the numerical values shown in the following figures are only examples used for illustration. They shall not be taken as typical or standard values and limits.

A combination of spectral properties, e.g., τ and ρ, may be shown in the same graphical representation. See the beam splitting function graphical representation for an example of this.

6.4.2 Reflecting function (RE)

The reflecting function shall be characterized by its lower tolerance limit, ρ_L, of spectral reflectance. The upper tolerance limit, ρ_U, should also be indicated if necessary, see Figure 1.

General designation:

RE ρ (λ_{2i-1} to λ_{2i}, θ) $> \rho_i$, ...; i = 1, 2, ...

Numerical example:

RE ρ (400 nm to 700 nm, 25° to 35°) > 0,98

ρ (730 nm to 770 nm, 25° to 35°) > 0,96

ρ_{ave} (400 nm to 700 nm, 25° to 35°) > 0,995

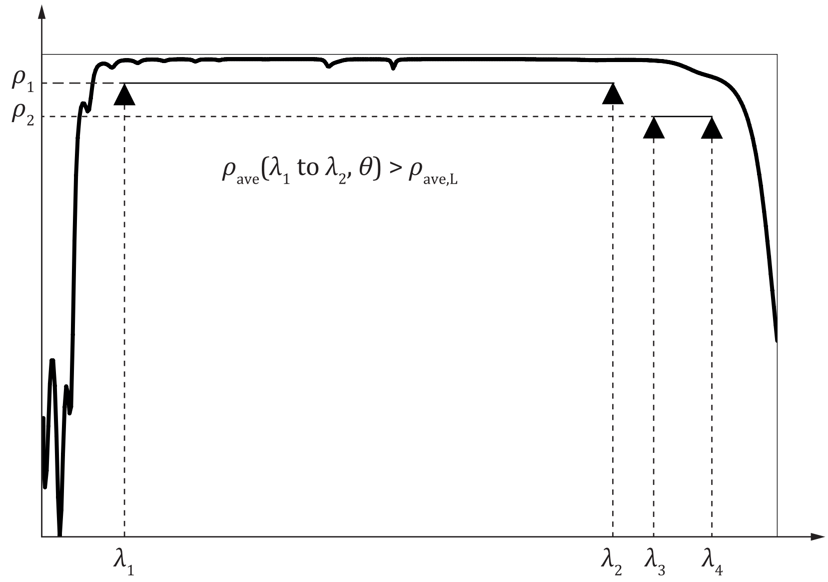

Figure 1 — Reflecting function

6.4.3 Antireflecting function (AR)

The antireflecting function shall be characterized by its upper tolerance limit of spectral reflectance, ρ_U. If necessary, the spectral transmittance with its lower tolerance limit, τ_L, may be indicated, see Figure 2.

General designation:

AR ρ (λ_i to λ_{i+1}, θ) < ρ_i [→ ρ_{i+1}], ...; i = 1, 2, ...

Numerical example:

AR ρ (410 nm to 420 nm, 0° to 30°) < 0,01 → 0,005

ρ (420 nm to 600 nm, 0° to 30°) < 0,005

ρ (600 nm to 640 nm, 0° to 30°) < 0,005 → 0,015

ρ (905 nm, 0° to 30°) < 0,01

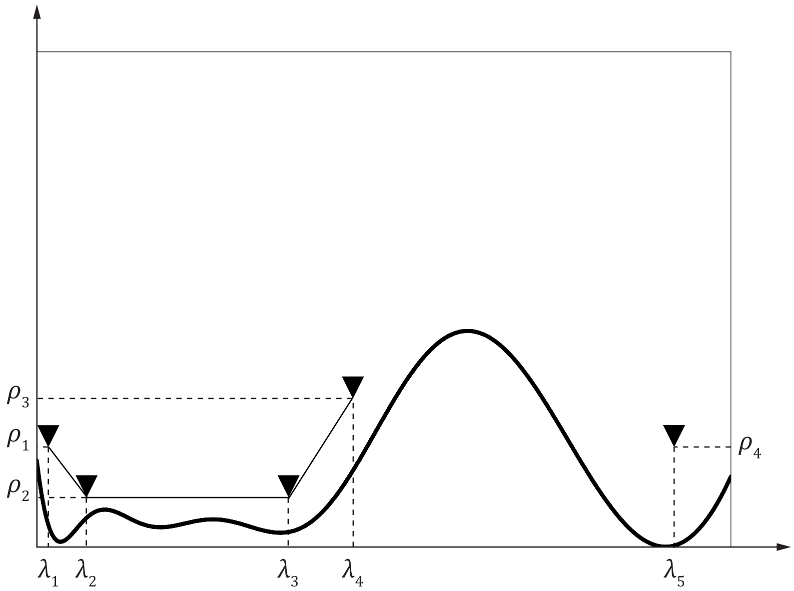

Figure 2 — Antireflecting function

6.4.4 Beam splitting function (BS)

The beam splitting function shall be characterized by its upper and lower tolerance limits (τ_U, τ_L, ρ_U, ρ_L) of spectral transmittance and spectral reflectance. These two representations may be shown in separate graphs, see Figure 3.

General designation:

BS $\tau_{Li} < \tau$ (λ_{2i-1} to λ_{2i}, θ) $< \tau_{Ui}$, ...,

$\rho_{Li} < \rho$ (λ_{2i-1} to λ_{2i}, θ) $< \rho_{Ui}$, ...; i = 1, 2, ...

Numerical example:

BS 0,25 < τ (0,4 µm to 0,7 µm, 40° to 50°) < 0,35

0,45 < τ (0,9 µm, 40° to 50°) < 0,55

0,65 < ρ (0,4 µm to 0,7 µm, 40° to 50°) < 0,75